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

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**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

![Graphs showing Contrast Threshold and Sensitivity](image)
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 = \( \frac{180}{\pi d r} \)
- No of sine cycles in \( \frac{180}{\pi d r} \) 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

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

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

Further Support
Physiological Support

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

Garbor 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

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

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