Sensitivity to color variations & Spatial Localization

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Outline

- Part 1
  - 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

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Visual System

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

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Wavelength Distribution

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

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Intensity Distribution

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

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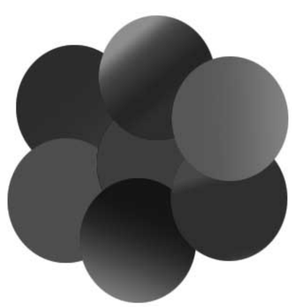
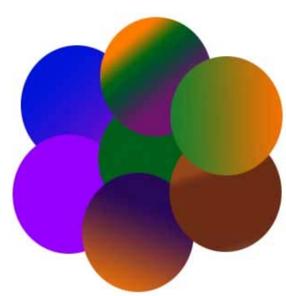
Chromaticity vs. Intensity



Mostly contours are recognized



Loses most of the information

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Chromaticity vs. Intensity

Mostly contours are recognized ➔ Loses most of the information

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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

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Color-mixture Grating

Result :

Red-Green grating ➔

-The same spatial frequency

-Varies sinusoidally (red-green)

-Invariant luminance

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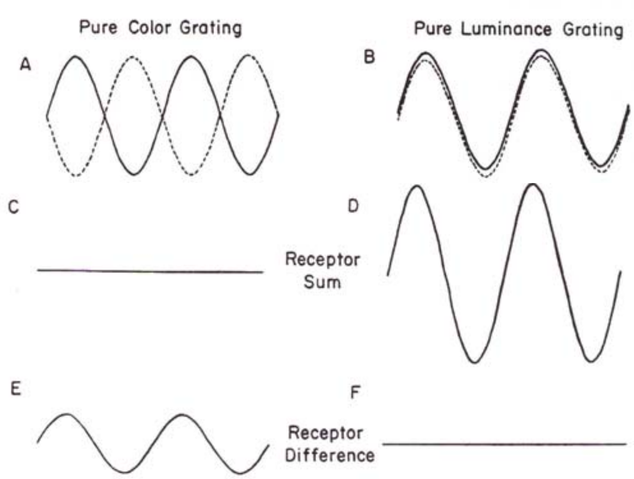
Cone Responses



C,D: Receptor sum: varies with luminance contrast
E,F: Receptor Difference: varies with color contrast

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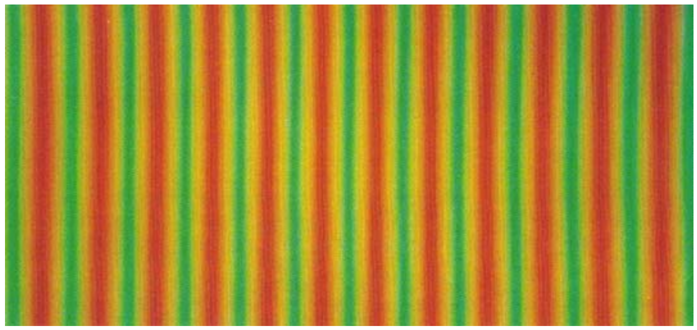
Pure Color Gratings



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

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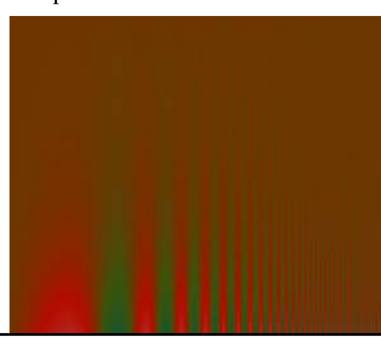
A Phenomenon

- 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!!!



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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

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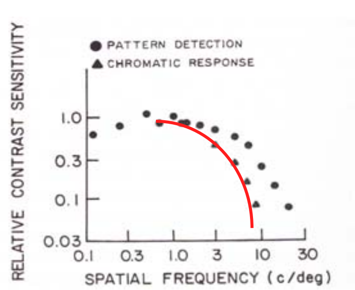
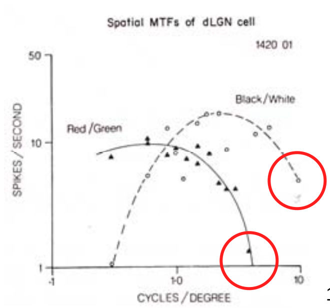
Spatial CSFs

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.





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RG vs. BY grating

- R.L. DeValois & K.K. De Valois, 1975; Boynton, 1979; Hurvich, 1981
  - Visual system color analysis:
    - Black-white axis
    - Red-Green axis (RG)
    - Yellow-Blue axis (YB)

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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.

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RG vs. YB grating

Mullen (1985) : no difference

– Effects of chromatic aberration
  - Affect blue-yellow more than red-green grating

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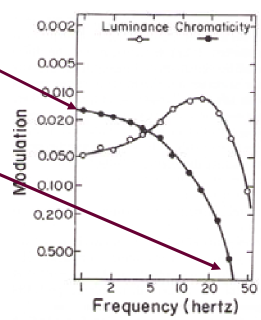
Temporal CSFs

- 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**



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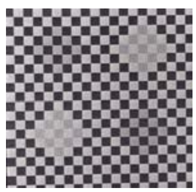
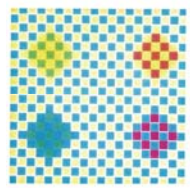
Color Contrast and Similitude

Patterns	Low Spatial frequencies	Mid Spatial frequencies	High Spatial frequencies	Very high Spatial frequencies
Luminance varying patterns	_	Contrast	Contrast	Similitude
Color varying patterns	Contrast	Similitude	_	_

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Minimally Distinct Borders

- First task in identifying objects
- Boynton (role of luminance and color differences)
  - Equal luminance gives <u>minimal</u> distinction
  - Indistinct borders with only chromatic differences
  - Sharper borders with luminance differences

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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, Switks, & K.K. De Valois, 1985
- Evidence 2:
  - Masking studies
    - K.K. De Valois & Switkes, 1983

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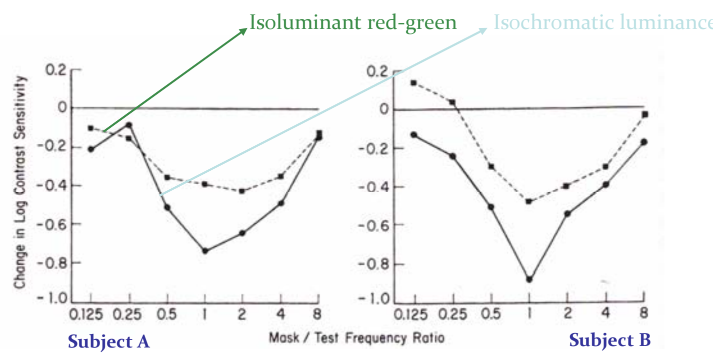
Spatial frequency masking functions

- Broader in bandwidth
- More sensitive



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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

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Summary

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

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Spatial Localization: Phase and Position

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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

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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)

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What can cause this adaptation?

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

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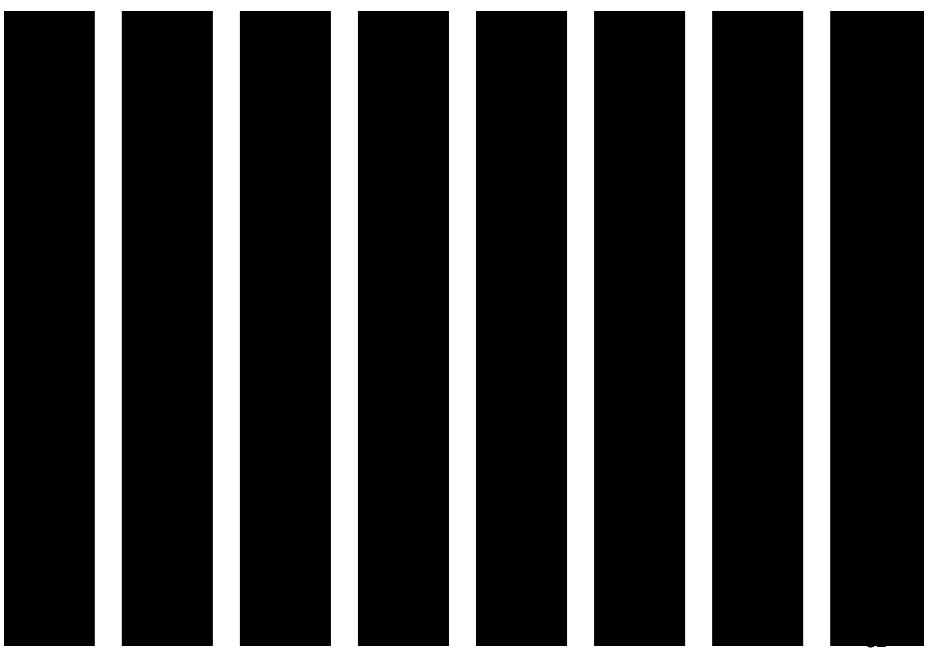

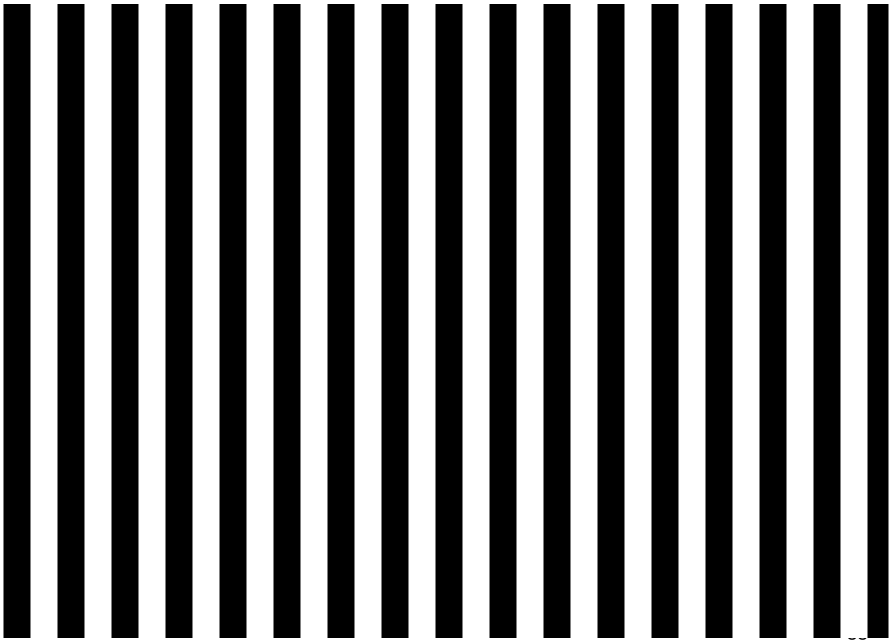

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Some points about phase sensitivity

- 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

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Sensitivity to absolute phase or position

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- 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.

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

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- 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!

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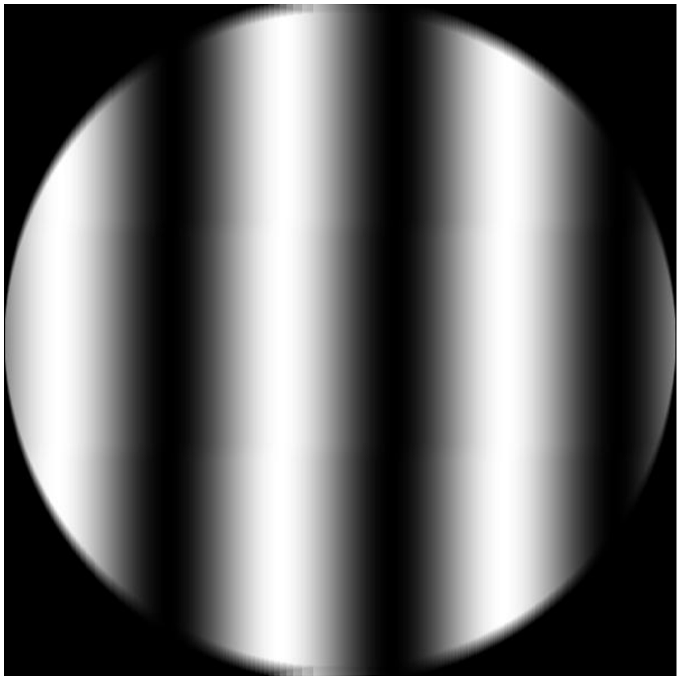

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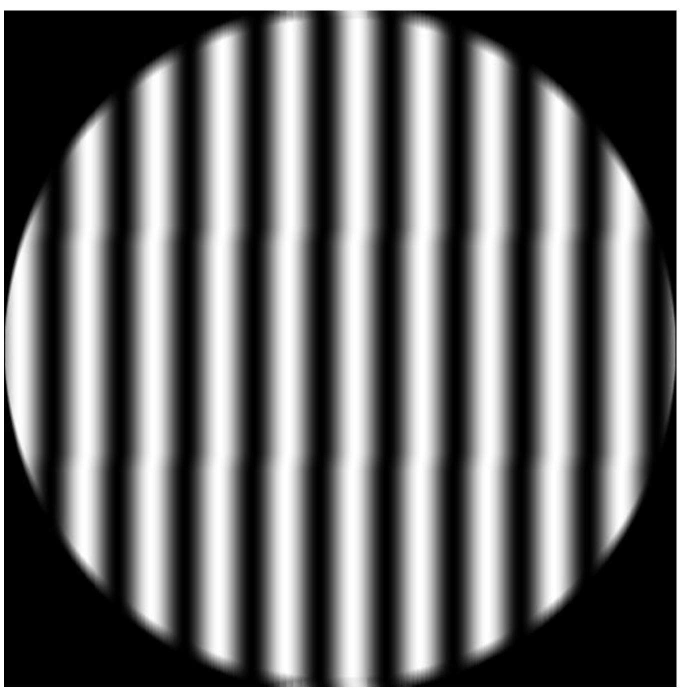

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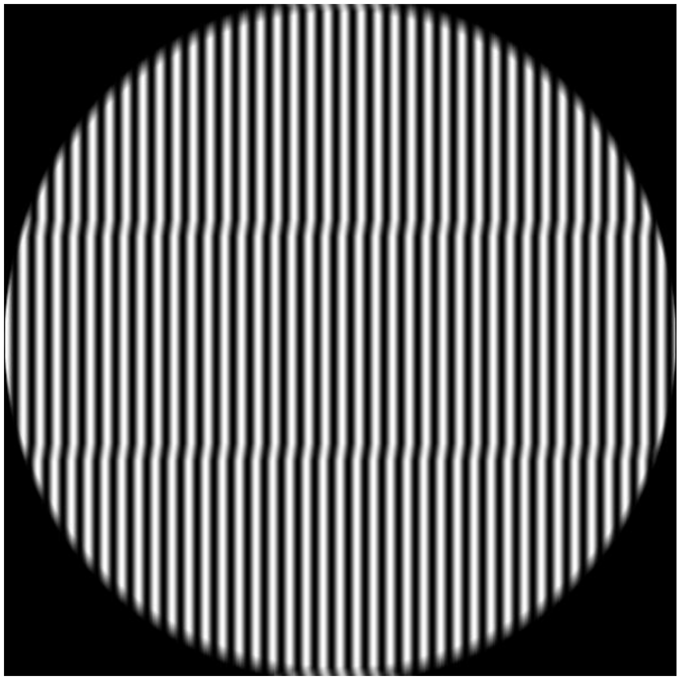

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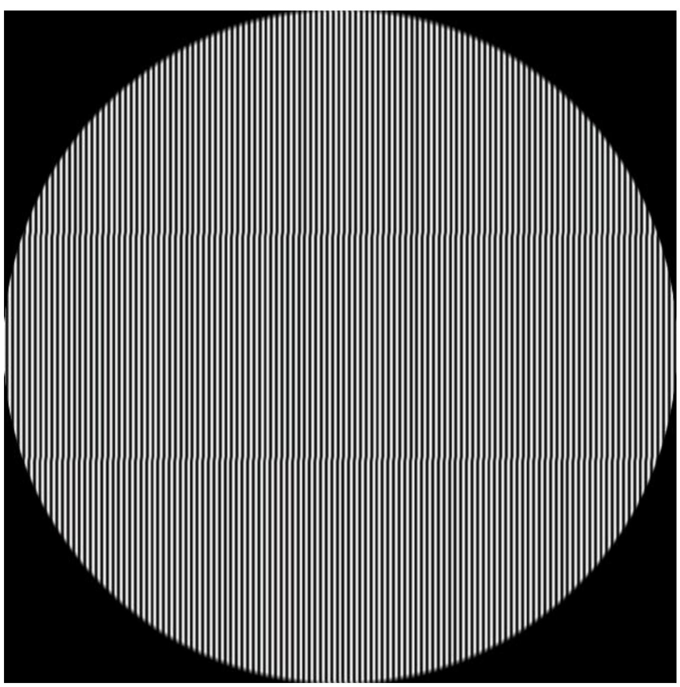

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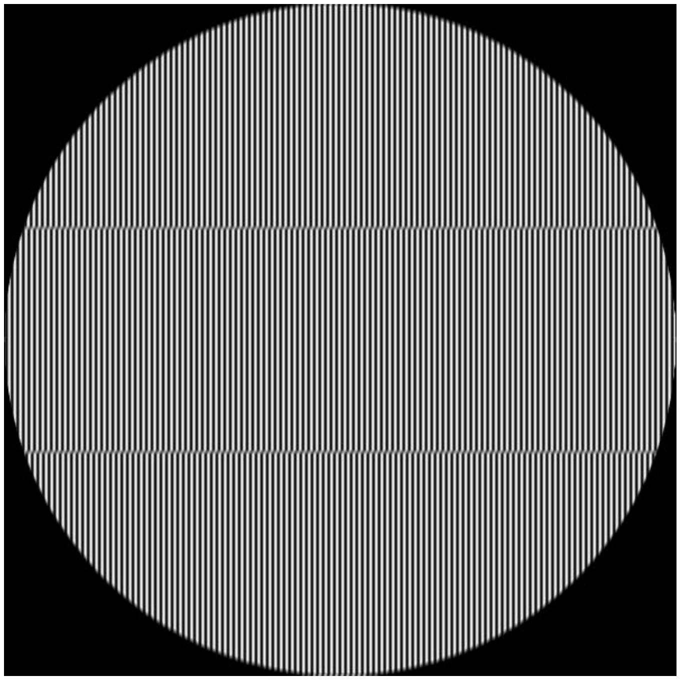

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Relative contribution of phase and position in localization

- 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

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Physiology of phase and position sensitivity

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- 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

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Phase sensitive and phase insensitive cells (Cont.)

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- 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

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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

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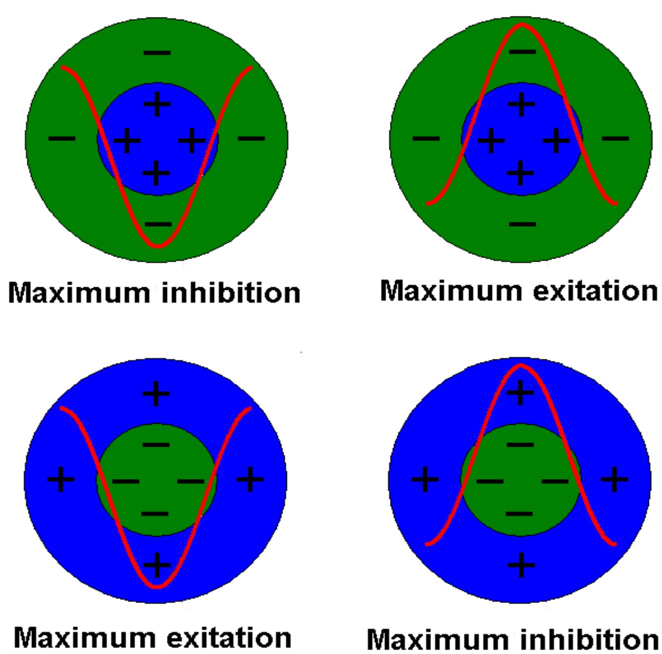

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Hubel and Wiesel's Model

- 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

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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

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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

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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

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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 can not be detected
- Hypothesis: Detection at a threshold is based on a pooled response. Frequency threshold is lower because there are more frequency sensitive cells.

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Sensitivity to color phase

- At low spatial frequencies we can distinguish different colors
- At high spatial frequencies we only a 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

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