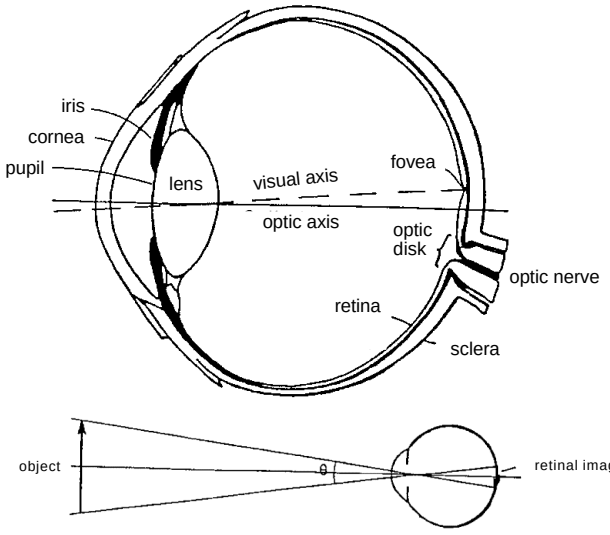
Human visual perception - topics

- Visual acuity
- Weber-Fechner Law
- Lateral inhibition and excitation
- Transfer functions of the color channels
- Spatial and temporal masking
- Eye movements

Anatomy of the human eye



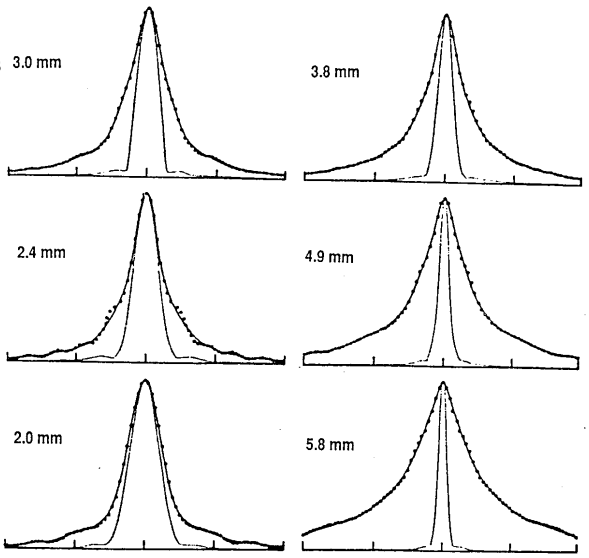
Optical properties of the human eye

- Deviations from ideal perspective projection due to
  - Aperture of the eye
  - Focus errors (spherical aberration)
  - Chromatic aberration
  - Dispersion
- Effects can be summarized by a 2D convolution with the optical point-spread function (PSF).
- Instead of a PSF, an optical line-spread function (LSF) is often given, which can be measured more easily.

Optical LSF of the human eye

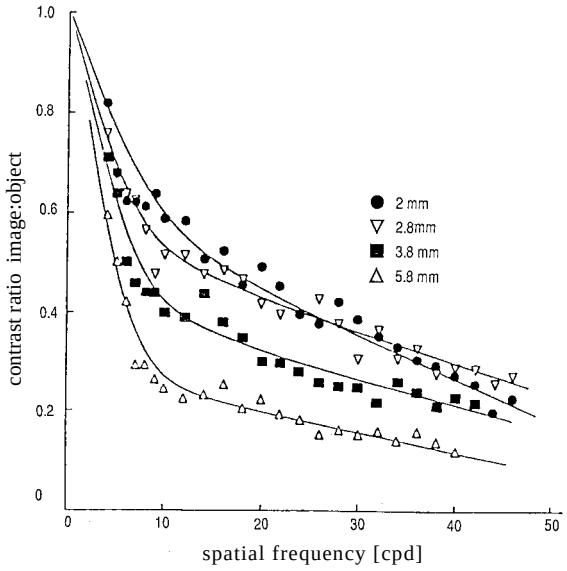
LSF measured for different pupil diameters (Campbell+Gubisch)

LSF calculated from eye aperture (due to diffraction)

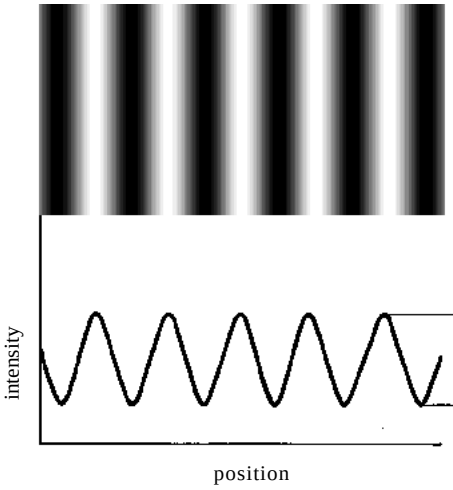


Optical modulation transfer function (MTF) of the human eye

- MTF is measured directly with sinewave gratings.
- The optical modulation transfer function (MTF) can be interpreted as Fourier transform of the optical LSF.



Sine wave grating



$$\text{contrast ratio} = \frac{L_2 - L_1}{L_2 + L_1}$$

Human retina I

Signal propagation in the retina:

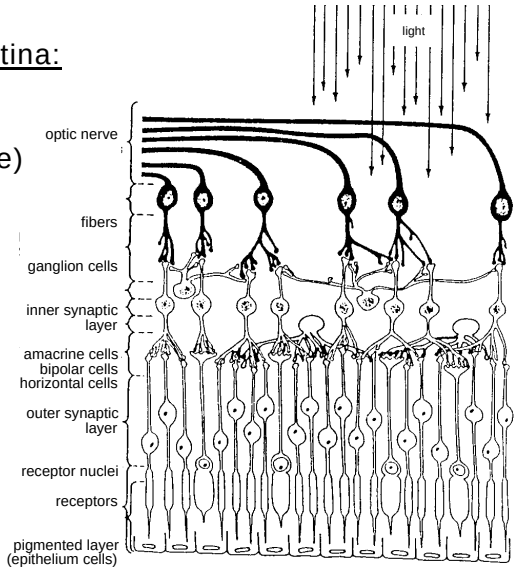
ganglion cells (=optic nerve)

↑

bipolar cells

↑

receptors

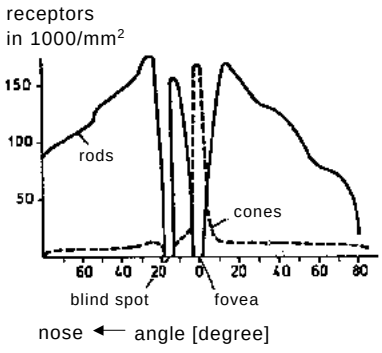


Human retina II

Rods	Cones
high sensitivity	low sensitivity
low light vision	day light vision > 1 cd/m^2
monochrome	color
"scotopic vision"	"photopic vision"

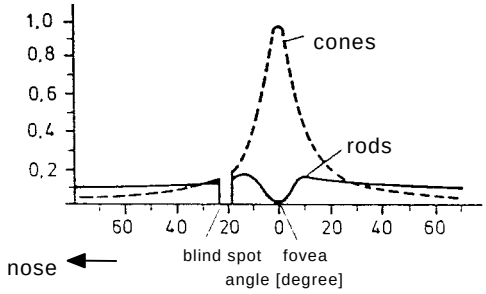
⇧

Video displays



Visual acuity

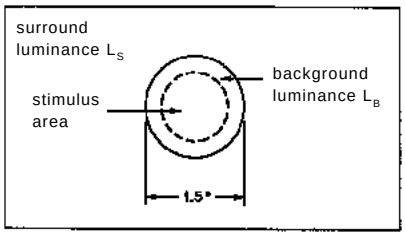
- Spatial resolution in lines/arcmin:



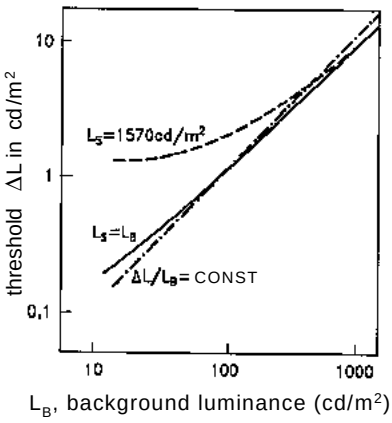
- Minimum distance of adjacent cones in the central fovea limits spatial resolution. (2 - 2.3 µm ↔ 25 . . . 29 sec of arc)

Weber-Fechner law, I

- Experiment:



- Result:



Weber-Fechner law, II

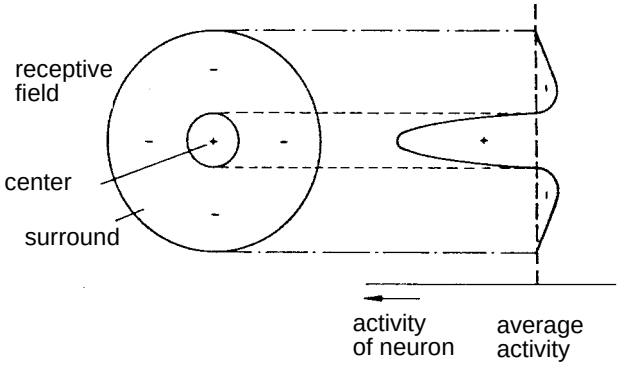
- "Weber-Fechner Law"

$$\Delta L = cL_B \qquad c = 0.01 \ldots 0.02$$

- Implies logarithmic relationship between physical luminance and subjectively perceived brightness.
- Other proposed nonlinearities: square-root, cube-root, polynomials
- γ-characteristic of CRT displays is approximate inverse of nonlinearity of human brightness perception.

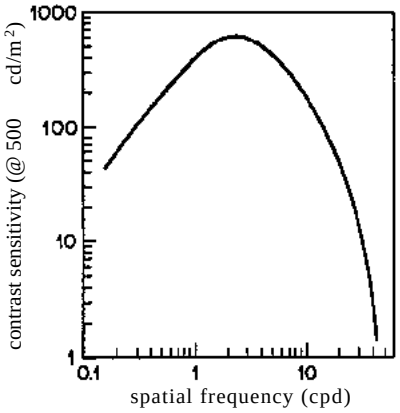
Inhibition and excitation in the retina

- Receptive field of a ganglion cell (=fiber of the optic nerve) shows „center-surround response“ with both
  - Lateral inhibition
  - Lateral excitation



Spatial contrast sensitivity

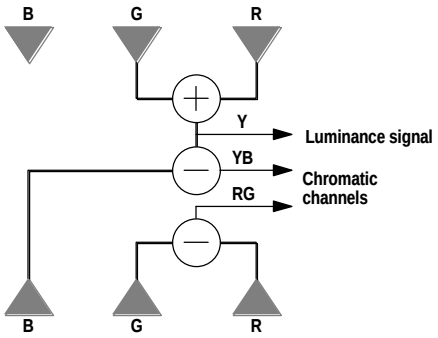
- Lateral inhibition and excitation together lead to a bandpass characteristic of the contrast sensitivity function of the human visual system



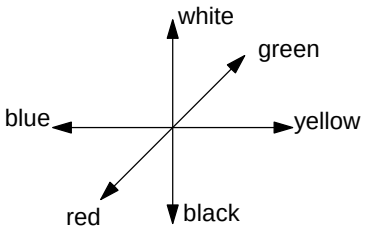
Color vision: opponent color theory

- Retina carries out "matrix operation" to represent colors in the opponent color system (Y, Y-B, R-G)

Opponent color model:

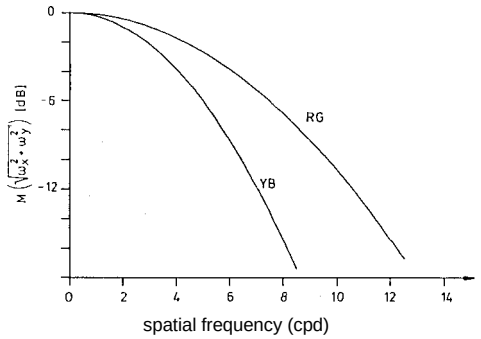


Opponent color space:



Color vision: contrast sensitivity in opponent color space

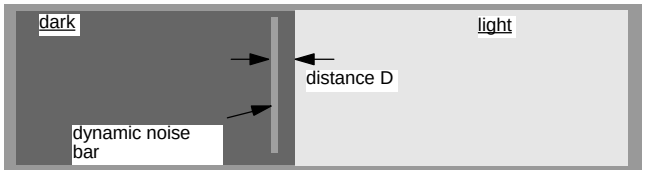
- Spatial frequency response of Y-B and R-G channel (Girod, 1988):



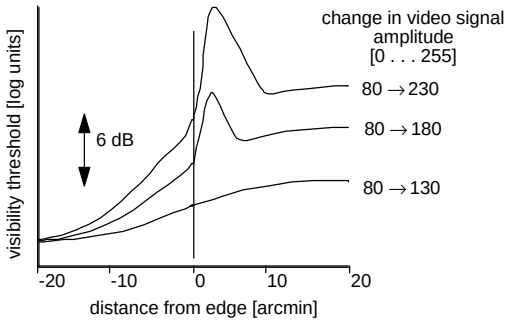
- Bandwidth Y:RG:YB approximately 8:5:3.
- Some researchers have observed bandpass characteristic also for chromaticity channels.

Spatial masking, I

Experiment:

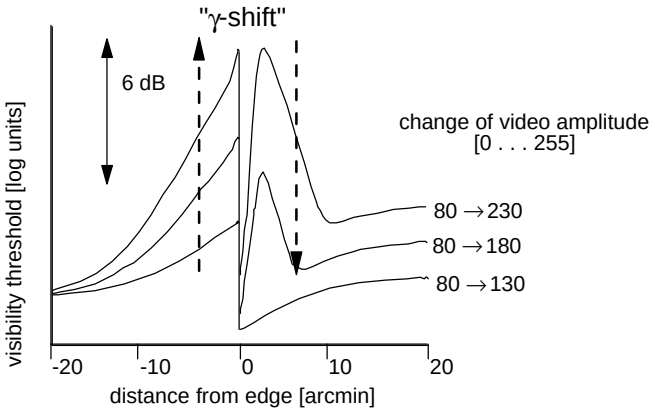


visibility threshold
(w-Modell, Girod, 1987)



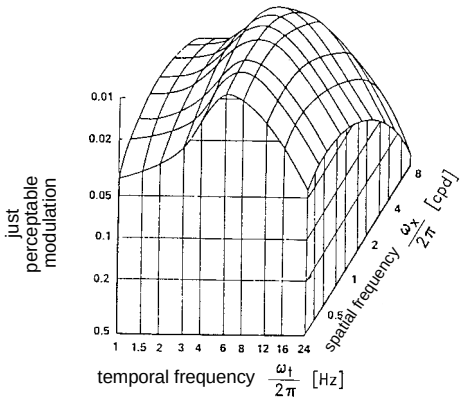
Spatial masking, II

Visibility threshold for the γ-predistorted video signal (w-Modell, Girod, 1987):



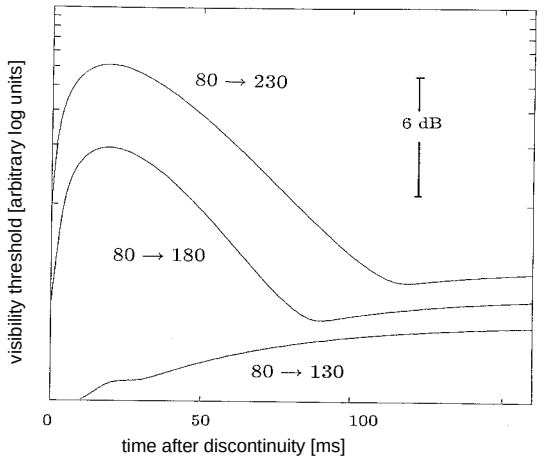
Spatiotemporal contrast sensitivity of luminance perception

- Spatiotemporal contrast sensitivity of the luminance channel has bandpass characteristic.
- Contrast sensitivity function separable for high spatial and temporal frequencies only.
- Plot of contrast sensitivity function (from Kelly):

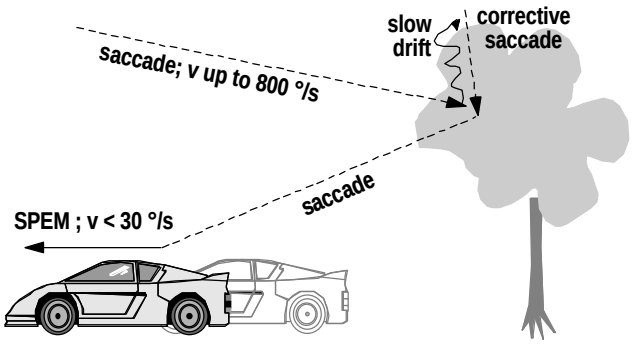


Temporal masking

- Visibility thresholds for γ-predistorted video signal after luminance discontinuity (w-model, Girod, 1987):

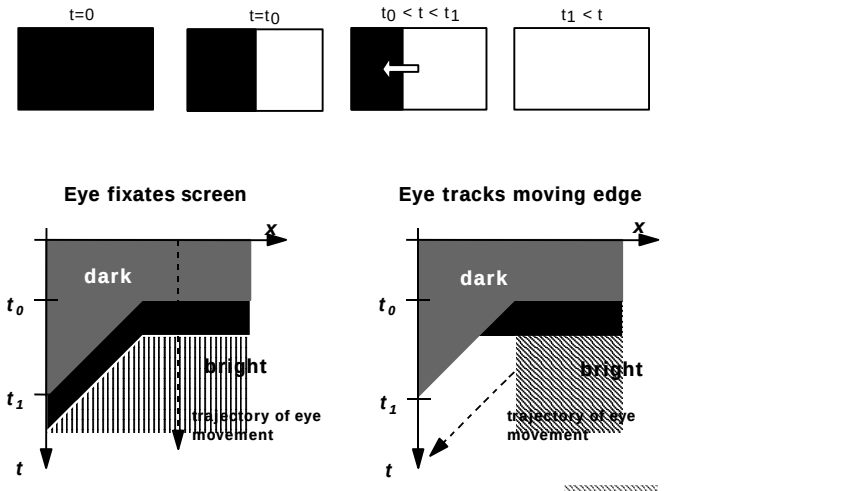


Eye movements



SPEM: smooth pursuit eye movement

Temporal masking and SPEMs



Eye movements and spatiotemporal frequency response of the human visual system, I

- Assume SPEM of constant velocity:

$$\begin{aligned} x' &= x - v_x t \\ y' &= y - v_y t \\ t' &= t \end{aligned}$$

retina coordinate system — display coordinate system

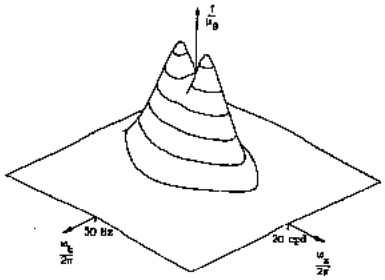
- Coordinate transformation in spatiotemporal frequency space ("Doppler effect")

$$\begin{aligned} \omega_{x'} &= \omega_x \\ \omega_{y'} &= \omega_y \\ \omega_{t'} &= \omega_t + \omega_x v_x + \omega_y v_y \end{aligned}$$

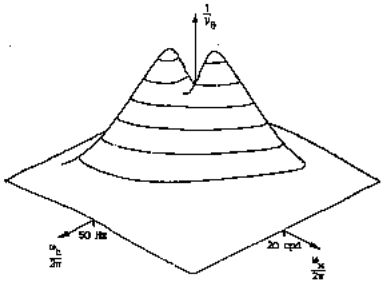
Eye movements and spatiotemporal frequency response of the human visual system, II

relative velocity between
eye and coordinate system

$v_x=0$



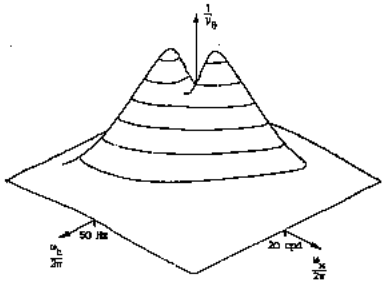
$v_x=2\,°/s$



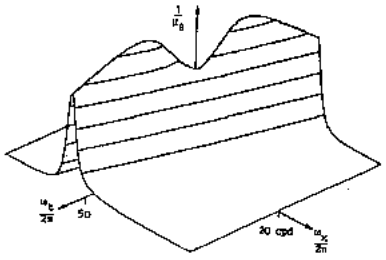
Eye movements and spatiotemporal frequency response of the human visual system, III

relative velocity between
eye and coordinate system

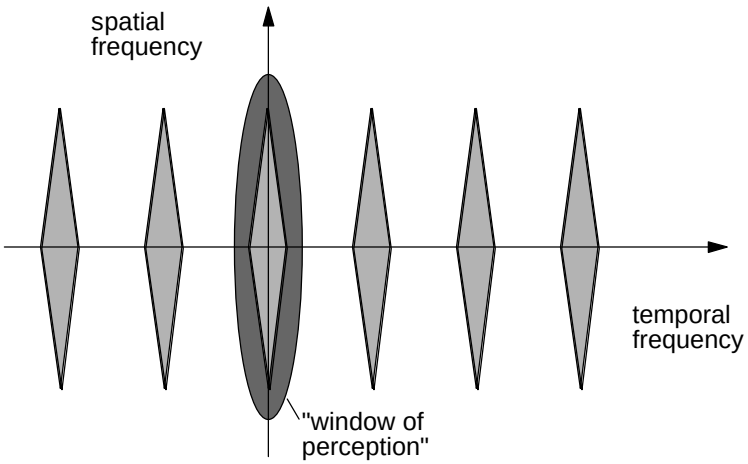
$v_x=2\,°/s$



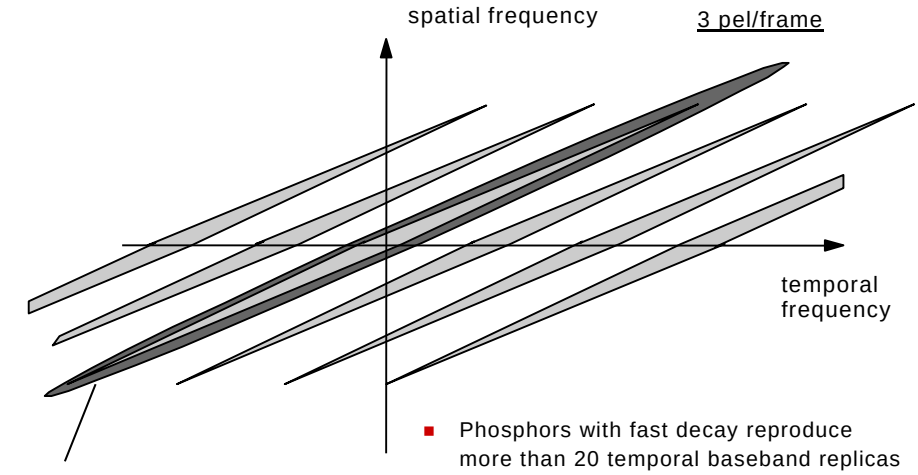
$v_x=8\,°/s$



Perception of a temporally sampled image signal, without movement

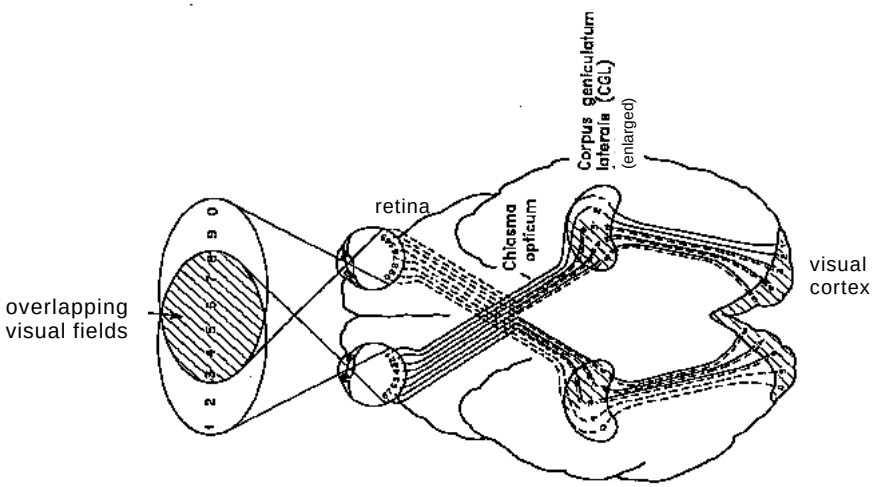


Perception of a temporally sampled image signal, translatory movement



- Phosphors with fast decay reproduce more than 20 temporal baseband replicas
- No spectral overlap -> perfect reconstruction of original signal possible

Anatomy of the human visual system



Human visual perception - summary

- Spatial frequency components visible up to 60 cpd
- Logarithmic relationship between luminance and subjective brightness perception
- Lateral inhibition -> spatial bandpass characteristic
- Chromaticity channels have lower bandwidth
- Visibility threshold often increased in the vicinity of edges, but sometimes decreased (“masking”).
- SPEMs shear window of perception in spatiotemporal frequency space.