Sensitivity to color variations & Spatial Localization

Setareh Rafatirad
Behzad Sajadi

Outline

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  – Color Spatial Contrast Sensitivity Function
  – Significance of Color CSFs for Vision
• Part 2
  – Multiple Color Spatial Frequency Channels
  – Luminance-Color Interactions
• Part 3
  – Introduction to Phase and Position
  – Spatial Localization in Visual System
• Part 4
  – Physiology of Phase and Position Sensitivity
  – Some Limitations in the Visual System
Visual System

- Study of Visual System
  - Spatial Vision
  - Color Vision
- Field intersections
  - Variation across both chromaticity and luminance
    - Shadowing
      - Objects in shadow

Wavelength Distribution

- Trivial color contrast
- More veridical
- More information
- Low and middle frequency
- Very expensive
- Birds, insects
Intensity Distribution

- Non-trivial luminance contrast
- Middle and high frequency
- Less veridical
- Rapidly changing or moving pattern
- Ungulates and grass eaters

Chromaticity vs. Intensity

- Mostly contours are recognized
- Loses most of the information
Chromaticity vs. Intensity

Mostly contours are recognized → Loses most of the information

Color-mixture Grating

- Mixing colors ➔ Intermediate colors
- Create an isoluminant red-green grating
  - Summing two out-of-phase isochromatic luminance gratings-
    matched in luminance
    - Red grating (180° out-of-phase) + Green grating
Color-mixture Grating

Result:

Red-Green grating ➔
- The same spatial frequency
- Varies sinusoidally (red-green)
- Invariant luminance

Cone Responses

C,D: Receptor sum: varies with luminance contrast
E,F: Receptor Difference: varies with color contrast
**Pure Color Gratings**

- Isoluminant | Equiluminant
- Chromaticity variation
- No variation in luminance or chromaticity along the orthogonal axis

**A Phenomenon**

- Van der Hoarst, de Weert, and Bouman (1967)
- Van der Hoarst and Bouman (1969)
- Measures of color sensitivity Experiment:
  - Low spatial frequencies
  - High spatial frequencies
    - Peculiar experiment: Luminance Artifacts!!!
Aberration

• Axial chromatic aberration
  – Partial demodulation
  – Variation in luminance and chromaticity
  – Elimination

• Diffraction by the pupil

• Radial chromatic aberration
  – Slightly different wavelengths are differentially magnified
  – Producing beats for extended patterns

Spatial CSFs

How different is the Color Spatial CSF from Luminance Spatial CSF?

1. Sooner sensitivity fall-off on high-frequency for pure color patterns.
2. Color CSF is low-pass while Luminance CSF is band-pass.
RG vs. BY grating

  - Visual system color analysis:
    - Black-white axis
    - Red-Green axis (RG)
    - Yellow-Blue axis (YB)

RG vs. YB grating

- Little information on RG & YB
- Both have the similar sensitivity
- YB gratings fall off sooner in high frequencies
  - Might be because of sparse distribution of S cones.
RG vs. YB grating

Mullen (1985): no difference
- Effects of chromatic aberration
  - Affect blue-yellow more than red-green grating

Temporal CSFs

- Experiments by Regan & Tyler, 1971; D.H. Kelly, 1974, 1975 conclude:
  - Temporal color CSF differs from Temporal luminance CSF in:
    - No low temporal frequency attenuation
    - Having lower high temporal frequency cut
Color Contrast and Similitude

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<th>Patterns</th>
<th>Low Spatial frequencies</th>
<th>Mid Spatial frequencies</th>
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Minimally Distinct Borders

- First task in identifying objects
- Boynton (role of luminance and color differences)
  - Equal luminance gives **minimal** distinction
  - Indistinct borders with only chromatic differences
  - Sharper borders with luminance differences
Psychophysical Evidence for Multiple Spatial Frequency Channels

- Evidence 1:
  - Selective adaptation studies (Blakemore & Campbell, 1969)
    - Adaptation to isoluminant red-green gratings:
      - K.K. De Valois, 1978
      - Bradley, Switkes, & K.K. De Valois, 1985
- Evidence 2:
  - Masking studies

Spatial frequency masking functions

- Broader in bandwidth
- More sensitive
Cross Masking Conditions

- Pure-color grating masking effect
  - Profound
  - More sensitivity
  - Effectively as luminance mask

- Luminance grating masking effect
  - Much less profound
  - Significant loss when mask and test are in the same frequency
  - Discriminating contours

Summary

- Pure color vs. pure luminance gratings
- Color mixture gratings
- Luminance artifacts
- Temporal CSFs
- Similitude
- Cross Masking effects
Introduction

- How visual system detects position of objects?
- Each neural element is integrating information over some spatial region ➔ loose some degree of localization
- In a Fourier Analysis phase is the localization component ➔ Is it relevant to spatial localization?
Absolute vs. Relative Phase

- Two ways can be considered for absolute spatial localization:
  - Absolute phase mechanism
  - Positional mechanism: Which local area is activated?

- Relative phase:
  - Two gratings at the same region (e.g. f & 3f)
  - Relative phase will result in different peaks and troughs

Is the visual system phase sensitive?

- Visual system process spatial info. similar to auditory system process temporal info.
- Auditory system use phase info minimally
- Unlike auditory system we can detect dark and light bars in a grating (absolute phase)
- We can discriminate an f + 3f combination in sine and cosine phase (relative phase)
What can cause this adaptation?

- Adaptation of phase sensitive system
- Adaptation of separate black bar and white bar detectors:
  - It should be frequency independent
Some points about phase sensitivity

- Relative phase can only be discriminated between gratings of nearby frequencies (about a 2 octave range: e.g. f and 3f)
- Delectability of compound gratings does not depend on their relative phase, however it changes the contrast
Sensitivity to absolute phase or position

- Auto kinetic
  - A subject in a dark room with a point light source: Light source will start to move in a random direction after a few minutes
  - Might be related to eye movement? Not enough for such an apparent movement.
- Dot within a box framework: We percent moving of dot or framework both as moving of the dot.
- We can perceive a line jump to right or left as small as 3° => Good in relative position, poor absolute position.

Relative contribution of phase and position in localization (Cont.)

- Two gratings of 1c/deg and 10c/deg
  - Threshold was 3’ for both of them
  - 3’ displacement: 18° and 180° phase shift respectively
  - Only position not phase contributes in spatial localization.
- For lower than 1c/deg frequencies phase threshold is constant!
Relative contribution of phase and position in localization

- Hypothesis: Threshold is linear sum of a position threshold and a phase threshold
- Roughly compatible with the experimental results
- Might be due to two successive processing stages
Physiology of phase and position sensitivity

- One-to-One retinotopic mapping
  - Different regions of the retina are mapped to different cortical regions in a symmetric way
  - Evidence: Destruction of restricted cortical areas produce correspondingly restricted scotomas
  - Is this mapping enough to detect small displacements within a cortical region consist of different cell types?

- Capacity of some specific cells to localize patterns within their input region

Phase sensitive and phase insensitive cells (Cont.)

- Recorded from cat ganglion cells two main cell types was found
  - Excitatory center, inhibitory annular surround
  - Inhibitory center, excitatory annular surround
  - Named X cells by Enroth-Cugell and Robson

- Another variety of cells which are totally phase insensitive was found: Named Y cell
Phase sensitive and phase insensitive cells

- Simple and complex cortical cells are functionally similar to X and Y cells respectively
- Simple cells: max excitation for 0°, no response for 90°, max inhibition for 180°
- Complex cells: Almost totally phase insensitive
Hubel and Wiesel’s Model

- Simple cells only act as inputs to the complex cells
- Consequence: Visual system should be totally unaware of phase information!
- Alternative hypothesis: Two parallel systems in the striate cortex
  - Complex cells with only frequency information
  - Simple cells with both frequency and phase information

Odd and even symmetric simple cells

- In addition to even symmetry cells cortical simple cells of odd-symmetry are also found
- Type one responds optimally to cosine gratings with 90° phase
- Type two responds optimally to cosine gratings with 270° phase
Variation with spatial frequency

- Found from monkey striate cortex: Most of the cells tuned for high spatial frequencies are complex cells
- Reasons for phase insensitivity at high spatial frequency
  - Small eye movements make it difficult
  - On the other hand a small complex cell tuned to a high frequency can determine position of the grating by just firing or not firing

Sensitivity to relative phase

- For complex cells addition of another frequency with a different phase found to has no effect on the response
- For simple cells response inhibited slightly more than half in a non-phase-specific manner by adding another frequency
- Some other simple cells found to be sensitive to relative phase of gratings of f and 2f, and less to gratings of f and 3f
Variations in phase sensitivity with eccentricity

- Nachmias and Weber found that a contrast interval in which:
  - Two gratings of \( f \) and \( 3f \) can be discriminated in a compound \( f + 3f \) grating
  - Relative phase cannot be detected

- Hypothesis: Detection at a threshold is based on a pooled response. Frequency threshold is lower because there are more frequency sensitive cells.

Sensitivity to color phase

- At low spatial frequencies we can distinguish different colors
- At high spatial frequencies we only perceive a mix of colors
- Because we don’t have spatial phase information in high frequencies we can not determine which part is which color