EECE 4353 Image Processing

Lecture Notes on Color Perception

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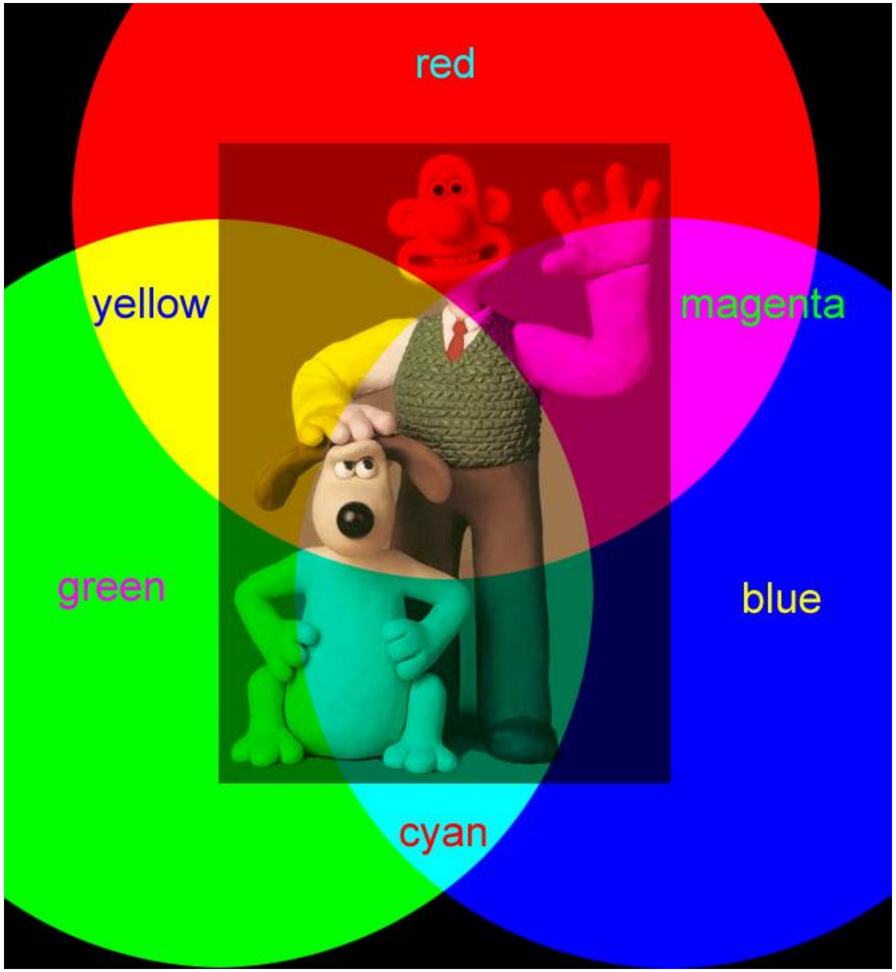
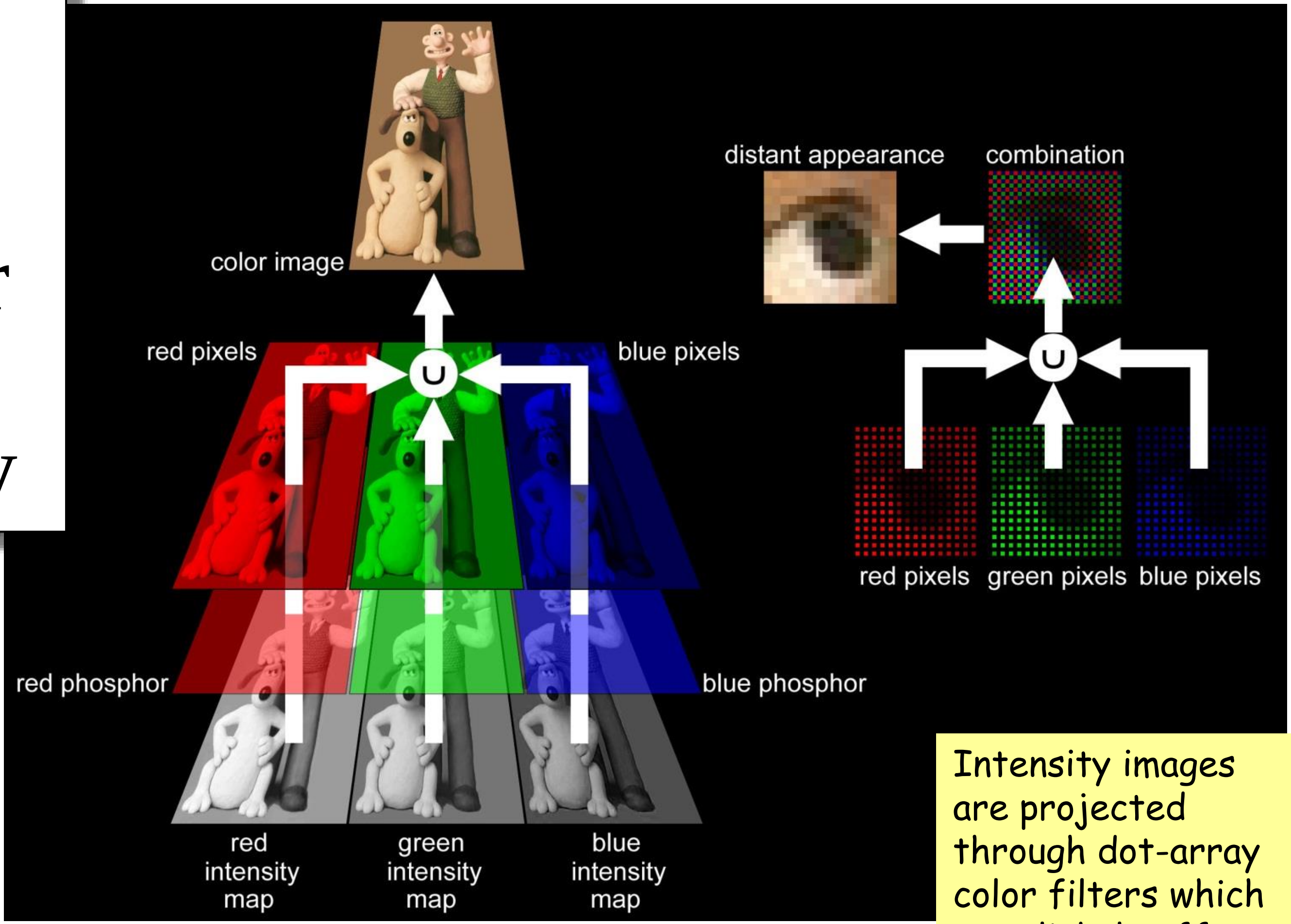
Color Images

- Are constructed from three intensity maps.
- Each intensity map is projected through a color filter (*e.g.*, red, green, or blue, or cyan, magenta, or yellow) to create a single color image.
- The intensity maps are overlaid to create a color image.
- Each pixel in a color image is a three element vector.



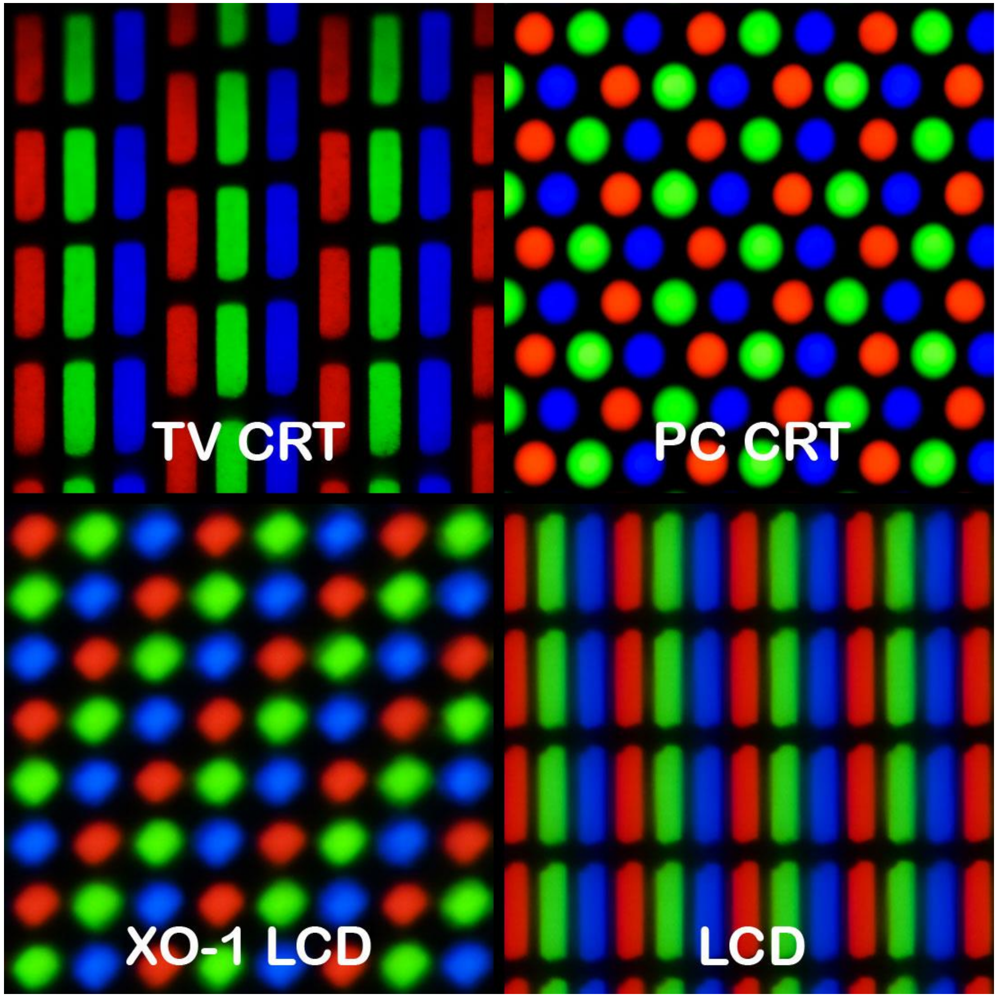
Color Images on a CRT or LCD Display



Projected image primary colors: red, green, and blue.

Intensity images are projected through dot-array color filters which are slightly offset from one another.

Color Images on a CRT or LCD Display



Photographs of various displays, showing various pixel geometries. Clockwise from top left, a standard definition CRT television, a CRT computer monitor, a laptop LCD, and the OLPC XO-1 LCD display. [Peter Halasz (user:Pengo), Wikipedia, http://en.wikipedia.org/wiki/Pixel_geometry]

Color Images In Print

Images are separated into four color bands, each of which is printed as a grid regularly spaced dots. A dot's diameter varies in proportion to the intensity of the color.

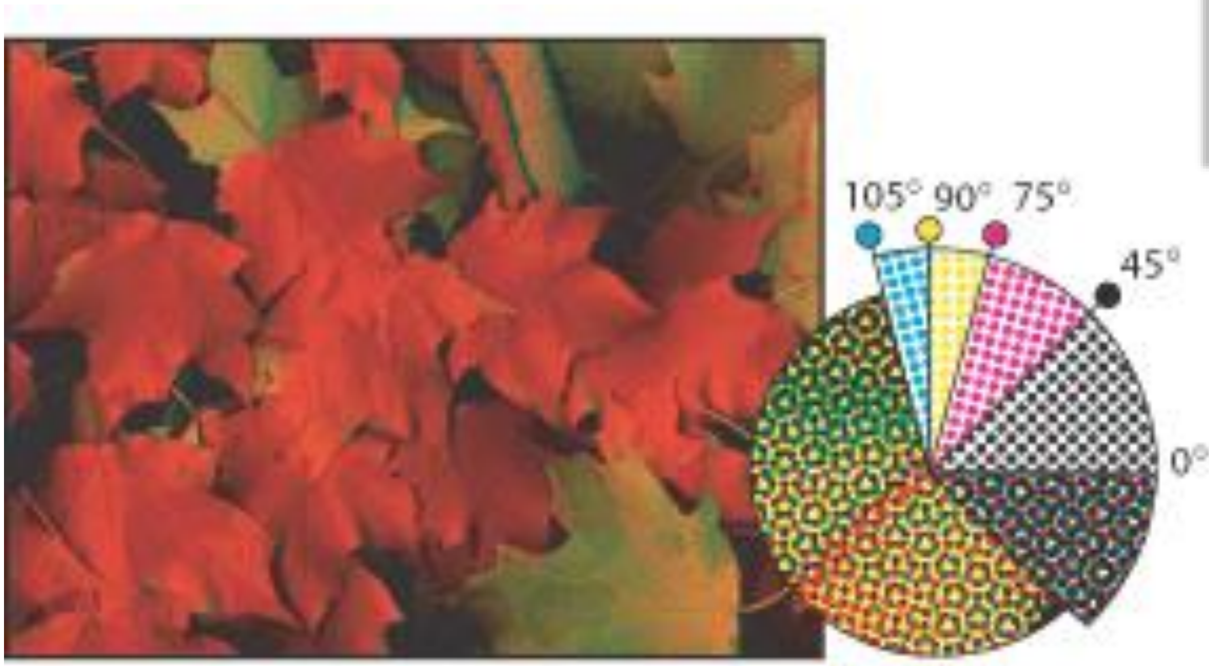
Color Images in Print

The four colors are magenta, cyan, yellow, and black

Standard Halftone Screen Angles

The dot grids are created with a screen that overlays the intensity images.

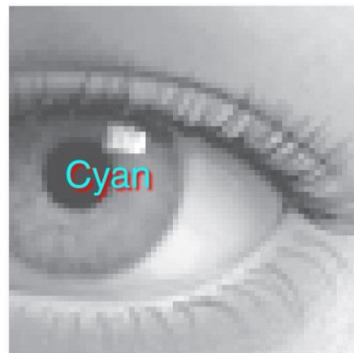
Cyan:	105°
Yellow:	90°
Magenta:	75°
Black:	45°

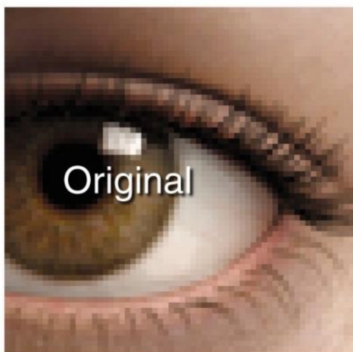


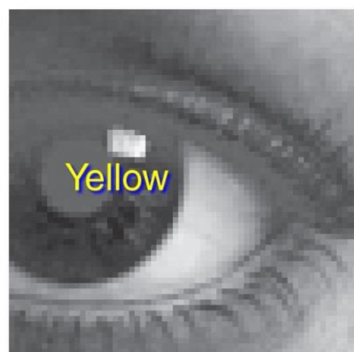
The screens are oriented at different angles.

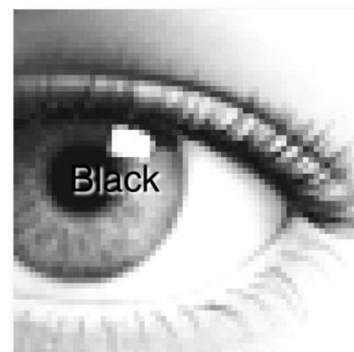
The resulting patterns are called “rosettes”.

Color Separation / Halftoning







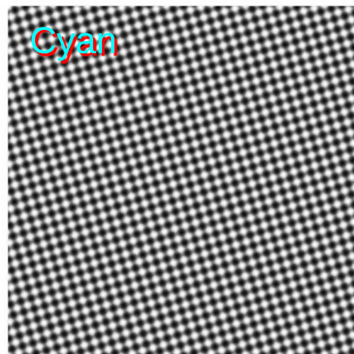


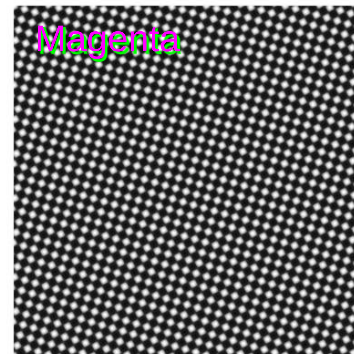
The original is separated into an intensity image for each of the four color bands.

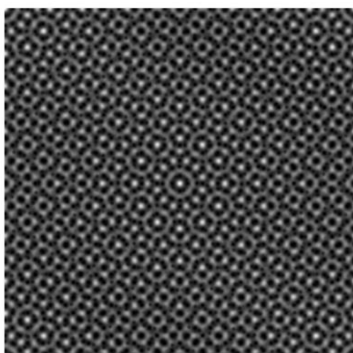
Color Separation / Halftoning

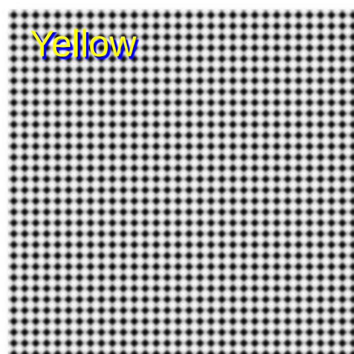
Color Separation / Halftoning

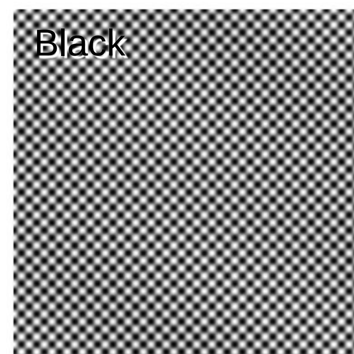
Each intensity image is multiplied by a corresponding "screen",







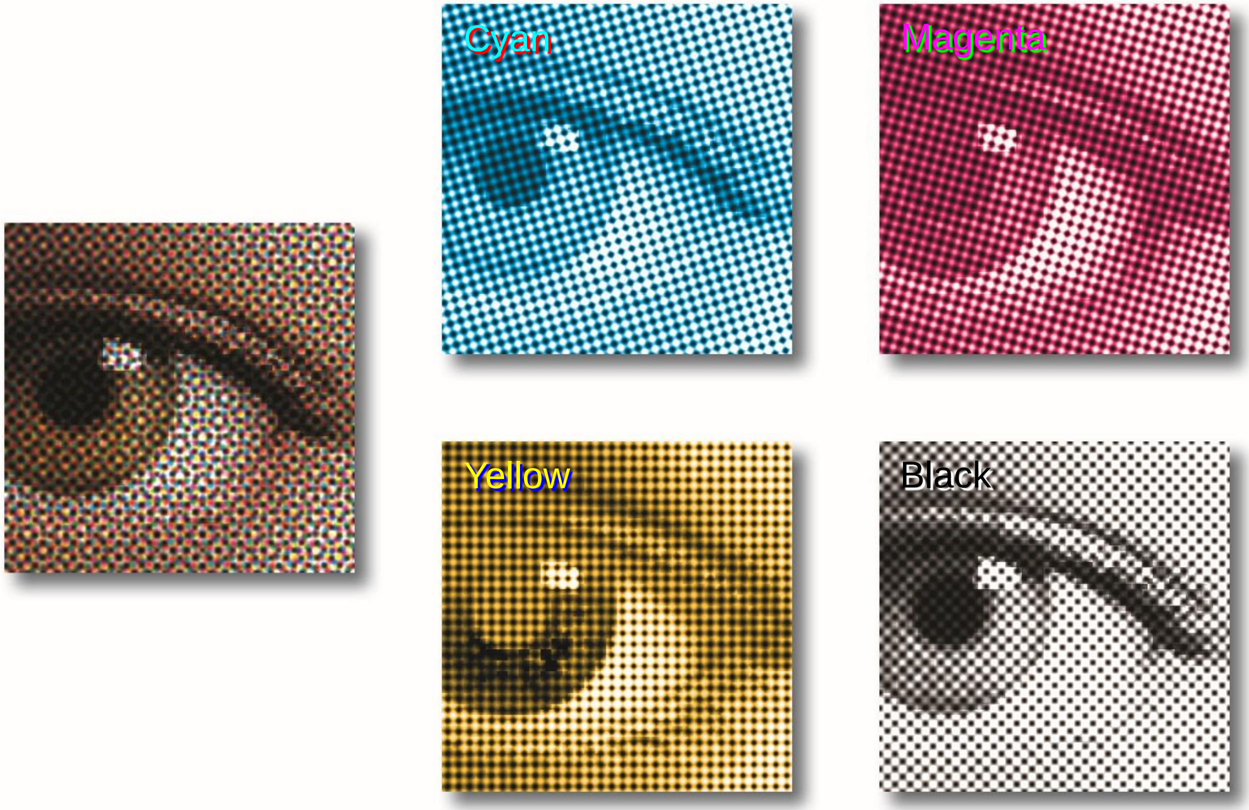




Each screened image is printed in its own color on the same page.

Color Separation / Halftoning

Results:



The Eye

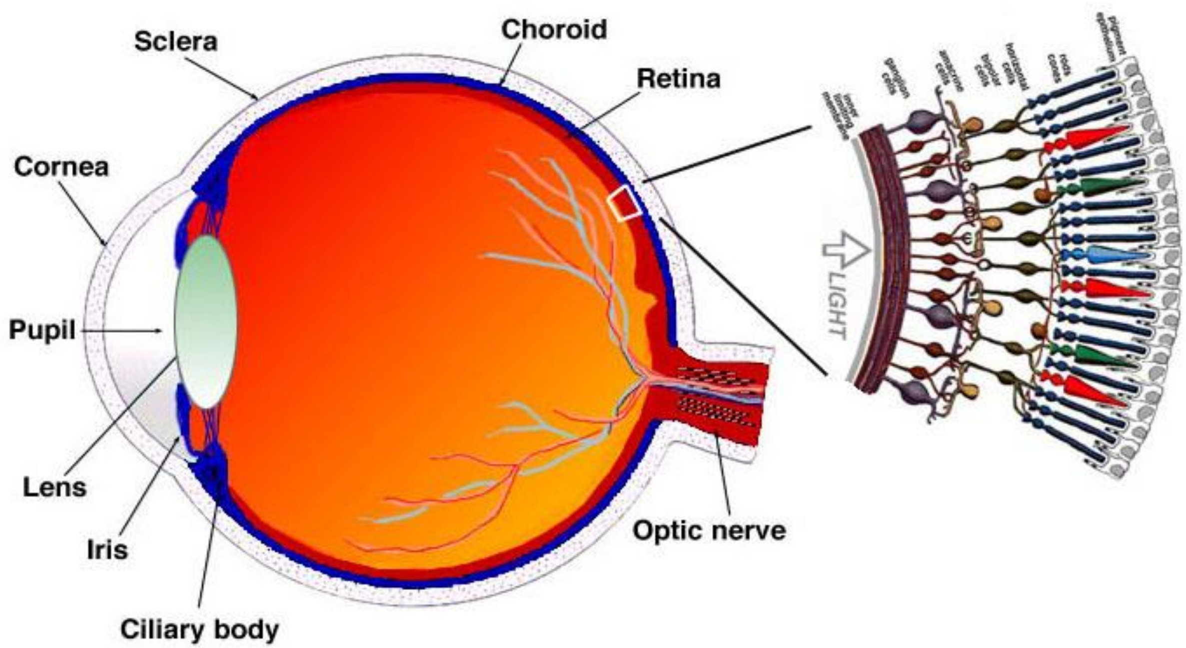


Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.

Diagram from http://webvision.med.utah.edu/

[1]Klaus Rohrschneider, "Determination of the Location of the Fovea on the Fundus," Invest. Ophthalmol. Vis. Sci. September 2004 vol. 45 no. 9 3257-3258

The Retina

When measured in 104 healthy people, the horizontal angle from the center of the fovea to the meridian through the center of the optic nerve head varied from 13.0° to 17.9°; the vertical angle from the foveal center to the parallel through the optic nerve head was in the range -3.65 to +0.65°.[1]

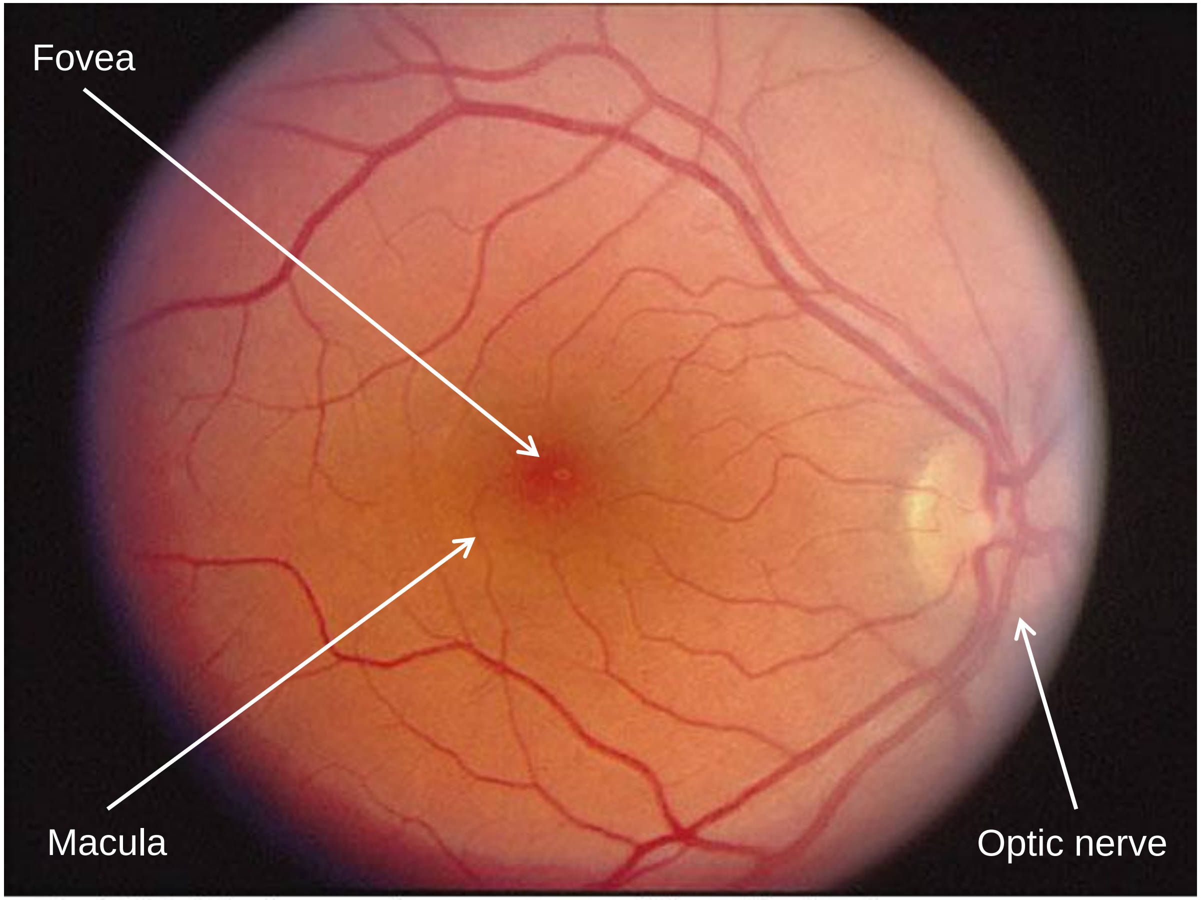


Diagram from http://webvision.med.utah.edu/

The Retina

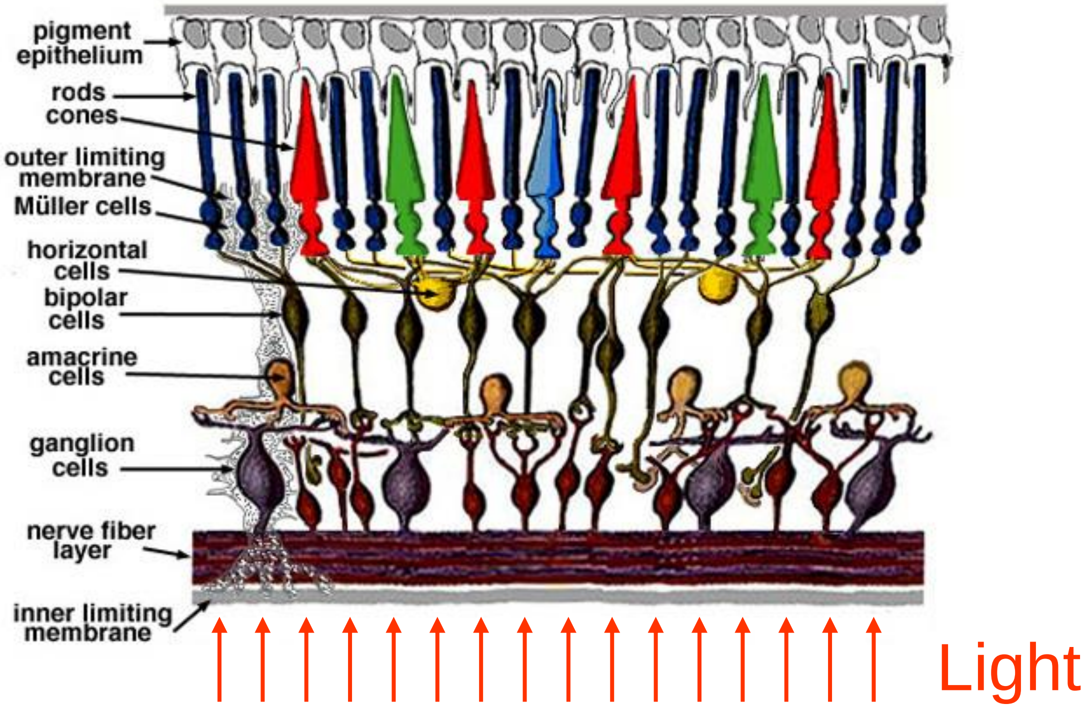


Fig. 2. Simple diagram of the organization of the retina.

Diagram from http://webvision.med.utah.edu/

Photoreceptor Densities

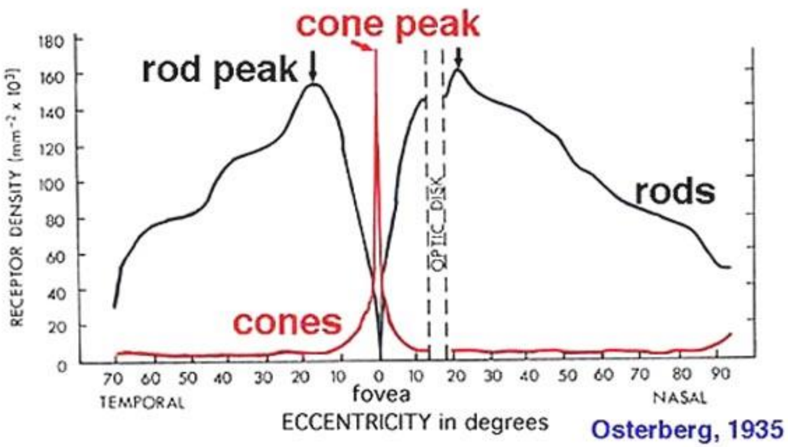


Fig. 20. Graph to show rod and cone densities along the horizontal meridian.

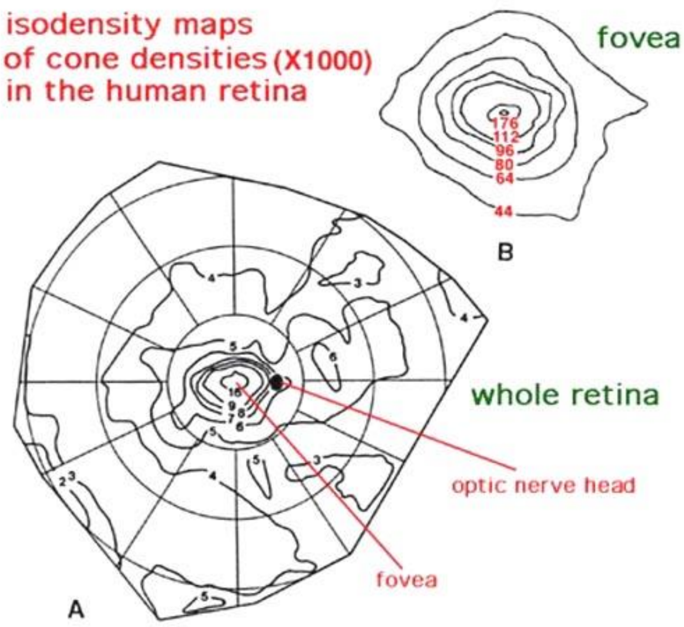


Fig. 21. Cone densities in human retina as revealed in whole mount. The foveal area is enlaged in B. (from Curcio et al., 1987).

Diagrams from http://webvision.med.utah.edu/

Photoreceptor Densities

The density of cone photoreceptors decreases from the high-resolution fovea to the periphery of the eye. A human eye's field of view is about 155° of that, the fovea comprises the central 2°. To see the world in detail requires active scanning by the eyes. A person *does not* see much more than he or she *does* see in most situations. The slides that follow mimic a multiresolution scan of a painting by a single eye. (The digital image processing in this case was done with a log-polar transform.)

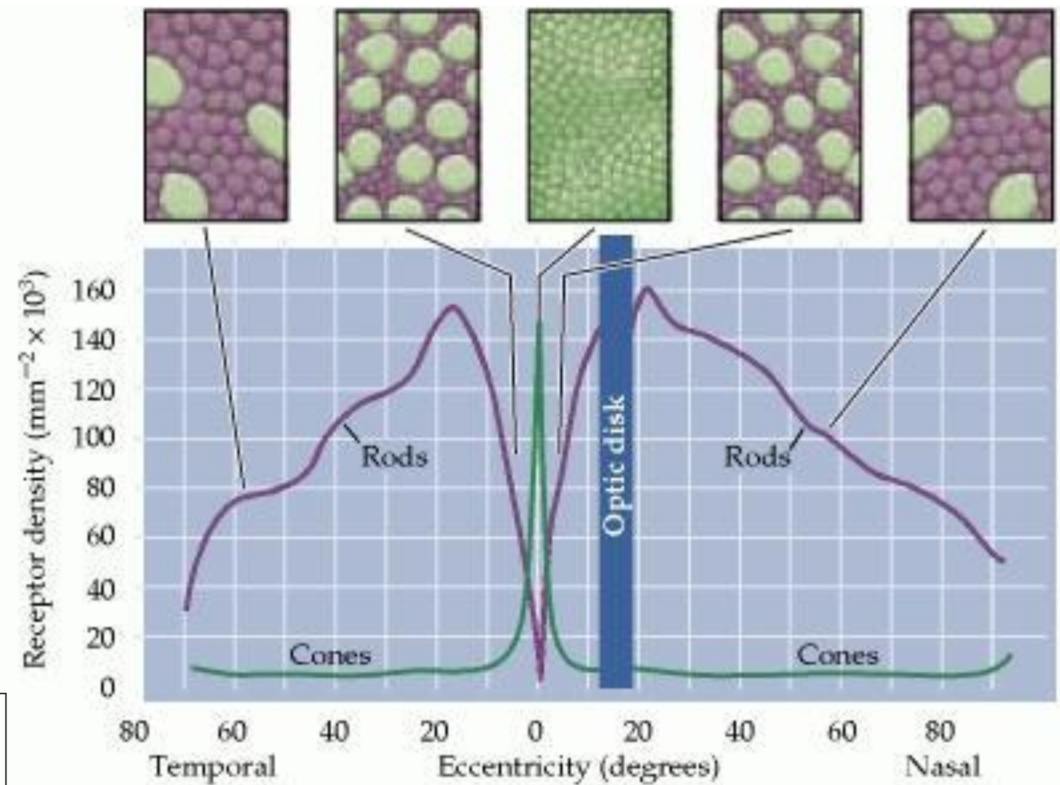


Figure: Anatomical Distribution of Rods and Cones from Neuroscience. 2nd edition.
Purves D, Augustine GJ, Fitzpatrick D, et al., editors. Sunderland (MA): Sinauer Associates; 2001.
http://www.ncbi.nlm.nih.gov/books/NBK10848/

Retinal Space-Variant Sensing

Louis Boilly (1761-1845) Thirty-Six Faces of Expression. Log-polar transform applied.

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Retinal Space-Variant Sensing

Louis Boilly (1761-1845) Thirty-Six Faces of Expression.

The Log Polar Transform

$$\mathbf{L}\big(\rho(x,y),\phi(x,y)\big)=\mathbf{I}(x,y),\ \ \text{where}$$

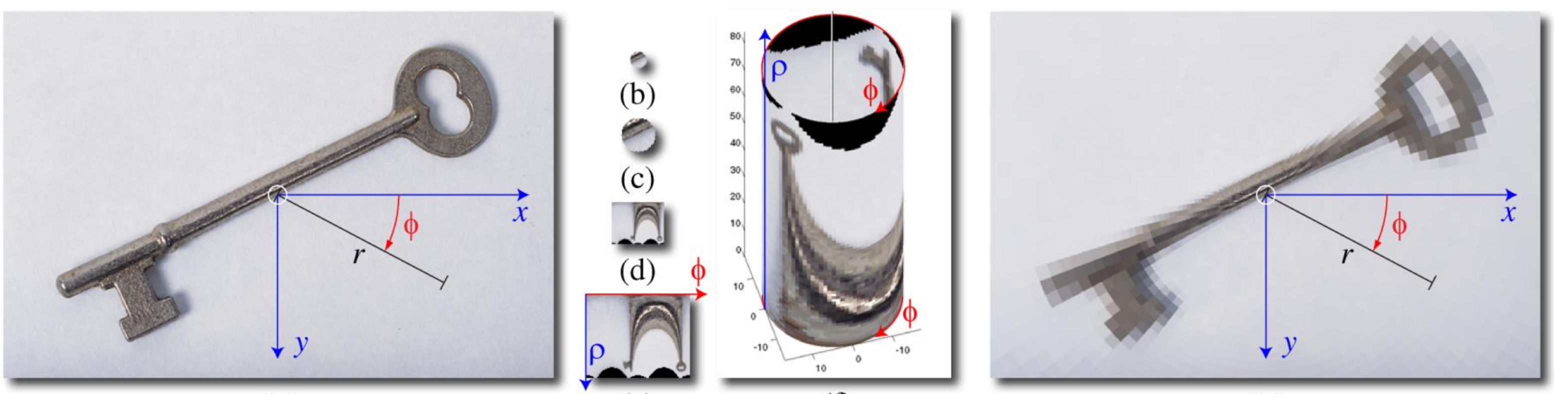
$$\rho(x,y)=M\log\big(r(x,y)+\alpha\big)-\beta,\ \text{with}$$

$$\mathrm{r}(x,y)=\sqrt{(x-x_0)^2+(y-y_0)^2},\ \text{and}$$

$$\phi(x,y)=\tan^{-1}\left(\frac{y-y_0}{x-x_0}\right).$$

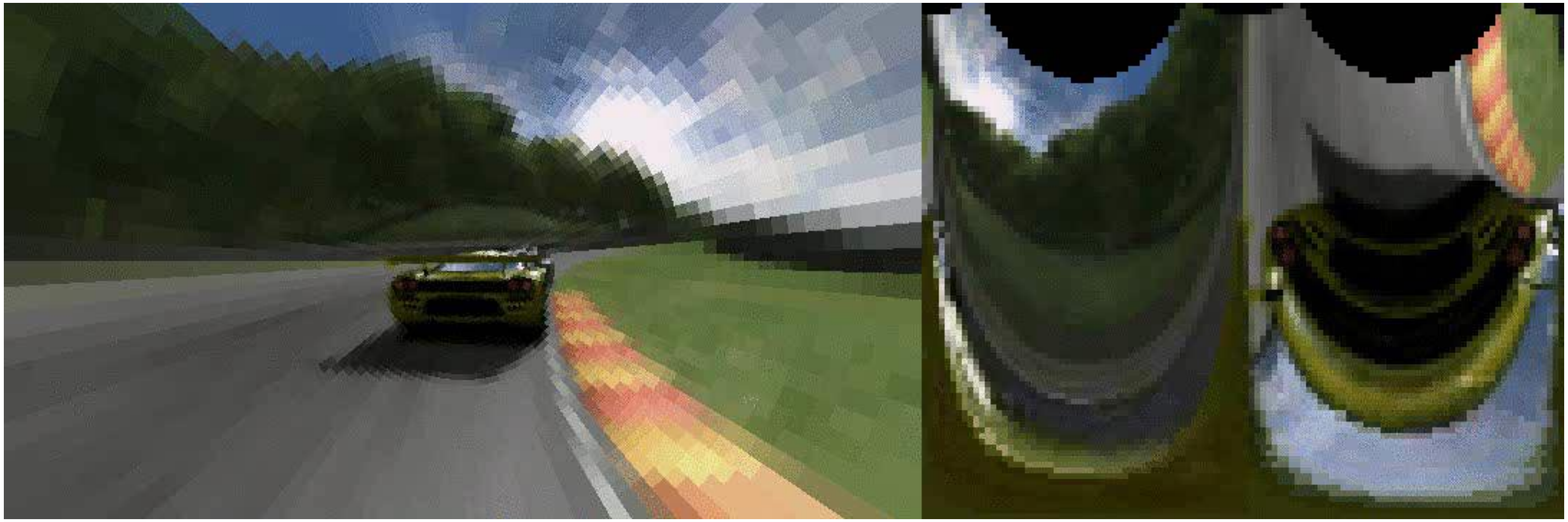
$$M,\alpha,\beta\in\mathbb{R}^+\ \text{such that}\ \ \beta\geq M\log\alpha,$$

(a) Original image with a left-handed coordinate system originating at (x_0, y_0), the center of the image. (b) Fovea (actual size for this particular transform). (c) Fovea (enlarged 2×). (d) Log-polar transform (LPT), unwrapped (actual size). The origin is in the upper left-hand corner. The ρ-axis is down and the φ-axis is to the right. (e) LPT, unwrapped, enlarged 2×. (f) LPT on cylinder. The origin is at the bottom. The ρ-axis is up and the φ-axis is clockwise to the left. (g) LPT image backward-mapped onto the original image.

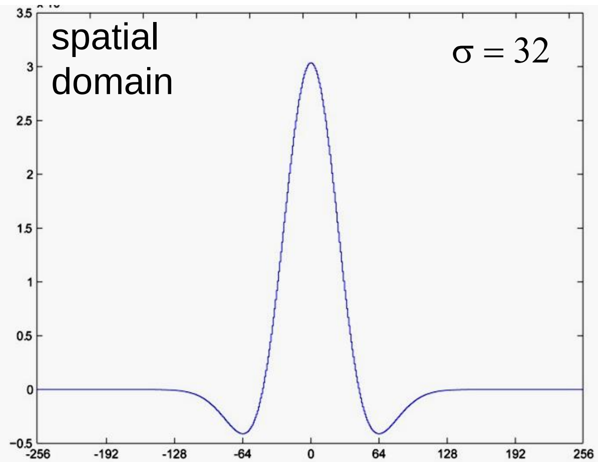


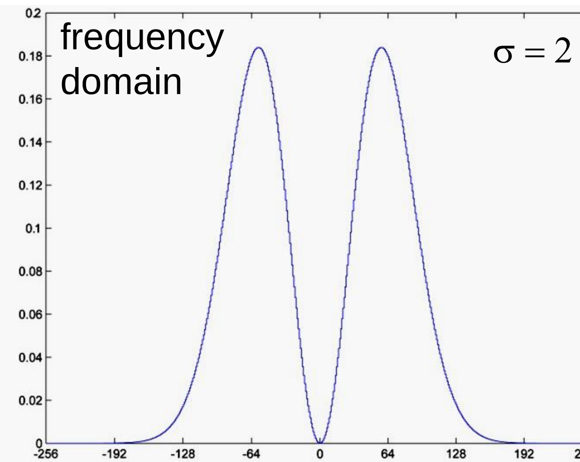
(a) (e) (f) (g)

Space Variant Visual Motion



Retina: Center-Surround Edge Detector

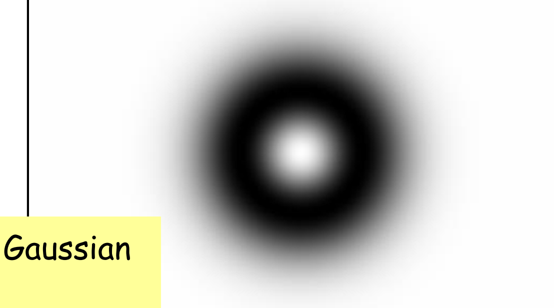




$$\nabla^2 g(r) = \frac{1}{\pi\sigma^4}\left[1 - \frac{r^2}{2\sigma^2}\right]\exp\left(-\frac{r^2}{2\sigma^2}\right)$$

$$r^2 = x^2 + y^2$$

$$G(\omega) = \omega^2 \exp\left(-\frac{\sigma^2\omega^2}{2}\right)$$

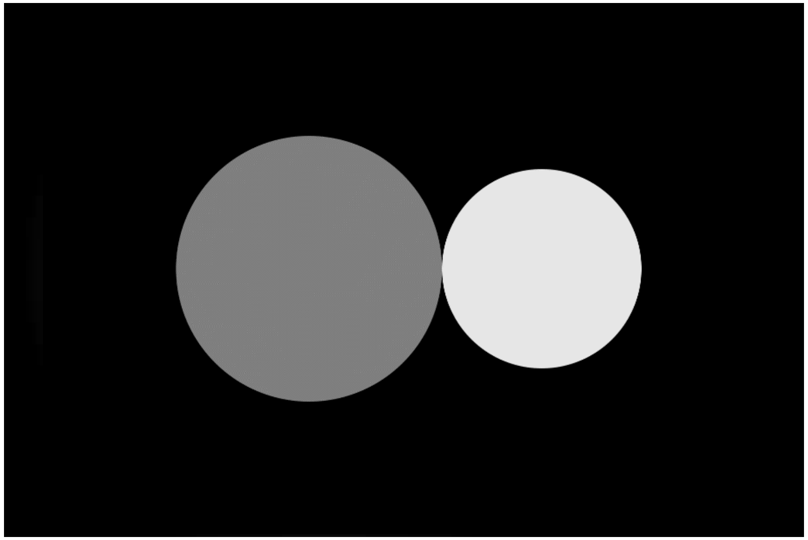


$$\omega^2 = u^2 + v^2$$

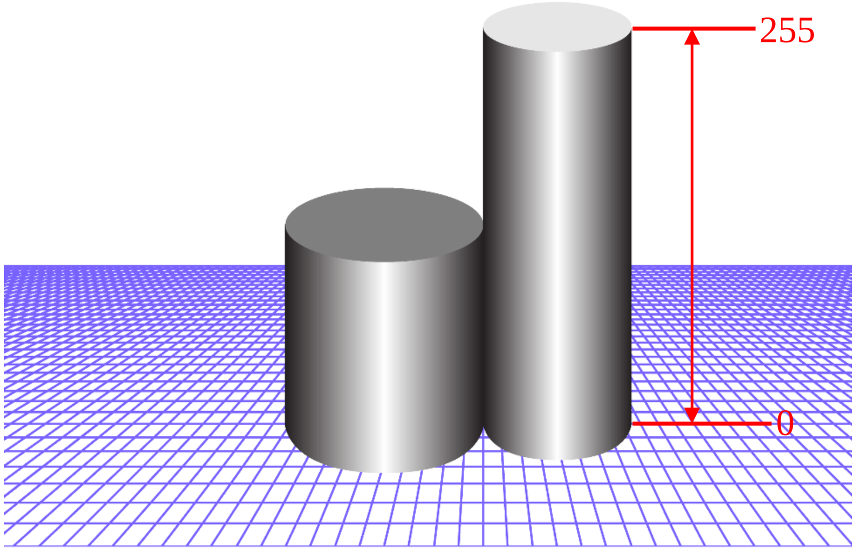
Laplacian of Gaussian (LoG) Filter

The interconnection of the photoreceptors by the other cells in the retina cause its output to be an edge map, similar to the action of a Laplacian of Gaussian filter on a digital image.

Center-Surround Brightness Perception



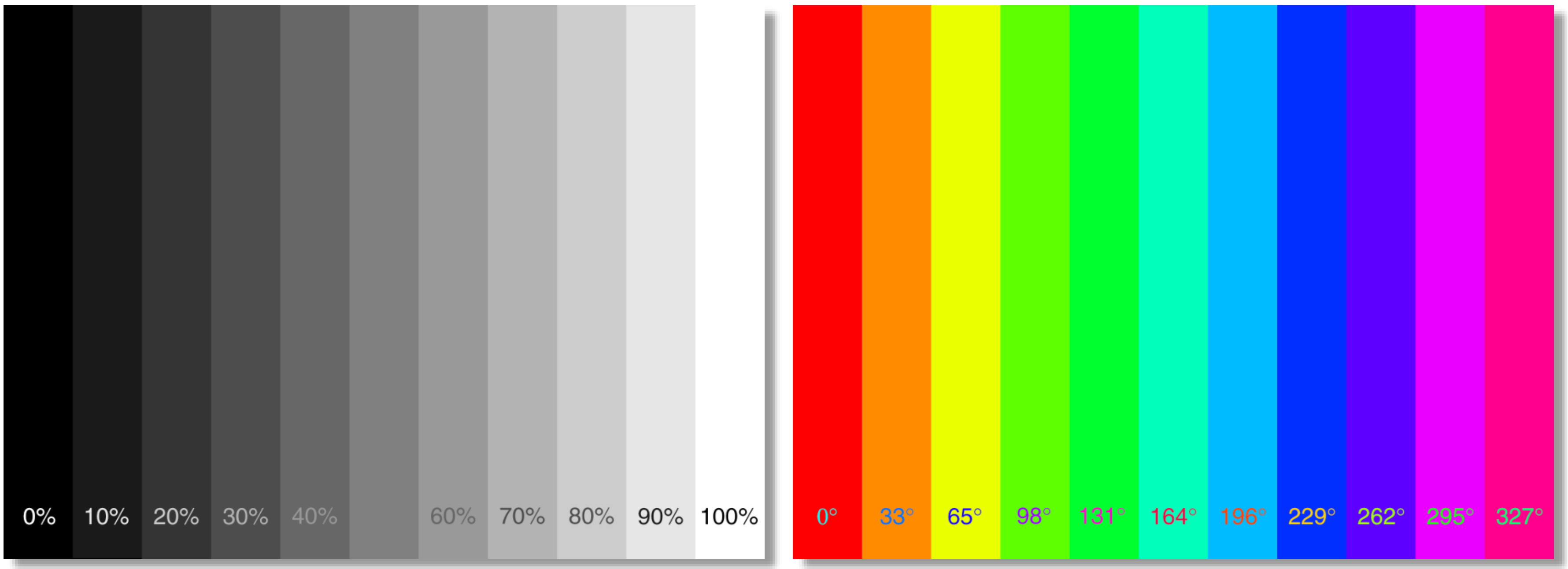
image



intensity profile

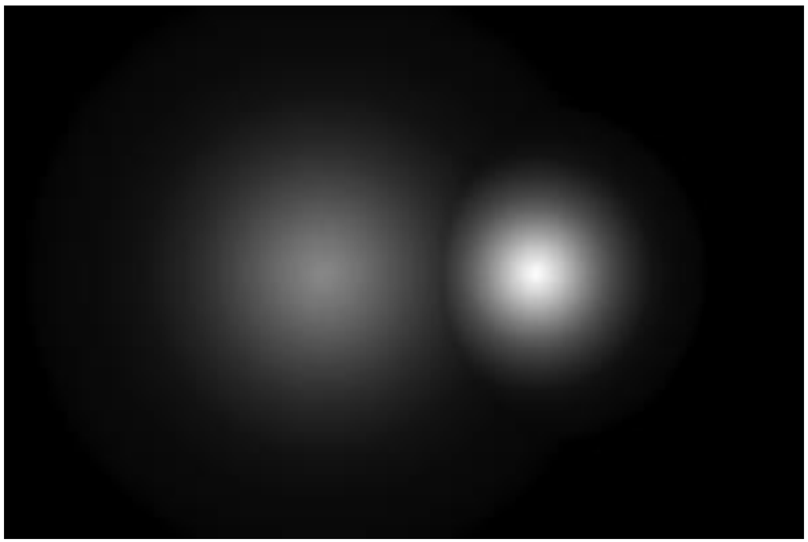
False bright edge next to dark edge.

Center-Surround Brightness Perception

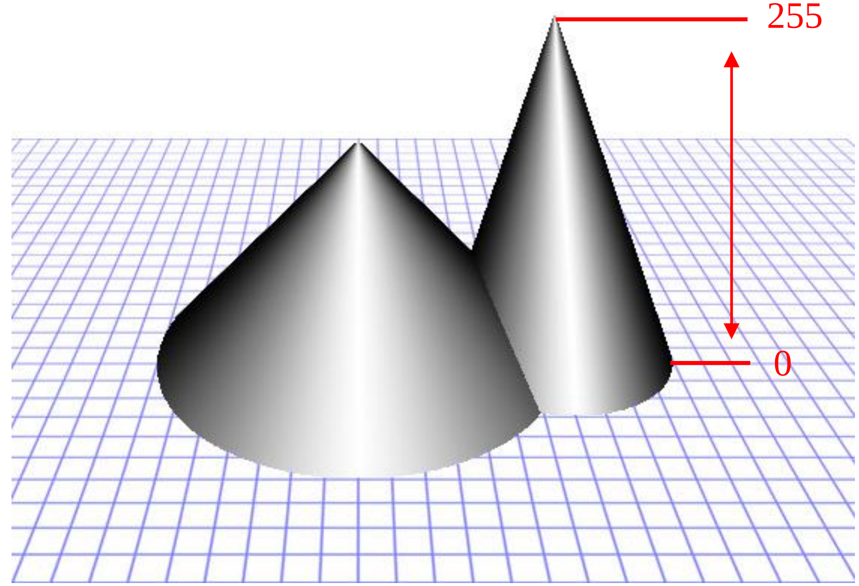


False gradients across constant bands

Center-Surround Brightness Perception



image



intensity profile

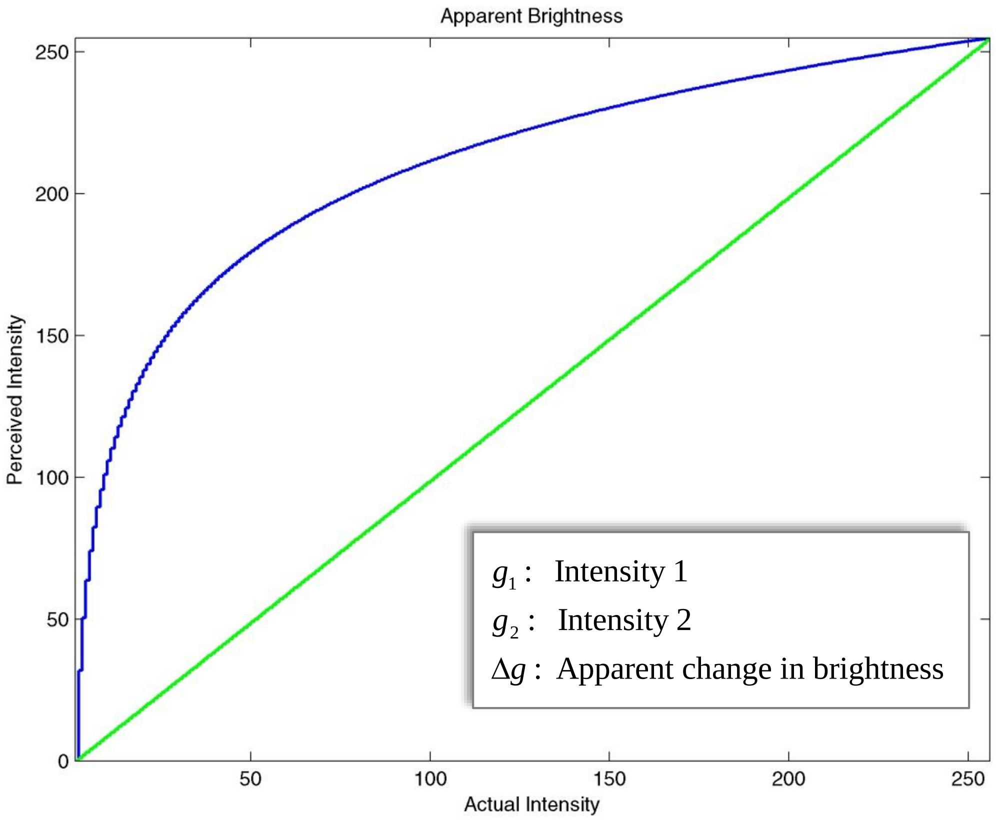
Linear intensity changes are not seen as such.

Brightness Perception: Weber-Fechner

The previous slide demonstrates the Weber-Fechner relation. The linear slope of the intensity change is perceived as logarithmic.

$$\Delta g = \frac{|g_1 - g_2|}{g_1 + g_2}$$

The green curve is the actual intensity; the blue curve is the perceived intensity.

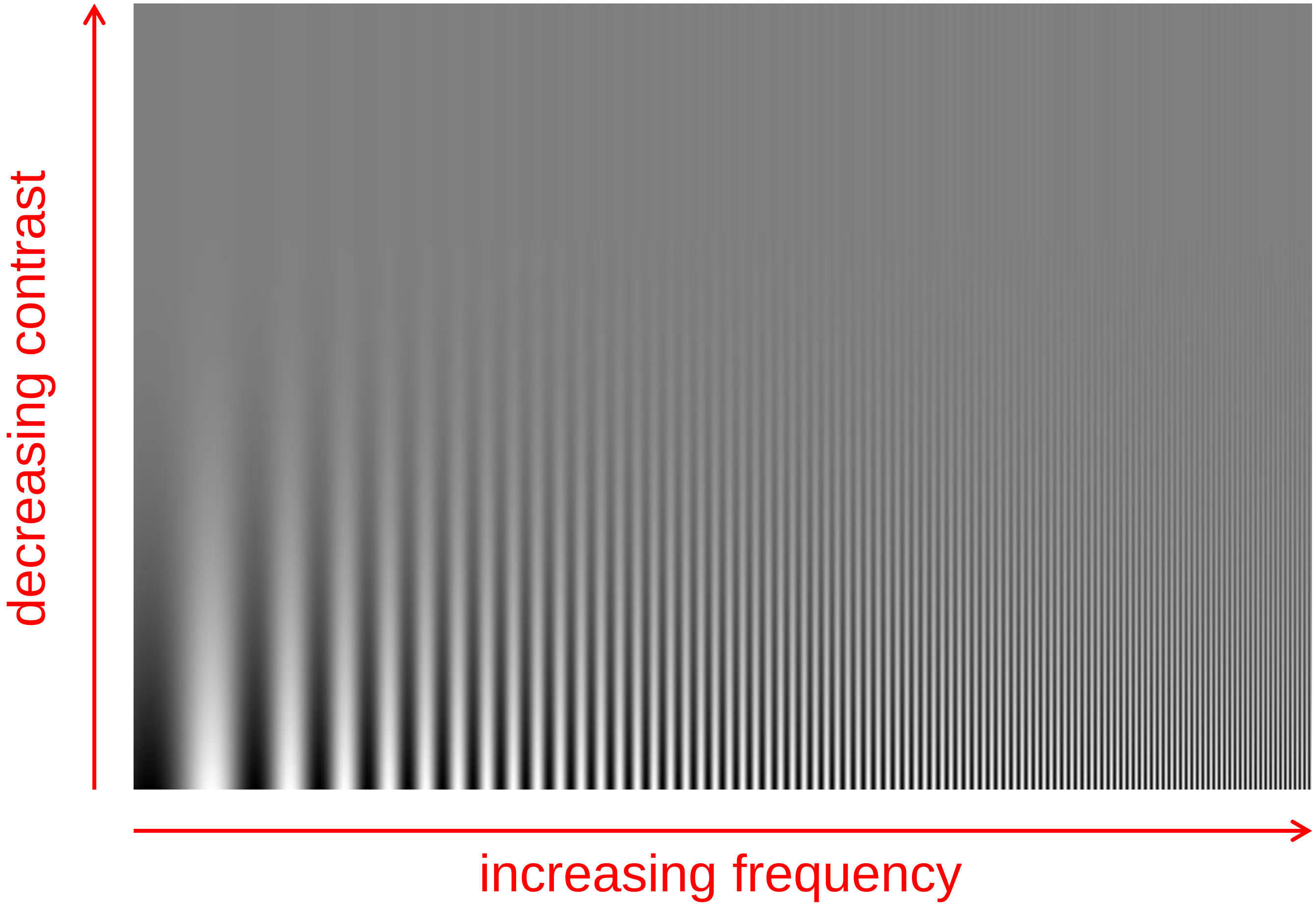


uniform in fact ≠
uniform in perception

Uniform Change in Intensity

uniform in fact ≠
uniform in perception

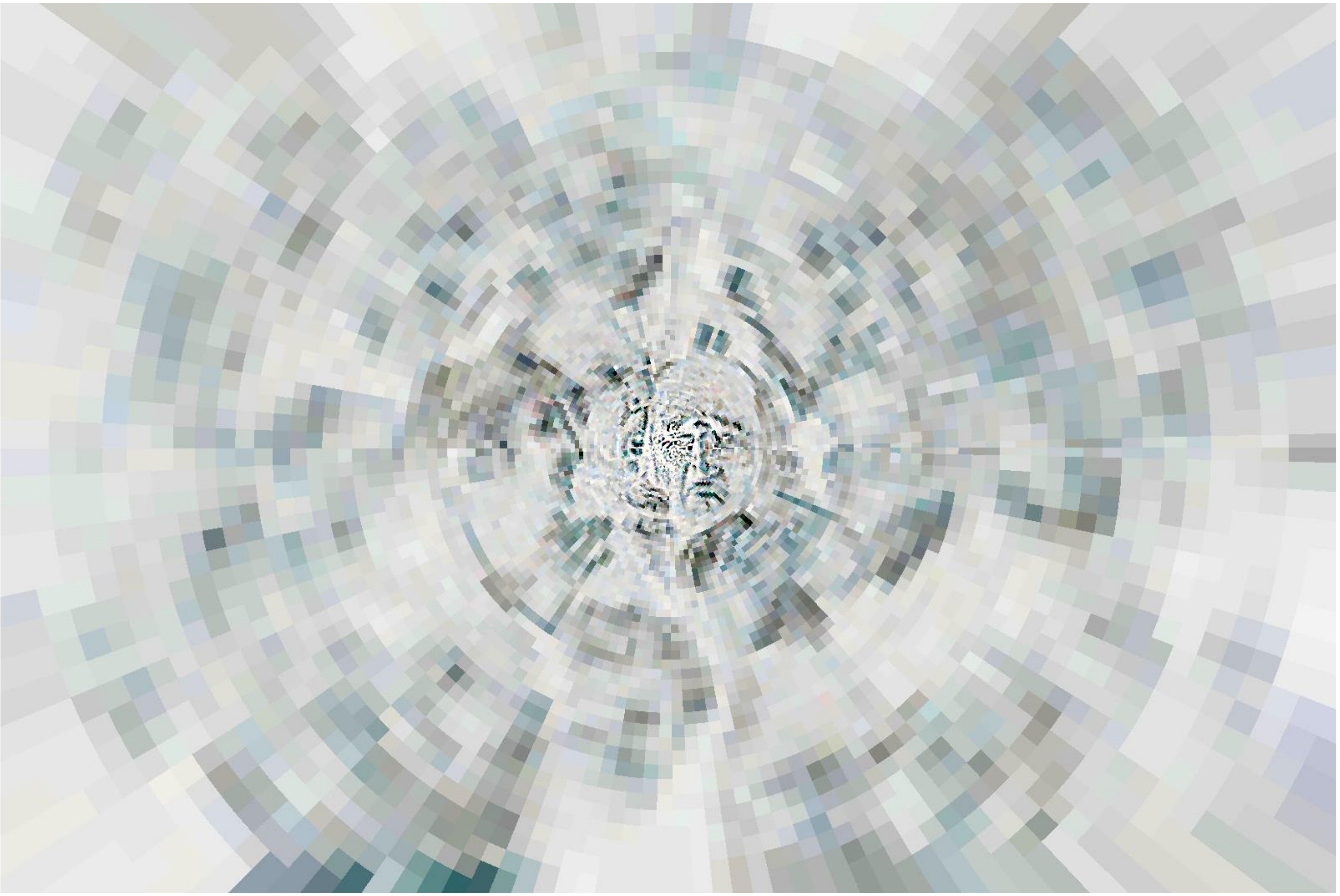
Uniform Change in Frequency and Contrast



Center Surround Retinal Edge Detection

Louis Boilly (1761-1845) Thirty-Six Faces of Expression. Photo negative of LoG output.

Space Variant Retinal Edge Detection



Louis Boilly (1761-1845) Thirty-Six Faces of Expression. Photo negative of LoG output.

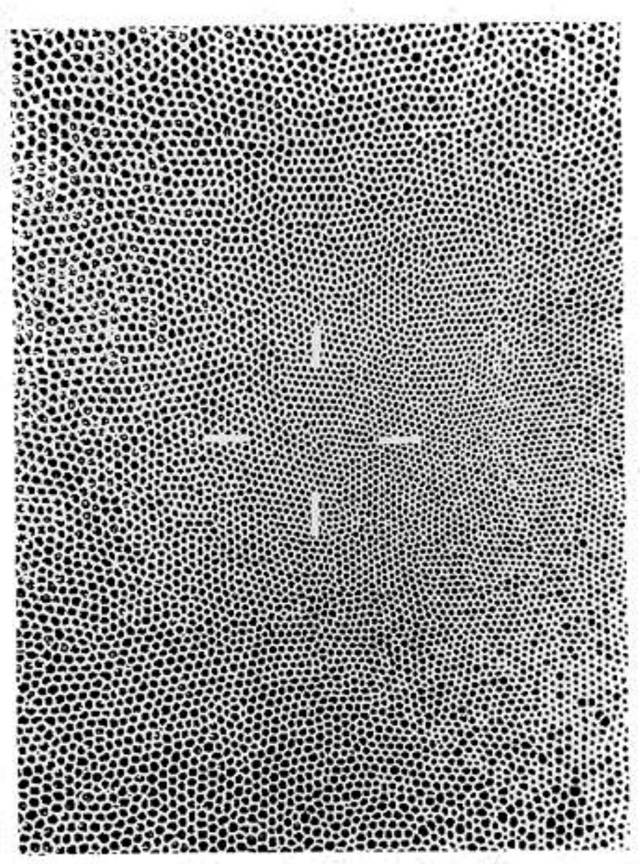
The Retinal Transform Minimizes Data Bandwidth

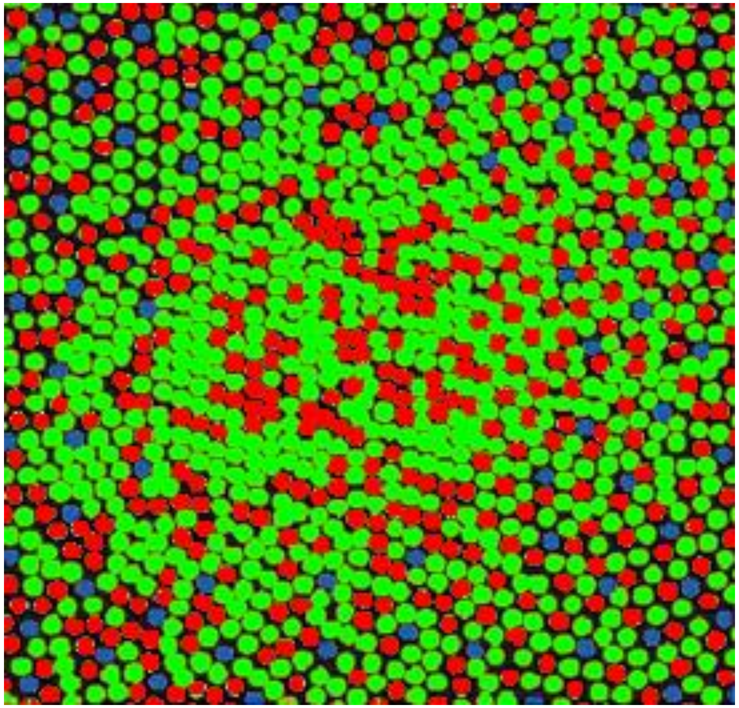
Louis Boilly (1761-1845) Thirty-Six Faces of Expression. Photo negative of LoG output.

This is the reduction in size from the full image to a compact multiresolution representation including the fovea (the disk) and the periphery.

Retinal Mosaic

Human retina:
#(R+G) receptors =
10 X #B receptors





Cepko, Connie, "Giving in to the blues", *Nature Genetics*, 24, 99 - 100 (2000)
cepko@genetics.med.harvard.edu

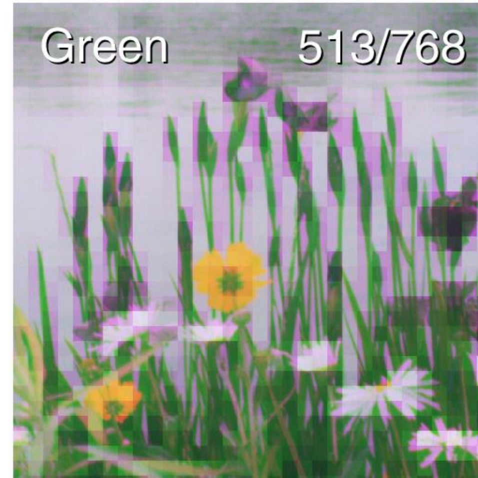
L – downsample factor
R – information content

Pixelization of Color Images: All Bands Equal

Photo: R. A. Peters II, 1998, The Lake, Central Park, NYC.

L – downsample factor
R – information content

16× Pixelization of Color Images: R, G, & B Bands



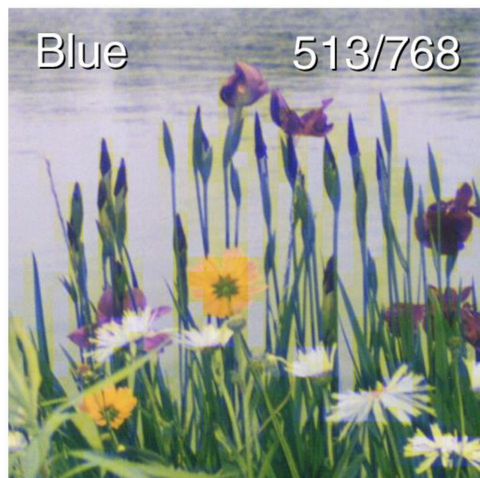
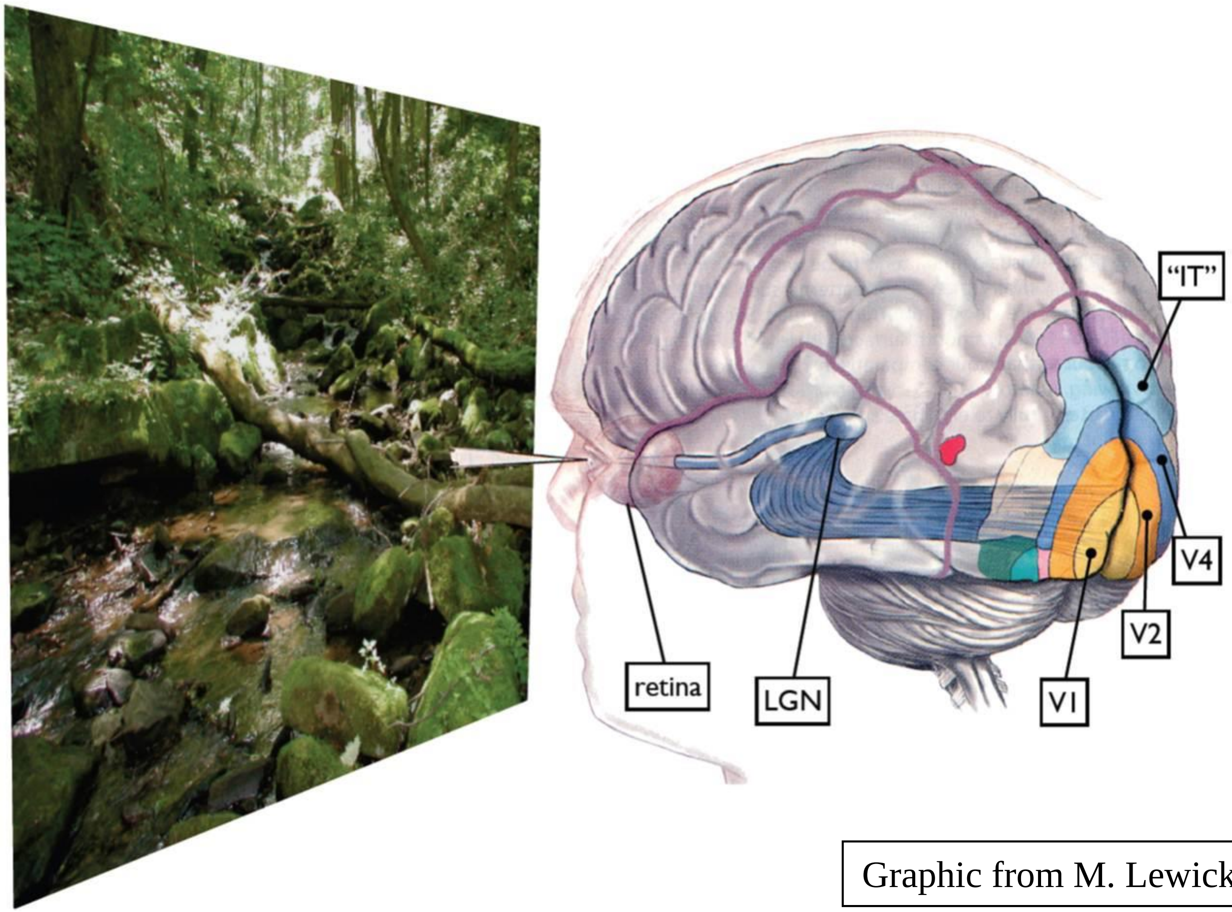


Photo: R. A. Peters II, 1998, The Lake, Central Park, NYC.

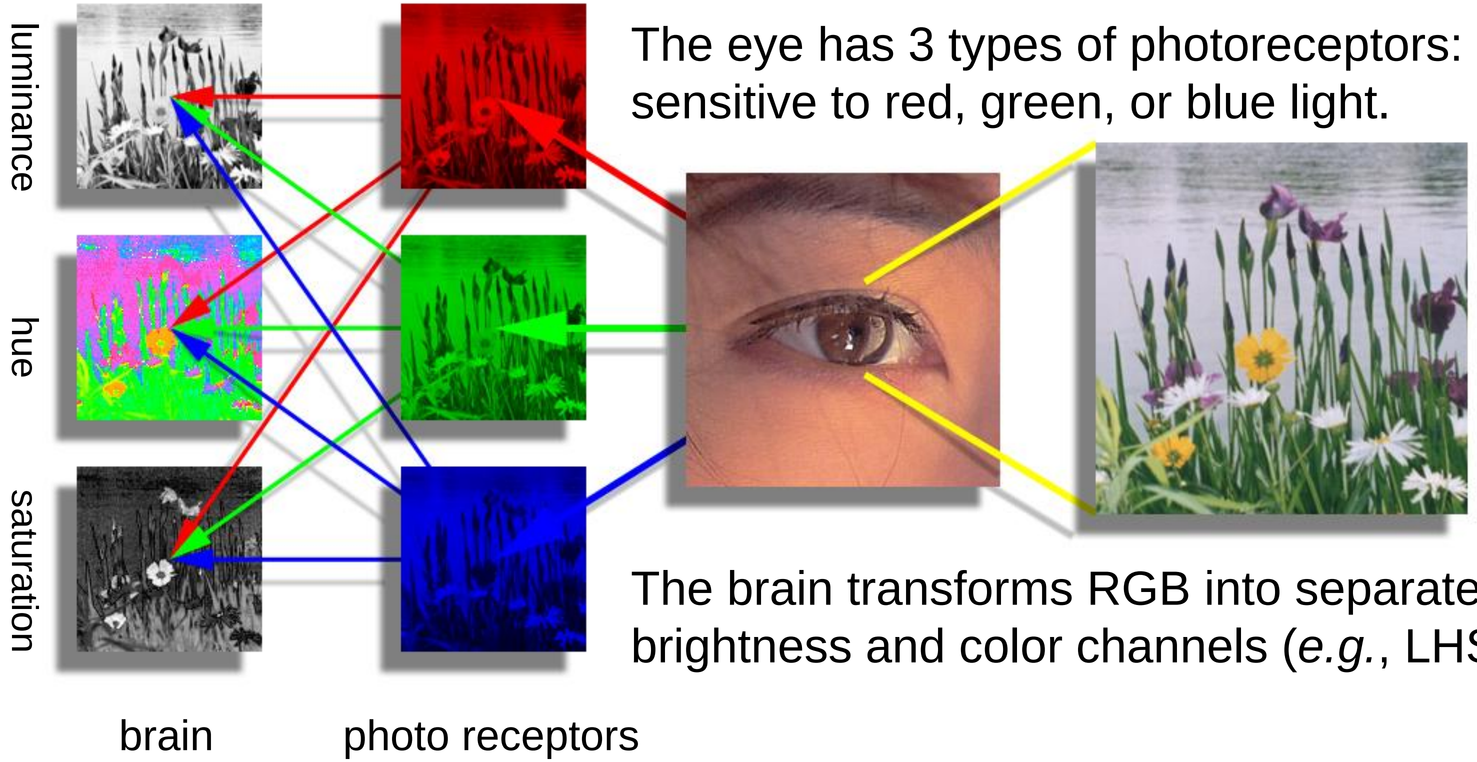
Visual Areas in the Brain

Retina: center-surround color feature detectors
LGN: (lateral geniculate nucleus) relay to V1; audio attention
V1: selective spatiotemporal filters
V2: feature aggregation
V3: visual attention
IT: (Inferior temporal gyrus) complex object features



Graphic from M. Lewicky

In the Brain: from RGB to LHS



The eye has 3 types of photoreceptors: sensitive to red, green, or blue light.

The brain transforms RGB into separate brightness and color channels (*e.g.*, LHS).

L – downsample factor
R – information content

16× Pixelization of Color Images: Luminance Only

Photo: R. A. Peters II, 1998, The Lake, Central Park, NYC.

L – downsample factor
R – information content

16× Pixelization of Color Images: Chrominance (H+S) Only

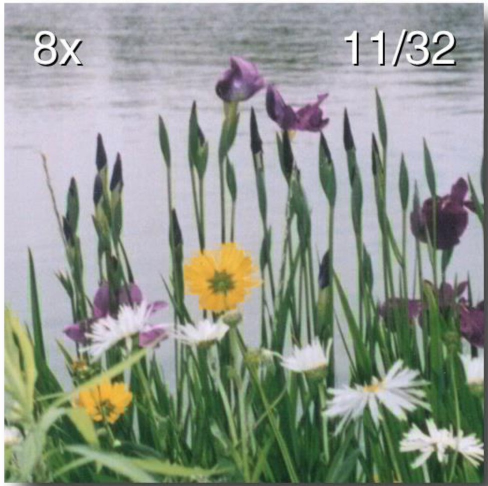


Photo: R. A. Peters II, 1998, The Lake, Central Park, NYC.

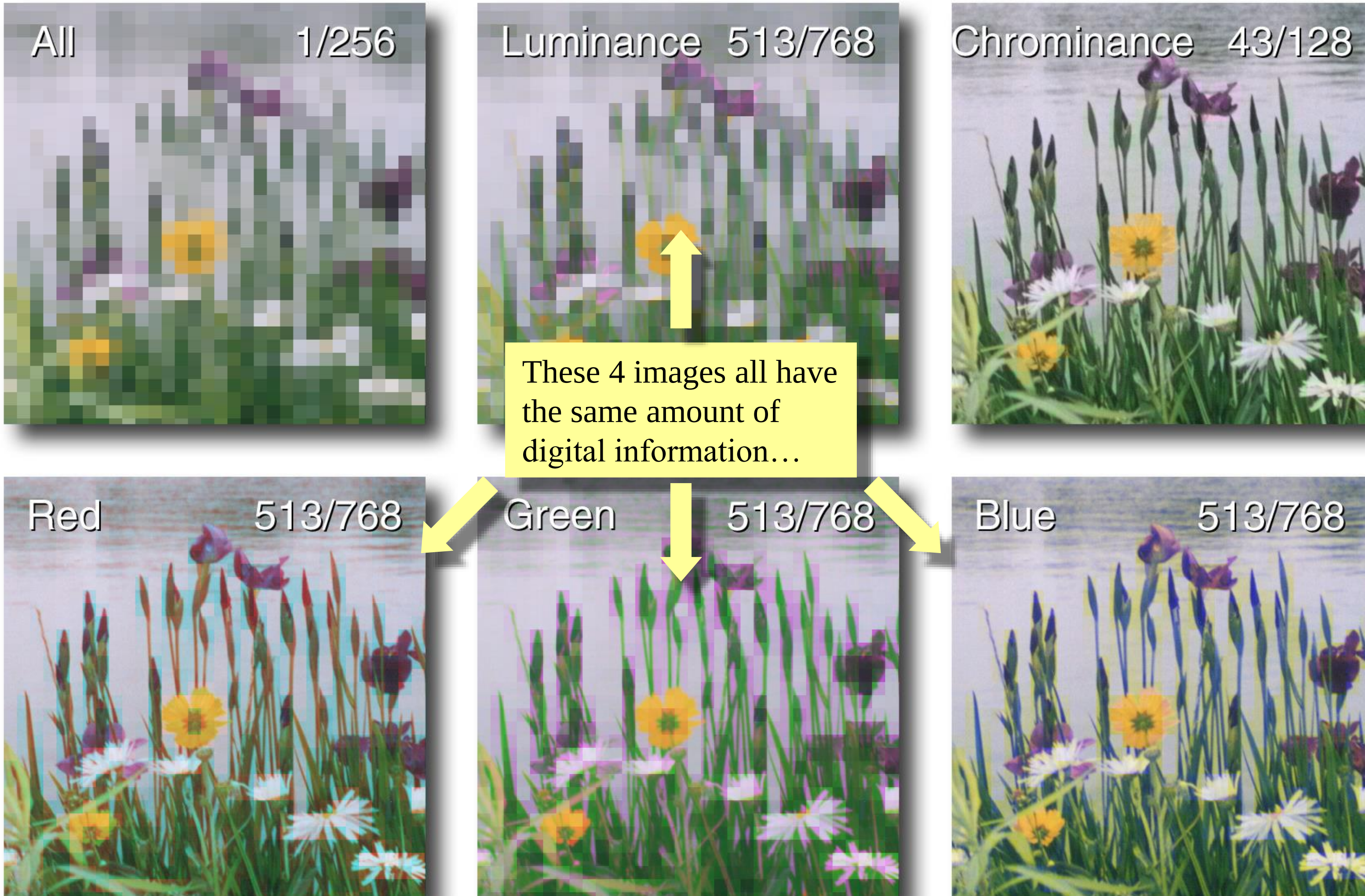
L – downsampled band
R – information content

16× Pixelization

Photo: R. A. Peters II, 1998, The Lake, Central Park, NYC.

L – downsampled band
R – information content

16× Pixelization



These 4 images all have the same amount of digital information…

Photo: R. A. Peters II, 1998, The Lake, Central Park, NYC.

L – downsampled band
R – information content

16× Pixelization

… but different visual information.

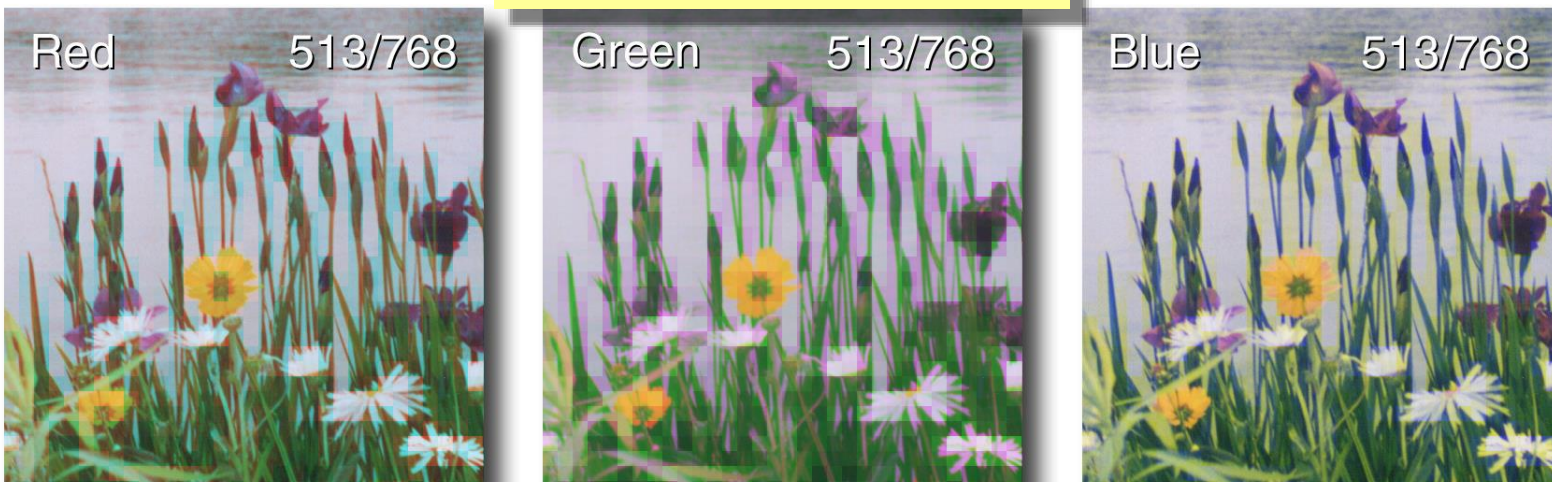
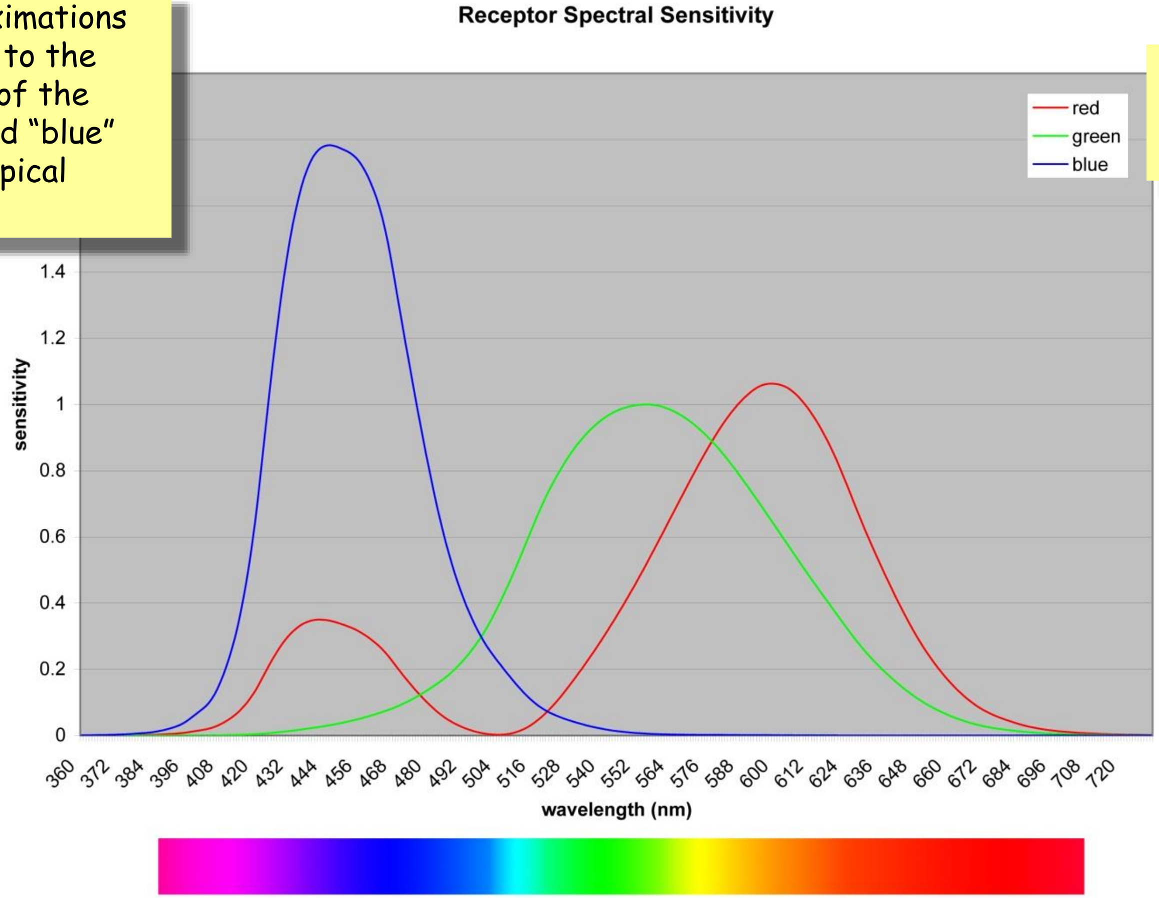


Photo: R. A. Peters II, 1998, The Lake, Central Park, NYC.

Color Sensing / Color Perception

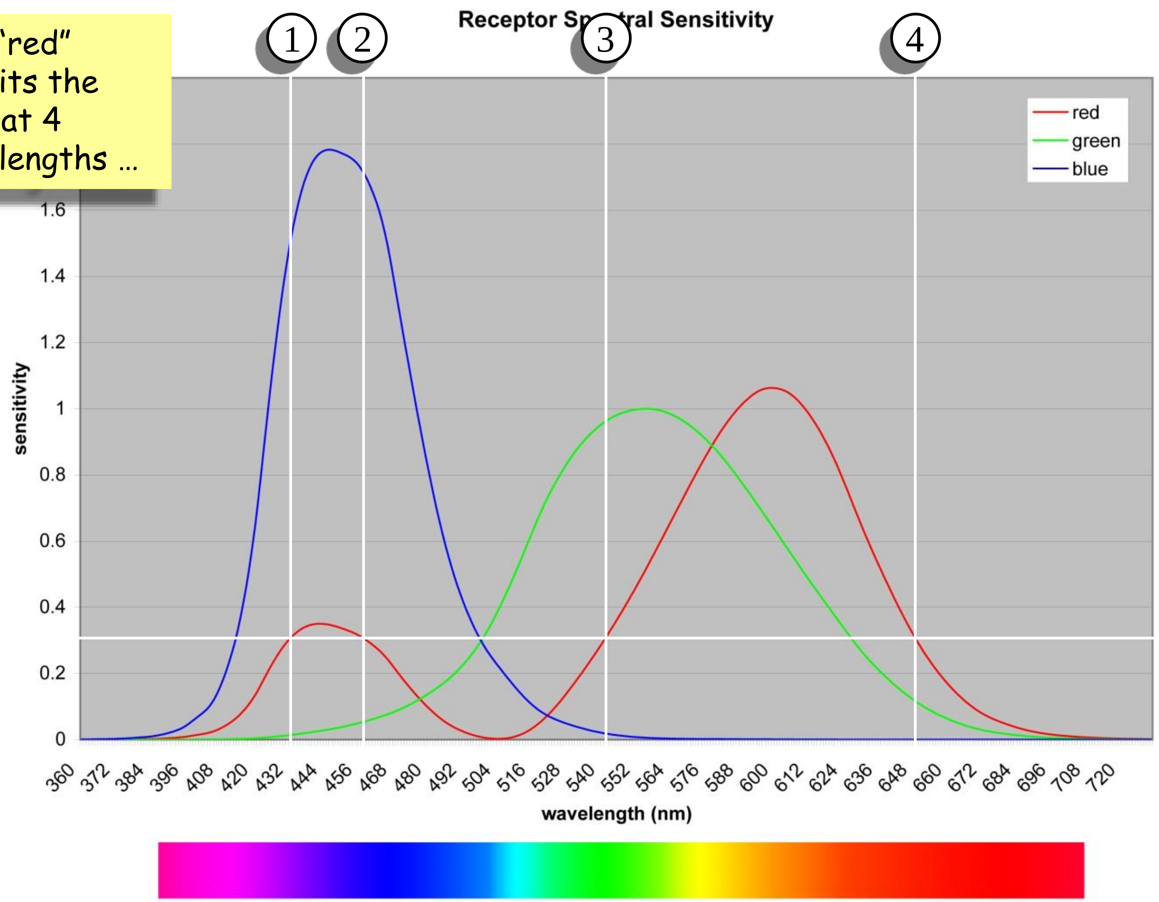
These are approximations of the responses to the visible spectrum of the "red", "green", and "blue" receptors of a typical human eye.



Called L, M, & S receptors in the bio-vision literature

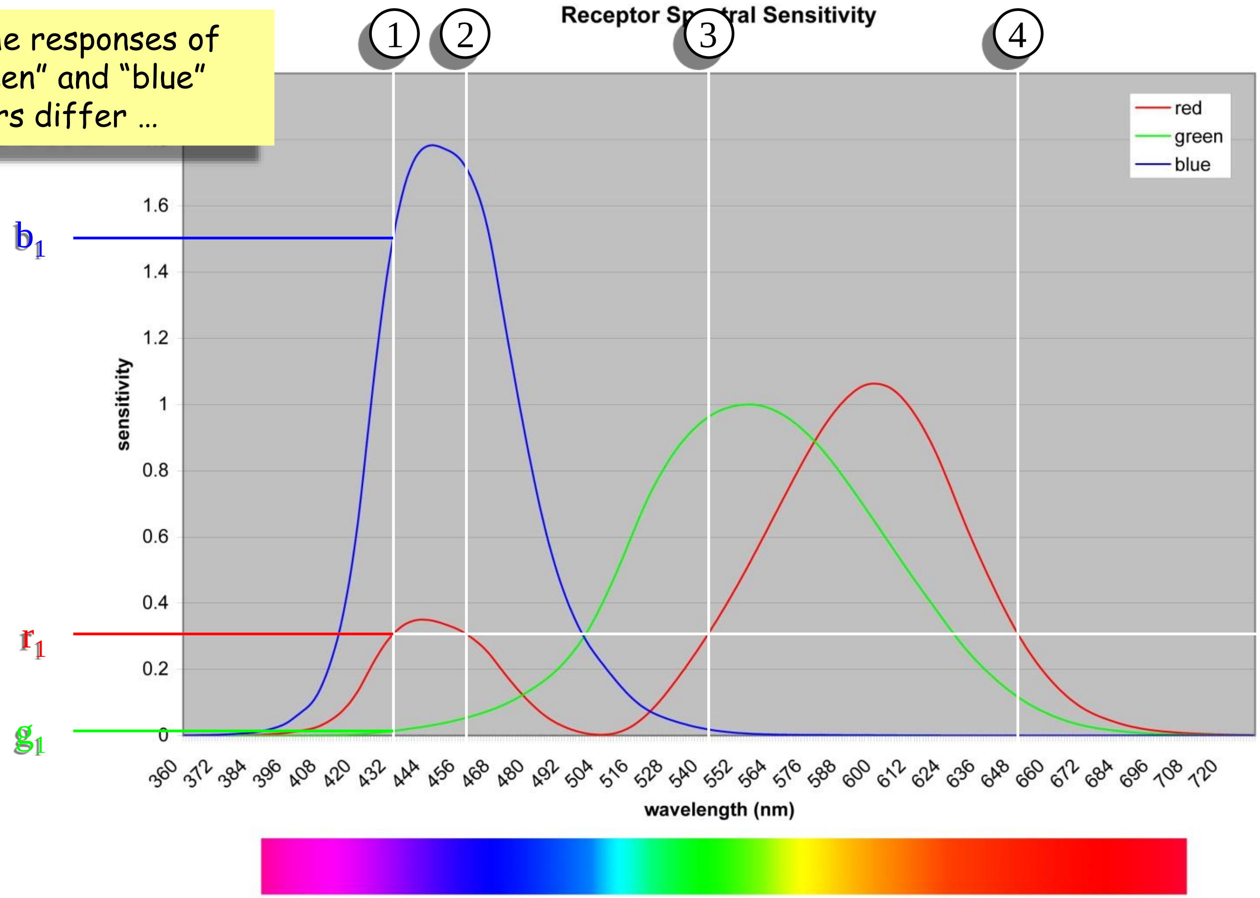
Color Sensing / Color Perception

Note that the “red” receptor exhibits the same response at 4 different wavelengths …



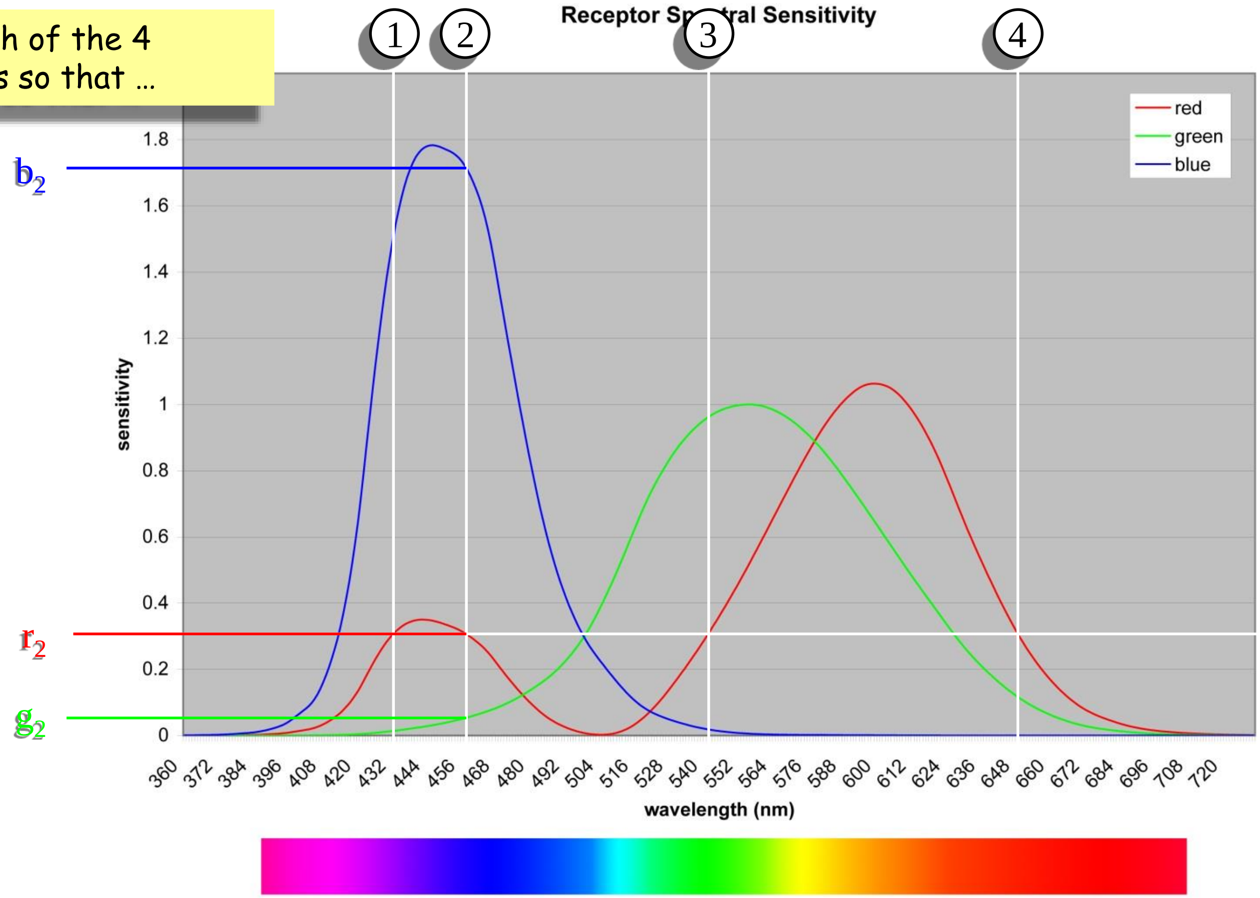
Color Sensing / Color Perception

… but the responses of the "green" and "blue" receptors differ …



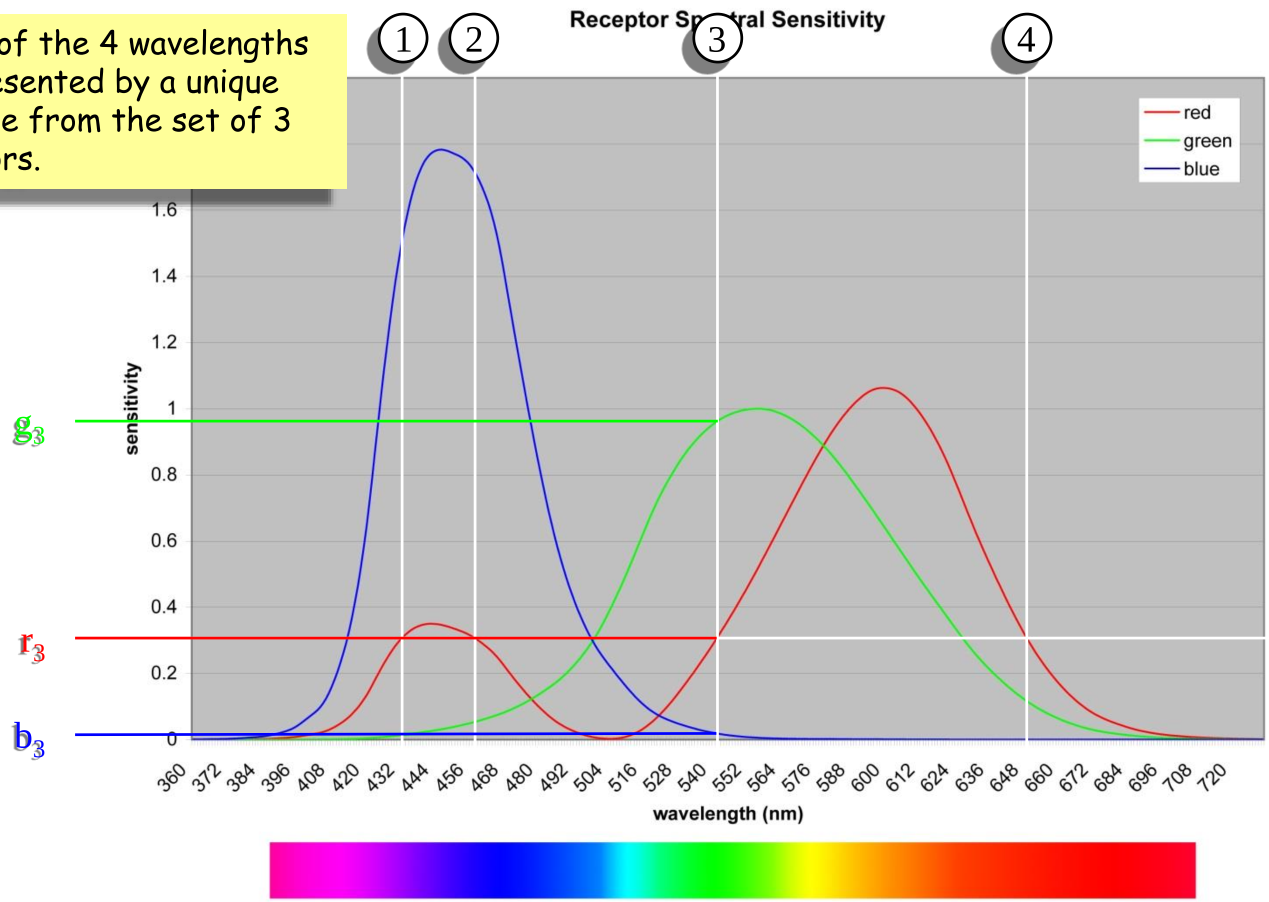
Color Sensing / Color Perception

… at each of the 4 locations so that …

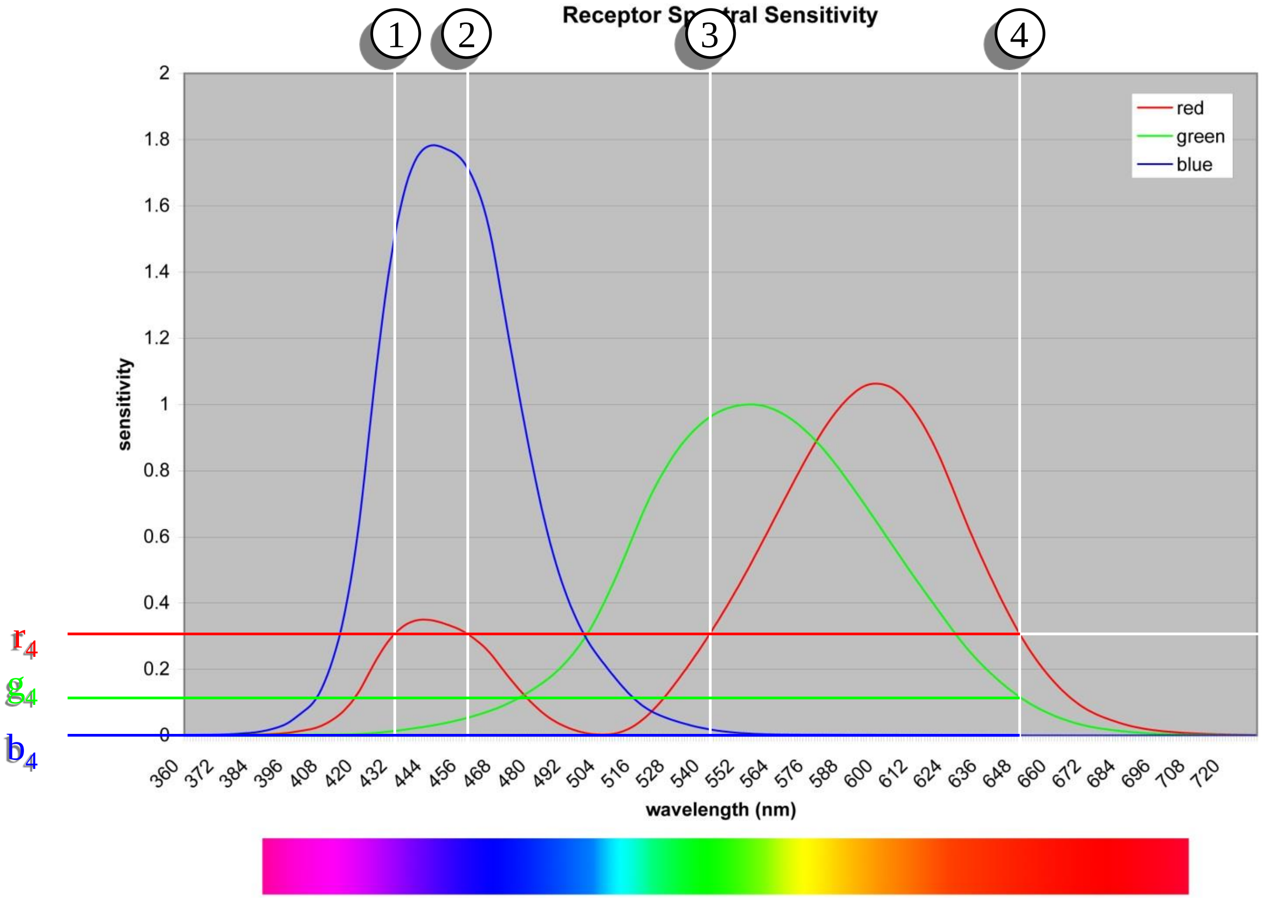


Color Sensing / Color Perception

… each of the 4 wavelengths is represented by a unique response from the set of 3 receptors.



Color Sensing / Color Perception



Color Sensing / Color Perception

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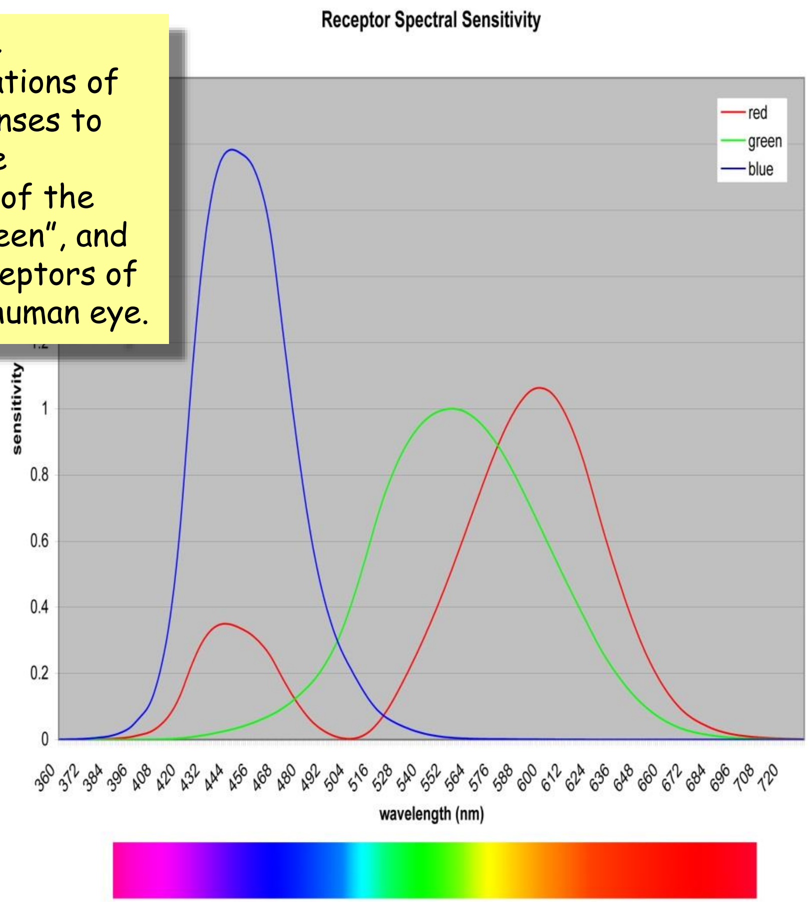
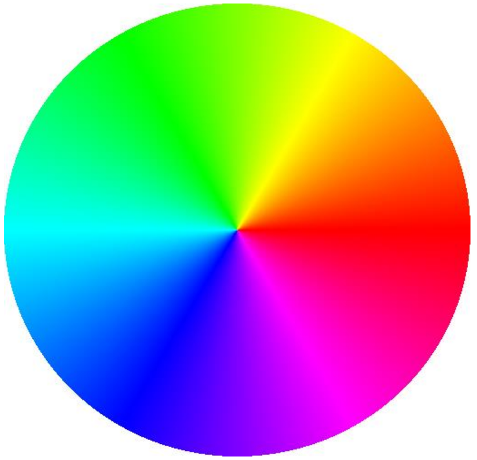
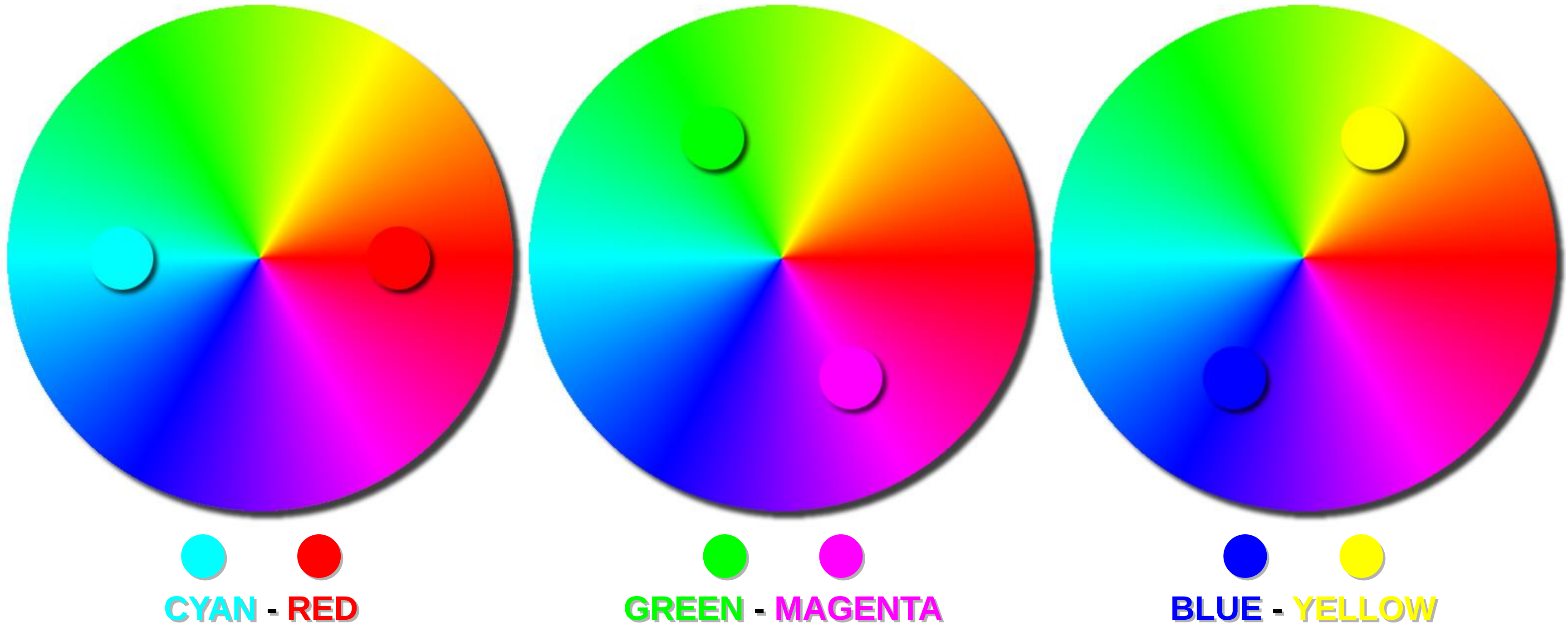




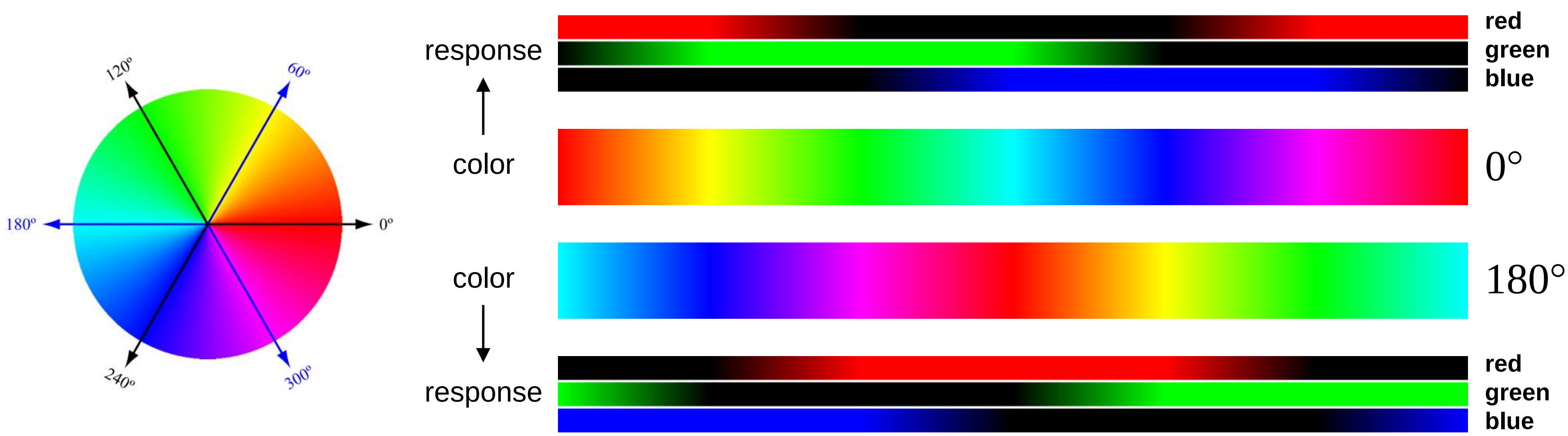
The simultaneous red + blue response causes us to perceive a continuous range of hues on a circle. No hue is greater than or less than any other hue.

Complementary Colors



Colors opposite each other on the color disk are called “complementary”.

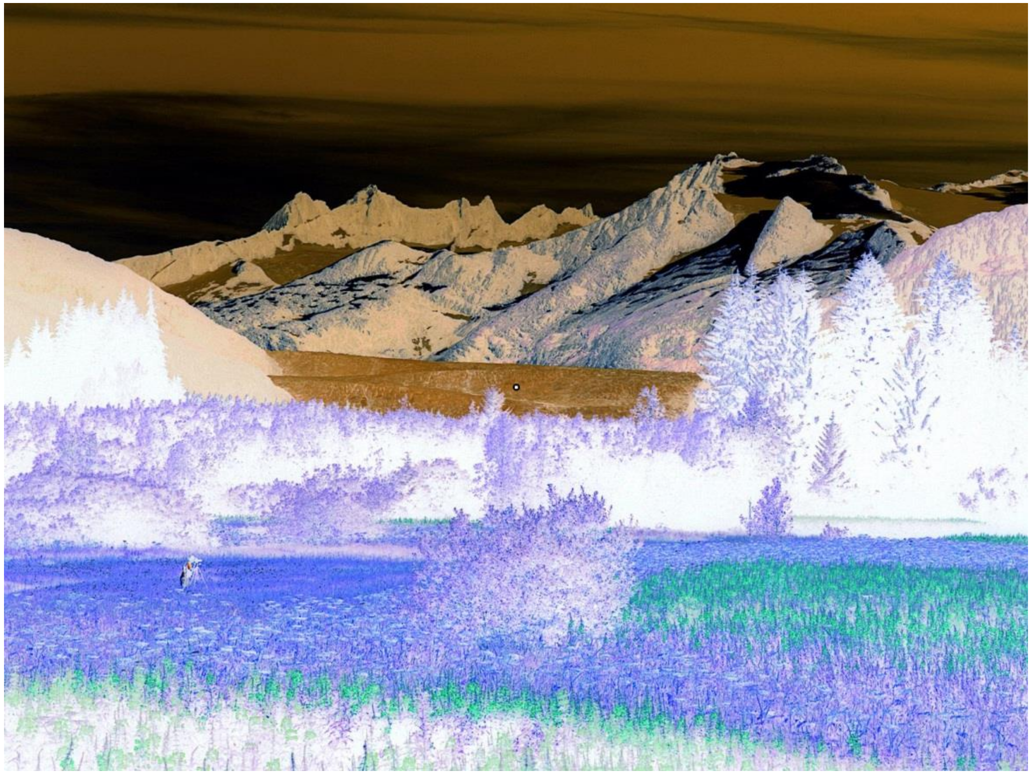
Complementary Colors



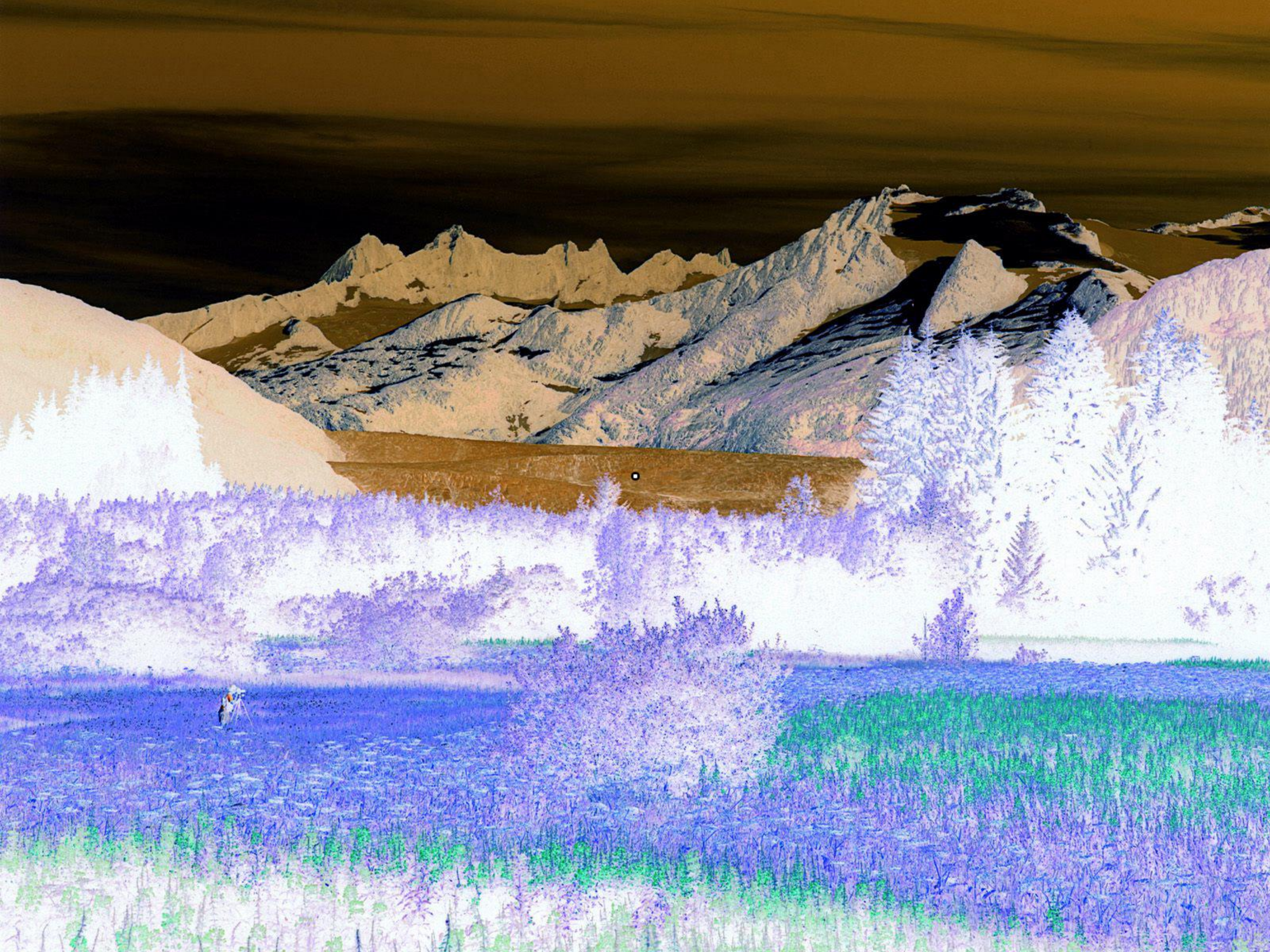
photoreceptor response is represented as proportional to brightness

To complementary colors, the response of the retina's photoreceptors is opposite.

Color Perception: The Afterimage Effect



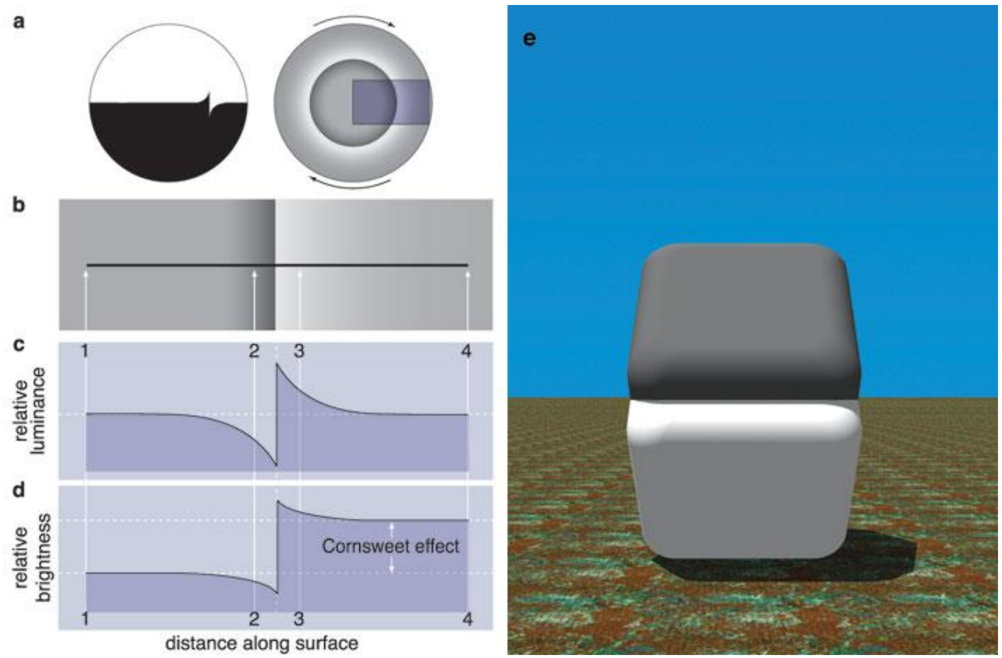
Stare at the dot in the center of the image



Color Perception: The Afterimage Effect

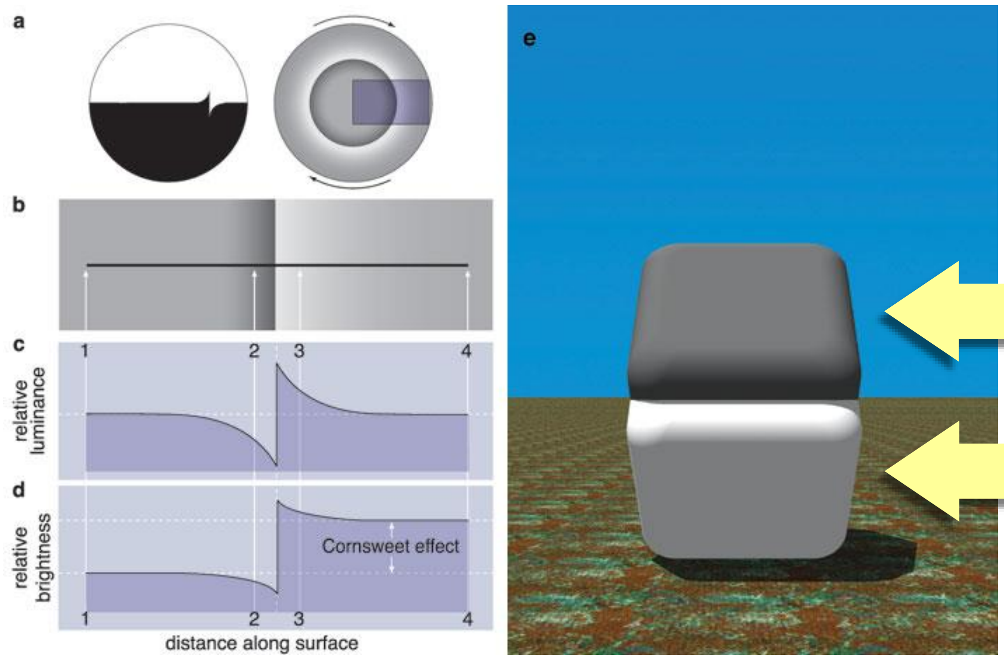
The color “negatives” saturate the local receptors so that when the color is removed the agonist (opposite) color receptors remain saturated.

Color Perception: the Cornsweet Effect



Dale Purves, R. Beau Lotto, Surajit Nundy, “Why We See What We Do”, *American Scientist*, Volume 90, No. 3, May-June 2002

Color Perception: the Cornsweet Effect



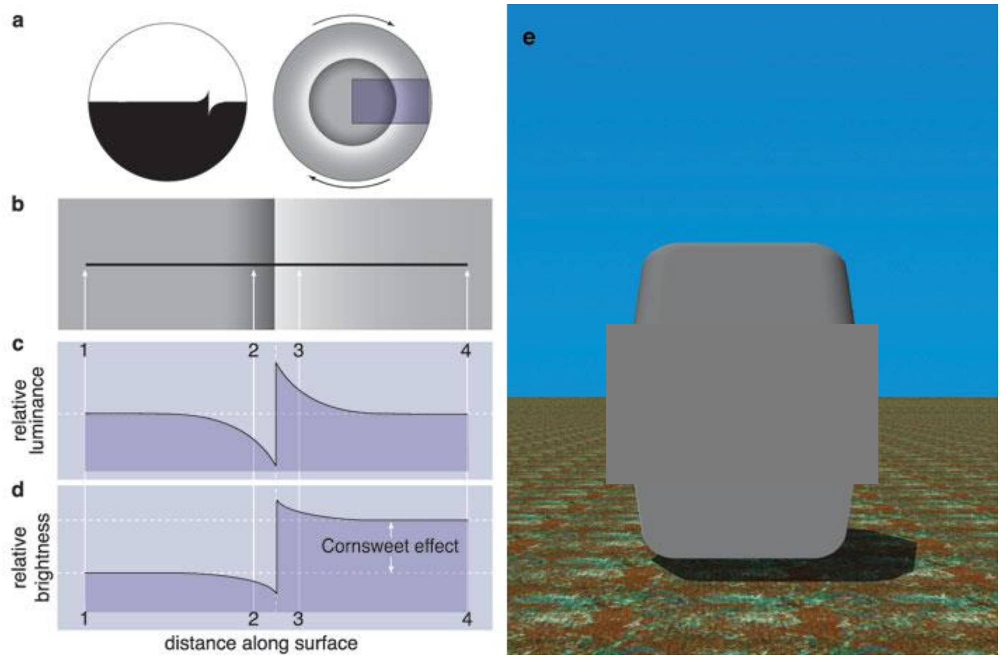
The top is darker…

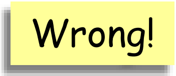
…than the bottom,

Right?

Dale Purves, R. Beau Lotto, Surajit Nundy, "Why We See What We Do", *American Scientist*, Volume 90, No. 3, May-June 2002

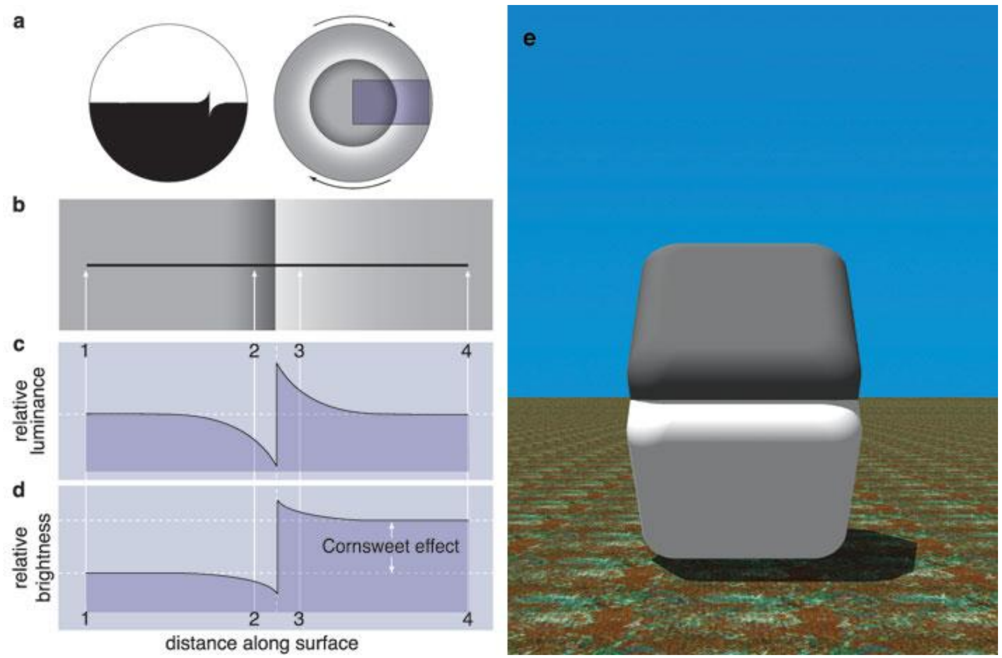
Color Perception: the Cornsweet Effect





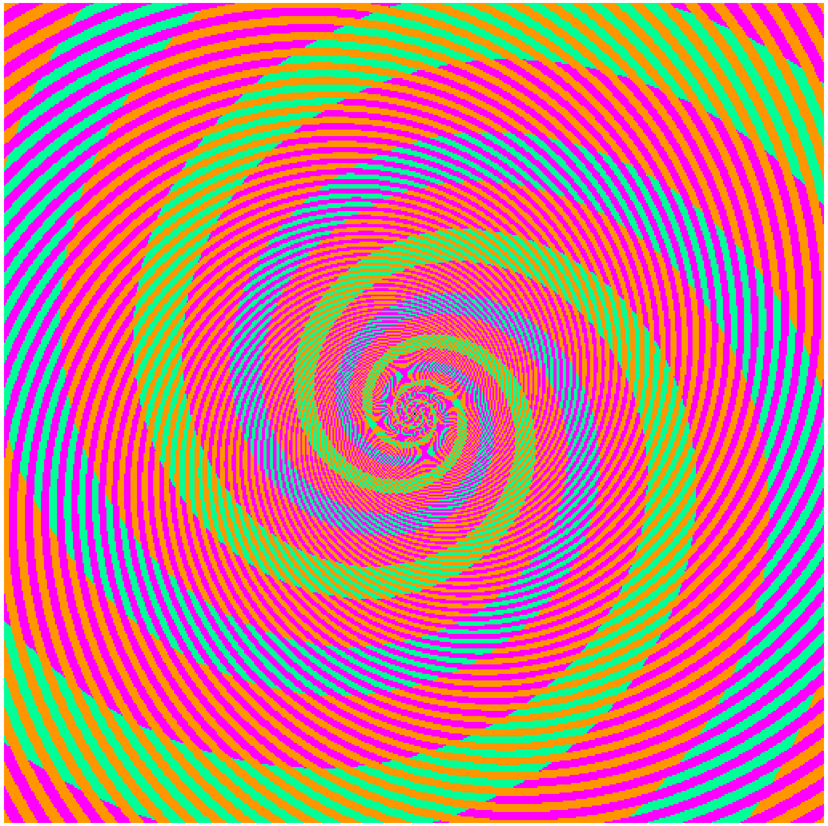
Dale Purves, R. Beau Lotto, Surajit Nundy, "Why We See What We Do", *American Scientist*, Volume 90, No. 3, May-June 2002

Color Perception: the Cornsweet Effect



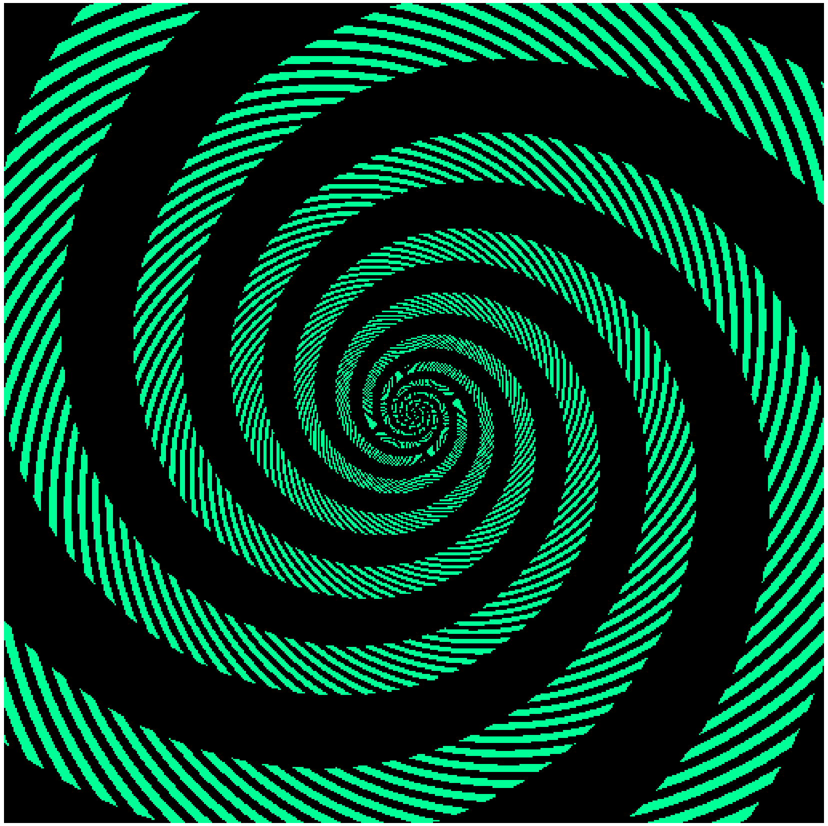
Dale Purves, R. Beau Lotto, Surajit Nundy, “Why We See What We Do”, *American Scientist*, Volume 90, No. 3, May-June 2002

Color Perception: the Munker Illusion



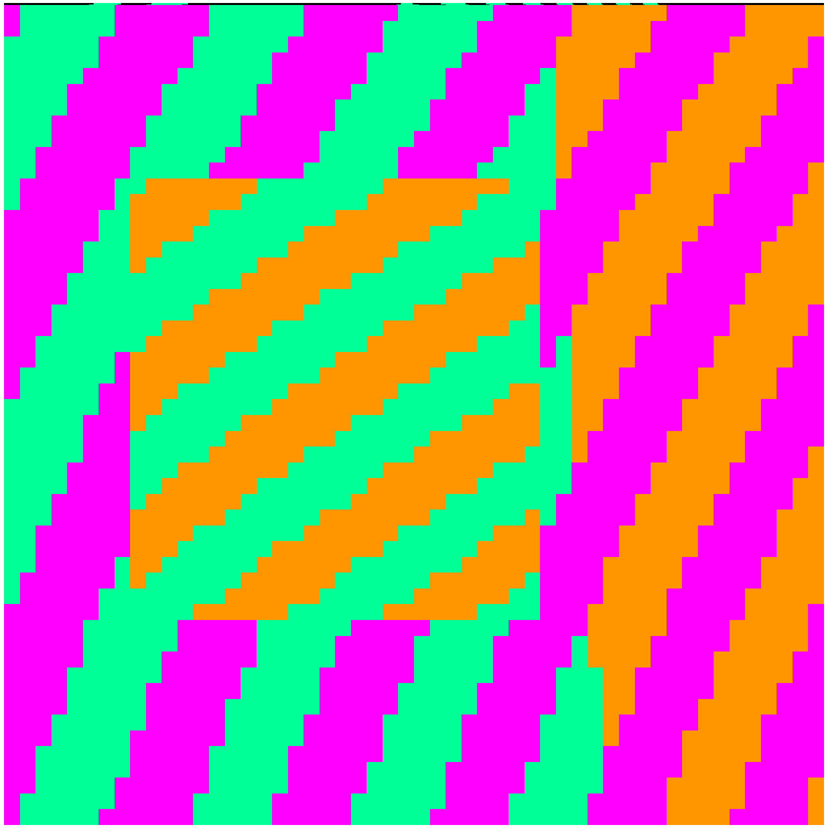
Blue and green spirals?

Color Perception: the Munker Illusion



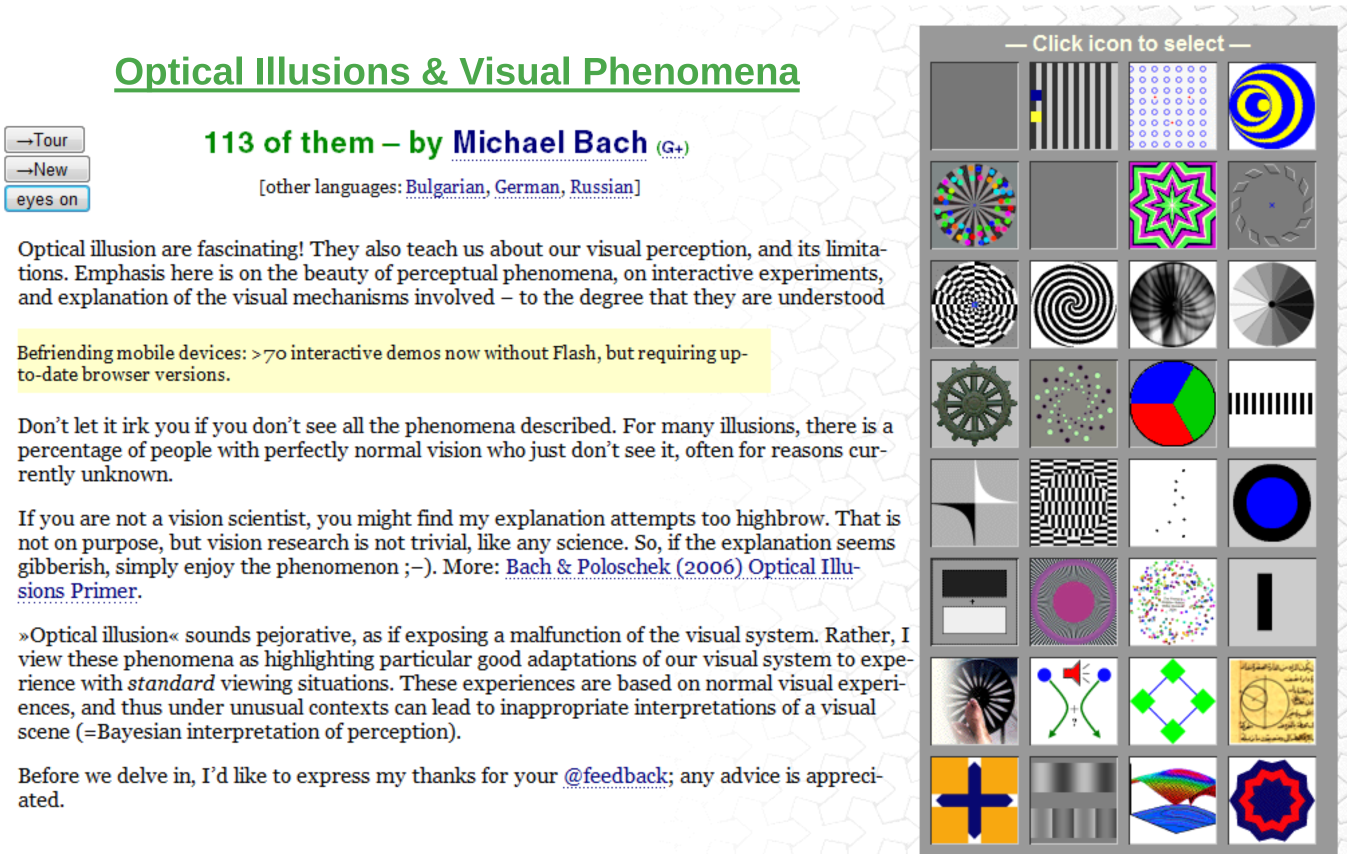
No. Blue-green spirals.

Color Perception: the Munker Illusion



No. Blue-green spirals.

An Excellent and Amusing Website



Optical Illusions & Visual Phenomena

→Tour
→New
eyes on

113 of them – by Michael Bach (G+)

[other languages: Bulgarian, German, Russian]

Optical illusion are fascinating! They also teach us about our visual perception, and its limitations. Emphasis here is on the beauty of perceptual phenomena, on interactive experiments, and explanation of the visual mechanisms involved – to the degree that they are understood

Befriending mobile devices: >70 interactive demos now without Flash, but requiring up-to-date browser versions.

Don't let it irk you if you don't see all the phenomena described. For many illusions, there is a percentage of people with perfectly normal vision who just don't see it, often for reasons currently unknown.

If you are not a vision scientist, you might find my explanation attempts too highbrow. That is not on purpose, but vision research is not trivial, like any science. So, if the explanation seems gibberish, simply enjoy the phenomenon ;–). More: Bach & Poloschek (2006) Optical Illusions Primer.

»Optical illusion« sounds pejorative, as if exposing a malfunction of the visual system. Rather, I view these phenomena as highlighting particular good adaptations of our visual system to experience with *standard* viewing situations. These experiences are based on normal visual experiences, and thus under unusual contexts can lead to inappropriate interpretations of a visual scene (=Bayesian interpretation of perception).

Before we delve in, I'd like to express my thanks for your @feedback; any advice is appreciated.

— Click icon to select —