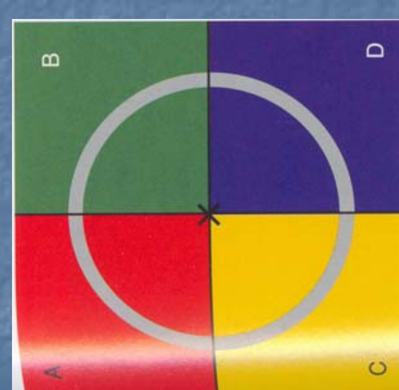
Trichromatic Theory Cannot Explain

- Complementary after images
  - Red and green complements
  - Blue and yellow complements

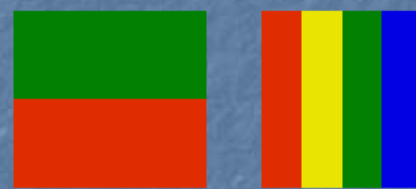
Trichromatic Theory Cannot Explain

- Simultaneous Color Contrast
- Visualizing colors



Chromatic Adaptation

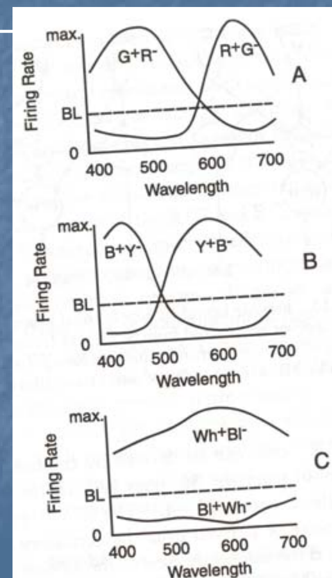
- Patterns on right
- Ganzfeld
  - Experiment with ping pong ball



Opponent-Process Theory

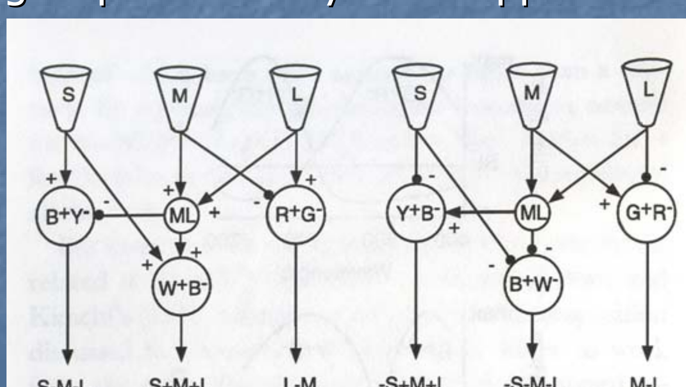
Opponent Theory

- Hering proposed six types of cells
- Long time struggle between trichromatic and opponent theory
- In 1965, such cells were found in our LGN (not eye, as Hering proposed)

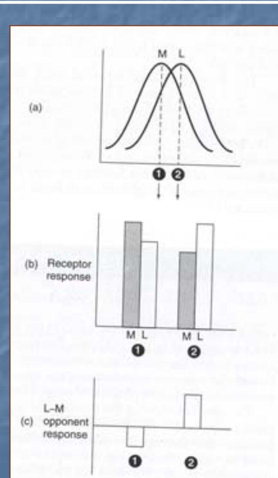


Opponent Theory

- How does signal from S, M and L cones gets processed by these opponent cells



Why Opponent Theory?



Adaptation

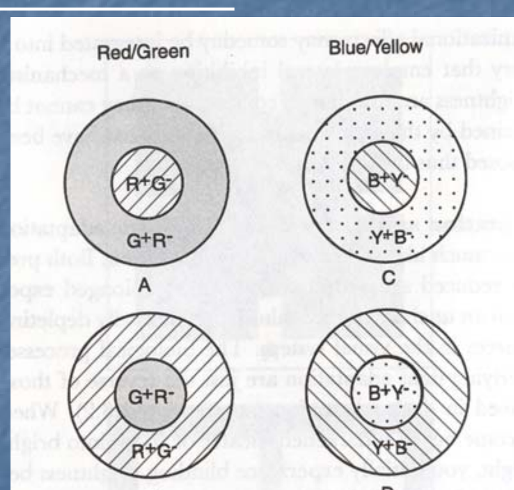
- Prolonged exposure to red
  - R^+G^- cells fire less strongly
  - G^+R^- cells fire more strongly
- Red looks less saturated
- Green looks more saturated
- Other colors seem to have a greenish tint

Aftereffects

- Prolonged exposure to green
  - G^+R^- is fatigued
- When try to view white
  - R^+G^- cells fire more and hence red afterimage
- Similar for blue/yellow
- Still Cannot explain simultaneous contrast

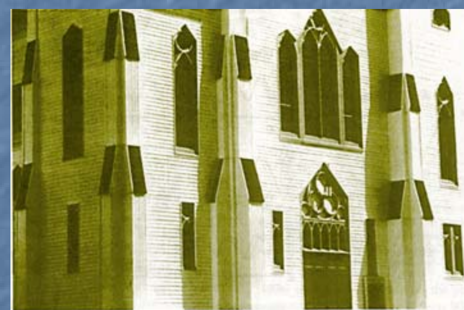
Simultaneous Contrast

- Double opponent cells in visual cortex
- Similar logic as lateral inhibition



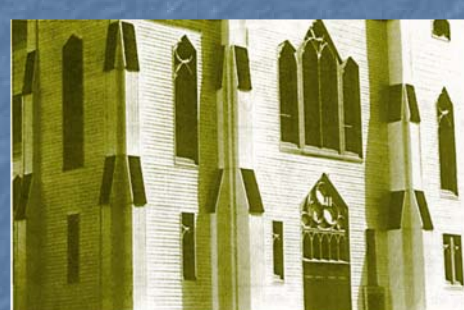
Surface Based Color Perception

- Many of the color perception phenomenon cannot be explained by the image based analysis



Surface Based Color Perception

- Image based perception
  - Part of walls are white and part of it is gray
- Actual Perception
  - White walls and gray shingles
  - We can tell exactly what is due to shadows



Underconstarined Inverse Problem

- Multiplication of
  - Illumination spectrum
  - Reflectance spectrum
- Together give the spectrum that we see
- No inherent difference in their representation
- How can we separate what is due to illumination and what is due to reflectance?

Color Constancy

- Same surface have different spectrum of reflected light depending on the illumination spectrum
- A white paper appears white in sunlight and also under a reading light
- Called color constancy
  - Lightness constancy
  - Chromatic constancy

Lightness Constancy

- An achromatic surface appears to have same lightness irrespective of different illumination conditions
  - Indoor illumination: 100 photons
    - Black: 10 photons
    - White: 90 photons
  - Outdoor Illumination: 10,000 photons
    - Black: 1000 photons
    - Whiie: 9000 photons
- Black in outdoor is almost 900 times more than white in indoor
  - Still it is perceived as black

Adaptation Theories

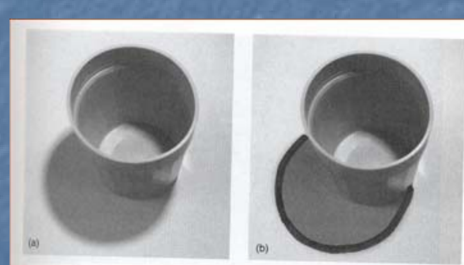
- Visual system adapts
  - More sensitive to dim light
  - Less sensitive to bright light
- Illumination is thus factored out by a average adaptation of the eye

Adaptation Cannot Explain Many Phenomena

- Adaptation needs time, at least a few minutes
  - Switch of the reading light, the paper does change appearance from white to gray, even for a few minutes
  - Even if adaptation was instantaneous
    - It would eliminate information about illumination
    - We would not be able to say that there is a change in the illumination, but paper would remain white
    - In reality, we can detect the change in illumination and at the same time the paper does not turn gray

Adaptation Cannot Explain Many Phenomena

- Adaptation occurs with change in illumination
- Color constancy with same illumination
  - Shadowed table is not perceived as gray
  - Without outline, it is perceived as gray region



Unconscious Inference Theory

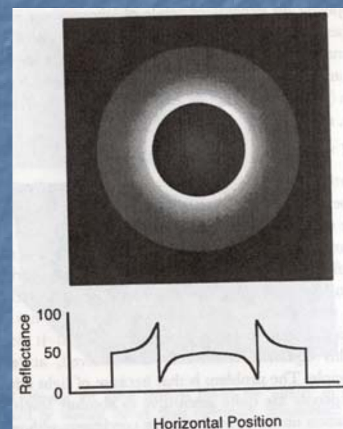
- Cannot be determined directly from the image
- Somehow, we make an estimate of $I(\lambda)$
  - Finding $R(\lambda)$ is just a division
- Left out all details
- Proposed by Helmholtz

Relational Theory of Hering

- Can be directly determined from the image
- Due to surface reflectance
  - Absolute amount of light from neighboring regions change *drastically*
  - But, relative amount of light from neighboring regions remain the same
- Perceived lightness depends on the relative contrast
- Wallach propses that luminance ratios are important
  - Two pair of projector experiment confirms this

Importance of Edges

- How to calculate such luminance ratios?
  - Local luminance ratios at *edges* matter



Retinex Theory

- How does these ratios at edges gets integrated over the image?
- Assumes illumination does not show any discontinuity
  - Multiplication of the contrast ratios at the edges

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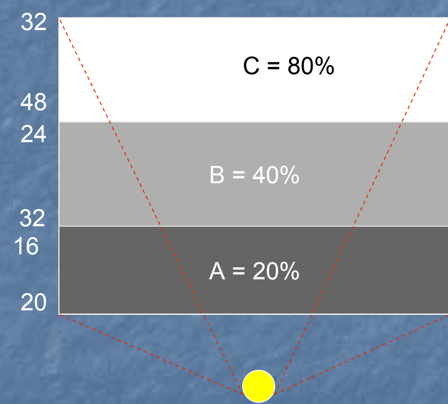

The Scaling Problem

- We know now how we decide between contrast of regions
- But how do we decide on the absolute value?
  - Gray to black OR White to Gray
- Assign white to the brightest element in the scene
- Experiment with restricted field of view
- Still cannot explain luminous objects

Illumination vs Reflectance Edge

- However, this theory fails if there is an illumination edge
  - Basis of the theory is edge is reflectance edge
- Identifying edges as illumination or reflectance edge is important
  - Experiments with same edge created by both shadow and reflectance and its effect on the perceived luminance of an object

Maps

- The solution
  - Illumination Map
  - Reflectance Map
- They are multiplied to get the image
- Somehow we need to find these two maps

Human eyes do it easily – How?

- Fuzziness
  - Illumination edges are often not sharp
    - Only point light sources create sharp edges
    - But real lights are extended and hence penumbra
  - Reflectance edge is usually sharp
- Planarity
  - Depth information separates out non coplanar region
  - Perceived as illumination edge
  - More information than just present in an image

Human eyes do it easily – How?

- Magnitude ratios
  - Reflectance edge can be at most 10:1
  - However, illumination edge can be as large as 1000:1
- Color produces additional information
  - Reflectance edge produces edge in both hue and saturation
  - Illumination edge produces edge only in luminance

Color Constancy

- Similar experience with color
  - Red does not cease to be red in different lighting conditions
- More constraints due to color
  - Consistency of illumination
    - Hue and saturation is probably same for all regions

Color Constancy

- Similar experience with color
  - Red does not cease to be red in different lighting conditions
- More constraints due to color
  - Restricted Illuminants
    - Strongly chromatic sources are rare
    - Color constancy fails in such cases
      - Red objects look black in blue light

Color Constancy

- Similar experience with color
  - Red does not cease to be red in different lighting conditions
- More constraints due to color
  - Restricted Reflectance
- Models proposed based on these retrictions

Illumination vs Reflectance Edges