Image Compression and Video Compression

Topics

- Introduction to Image Compression
- Transform Coding
- Subband Coding, Filter Banks
- Haar Wavelet Transform
- SPIHT, EZW, JPEG 2000
- Motion Compensation
- Wireless Video Compression

Standards

- JPEG
  - Joint Photographic Expert Group
  - Still Image Compression Standard
- JBIG
  - Bi-level Compression (Not used much)
- JPEG-2000
  - Wavelet Based
- H.261, H.263 and H.264
  - Interactive Video Standards.
- MPEG-1, MPEG-2
  - Moving Picture Expert Group
  - Video Compression Standards for CD ROM's, internet and television.
- MPEG – 4
  - Low Bit Rate Video Compression
- MPEG - 7
  - (follow-on to MPEG-4) Content searchable video

Contents

- Capture and represent digital images
- Light and Color
- Why can Images be Compressed?
  - Spatial Redundancy
  - Temporal Redundancy
  - Spectral Redundancy
  - Psycho-visual Redundancy

  } **Human Visual System** (Spectral Redundancy, Psycho-visual Redundancy)
- Distortion Measures

Image Formulation

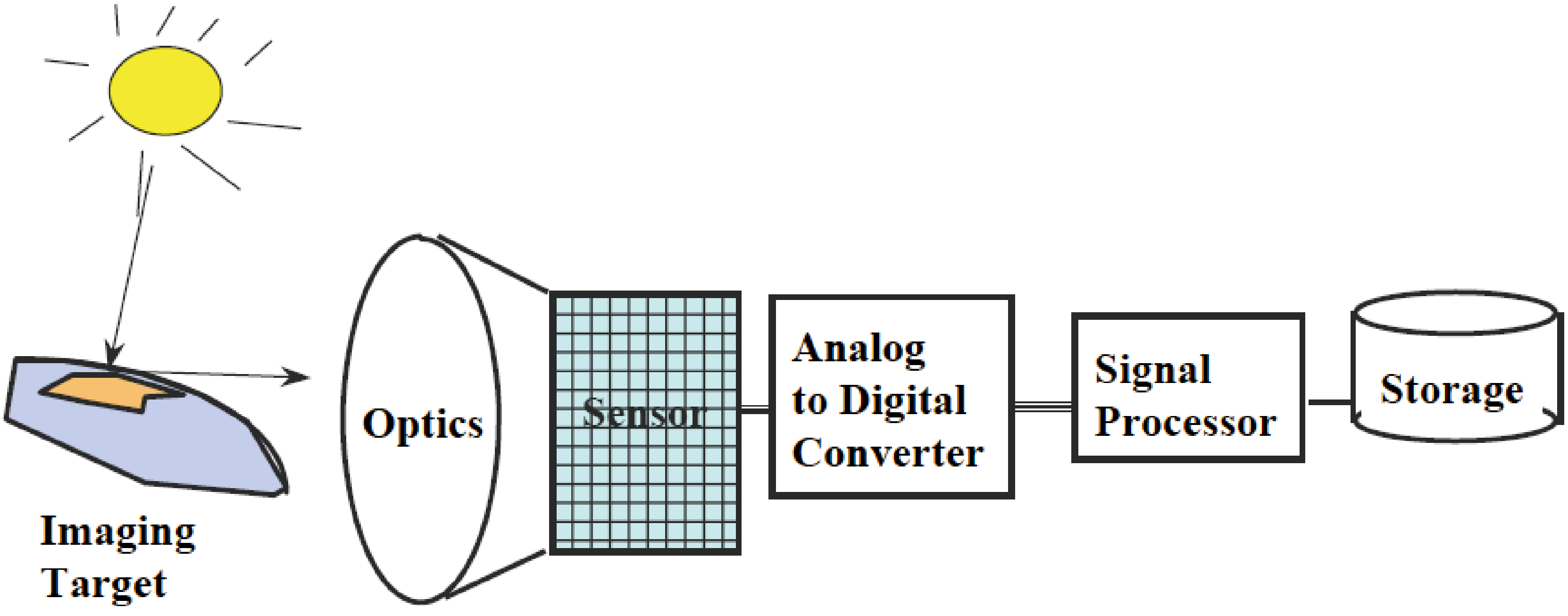
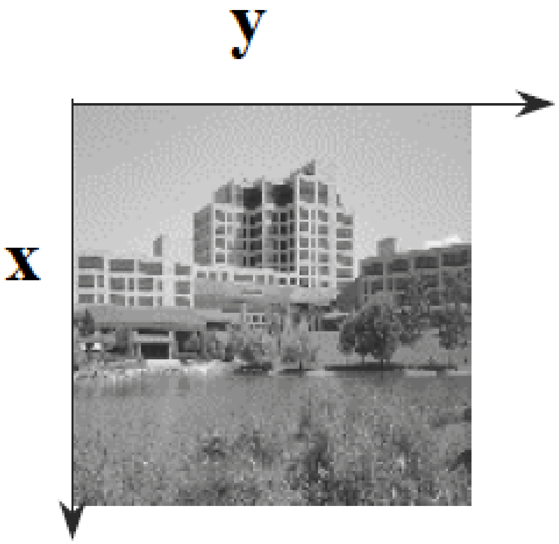


Image Orientation

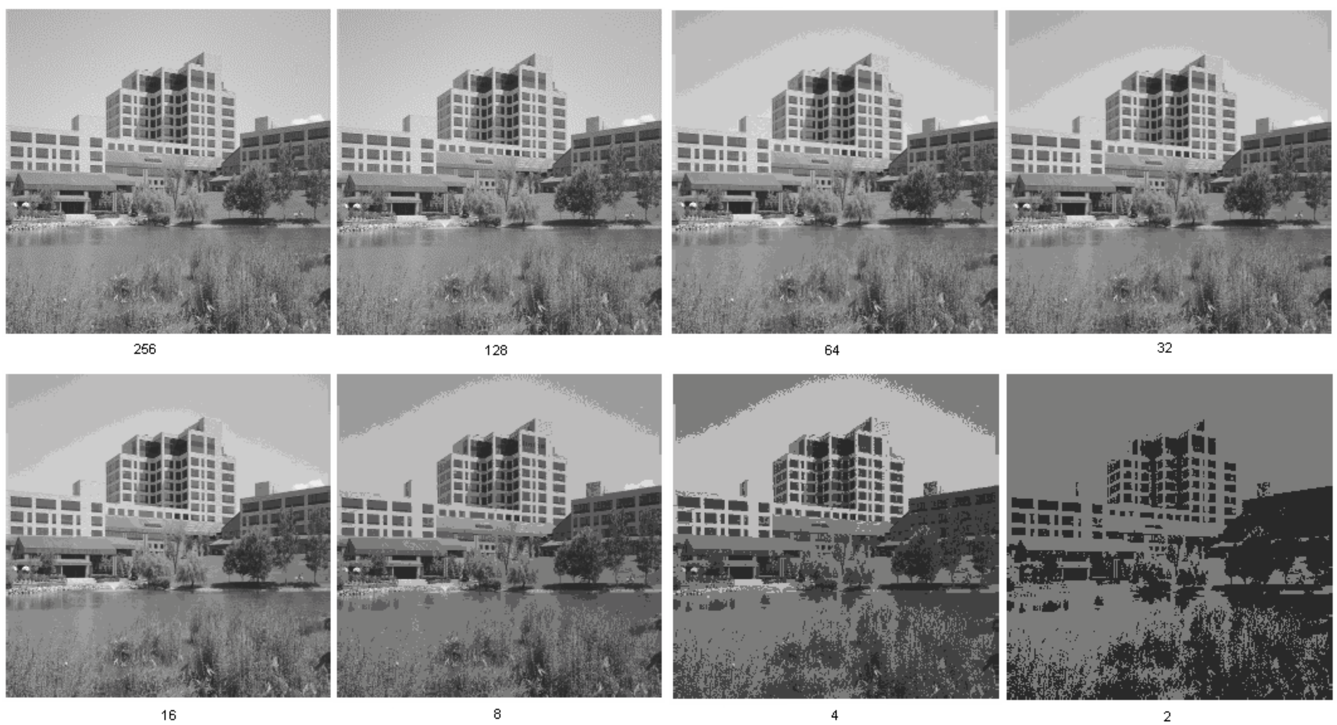
- An image consists of a two-dimensional array of pixels.
- Neighbors of a pixel

(x-1,y-1)	(x-1,y)	(x-1,y+1)
(x,y-1)	(x,y)	(x,y+1)
(x+1,y-1)	(x+1, y)	(x1,y+1)



Number of Gray Levels

- Decreasing gray level results in visual unpleasure and loss of detail.



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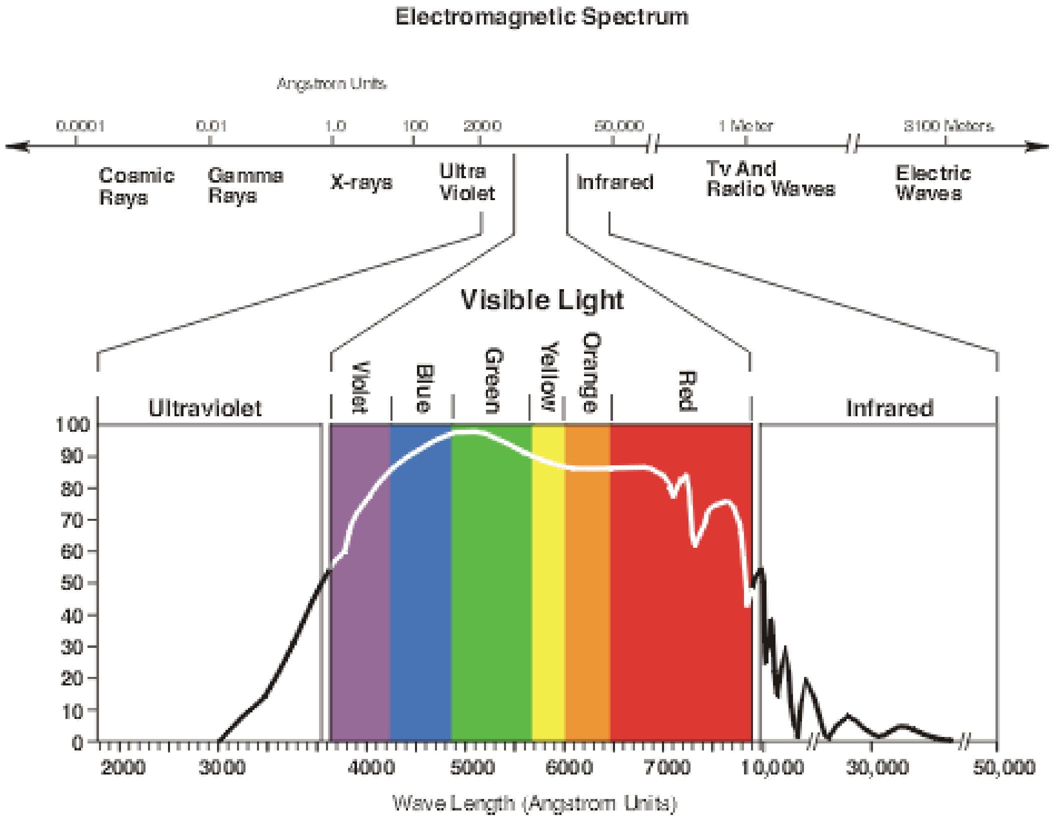
Human Visual System

Light and Color

- The wavelengths of electromagnetic radiation between roughly 370nm and 730nm account for light visible to the human visual system.

- The curve is the spectrum of the solar radiation (the WHITE light) reaching the earth's surface.

- The white light is a mixture of all wavelengths.



Visible Light

- Color is the visual perception to different wavelengths of visible light.
- Different ranges give rise to different color response.

Range* (in nm)	Color
380 - 450	Violet
450 - 490	Blue
490 - 560	Green
560 - 590	Yellow
590 - 640	Orange
640 - 730	Red

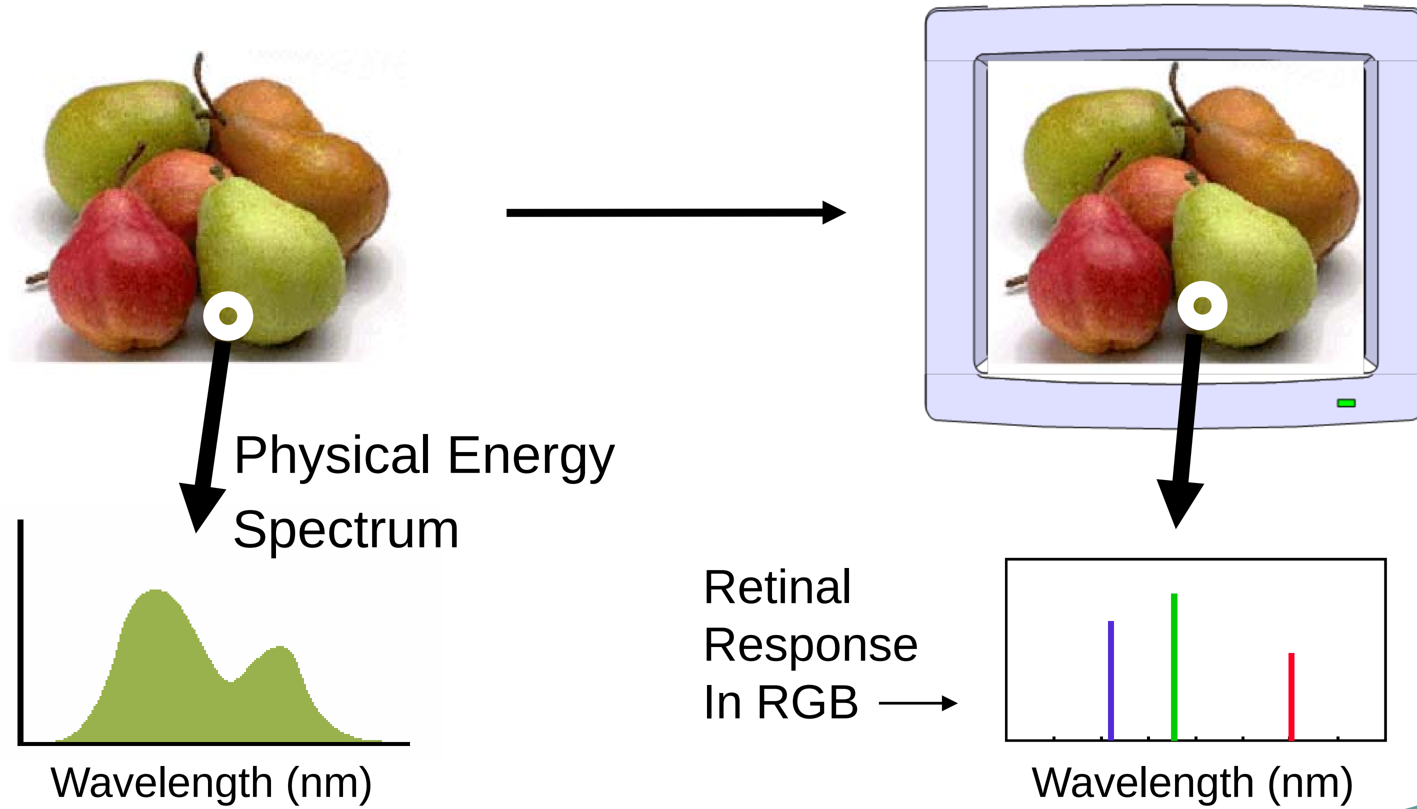
*
- Ranges are approximate
- There is no sharp boundary

Tri-chromatic Nature of Color

- Almost any color can be described as the mixture of the basic color: R, G, B (YES, theoretically there are some colors that cannot be encoded as a combination of three colors).
- This is the basis of the digital color techniques. Used in the digital camera, CRT/LCD monitor, projector, etc.
- Directly due to the three photoreceptors on the retina (explained later).

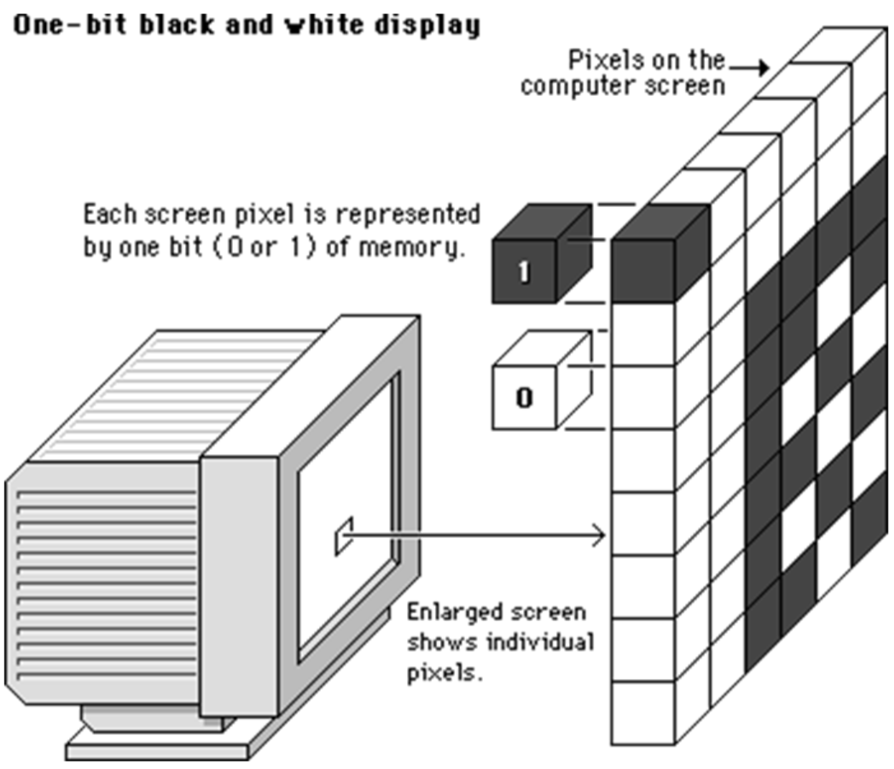
Color Reproduction

- Each pixel can be represented by a spectrum (left). On the monitor it is represented by the [RGB] value.



Black and White Image

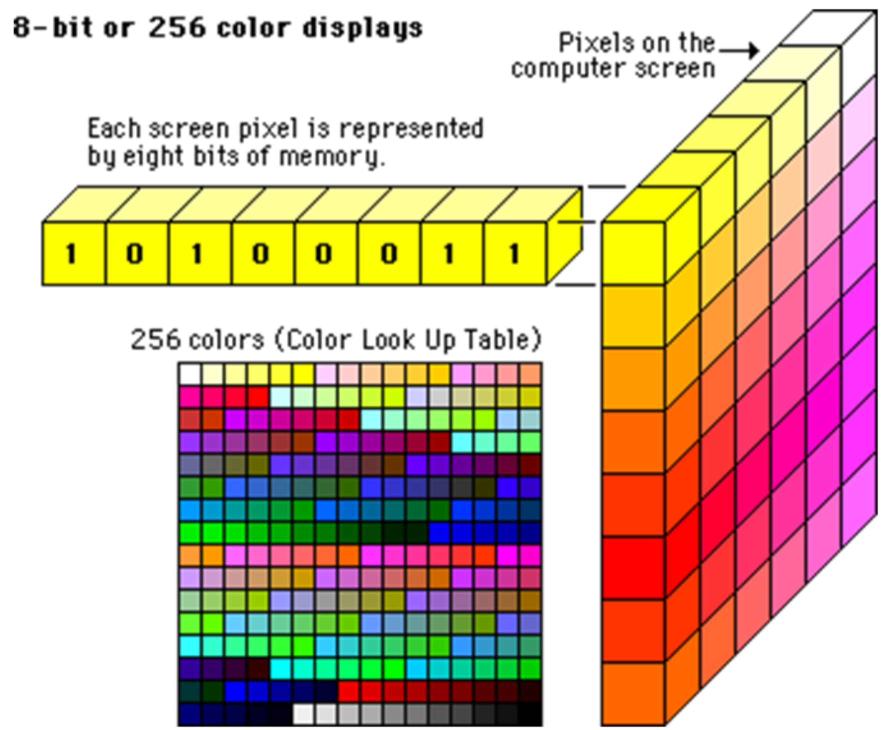
- Only two colors (black or white) for each pixel on the screen.
- Color Depth = 1 is black and 0 is white.



Color Index scheme

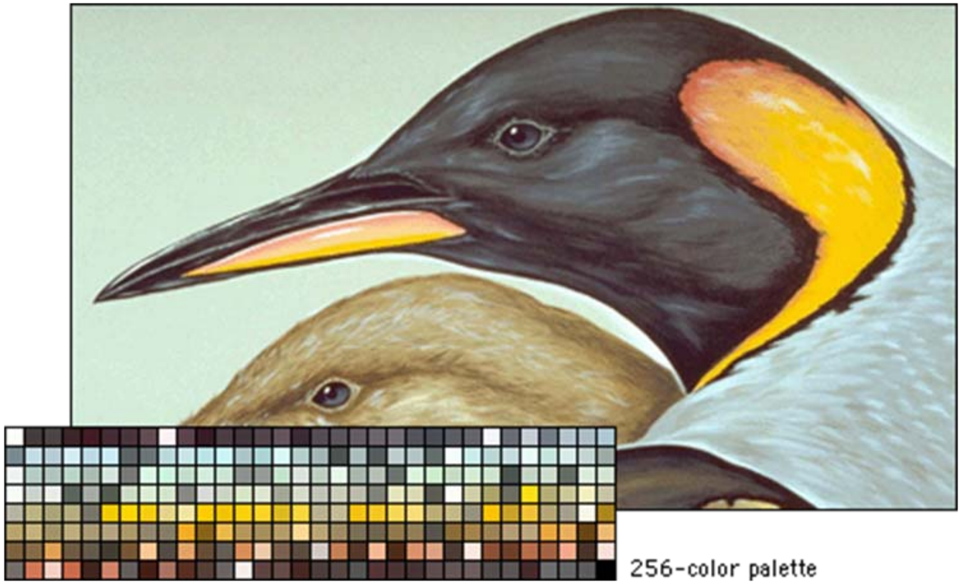
- Although the exact colors that an 8-bit screen can display are not fixed, there can never be more than 256 unique colors on the screen at once. You may **assign colors** as follows and other variations are possible.

3	2	3
R	G	B



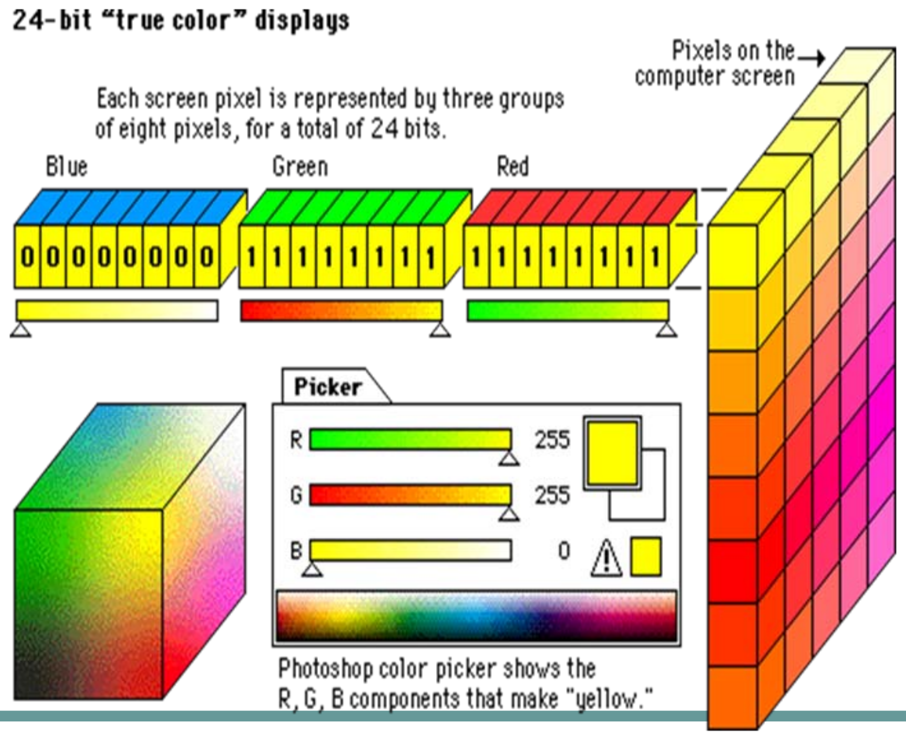
Color Index Example

- In 8-bit images the 256 colors that make up the image are stored in an array called a "palette" or an "index“.
- As mentioned above, 8-bit images can never contain more than 256 unique colors



True Color

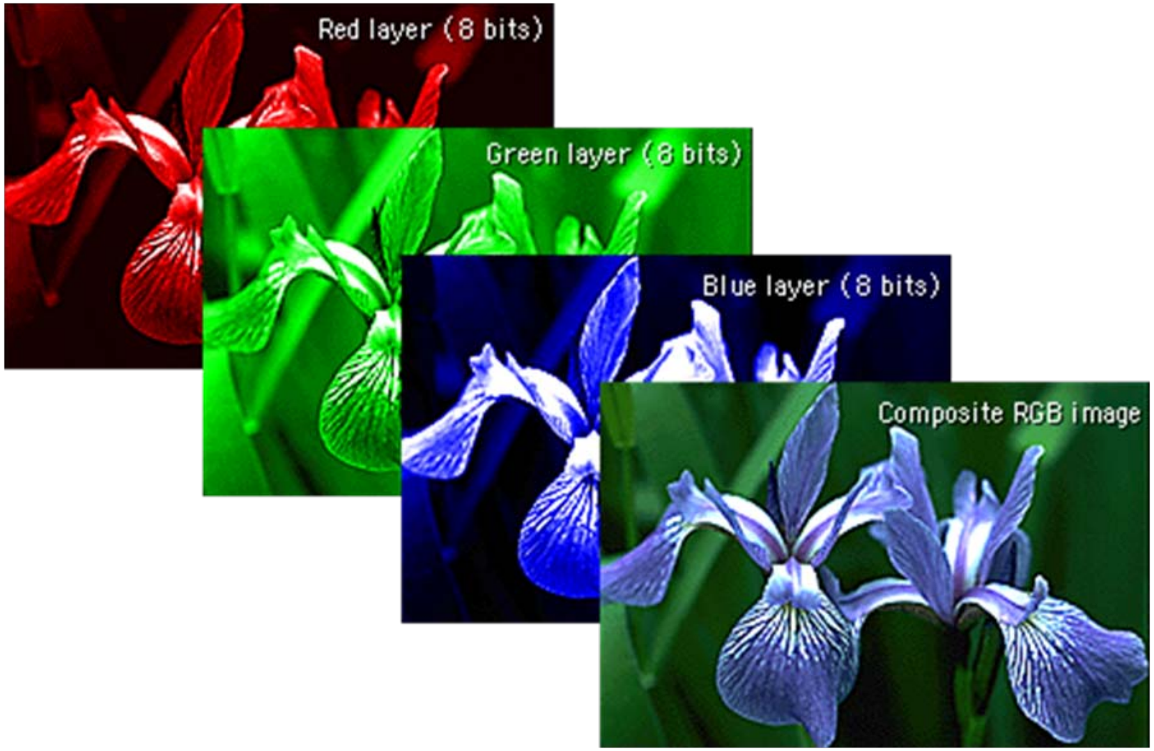
- "True-color" or "24-bit" color displays can show millions of unique colors simultaneously on the computer screen.
- 8 bits each for the red, green, and blue channel.



2^{24}= 16.78 million colors. 3-dimensional Color space

True Color Example

- True-color, or 24-bit, images are typically much larger than 8-bit images in their uncompressed state.



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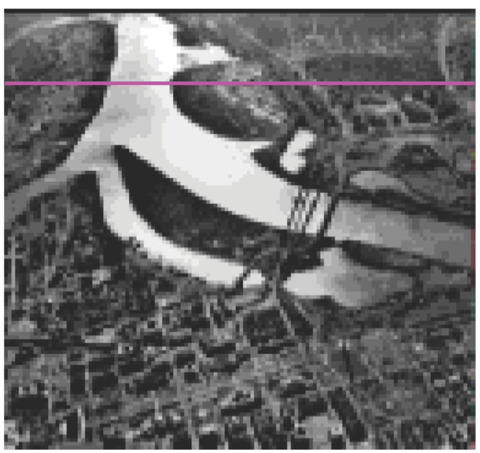
Human Visual System

Why can Images be Compressed?

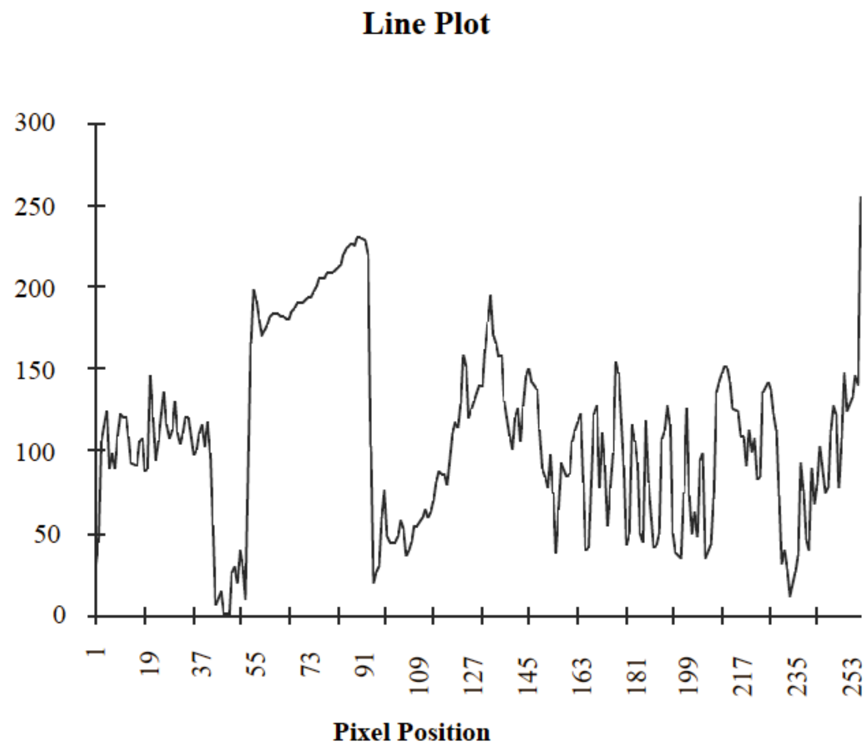
- Image compression can be achieved primarily because image data are highly redundant.
- The degree of redundancy determines how much compression can be achieved.
- Four types of redundancy can be identified:
  - Spatial Redundancy
    - Correlation between adjacent data points
  - Temporal Redundancy
    - Correlation between different frames in an image
  - Spectral Redundancy
    - Correlation between different color planes or sensors
    - Limitation of <u>Low-level</u> Human Vision System
  - Psycho-visual Redundancy
    - Limitation of <u>high-level</u> Human Vision System

Spatial Redundancy

- Neighboring pixels are **highly correlated.**

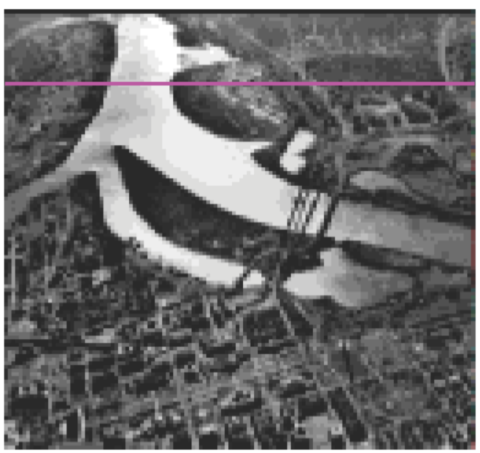


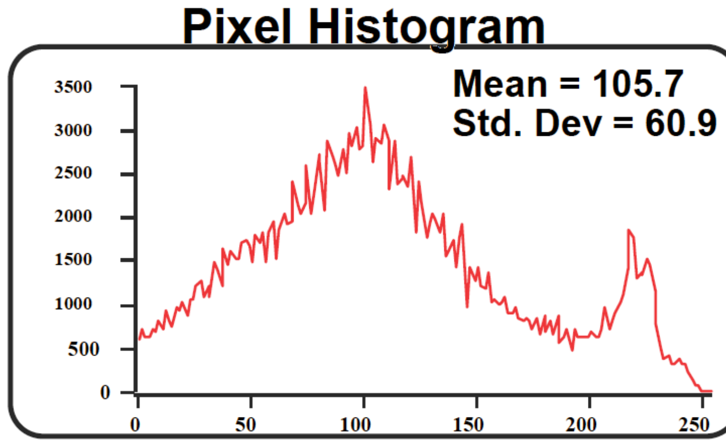
Washingtion DC Image

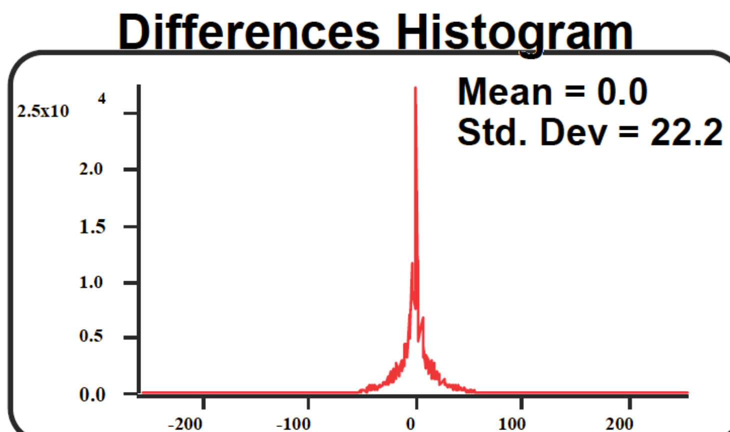


Spatial Redundancy

- The histogram of the <u>difference signal</u> is highly peaked at origin which can be exploited by the Entropy Coder.







Spread of differences in neighboring pixels

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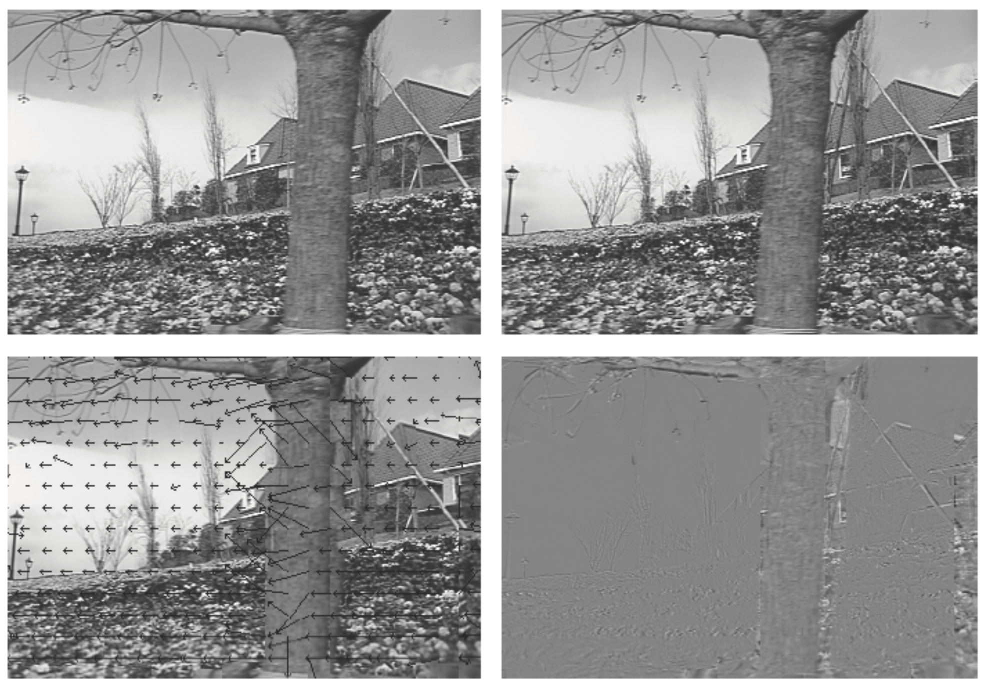
Temporal Redundancy

- Adjacent frames are highly correlated.



Previous frame

Current frame

Current frame with displacement vectors

Motion-compensated Prediction error

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  - Psycho-visual Redundancy
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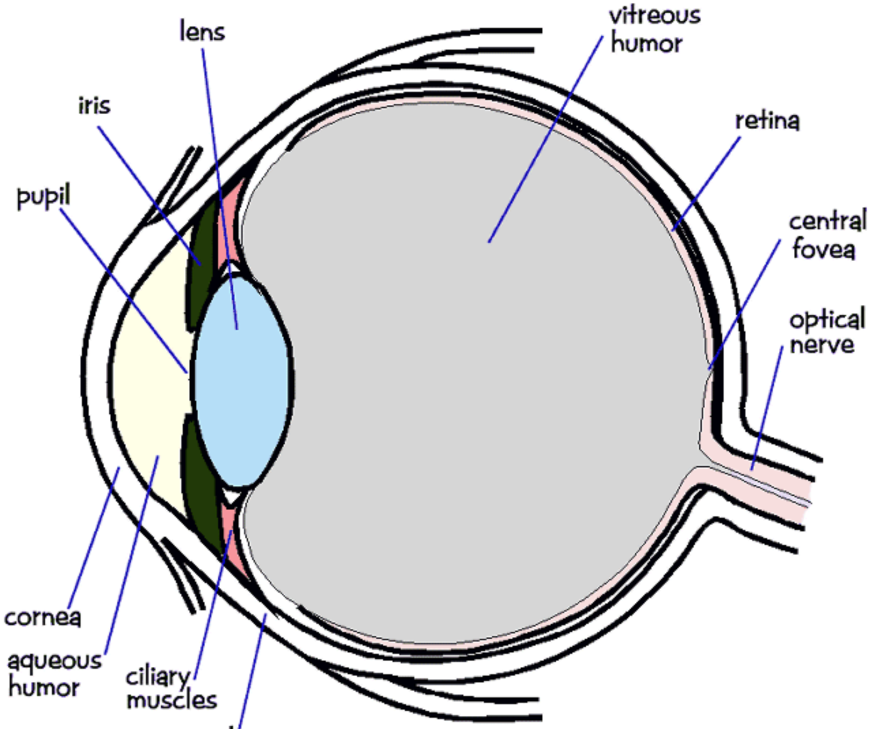
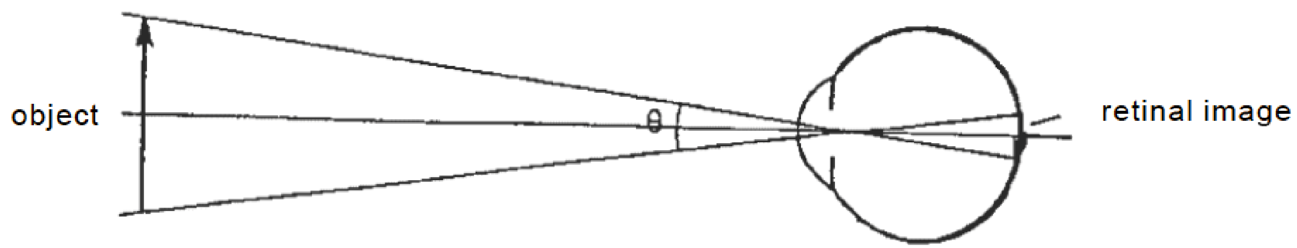
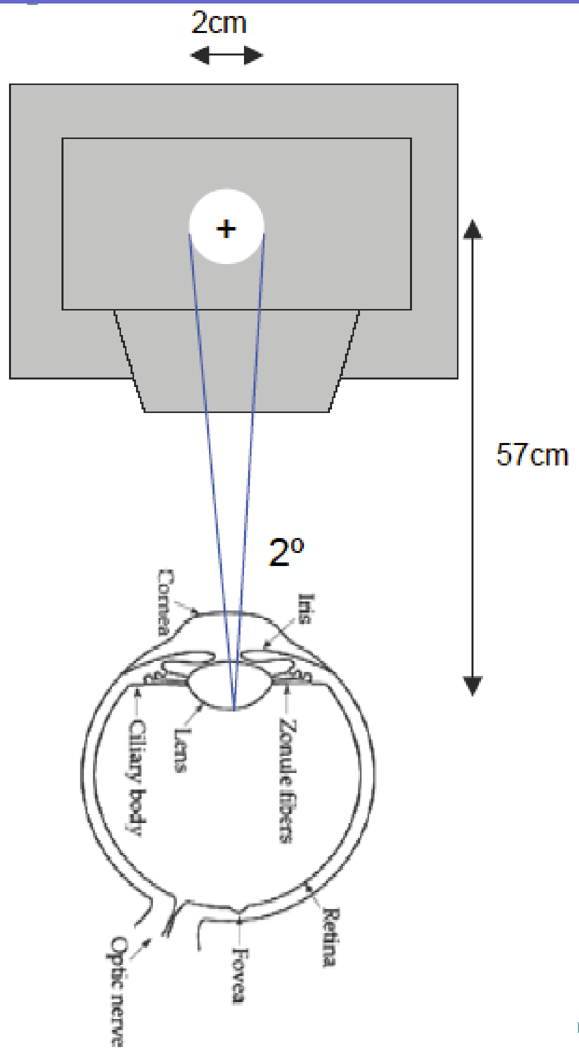
The Eye

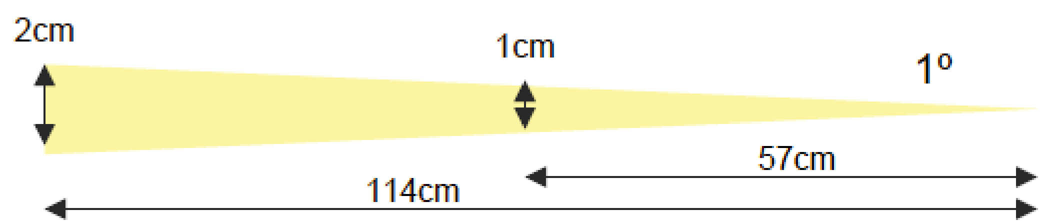

lens
vitreous humor
iris
retina
pupil
central fovea
optical nerve
cornea
aqueous humor
ciliary muscles


object
θ
retinal image

Eccentricity

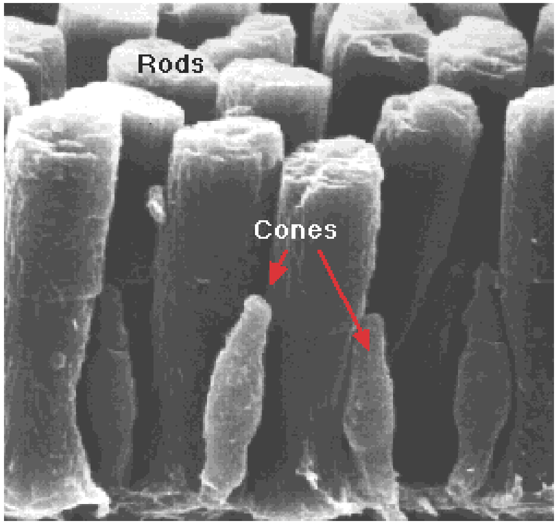


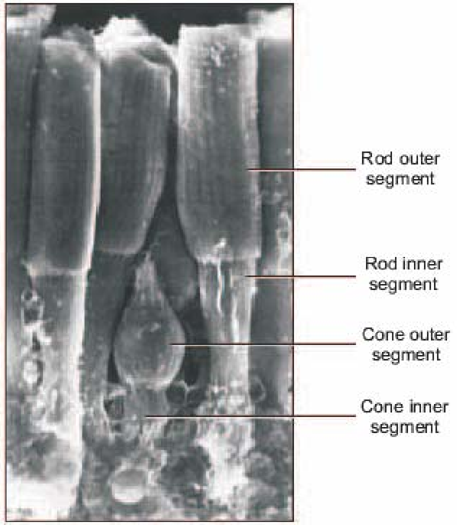
- The fovea subtends 2 degrees of visual angle
- To stimulate the fovea the stimulus must be centered on the screen and cover a visual angle of 2 degrees
  - 2cm on the screen at 57cm
  - 4cm on the screen at 114cm

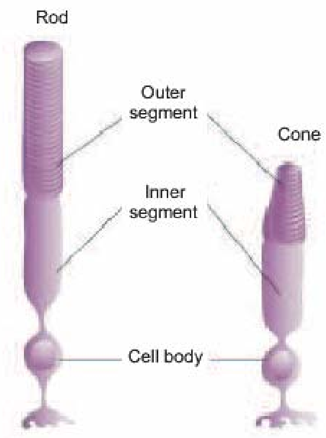


Cones and Rods Shapes

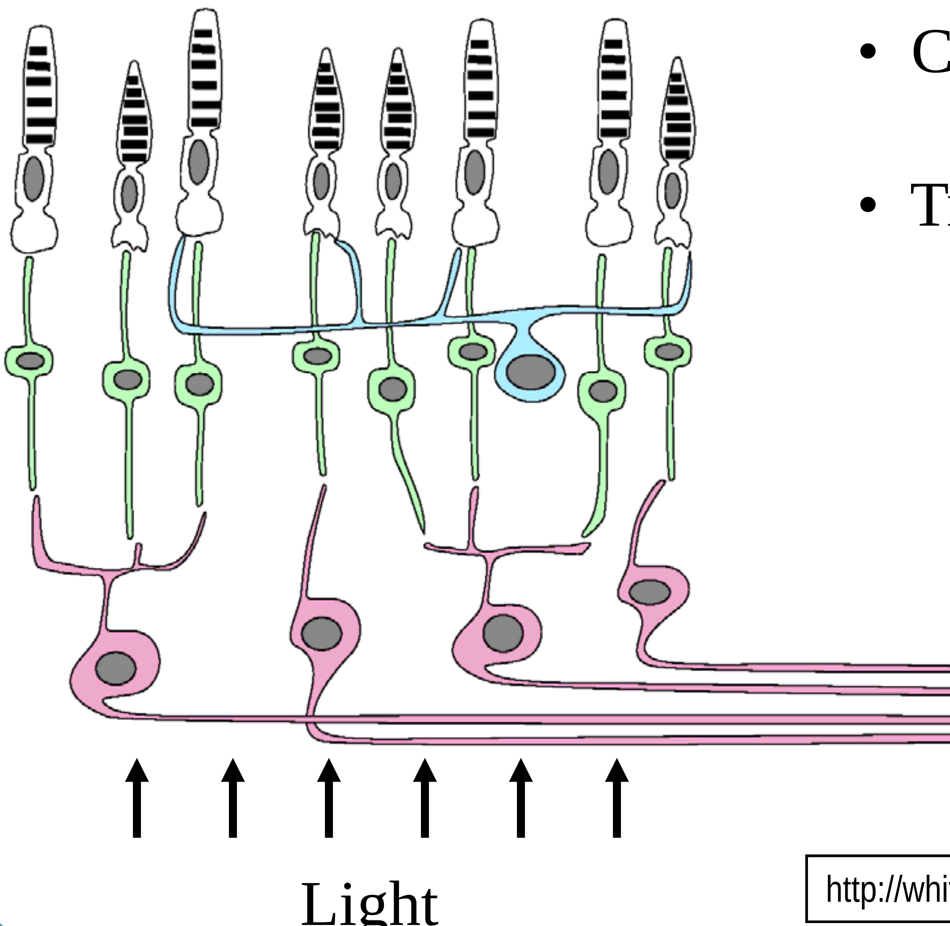
- The light enters the inner segment and passes into the outer segment which contains light absorbing photopigments.
- Less than 10% photons are absorbed by the photopigments.







Cones and Rods



- Converts light in to signals
- Transmits signal to brain

 # cones in each retina: 5 x 10^6

 # rods in each retina: 10^8

 # optic nerves : 1.5 x 10^6

Therefore, the rods and cones must be interconnected to nerve fibers on a many-to-one basis.

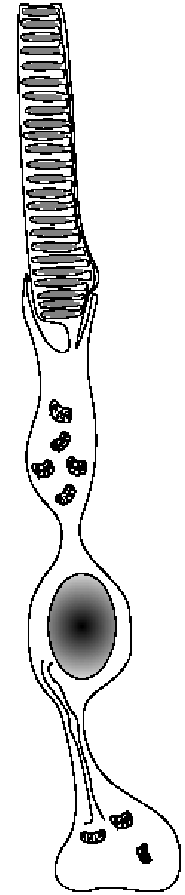
http://white.stanford.edu/~brian/numbers/numbers.html

Rods

Number of rods in each retina: 10^8

Photoreceptors which

- Generate **achromatic** response.
- Sensitive only in low light levels
  (scotopic range… night vision).

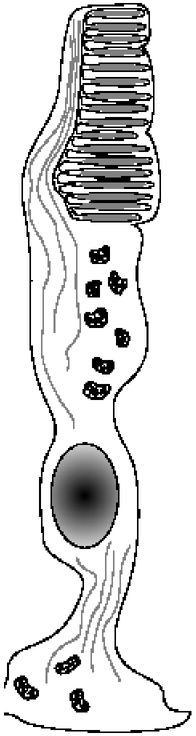


Cones

Number of cones in each retina: 5×10^6

Photoreceptors

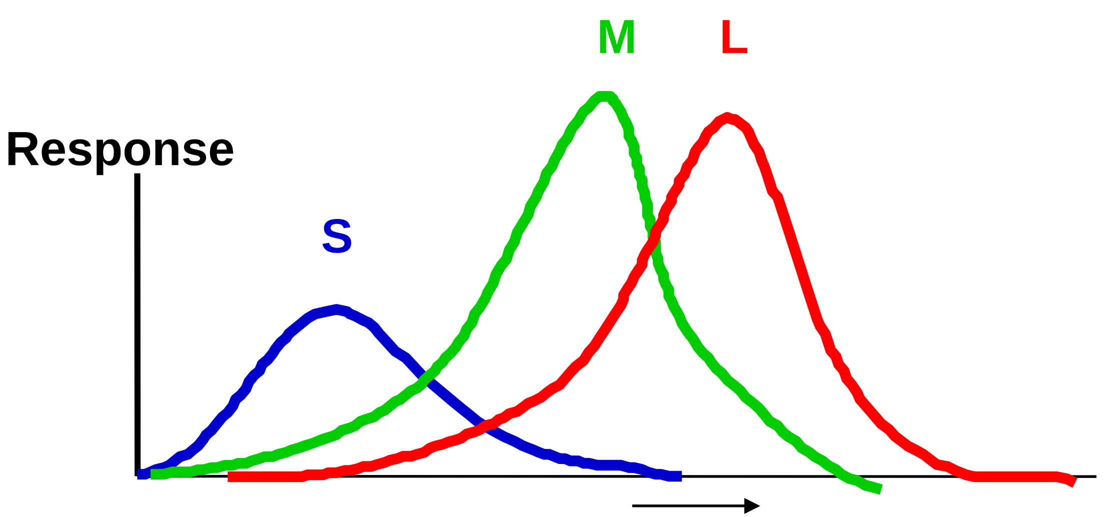
- Responsible for **COLOR** vision.
- 3 Types of cones: **S**, **M**, **L** in Fovea
- Sensitive only in high light levels.
  - Human being have difficulty to see color in the dark.



Dogs have 2 type of cones.
Bees have 4, Mantis Shrimp has record 10.

Cones : S, M and L

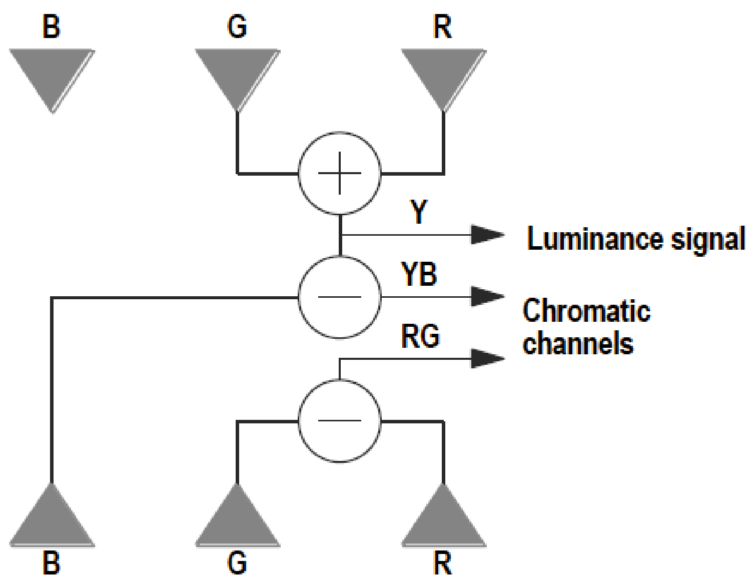
- S : Blue response (peak: 445nm)
- M : Green or yellow response (peak 535nm)
- L : Red response (peak: 575nm)
- Not uniformly sensitive
  - more sensitive to green than red (64%L, 32%M, 2%S).



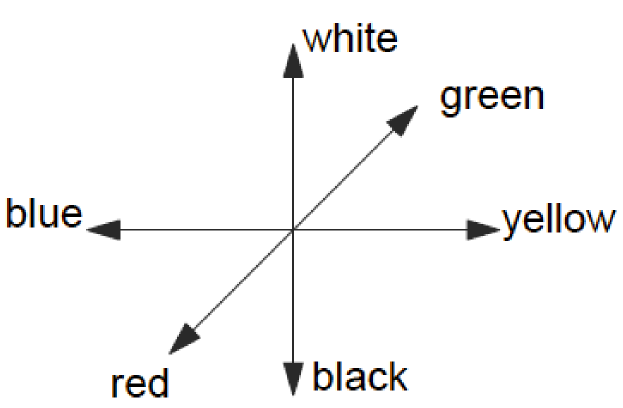
Opponent Processing

- Retina carries out “matrix operation“ to represent colors in the opponent color system (Y, Y-B, R-G)
- Cannot see BLACK and WHITE at the same time.

Opponent color model:



Opponent color space:



Spectral Redundancy

- The output of the three cone color is transformed into an achromatic channel (such as luminance) and two chromatic channels (opponent channels).
- High-level HVS (Human Vision System) is much more sensitive to the variations in the achromatic channel than in the chromatic channels (explained later).
- The chromatic components are often sub-sampled by a factor of 2:1 or 4:1 in both horizontal and vertical directions (as in JPEG, MPEG).

Spectral Redundancy

- Many transformations, depending on the application, have been suggested to exploit the correlation in the R,G, B channel.

- The JPEG standard does not provide a definition for the color space to be used; the choice has intentionally been left to the user.

Spectral Redundancy

- An example of a transformation used for color image compression is that used in the NTSC national color television standard.
- The RGB values are transformed into a new set of values known as Y (gray scale info), I (hue), and Q (saturation), (also called luminance, in-phase, and quadrature, respectively) according to

$$\begin{pmatrix} Y(i,j) \\ I(i,j) \\ Q(i,j) \end{pmatrix} = \begin{pmatrix} .299 & .587 & .114 \\ .596 & -.274 & -.322 \\ .212 & -.523 & .311 \end{pmatrix} \begin{pmatrix} R(i,j) \\ G(i,j) \\ B(i,j) \end{pmatrix}$$

First row sum=1, second and third row sum=0. For gray scale R=G=B

Spectral Redundancy

- The transformation to convert YIQ back to RGB values is:

$$\begin{pmatrix} R(i,j) \\ G(i,j) \\ B(i,j) \end{pmatrix} = \begin{pmatrix} 1.000 & .956 & .621 \\ 1.000 & -.272 & -.647 \\ 1.000 & -1.106 & 1.703 \end{pmatrix} \begin{pmatrix} Y(i,j) \\ I(i,j) \\ Q(i,j) \end{pmatrix}$$

Spectral Redundancy

- A transform similar to the YIQ, but easier to implement in hardware is the color difference transform, which generates the Y, R-Y, and B - Y components. This is also denoted as YC_bC_r(Luminance, Chrominance-blue, Chrominance-red representation)

- The perfect transform has yet to be agreed on, but with respect to data compression, the performance difference are insignificant.

Color transform: YCrCb <->RGB

- The transformation is a matrix operation.

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.16875 & -0.33126 & 0.5 \\ 0.5 & -0.41869 & 0.08131 \end{bmatrix} * \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\begin{bmatrix} \boldsymbol{R} \\ \boldsymbol{G} \\ \boldsymbol{B} \end{bmatrix} = \begin{bmatrix} 1.0 & 0 & 1.402 \\ 1.0 & -0.34413 & -0.71414 \\ 1.0 & 1.772 & 0 \end{bmatrix} * \begin{bmatrix} \boldsymbol{Y} \\ \boldsymbol{U} \\ \boldsymbol{V} \end{bmatrix}$$

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Human visual perception

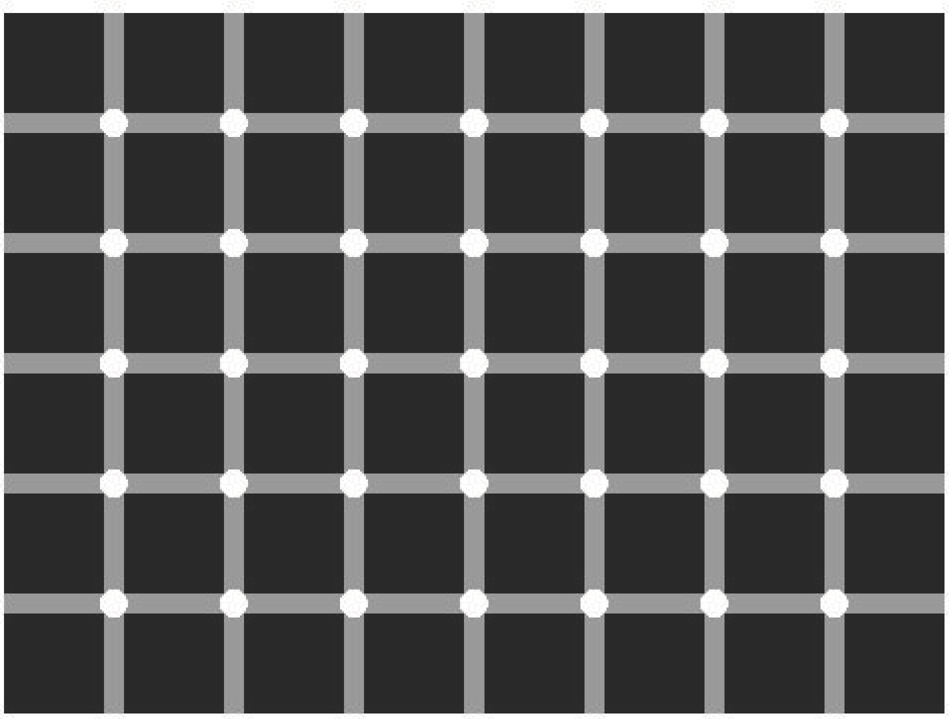
- The spectral redundancy occurs in the low-level vision system (first three layers of the retina in the eyes). At higher levels of human brain visual perception takes place.
- Human visual perception is very complex.

Human visual perception

- Can you believe your eyes?

Black dot?

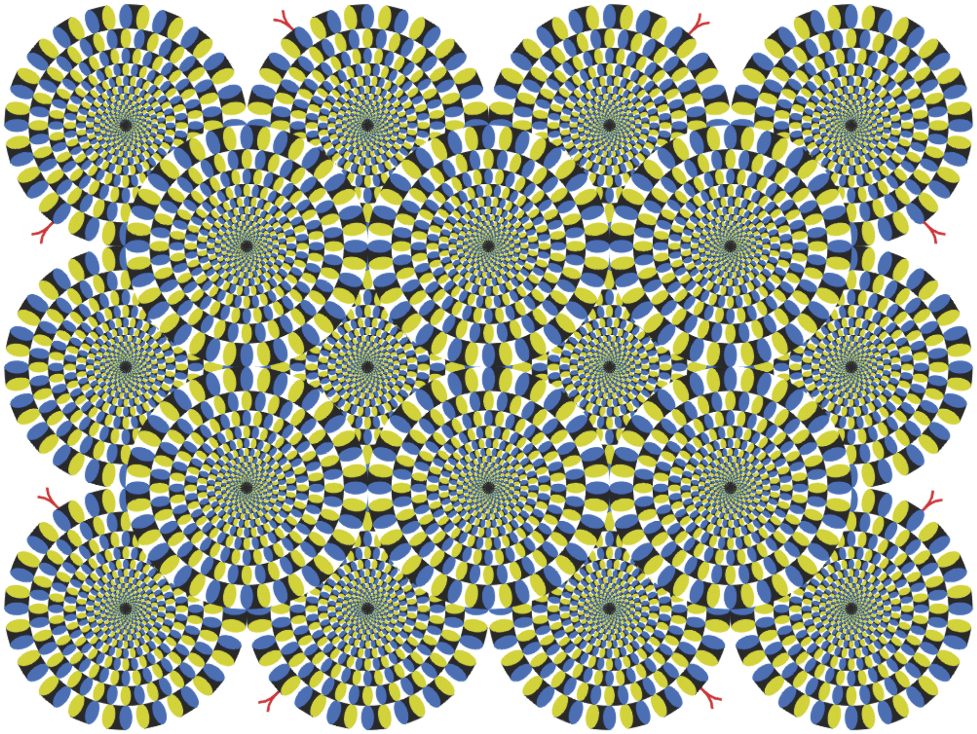
White dot?



Human visual perception

- Can you believe your eyes?

Wheel circling?



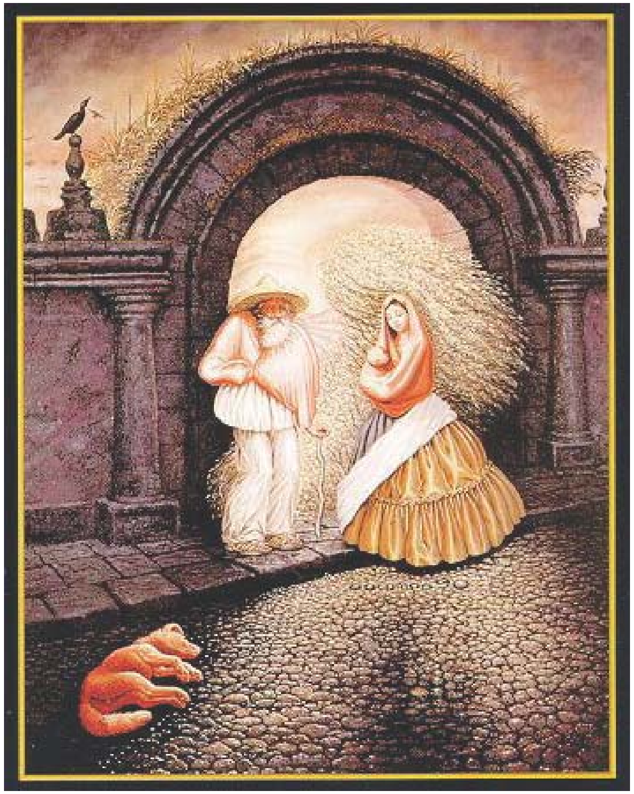
LOOK and FIND

"Look and you will find it -- what is unsought will go undetected"

Human visual perception

- Can you believe your eyes?

How many faces here?



Human visual perception

- Can you believe your eyes?

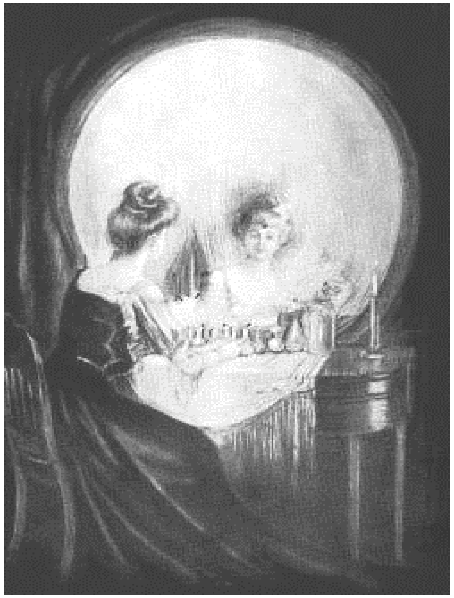
Halloween?

Human visual perception

- Can you believe your eyes?

Halloween?

Lady?

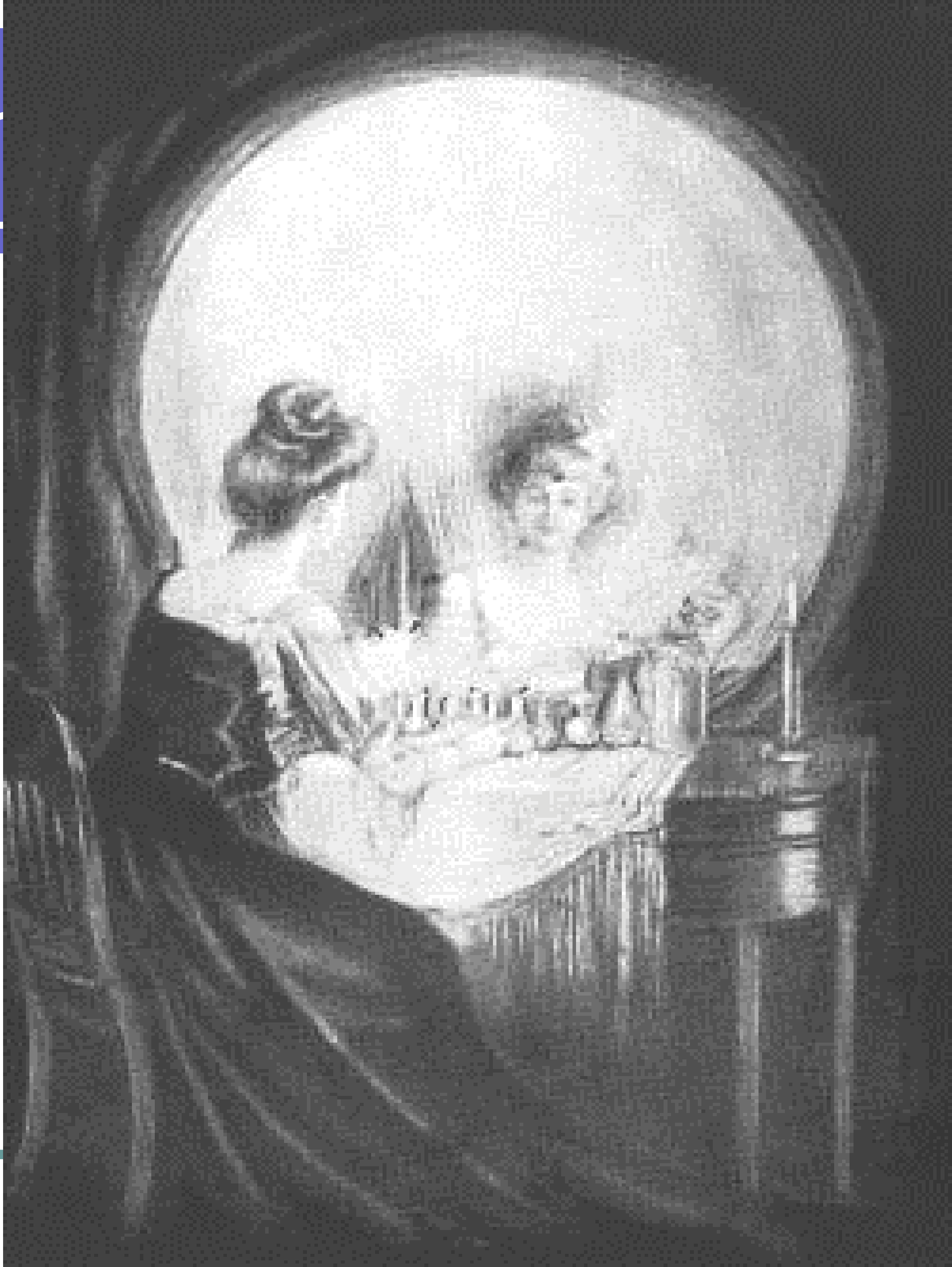


Human visual per

- Can you believe

Halloween!

Lady!

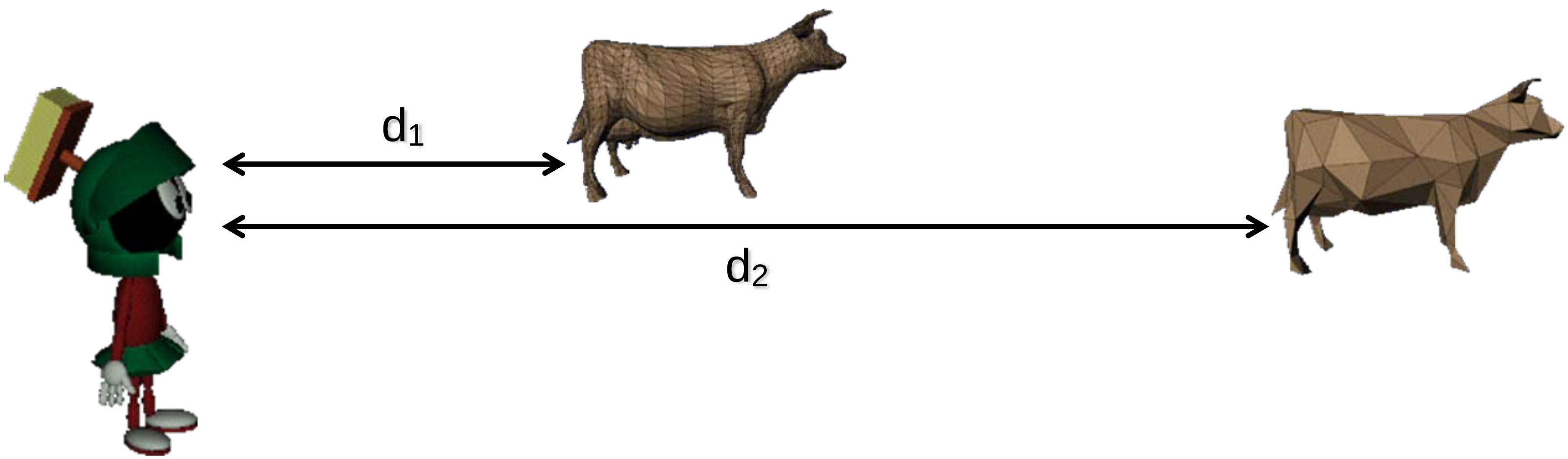


Human visual perception

- Human vision system is very complex.
- Only part of it is explored.
- Some can be applied to compression.

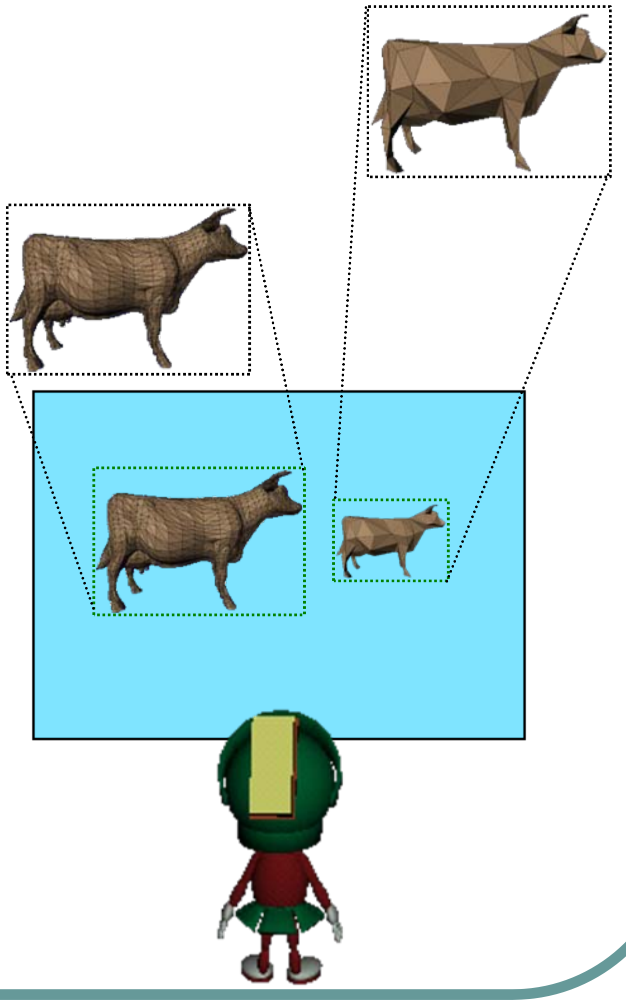
Human visual perception

- Our sensitivity to the resolution is a function of the distance.



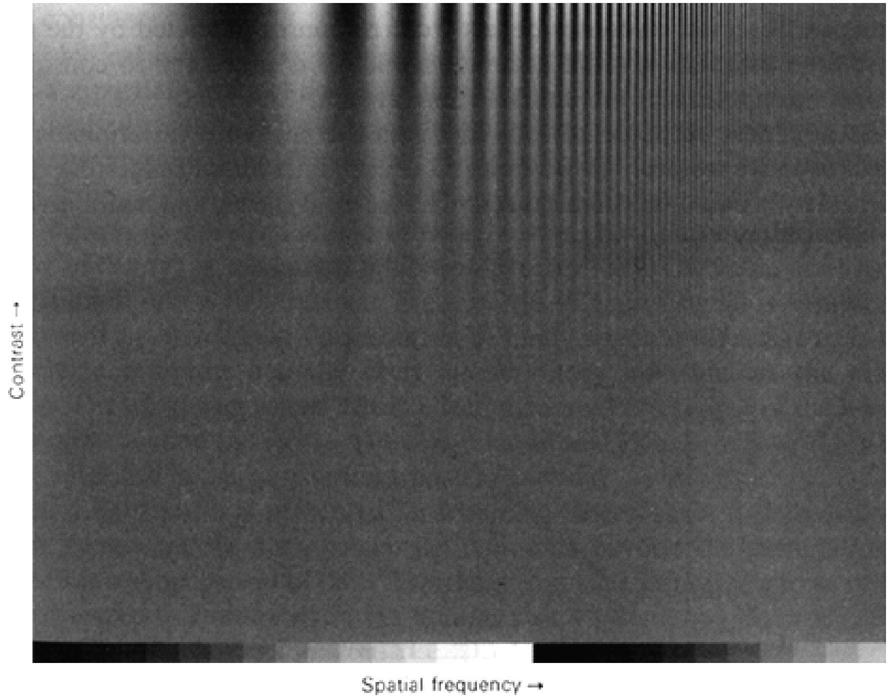
Human visual perception

- This knowledge is exploited for the progressive geometry compression.
- Select resolution based upon the projected screen size (or area) of an element. Objects appear smaller as they move further away.



Human Visual Perception

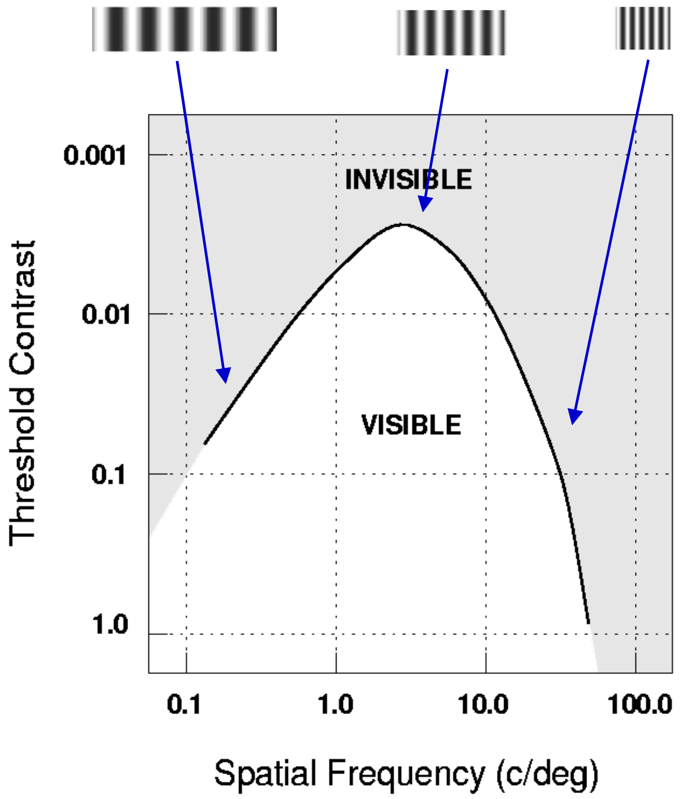
- Spatial frequency components visible up to 60 cpd.



Modeling Limits of Vision

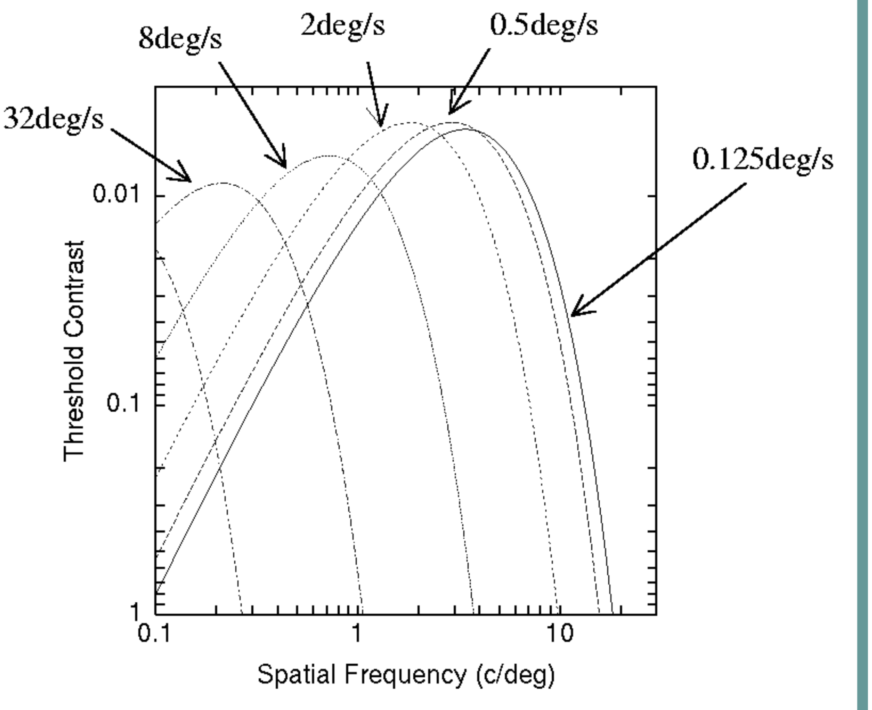
- Results of Contrast Grating tests can be modeled with a Contrast Sensitivity Function.
- CSF defines the bandwidth of vision.
- Note that the axis is in the log form.

- Human eyes are less sensitive to high frequencies.
- Partially applied in image compression.



Velocity CSF - **Motion Sensitivity**

- **Motion Sensitivity**
  - Human eyes are less sensitive to detail moving across retina.
  - Fast moving objects become “blurred”.



- Partially applied in Video compression.

Eccentricity CSF – Region of Interest

- Not fully supported in JPEG 2000.

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Human Visual System

Distortion Measures

- Since most image compression algorithms are lossy, there is a need to develop standard metric to define the quality of the reconstructed image.
- The deviation of the reconstructed image with the original image is called **distortion.**
- If the reconstructed image is close to the original image, the distortion measure should indicate a low value or alternately, the quality metric must show a higher value.

Mean Square Error (MSE)

- Denoting the pixels of the original image by x_i, and the pixels of the reconstructed image by y_i , i = 1, 2, … , N, where N denotes the number of pixels in the image, the ***mean squared error (MSE)*** between the two images is defined as

$$MSE = \sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(x_i - y_i)^2$$

- σ is called the **root mean square error (RMSE).**

Peak Signal-to-Noise Ratio (PSNR)

- Defined as

$$PSNR = 20\log_{10}\frac{\max(x_i)}{\sigma}$$

- Some authors use the following to define PSNR:

$$PSNR = 10\log_{10}\frac{[\max(x_i)]^2}{\sigma^2} = 20\log_{10}\frac{\max(x_i)}{\sigma}$$

- Either definition is acceptable since only the relative PSNR values are used in practice.

PNSR

- If the reconstructed image is close to the original image, then σ is small and PSNR takes a large value.
- PSNR is dimensionless and is expressed in *decibel*, a unit originally defined to express sound intensity in a logarithmic scale.
- Typical PSNR values for images range between 20 to 40, anything above 35 is a very good quality image.

RMSE and PSNR

- Assuming pixel values [0,255].
- RMSE(σ) of 25.5 results in PSNR of 20.
- σ =2.55 results PSNR of 40.
- If σ =0, PSNR is infinity.
- If σ=255 then PSNR will be negative.

Signal-to-Noise Ratio

$$SNR = 10\log_{10}\frac{\sigma^2{}_x}{\sigma^2} = 10\log_{10}\frac{\frac{1}{N}\sum_{i=1}^{N} x_i{}^2}{\sigma^2}$$

$$= 10\log_{10}\frac{\frac{1}{N}\sum_{i=1}^{N} x_i{}^2}{\frac{1}{N}\sum_{i=1}^{N}(x_i - y_i)^2}$$