# Image Processing

Lecture Notes on Color Perception

Kai-Lung Hua

## The Eye

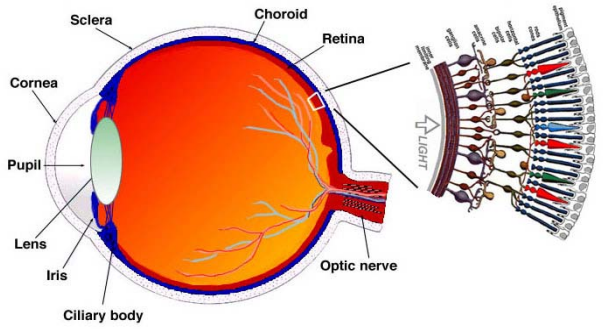



*Fig. 1.1. A drawing of a section through the human eye with a schematic enlargement of the retina.*

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

# The Retina

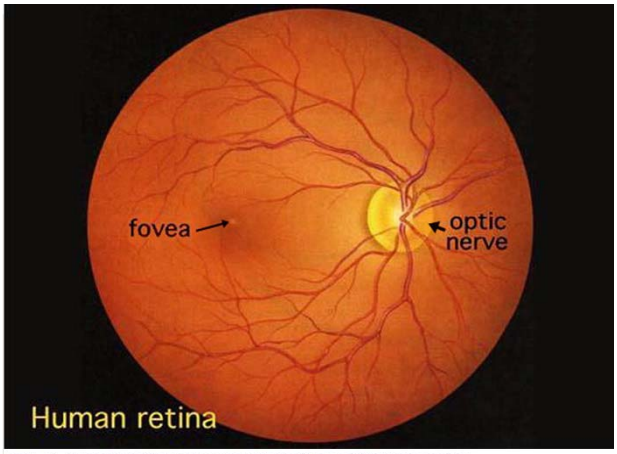



*Fig. 1. Human retina as seen through an opthalmoscope.*

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



# The Retina

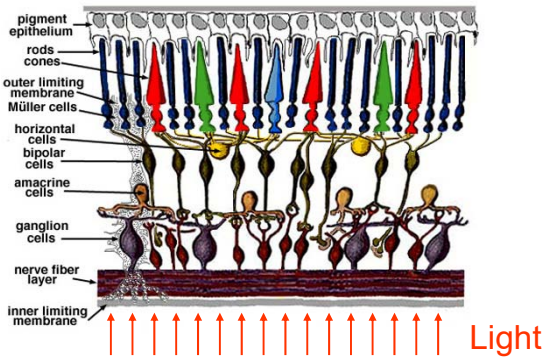



*Fig. 2. Simple diagram of the organization of the retina.*

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

# Photoreceptor Densities

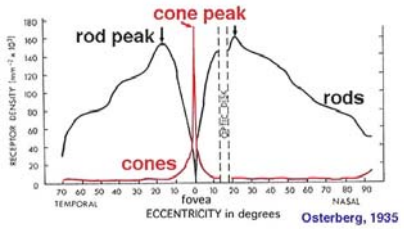



*Fig. 20. Graph to show rod and cone densities along the horizontal meridian.*

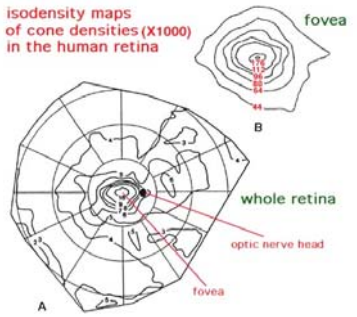
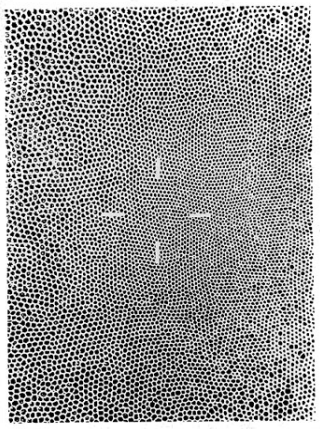


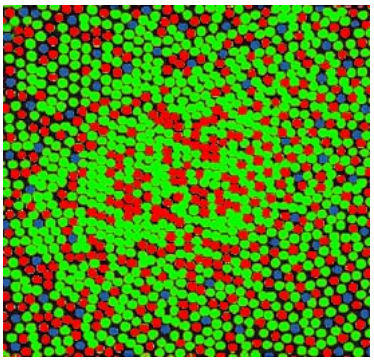

*Fig. 21. Cone densities in human retina as revealed in whole mount. The foveal area is enlaged in B. (from Curcio et al., 1987).*

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



# Retinal Mosaic





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

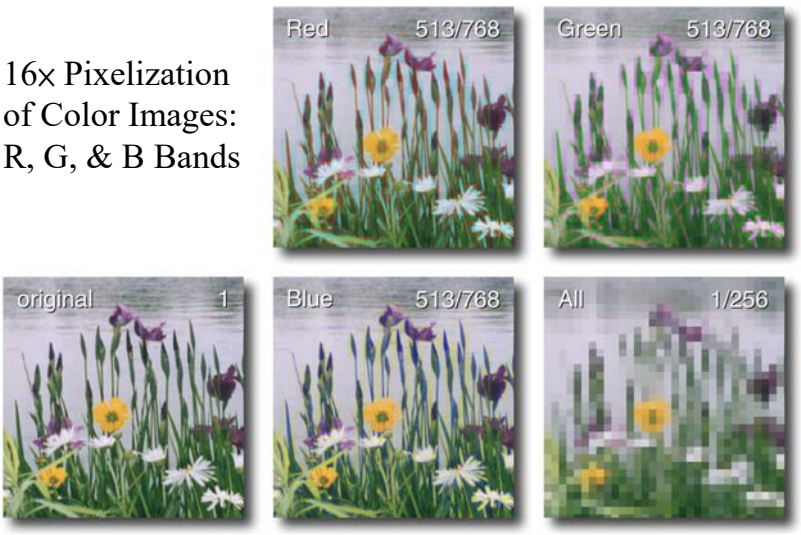
L – downsample factor
R – information content

## Pixelization of Color Images: All Bands Equal

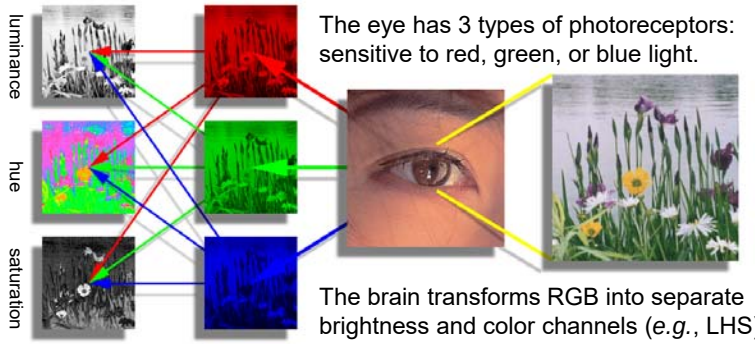



L – downsampled band
R – information content

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



## 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

## 16x Pixelization of Color Images: Luminance Only

L – downsample factor
R – information content

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




L – downsampled band
R – information content

16× Pixelization

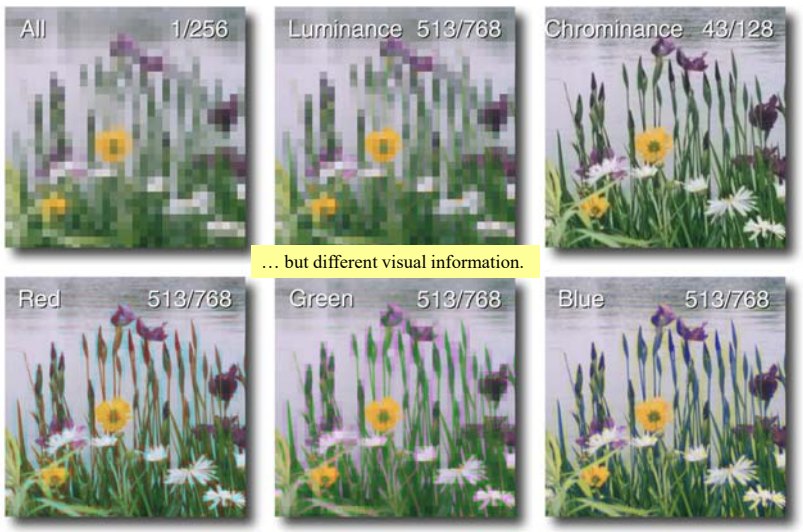
L – downsampled band
R – information content

16x Pixelization



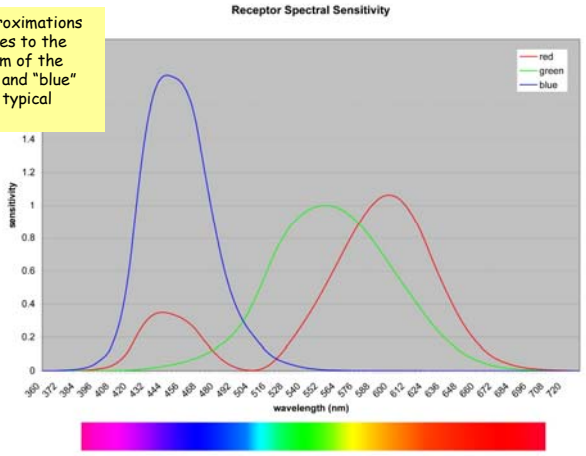

L – downsampled band
R – information content

16x Pixelization



# Color Sensing / Color Perception

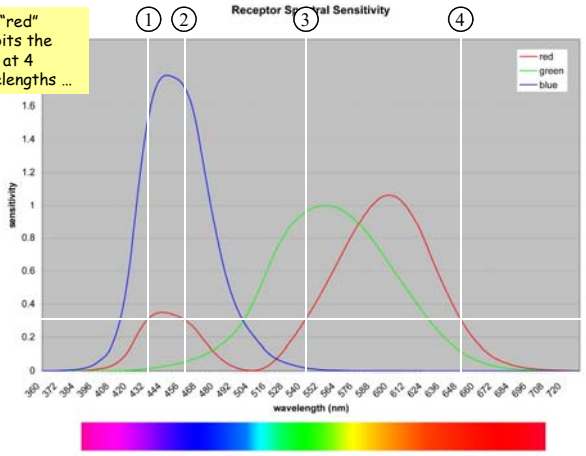
These are approximations of the responses to the visible spectrum of the "red", "green", and "blue" receptors of a typical human eye.





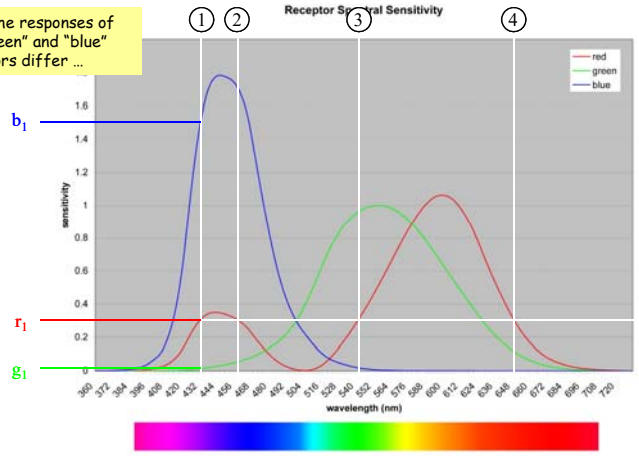

# Color Sensing / Color Perception

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



# Color Sensing / Color Perception

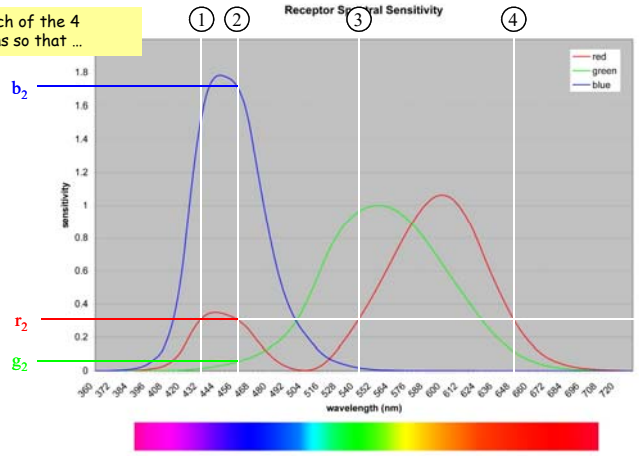
… but the responses of the "green" and "blue" receptors differ …





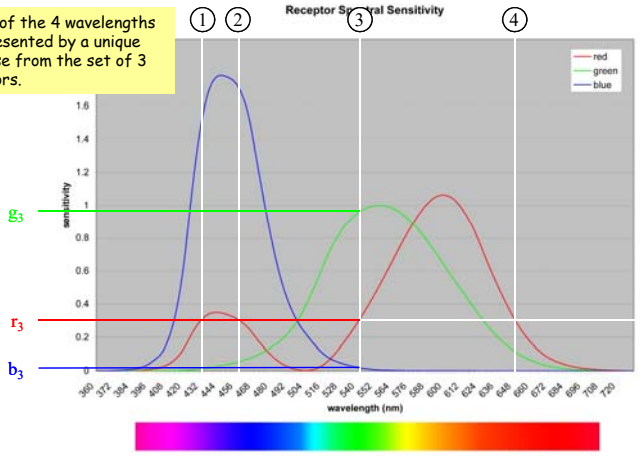

# Color Sensing / Color Perception

… at each of the 4 locations so that …



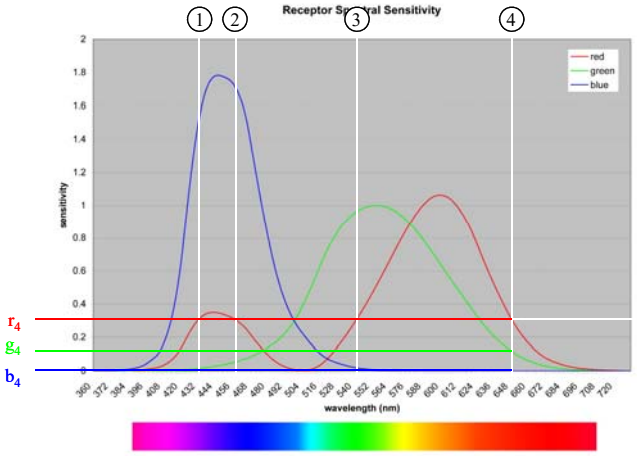
# Color Sensing / Color Perception

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



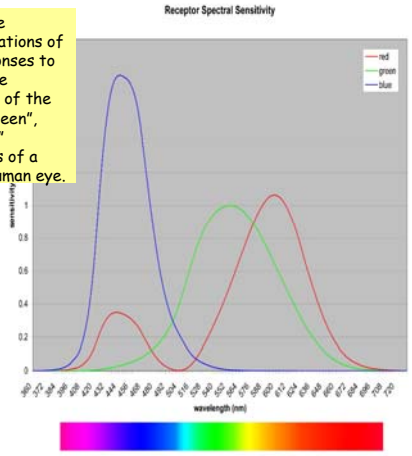


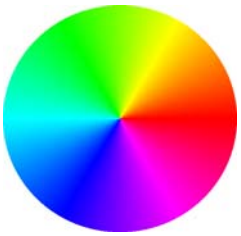

# Color Sensing / Color Perception



## Color Sensing / Color Perception

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



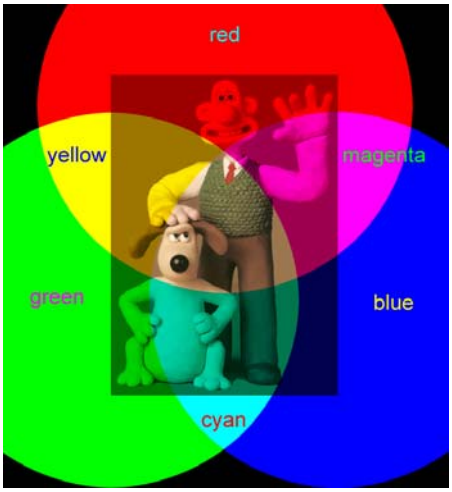



The simultaneous red + blue response causes us to perceive a continuous range of hues on a circle. No hue is greater than or less than any other hue.

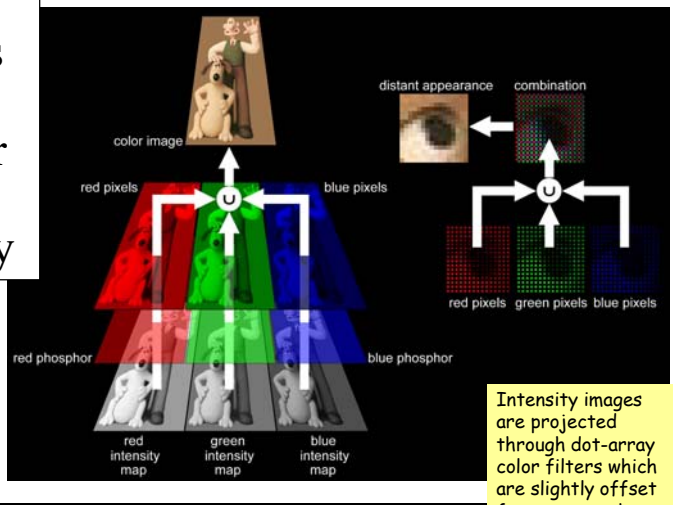


## Color Images

- 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




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



# 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

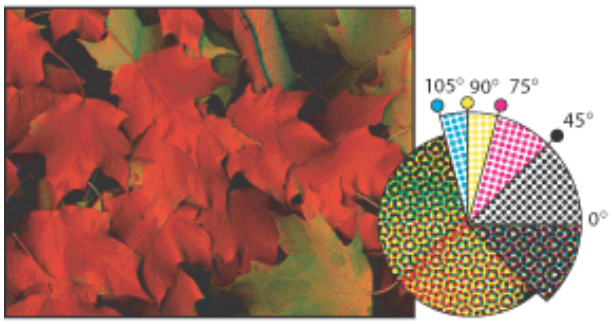

The four colors are magenta, cyan, yellow, and black



# Standard Halftone Screen Angles

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

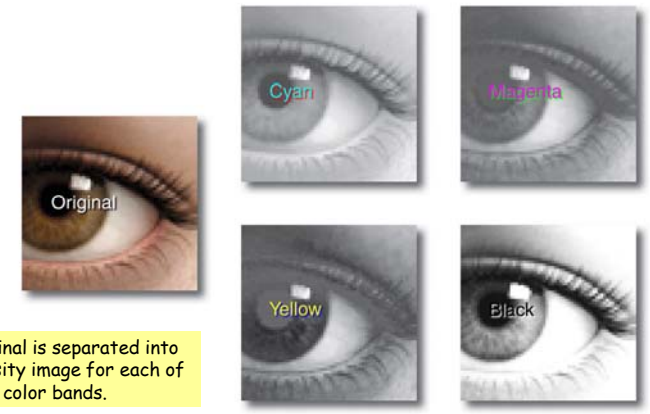
| | |
|---|---|
| Cyan: | 105° |
| Yellow: | 90° |
| Magenta: | 75° |
| Black: | 45° |




The screens are oriented at different angles.

The resulting patterns are called "rosettes".

# Color Separation / Halftoning



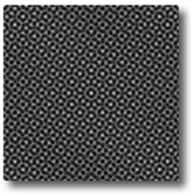

The original is separated into an intensity image for each of the four color bands.



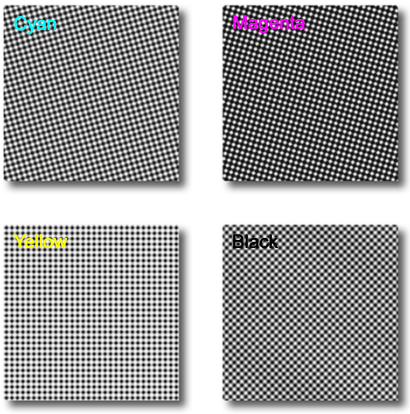
# Color Separation / Halftoning

# Color Separation / Halftoning

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



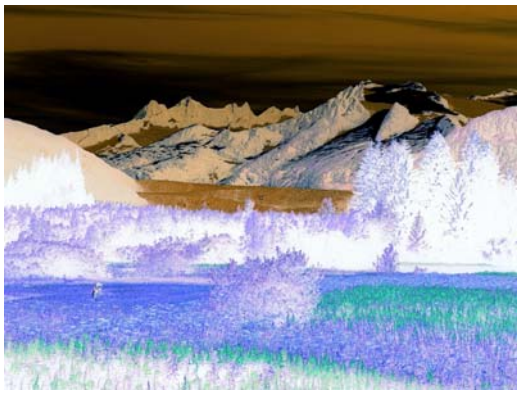
Each screened image is printed in its own color on the same page.





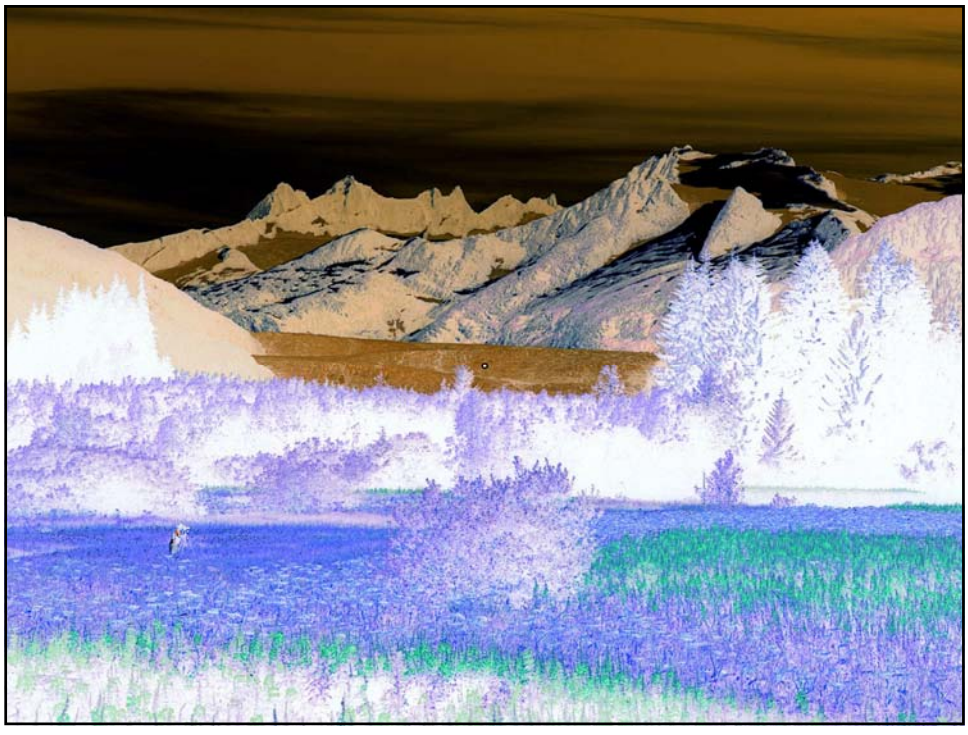

# Color Separation / Halftoning

# Color Perception: The Afterimage Effect



Stare at the dot in the center of the image



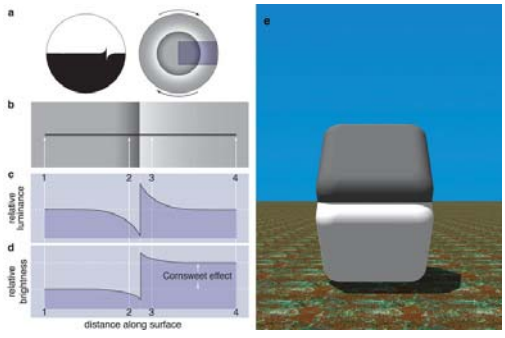


# Color Perception: The Afterimage Effect

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

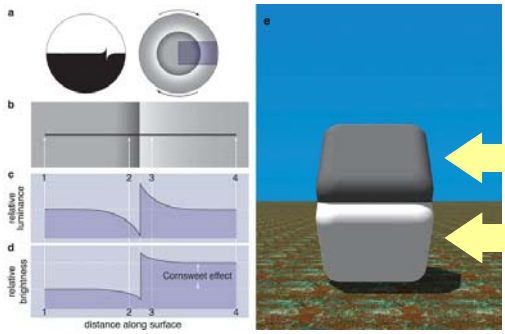


# Color Perception: the Cornsweet Effect




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…

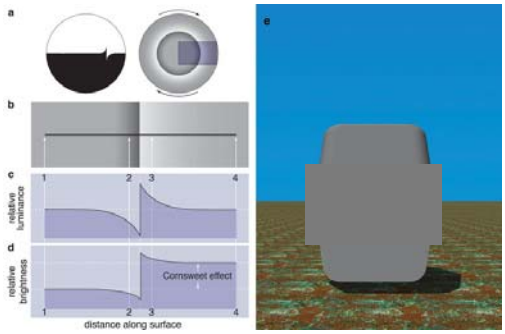
…than the bottom,

Right?

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



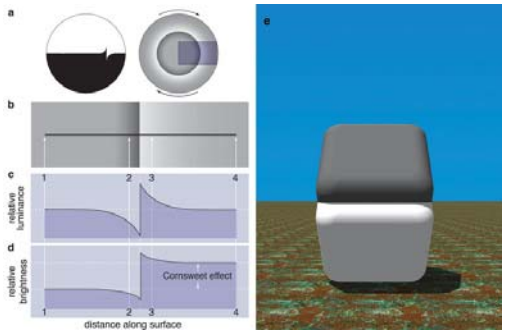
# Color Perception: the Cornsweet Effect




Wrong!

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

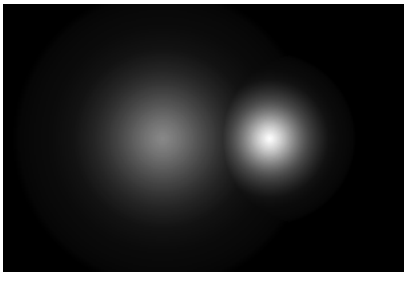
# Color Perception: the Cornsweet Effect



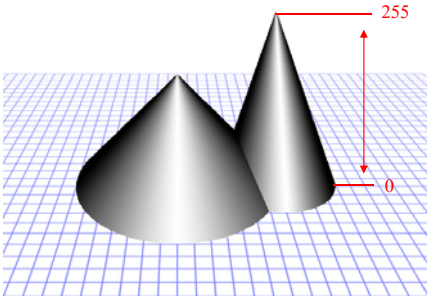

Dale Purves, R. Beau Lotto, Surajit Nundy, "Why We See What We Do", *American Scientist*, Volume 90, No. 3, May-June 2002



# Brightness Perception



image




intensity profile

Linear intensity changes are not seen as such.

# Brightness Perception

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.