Image Perception summary

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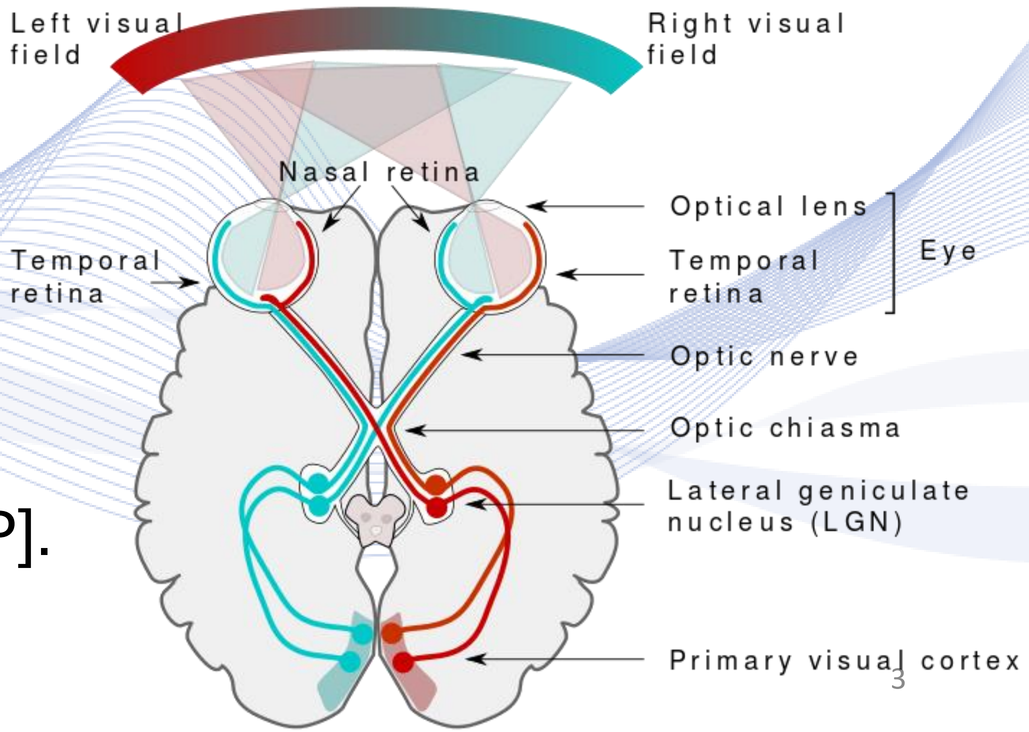
Artificial Intelligence & Information Analysis Lab

Outline

- **Human Vision Modeling**
- Spatial HVS models
- Gestalt theory
- Visual illusions

Human Vision Modeling

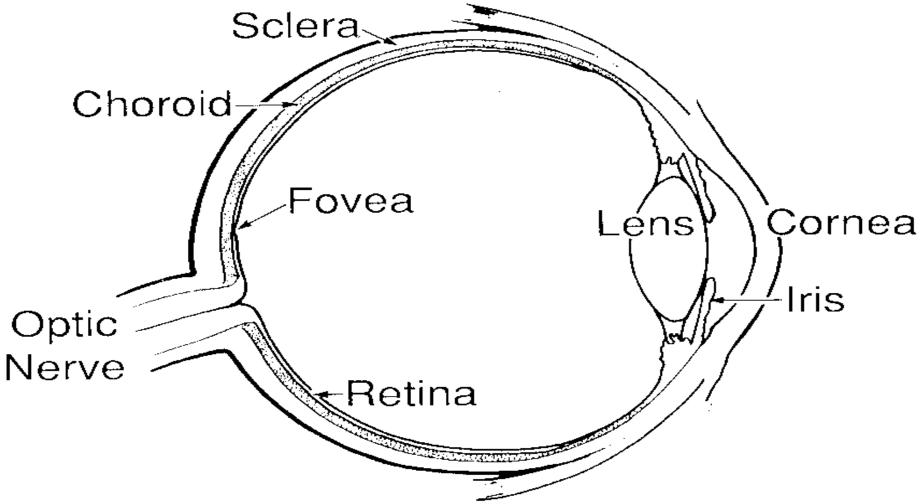
- One of digital image and video processing aims is image quality improvement.
- ***Human Visual System*** (HVS) modeling is difficult, because of its complex structure.



Human visual system [HVP].

Human Vision Modeling

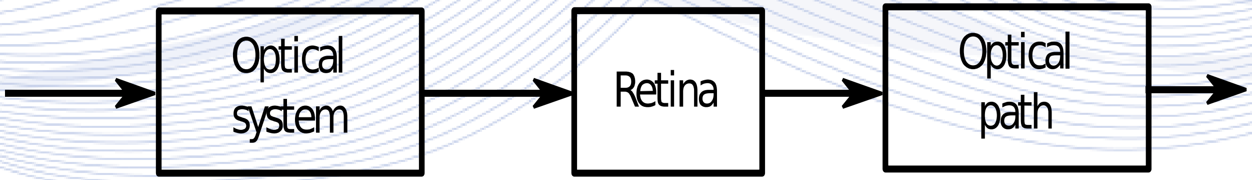
- ***Human eye*** has spherical shape with a diameter of 20 mm.
- Light enters the ***pupil*** of the ***iris*** (diameter 2 - 8 mm).
- It passes through ***lens***, ***vitreous humor*** and focuses on the ***retina***.



Human eye.

Human Vision Modeling

- Retina light detectors: cones and rods.
  - ***Cones***: sensitive to color.
    - Photopic (high brightness, daylight) vision.
  - ***Rods***: sensitive to light intensity, not color.
    - They create a general idea of the contents in the visual field.
    - Scotopic (night) vision.

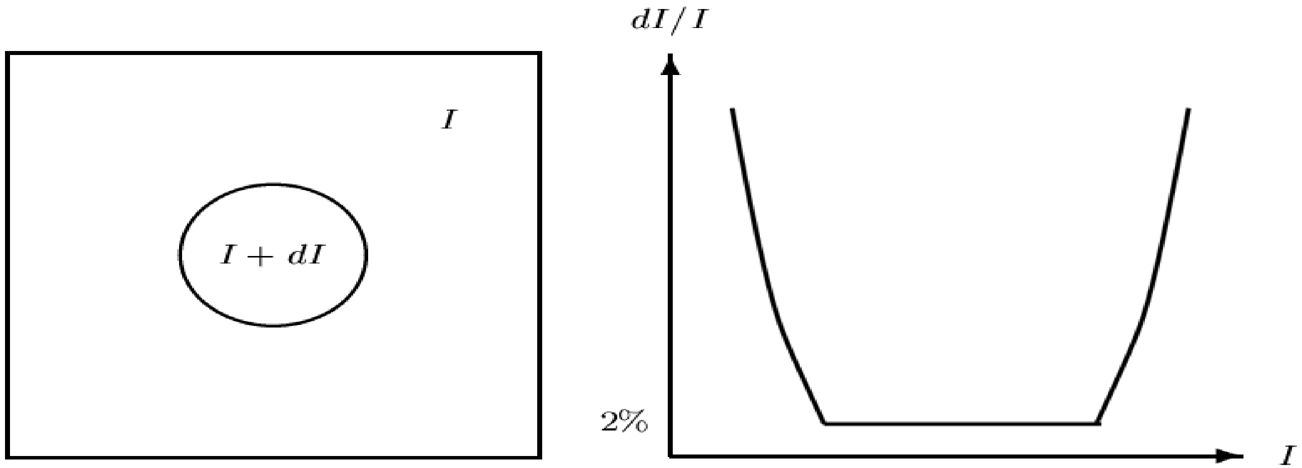


Human visual system model.

Human Vision Modeling

Weber ratio:

- Humans observe an image consisting of a constant background intensity I and a spot having intensity $I + dI$.
- dI increases from 0 to a value until the spot is observable.
- Weber ratio $\frac{dI}{I}$ is constant at around 2% for large image intensity range.



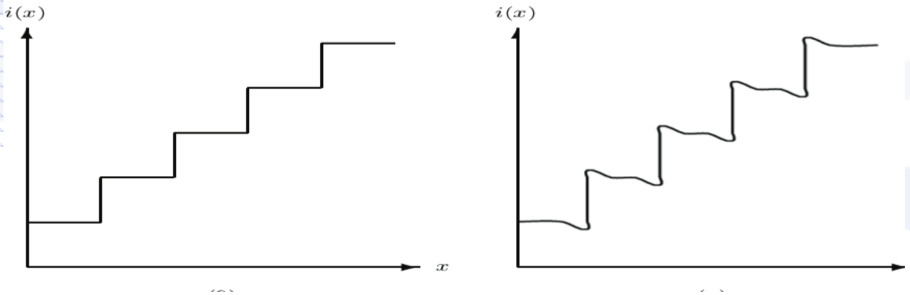
Weber ratio as a function of background image intensity I.

Human Vision Modeling

Mach Phenomenon:

- Image column intensity appears non-constant along the horizontal direction.
- In fact, it is constant.
- High-pass HVS characteristics.
- Edge sensitivity.

(α)



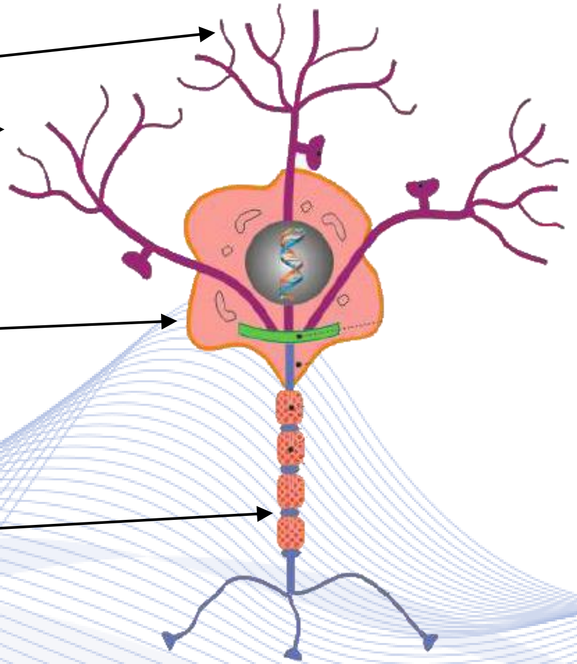
a) Mach image; b) true image intensity along the horizontal direction, c) perceived image intensity.

Human Vision Model

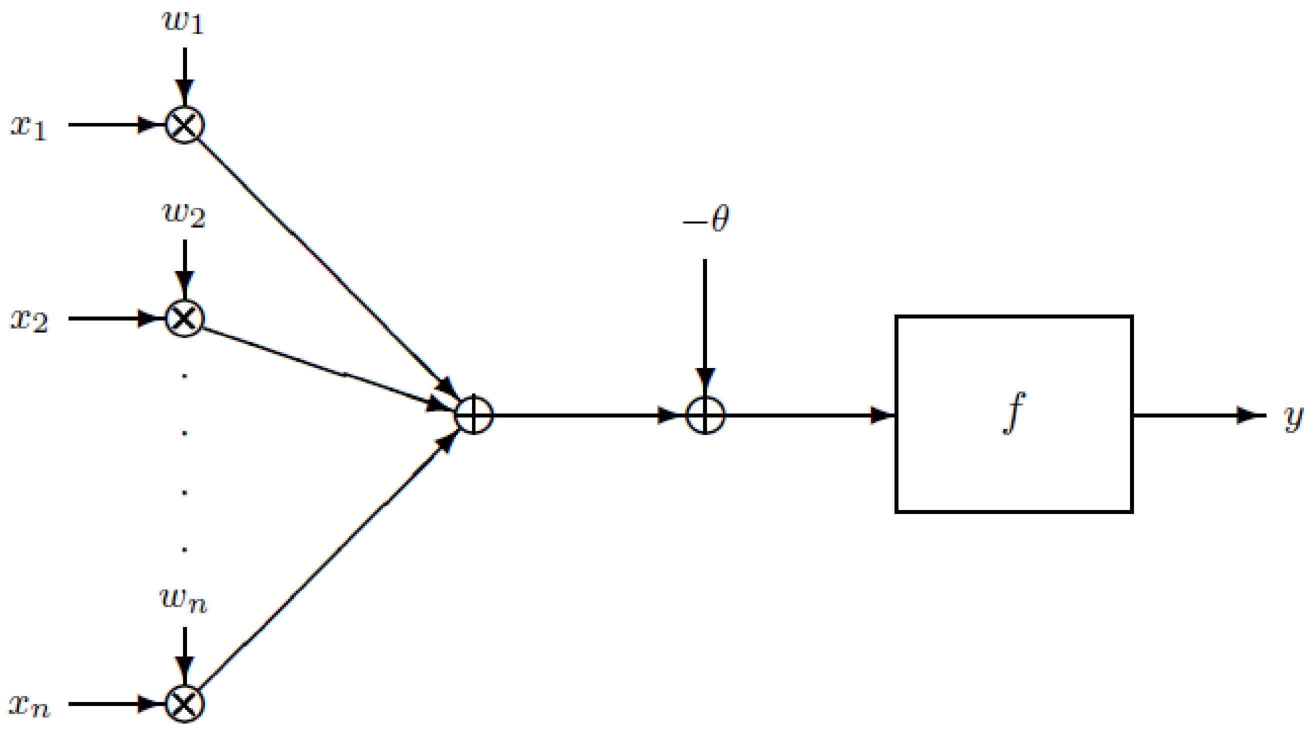
a) Original image; b) Perceived image without high-pass information.

Human Vision Modeling

- Basic computational unit of HVS.
- Main parts:
  - Dendrites
    - → Act as inputs.
  - Soma
    - → Main body of neuron.
  - Axon
    - → Acts as output.
- Neurons connect with other neurons via ***synapses***.



Human Vision Model



Mathematical neuron model.

Human Vision Model

- HVS functionalities can be explained by neuron physiology.
- McCulloch-Pitts neuron model:

$$y = f\left(\sum_{j=1}^{n} w_j x_j - \theta\right),$$

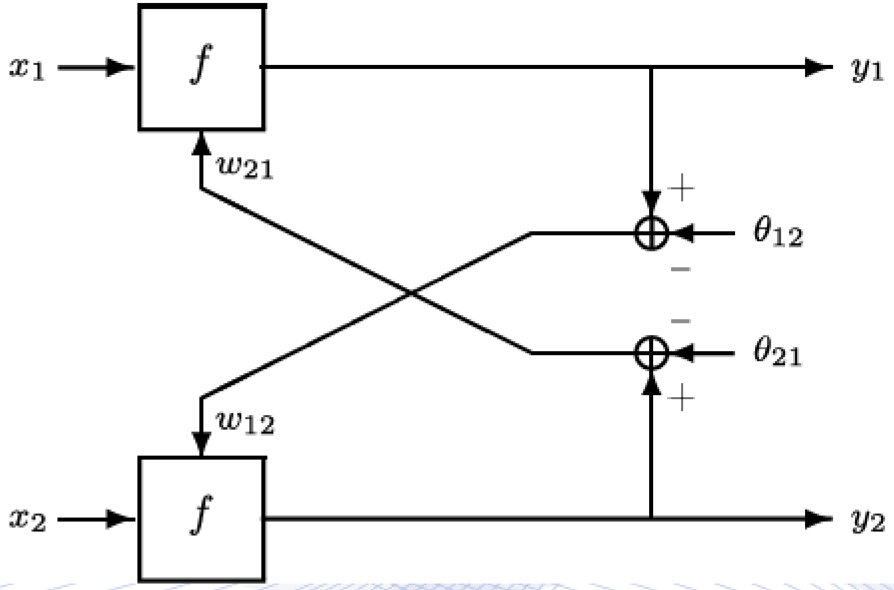
$w_j, x_j, j = 1, \dots, n$: synaptic weights/inputs,

f monotonic nonlinearity, e.g., sign function:

$$f(x) = \mathrm{sign}(x) = \begin{cases} -1, & x < 0 \\ 1, & x \geq 0. \end{cases}$$

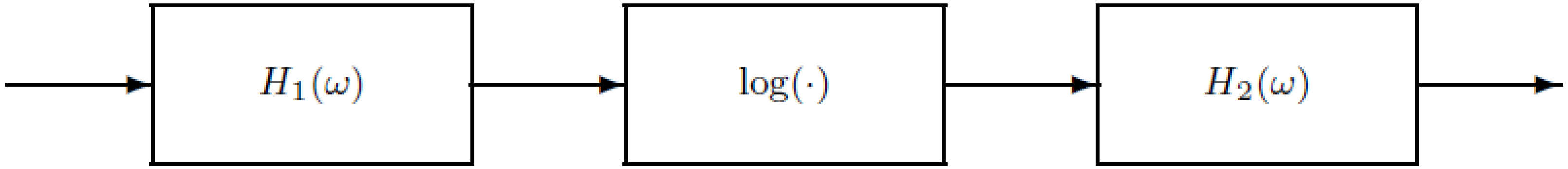
- ***Excitatory/Inhibitory*** synapses have positive/negative weights w_i.

Human Vision Model



Neural pipeline.

Human Vision Model



Mathematical HVS model.

Human Vision Model

Laplacian-of-Gaussian (***LoG***) HVS model $\nabla^2 G(x,y)$:

- $G(x,y)$ is a low-pass Gaussian function:

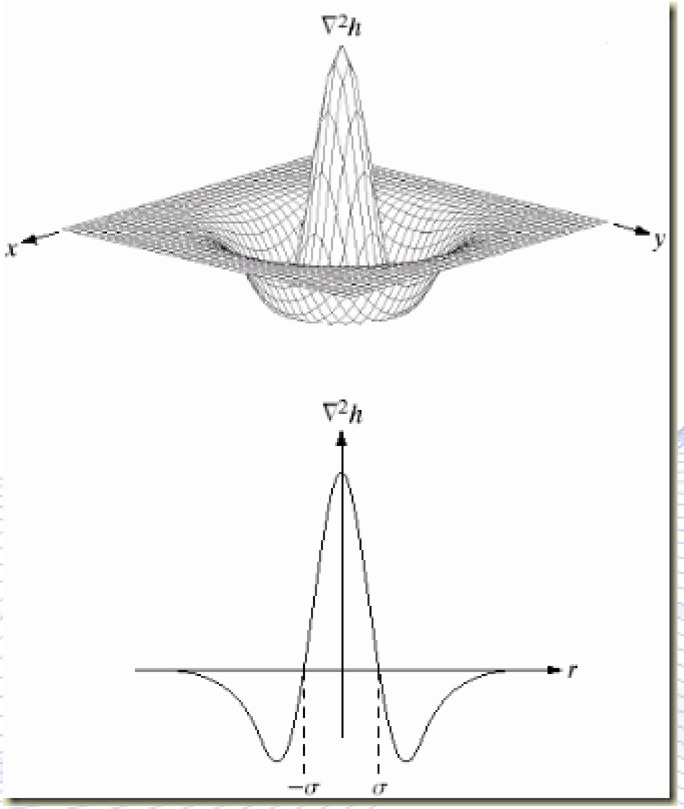
$$G(x,y)=\frac{1}{2\pi\sigma}\exp\left\{-\frac{1}{2\sigma^2}(x^2+y^2)\right\}.$$

- Laplacian operator $\nabla^2 f(x,y)$ is a ***2D high-pass filter***.

- LoG operator is given by:

$$\nabla^2 G(x,y)=-\frac{1}{\pi\sigma^4}\left(1-\frac{x^2+y^2}{2\sigma^2}\right)\exp\left\{-\frac{1}{2\sigma^2}(x^2+y^2)\right\}.$$

Human Vision Model



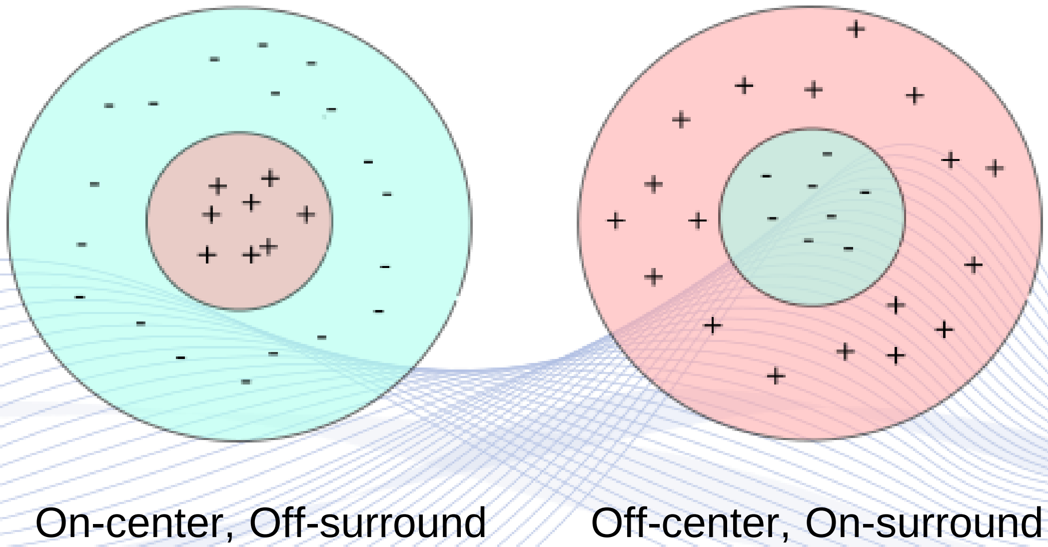
Negative LoG function [LOG].

Human Vision Model

- There are two models of ***ganglion receptive fields:***
  - ***on-center/off-surround*** and ***off-center/on-surround***, depending on whether the central region is excitatory or inhibitory, respectively.
  - Both positive and negative image intensity changes can be encoded with positive-only neuron action potentials.

Human Vision Model

Ganglion Receptive Fields



Center-surround organization of ganglion receptive fields.

Human Vision Model

Simple-cells and ***complex-cells*** in the V1 visual cortex area are ***orientation-selective***:

- they respond to spatial intensity changes only along a certain orientation (and scale).
- Simple-cells can be modeled by ***Gabor functions***:

$$h(x,y)=\frac{1}{2\pi\sigma}\exp\left\{-\frac{1}{2\sigma^2}(x_r^2+r^2y_r^2)\right\}\exp\left\{i\left(\frac{2\pi x_r}{\lambda}+\varphi\right)\right\},$$

$$x_r = x\cos\theta + y\sin\theta,$$

$$y_r = -x\cos\theta + y\sin\theta.$$

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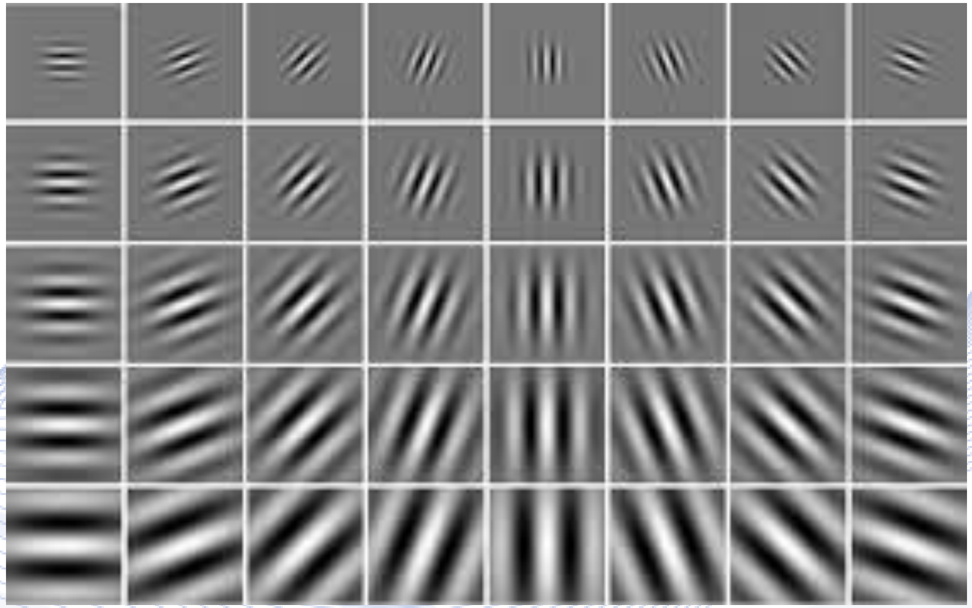
Human Vision Model

Gabor function parameters:

- θ: Gabor filter normal orientation.
- φ: phase offset.
- σ: Gaussian standard deviation (scale).
- r: spatial aspect ratio defining the Gabor function ellipticity.
- λ: sinusoidal wavelength.
- φ: sinusoidal phase.

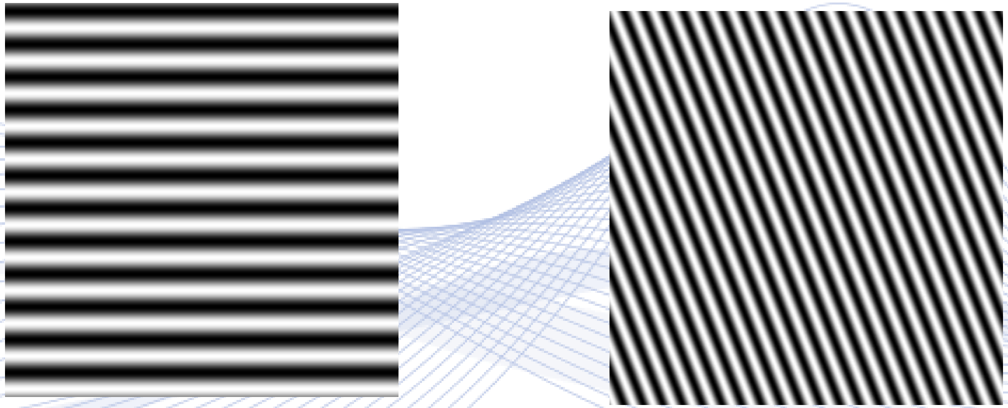


Outline

- Human Vision Modeling
- **Spatial HVS models**
- Gestalt theory
- Visual illusions

Spatial HVS models

- A frequency F is linked with angular frequency $\Omega = 2\pi F$.
- Spatial frequencies (video content changes along x, y axes):
  - $\Omega_x = 2\pi F_x$ and $\Omega_y = 2\pi F_y$.



2D sinusoidal signals: a) $(F_x, F_y) = (0{,}6)$; b) $(F_x, F_y) = (10{,}4)$.

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Spatial Image frequencies

Spatial frequencies F_x, F_y:

- They show spatial luminance changes on the image plane.
- Local frequency vector $\mathbf{\Omega} = [\Omega_x, \Omega_y]^T$ is colinear to local image content change direction (perpendicular to edge direction).
- Spatial frequencies can be defined along different orthogonal axes than (x, y).
- They are measured in cycles per unit length:
  - e.g., a 2D sinusoidal spatial pattern $f(x, y) = \sin(20\pi y)$ has a frequency $(0{,}10)$.

Spatial Image Frequencies

Image spatial frequency perception depends on the viewing conditions:

- Screen width/height (typically quantified by diagonal length (inch).
- Viewing distance D.
- They determine image ***viewing angle***.

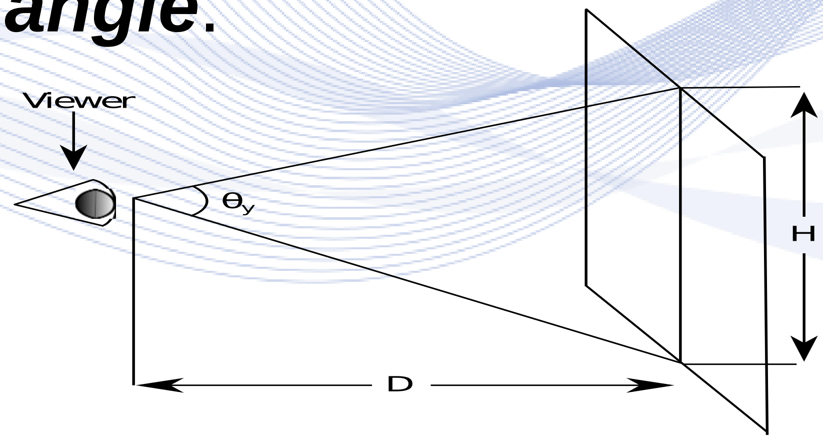


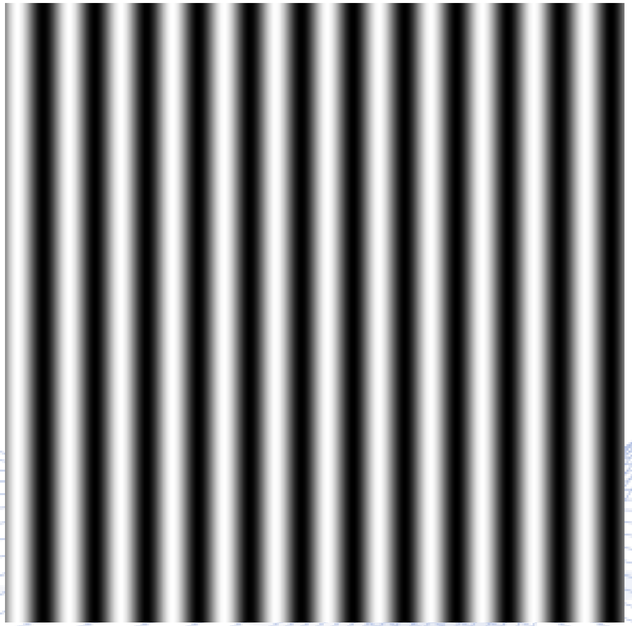
Image viewing setup.

Spatial HVS models

HVS Spatial Frequency Response (***SFR***):

- Assumption: spatial HVS sensitivity is isotropic, the spatial frequency response can be measured along any arbitrary spatial axis.
- Spatial sensitivity normalization to the observation distance: SFR expressed as a function of the spatial angular frequency.

Spatial HVS models



Horizontal 2D sinusoidal signals having $(F_x, F_y) = (6,0)$.

Spatial HVS models

Kelly experiments

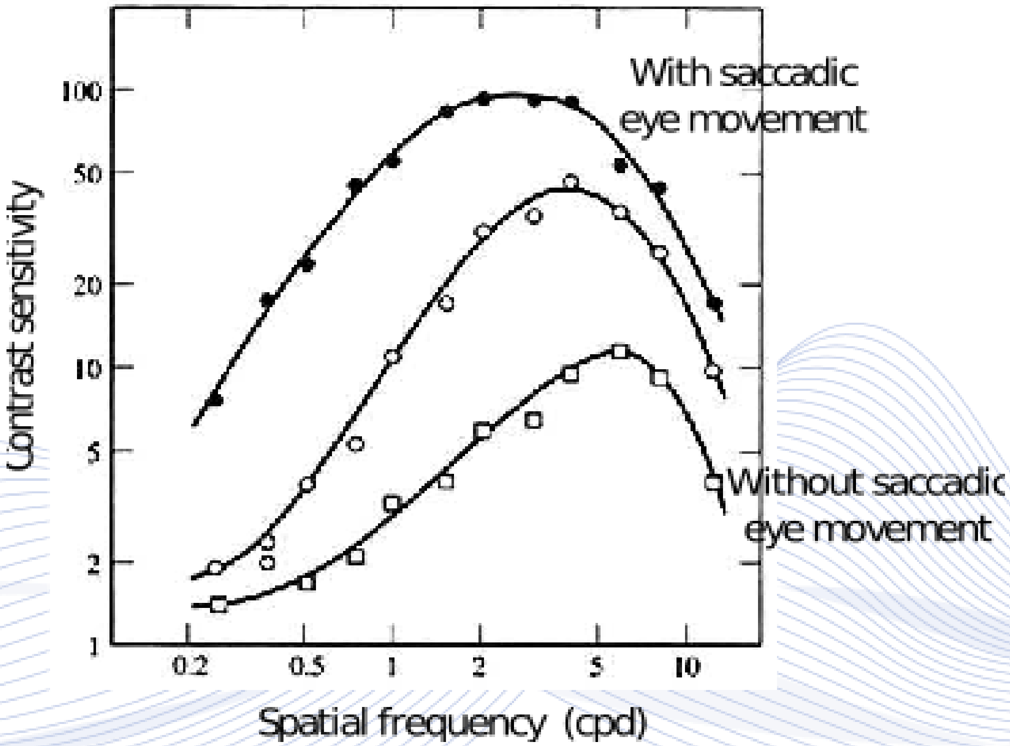
- Human observers observe vertical sinusoidal patterns of amplitude Cs and frequency F_x superimposed on a constant background having illumination C:

$$f(x,y) = C(1 + s\cos 2\pi F_x x).$$

- When they first observe the existence of the pattern having amplitude Cs_{min}, contrast sensitivity is defined by:

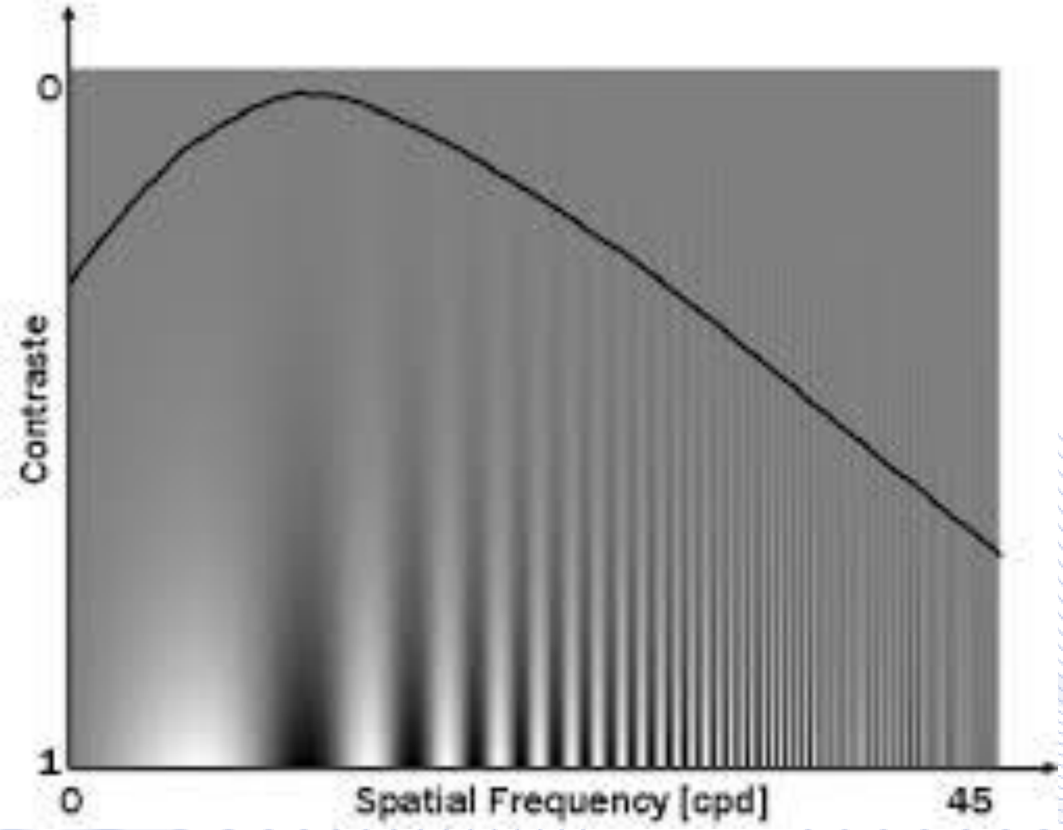
$$S_e = \frac{1}{s_{min}}.$$

Spatial HVS models



Spatial HVS frequency response.

Spatial HVS models



Contrast sensitivity.

Outline

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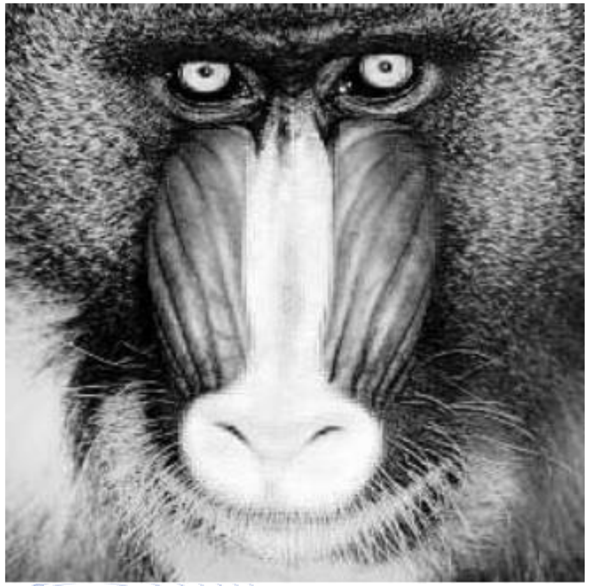
- Spatial HVS models
- **Gestalt theory**
- Visual illusions

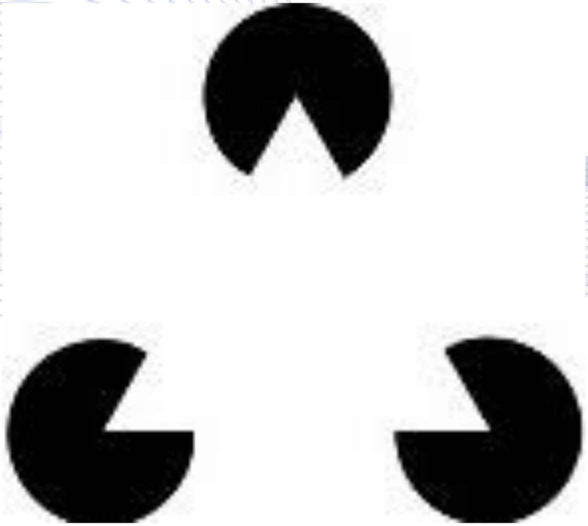
Gestalt theory

Gestalt psychology claims that humans perceive entire image patterns than merely their components.

Gestalt principles:

- ***Emergence***: we identify the whole before its parts.
- ***Reification***: we perceive more explicit spatial information than the one contained in sensory stimulus.





Gestalt laws

- ***Figure/Ground law*** states that we instinctively perceive objects as either being in the ***foreground*** or ***in the background***. Unless an image is ambiguous, we see its foreground first.

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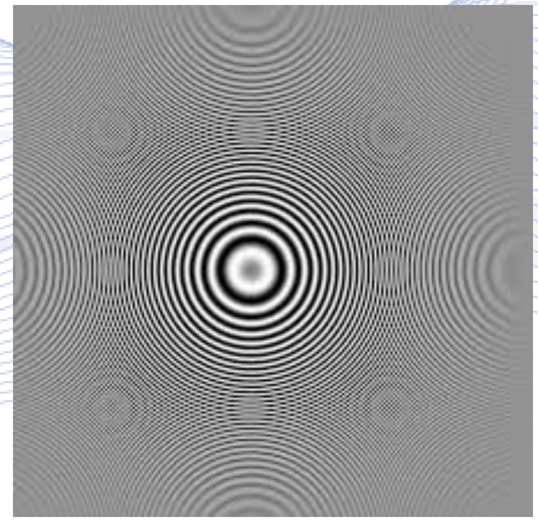
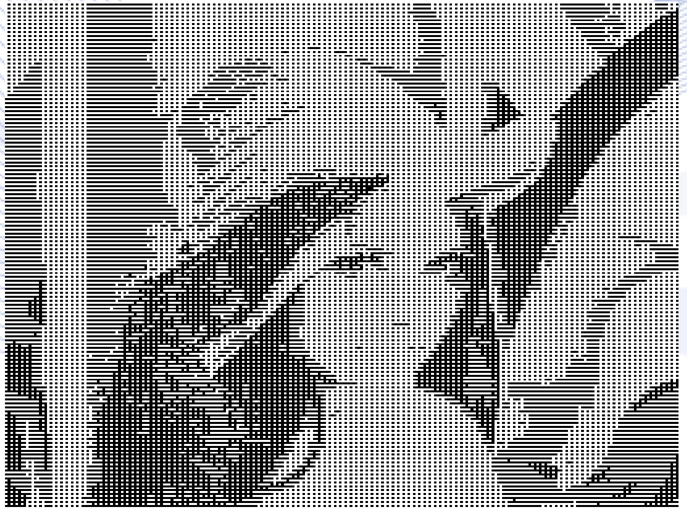
Visual illusions

Visual illusions are due to visual patterns that can be deceptive or misleading to HVS.

- Moire patterns in printed images.
- Halftoned images.

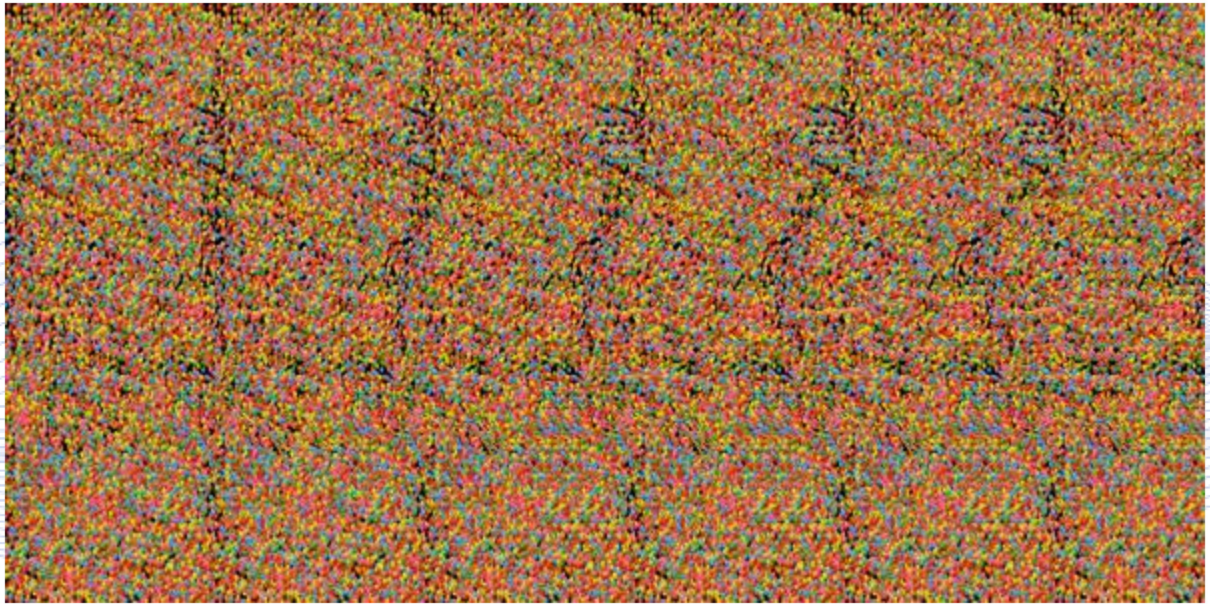




Visual illusions

3D image illusions.

Stereo illusions are 2D images trick the brain into perceiving an illusion of depth.



Autostereogram [STE].

Visual illusions

Escher illusions.

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Q & A

Thank you very much for your attention!

More material in
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