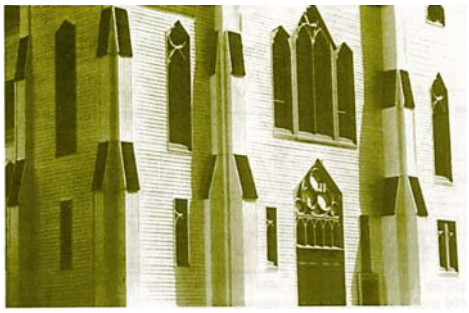
Higher Visual Mechanisms

- Many of the color perception phenomenon cannot be explained thrichromatic, opponent or adaptation theories



Higher Visual Mechanisms

- 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

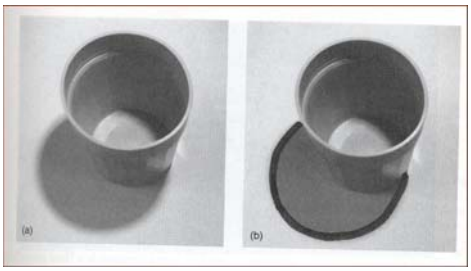
- Multiplication of
  - Illumination spectrum
  - Reflectance spectrum
- Together give the spectrum that we see
- No inherent difference in their representation
- How can we separate what is due to illumination and what is due to reflectance?

Other unexplained phenomena

- Adaptation needs time, at least a few minutes
  - Switch off 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

Other unexplained phenomena

- Adaptation occurs with change in illumination
- Color constancy with same illumination
  - Shadowed table is not perceived as gray
  - With outline, it is perceived as gray region



Unconscious Inference Theory

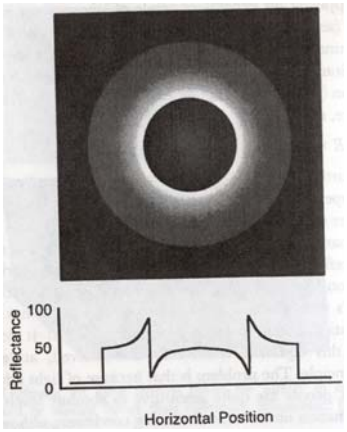
- Cannot be determined directly from the image
- Somehow, we make an estimate of $I(\lambda)$
  - Finding $R(\lambda)$ is just a division
- Left out all details
- Proposed by Helmholtz

Relational Theory of Hering

- Can be directly determined from the image
- Due to surface reflectance
  - Absolute amount of light from neighboring regions change *drastically* with change in illumination
  - 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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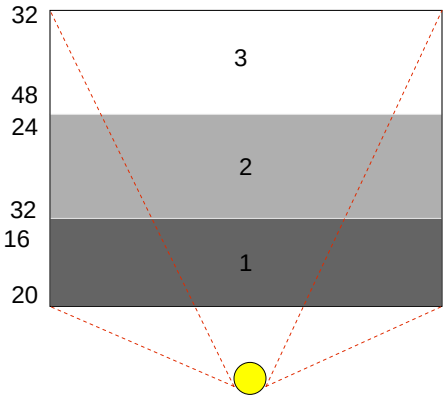


The Scaling Problem

- 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

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

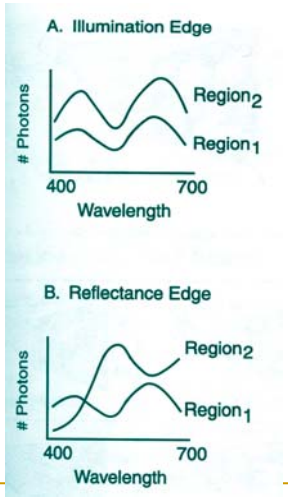
Human eyes do it easily – How?

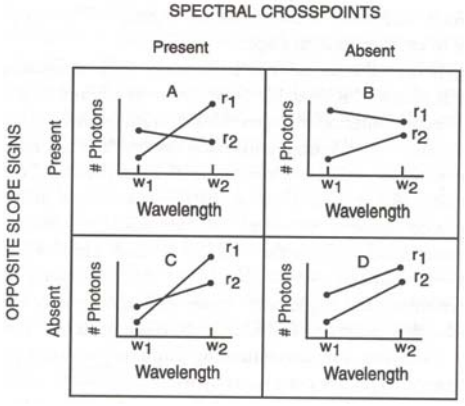
- Magnitude ratios
  - Reflectance edge can be at most 10:1
  - However, illumination edge can be as large as 1000:1
- Color produces additional information
  - Reflectance edge produces edge in both hue and saturation
  - Illumination edge produces edge only in luminance

Does color help?

- 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
  - Models proposed based on these restrictions

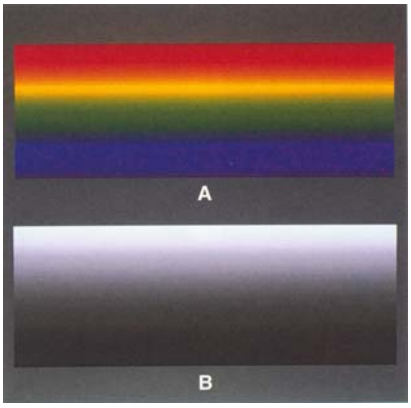
Illumination vs Reflectance Edges





Category Based Color Perception

- We are incredibly good at identifying colors by name
- Question is
  - Did this naming develop just because we have to name to communicate?
  - OR, Does our biological responses have anything to do with the way we name it?
  - Does it help?



Previous Theory

- Completely dependent on culture
- Our biological make up does not have any influence
  - Cultural Relativism
  - Sapir-Whorf Hypothesis
  - Prevalent for a long time
- Refuted by famous study by Berlin and Kay

Berlin and Kay Theory

- Identified 11 *basic colors* in English
  - Monolexemic
    - No whitish-brown or light-blue or off-white
  - Primary chromatic reference
    - No gold, silver, lime
    - Orange was allowed since in many cultures this is not associated with the fruit

Berlin and Kay Theory

- Identified 11 *basic colors* in English
  - General Purpose
    - Widely applied to different kinds of objects
    - No blonde (for hair) and roan (for horses)
  - High frequency
    - Must be used frequently in the language
    - No mauve, taupe, burgundy

Berlin and Kay Theory

- Identified 11 *basic colors* in English
  - Red, Green, Orange, Blue, Yellow, Black, White, Gray, Purple, Pink, Brown
- Studied color naming in 20 languages
  - 16 basic terms
    - Term for sky blue
    - Warm (red and yellow)
    - Cool (blue and greens)
    - Light warm (white or red or yellow)
    - Dark cool (black or green or blue)
    - Arranged in similar hierarchy

How to create categories?

- What is categories?
  - Is it a set of items that all follow a set of rules?
    - Aristotle's definition
  - More of a prototyping
    - May not follow all rules of one category
    - Thus may belong *kind of* to both

Experiments

- Recognized a set of focal colors
  - Boundary Method
    - Which focal color does each of 329 color chips belong to?
  - Focal Method
    - Which chip is the best example of the focal colors?
- Second was much easier for people
  - Proportional to the time taken
- Tested with different focal colors

Rosch's Experiment with the Dani's

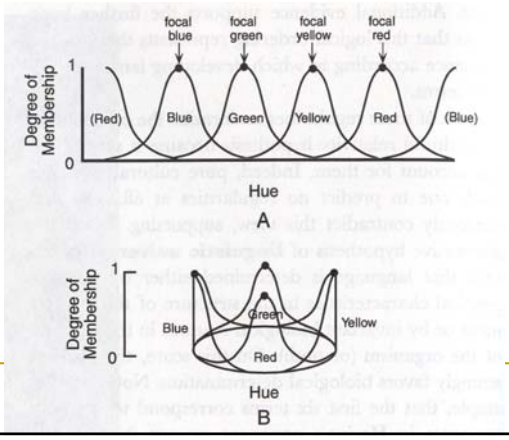
- Dani: Old tribe in New Guinea
  - Two terms of color: *mili (light warm) and mola (dark cool)*
- Tried to teach them colors
  - Learned red, green, blue and yellow very easily

More Experiments

- Present a series of colors
- Identify if the color was an instance of the category name mentioned before
  - Faster for focal colors
  - Time to identify increased proportionally with the increase in distance from the focal colors

Focal Colors

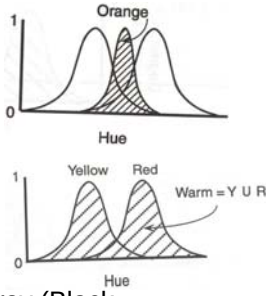
- Rosch proposed focal colors and boundary colors around it



Fuzzy Set Theory

- Set theory
  - Element belongs to a set or does not
- Fuzzy set theory
  - Element can belong to a set partially
  - Hence, can belong to more than one set
- Focal colors have a membership of value 1
- Boundary colors have a membership depending on the distance from the focal color

Model of Color Naming (Kay McDaniel)



- Primary Colors
  - Focal colors
    - White, Black, Red, Green, Yellow and Blue
- Derived Colors
  - Fuzzy AND
    - Orange (Red-Yellow), Purple (Red-Blue), Gray (Black-White), Pink (Red-White), Brown (Yellow-Black)
- Composite Color
  - Fuzzy OR
    - Warm (Red-Yellow), Cool (Blue-Green), Light warm (white-red-yellow), Dark Cool (Black-blue-green)

Development of Color Vision

- Are not born with full color vision
- By two months they have full color vision
- Less than that they cannot discriminate yellow greens and mid purples from white
- Color constancy is not fully developed till four months of age