SPATIAL VISION

Visual Perception
Spatial Frequency Theory

- So far, we have considered, feature detection theory
- Recent development
  - Spatial Frequency Theory
  - The fundamental elements are spatial frequency elements
  - Does not preclude having feature detectors
- Spatial vision
  - No good convergence in physiology and psychophysics *yet*
    - Unlike color vision
Gratings

- Images representing sine waves
  - Frequency
  - Orientation
  - Amplitude
  - Phase
Fourier Transform

- Any image can be expressed as a linear combination of a bunch of sine gratings of different frequency and orientation
  - Amplitude
  - Phase
Fourier Synthesis

- These component gratings can then be added together to create the original image back
Spatial Frequency Content

- Lower frequencies
  - Global pattern of light
- Higher frequencies
  - Feature details like edges
Contrast Sensitivity Function (CSF)

- Present a sine wave of particular frequency
- Start from 0 contrast and keep increasing contrast
- Note the contrast at which it becomes barely visible from an uniform gray field
- Defines the contrast threshold for that frequency
- Performed for a range of frequencies
Contrast Sensitivity Function (CSF)

- Minimum contrast required to detect a particular frequency
- Maximum sensitive at 4-5 cycles per degree
Testing Contrast Sensitivity
Calculating Cycles per Degree

- Distance of the subject from the screen in inch = d
- Resolution of the screen in pixels/inch = r
- No. of pixels per degree = \( \frac{180}{\pi} \times d \times r \)
- No of sine cycles in \( \frac{180}{\pi} \times d \times r \) pixels tells the number of cycles per degree
Changes with Illumination

- Sensitivity decreases with dark
  - Especially in high frequency regions
  - Lower visual acuity in dark

- The peak sensitivity occurs at lower frequencies
  - 5 to 2 cycles/degree
Development with Age

- Not great for babies
  - Infants cannot recognize people
- Monkeys and macaque have similar CSF as humans
Development with Evolution

![Graph showing relative contrast sensitivity for different species vs. spatial frequency.](image)
Temporal Contrast Sensitivity

- Present image of flat fields temporally varying in intensity like a sine wave
- If the flicker is detectable
- Cycles per second
CSF and filters

- Both spatial and temporal CSF act as band pass filters.
- How do they interact?
  - At higher temporal frequency, acts as low pass filter.
How does this help us?

- Detecting objects versus illumination
  - Illumination changes are low frequency
    - Both in space and time
      - Morning to day to night
      - Changes over regions slowly
        - Can phase out illumination and be more sensitive to reflectance
  -Insensitive to afterimages
    - Usually blurred low frequency ones
Selective Adaptation of Channels

- Adaptation to certain ranges of frequencies
- Selective adaptation aftereffects
Experiment
Experiment
Selective Adaptation of Channels

- CSF changes before and after adaptation
- Subtraction from the original CSF gives the response of the cells that are adapting
Selective Adaptation of Channels

- Multiple channels that adapt to different ranges of frequencies
Spatial Frequency Theory

- Each channel sensitive to particular range of frequencies and orientations
- Can overlap with each other
- Similar to the color primaries
- Acts like band pass filters
Selective Adaptation to Orientations

- Similarly, for orientation
- Orientation adaptation aftereffects
Experiment
Experiment
Further Support

- Checking the threshold for square and sine grating of same frequency (above 4-5 cycles per degree)
- Should be same
  - Square wave made of many sine waves
  - Will be visible as soon as one of the sine waves are visible
  - The threshold for the higher sine waves are lower
Physiological Support

- Infinite sine waves
- Eye has finite receptive fields
- Local piecewise frequency analysis
  - Small patches of sine waves that fade out
  - Gabor Functions
    - Multiplying sine waves with a gaussian
Physiological Support

- Gabor Functions
  - Cells with such response found in the simple cells of visual cortex
Filters

- **Low pass filters**
  - Blocks high frequencies
  - Image blurring

- **Band pass filters**
  - Blocks both high and low frequencies allowing only medium ones

- **High Pass filter**
  - Blocks low frequencies
  - Edge detection
Role of Color
Studying Chromatic Contrast

- Adding iso-chrominance gratings
  - Out of phase creates iso-luminance color gratings

[Diagram showing red and green waves out of phase]

[Color pattern image]
Testing Contrast Sensitivity
Chromatic Contrast

- **Gratings**
  - Red-Green (602, 526nm)
  - Blue-Yellow (470, 577nm)
- **Summation of band responses**
Comparison

- Low pass filter rather than bandpass filter
- Sensitivity is lower
  - More sensitive to luminance change than to chrominance change
- High frequency cut-off is 11 cycles per degree rather than 30 cycles per degree
  - Color acuity is lower than luminance acuity
Similitude

Similarity of a pattern with its background

<table>
<thead>
<tr>
<th>Patterns</th>
<th>Low Spatial frequencies</th>
<th>Mid Spatial frequencies</th>
<th>High Spatial frequencies</th>
<th>Very high Spatial frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminance patterns</td>
<td>_</td>
<td>Contrast</td>
<td>Contrast</td>
<td>Similitude</td>
</tr>
<tr>
<td>Color patterns</td>
<td>Contrast</td>
<td>Similitude</td>
<td>_</td>
<td>_</td>
</tr>
</tbody>
</table>
• Which one stands out more?
• Exactly same red
  • More similitude in color
  • Perception driven by similitude
  • Top – Red similar to yellow (towards orange)
  • Bottom – Red similar to blue (towards purple)
• Same effect for green
• But for luminance, directed by contrast
Visual Masking

- Certain frequencies and orientation mask others perceptually

- Experiments
  - Test grating presented on a masking grating
  - At different contrast of the masking grating
  - Measure the CSF for the test grating
Orientation

- Test: Vertical 2 cycles/deg
- Contrast sensitivity with different mask contrast
- For different orientation masking grating
- As difference in angle increases, masking effect reduces
- Masking more effective at higher contrasts
- Facilitation at low contrast for similar orientation
Spatial Frequency

- Similar plot but with threshold
- Test frequency: 2 cycles/deg
- Masking frequency: 1-4 cycles/deg
- Low contrast creates facilitation
  - Threshold decreases (more sensitive)
- High contrast creates masking
  - Threshold increases (less sensitive)
Effects

- **Contrast**
  - a-1
  - a-2 (ΔR = 1.37)
  - a-3 (ΔR = 1.14)
  - a-4 (ΔR = 1.0)
  - a-5 (ΔR = 0.9)

- **Spatial Frequency**
  - b-1
  - b-2 (ΔR = 1.32)
  - b-3 (ΔR = 1.05)
  - b-4 (ΔR = 0.90)
  - b-5 (ΔR = 1.11)

- **Orientation**
  - c-1
  - c-2 (ΔR = 1.26)
  - c-3 (ΔR = 1.19)
  - c-4 (ΔR = 1.09)
  - c-5 (ΔR = 0.99)