Machine vision
Lecture 2
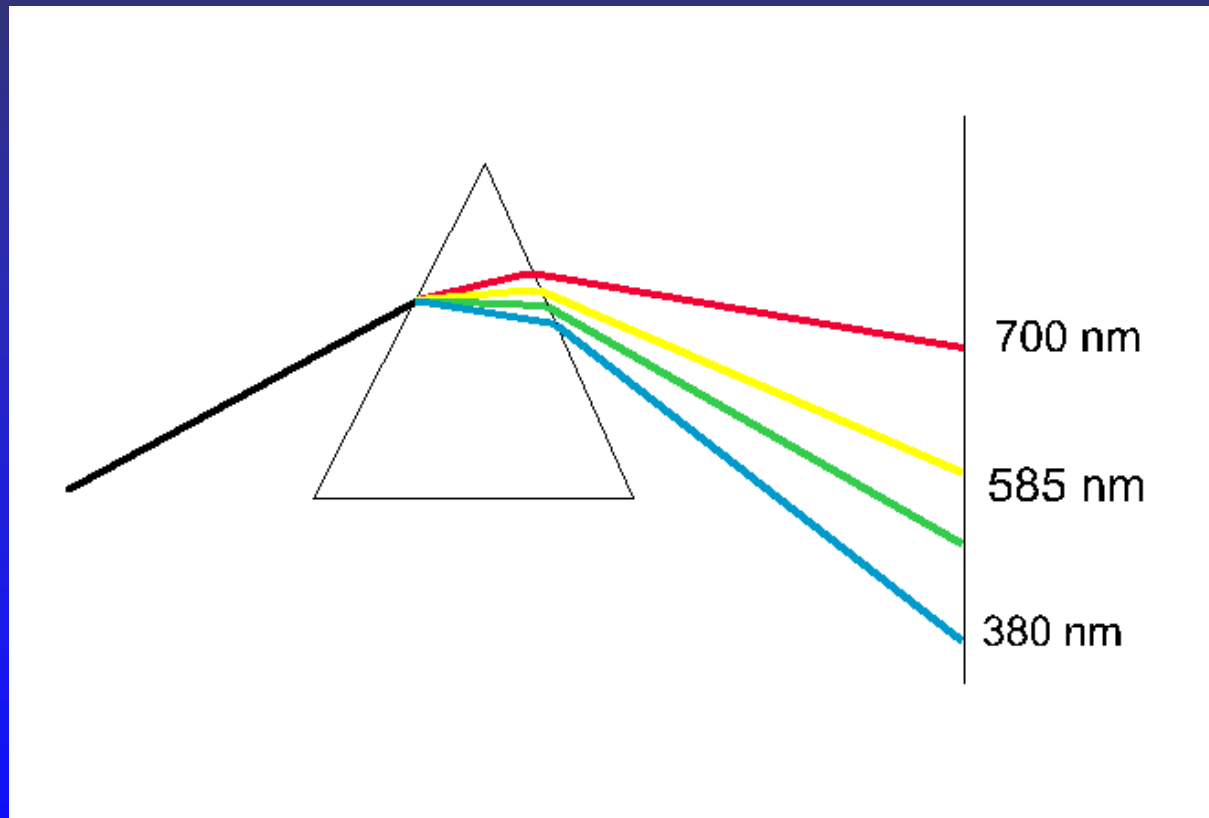
The Visual System
and
Visual Performance

Electromagnetic Spectrum

$\lambda \sim 10^{-3}$ Å

$\lambda \sim 10$ Å

$\lambda \sim 80 - 912$ Å   (1 Å = 10^{-10} m)

λ = wavelength

γ rays   X rays   EUV   UV   visible   IR   sub-mm   radio

$\lambda \sim 100 - 400$ nm

$\lambda \sim 400 - 700$ nanometers
(1 nm = 10^{-9} m)

$\lambda \sim 0.01$ mm

$\lambda \lesssim 1$ mm

$\lambda \sim$ meters to kilometers
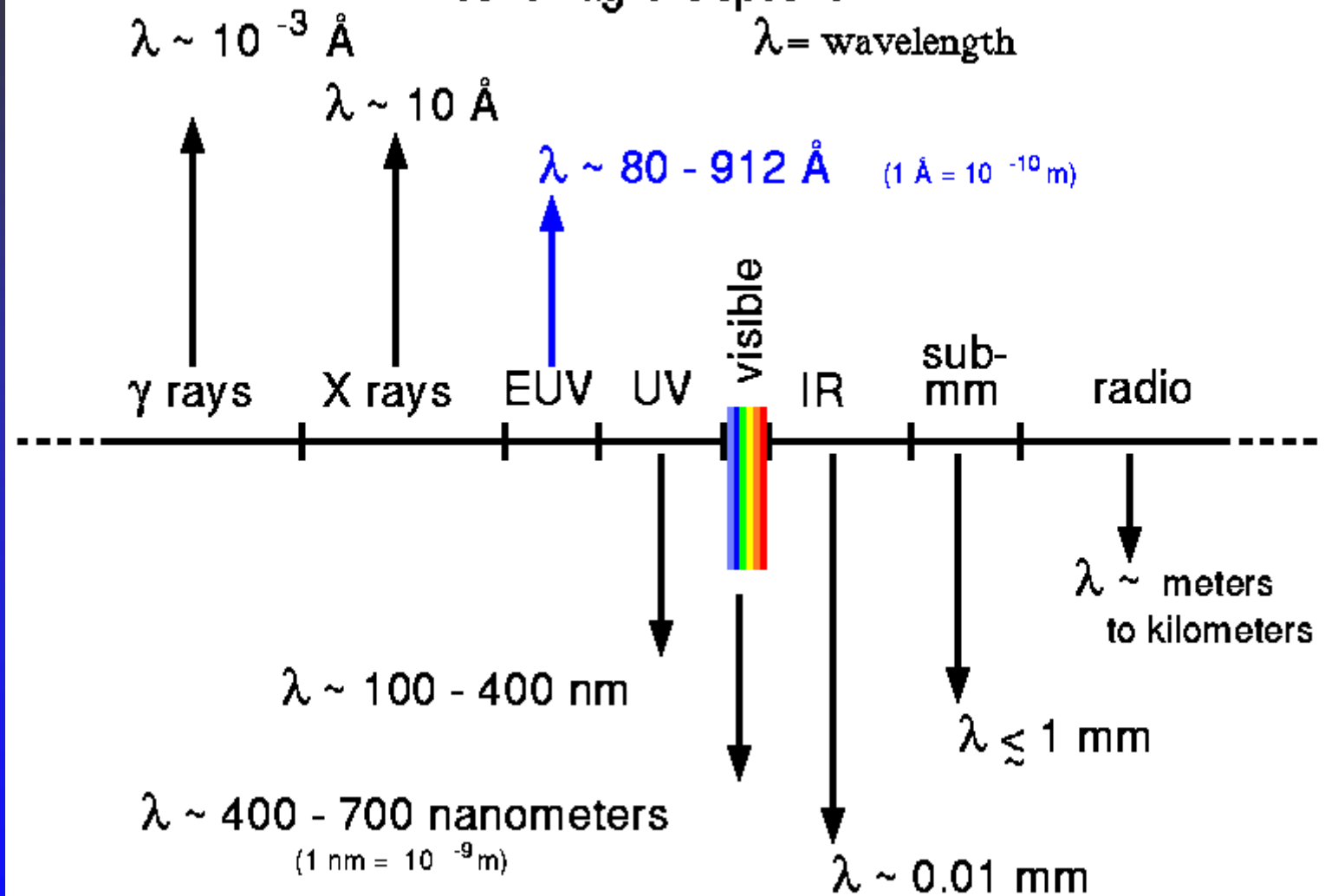
The Visible Spectrum

700 nm

585 nm

380 nm
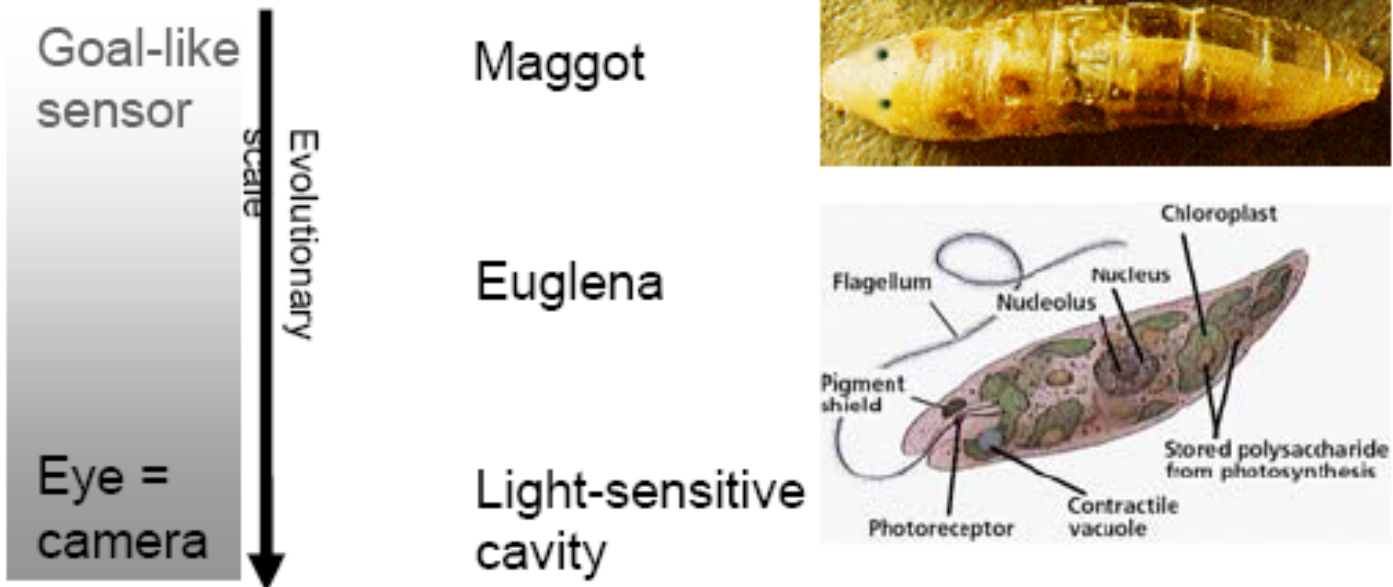
The eye

- Information filter, no perfect projection of the world. Sensory organ forming a representation.
Other organs (in combination with visual perception) can be used to make a representation of the world.


Goal-like sensor

Eye = camera

Evolutionary scale

Maggot

Euglena

Light-sensitive cavity

Chloroplast

Flagellum

Nucleus

Nucleolus

Pigment shield

Stored polysaccharide from photosynthesis

Photoreceptor

Contractile vacuole

Autonomous Systems – Tony Belpaeme

Higher-order species

- Single lens.
- Molluscs (squid, octopus) and chordates (fish, amphibians, birds, mammals & humans).

- Multilens compound eye
- Arthropods (insects, lobsters, crabs, spiders, centipedes).
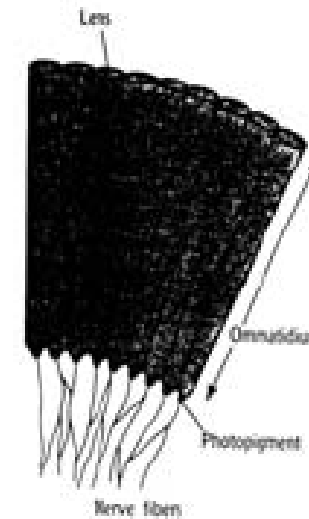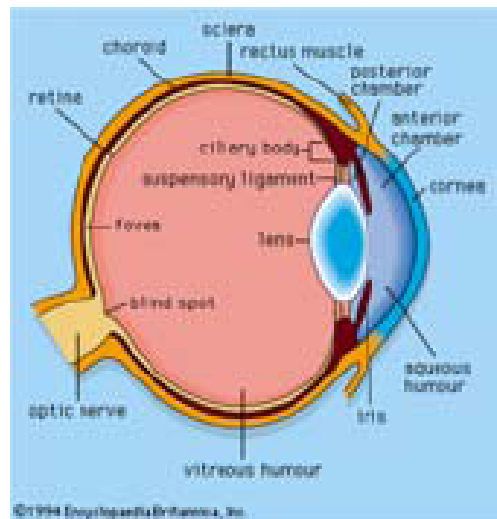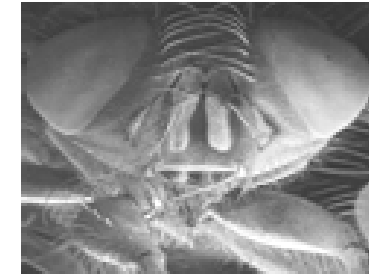
Autonomous Systems – Tony Belpaeme

Higher-order species (2)

- Both have a 'mosaic' structure.

- Single lens forms a wider angle image.

- Compound eye: less resolution, no focus
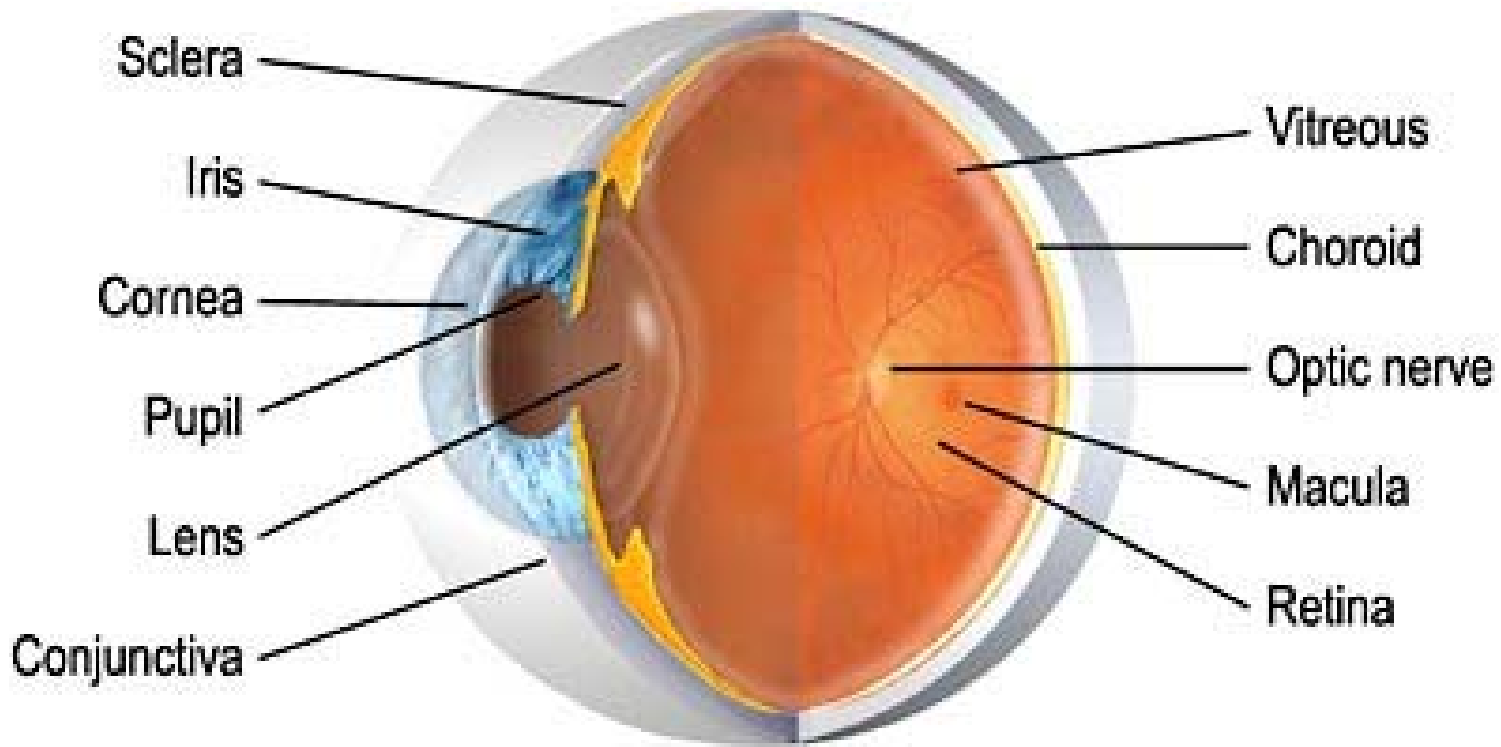
Autonomous Systems – Tony Belpaeme

Anatomy of the Eye

Illustration by Mark Ericksen, St. Luke's Cataract and Laser Center, StLukesEye.com

UCLab, Andrey Gavrilov

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The Eye (2)

- Cornea
  - Protection
  - Focusing
- Aqueous Humor
  - Shape
  - Nutrition
- Iris
  - Light control
  - Focusing

The Eye (3)

- **Lens**
  - Focusing
  - Accommodation
- **Vitreous Humor**
  - Shape
- **Retina**
  - Rods: black & white, night vision
  - Cones: color, day vision
  - Fovea: sharpest vision (concentration of cones)

The Eye (4)

- Optic Nerve
  - Nerve signals to brain
  - Optic Disk: blind spot

- Eye Muscles
  - Eye movement
  - Convergence
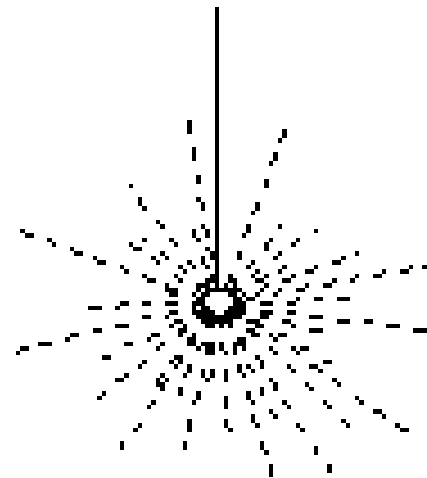
Visual Performance

- Brightness

- Visual Angle

- Visual Acuity

- Color

- Visual Field

Brightness

- Relative amount of light reflected from an object produces a sensation of lightness or brightness.

- Brightness is related to the luminance of light as well as a subjective response to color
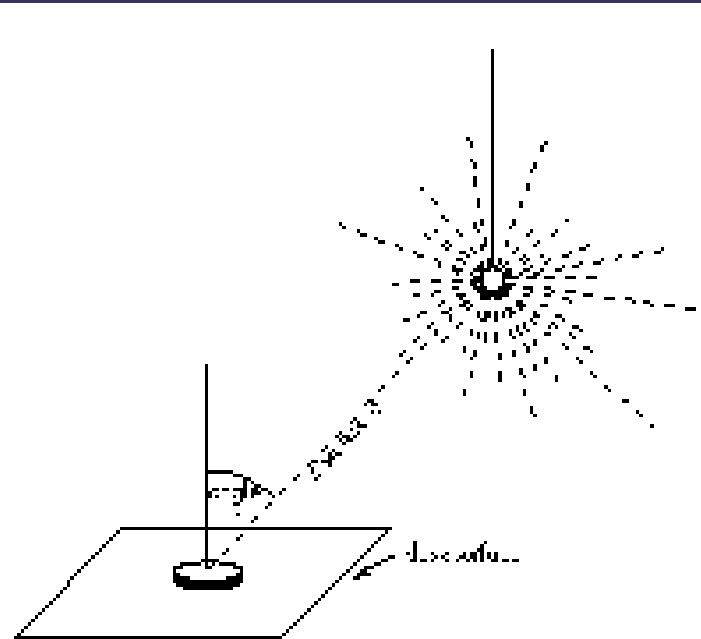
Luminous Intensity

A point light source giving off photons equally in all directions, with a luminous intensity of x candelas

Luminous Flux
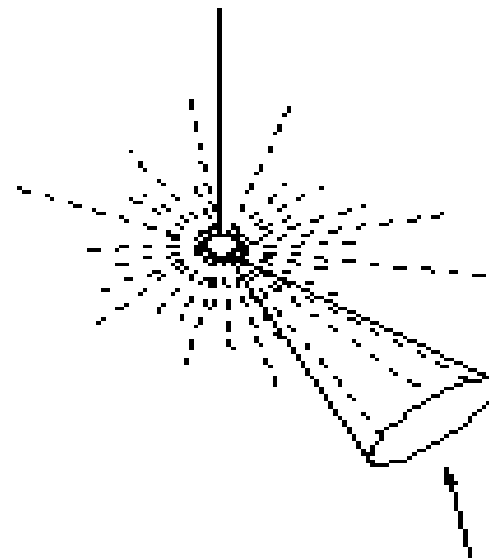
Luminous flux - for a solid angle of 1 steradian there will be x lumens

Illuminance

The photocell is placed flat on the desk, and is in effect counting the number of photons falling on it - i.e. measuring illuminance in lumens per square metre (LUX)

Illuminance v. Luminance

- Illumination/Illuminance: The amount of light striking any point on the inside surface of a sphere surrounding the light source (Luminous flux/unit area)
  - Foot candle: 1 lumen/square foot
  - Lux: 1 lumen/square meter
- Luminance: The amount of light per unit area leaving (reflected from) a surface
  - Foot Lamberts: 1 lumen/square foot
  - Candelas/square meter

Luminance

Luminance, milliLamberts (mL)	Example
1,000,000,000	sun's surface at noon
1,000,000	tungsten filament
10,000	white paper in sunlight
1,000	earth on clear day
100	earth on cloudy day
10	white paper in reading light
1	white paper 1 ft from candle
0.001	earth in moonlight
0.0001	white paper in starlight

Note: 1 foot-Lambert (ft-L) = 0.929 mL, so 1 ft-L ~ 1 mL.

Luminance (2)

● Threshold of detectability

  1×10^{-6} mL

● Threshold of pain

  3×10^{4} mL

● Limits to discriminability
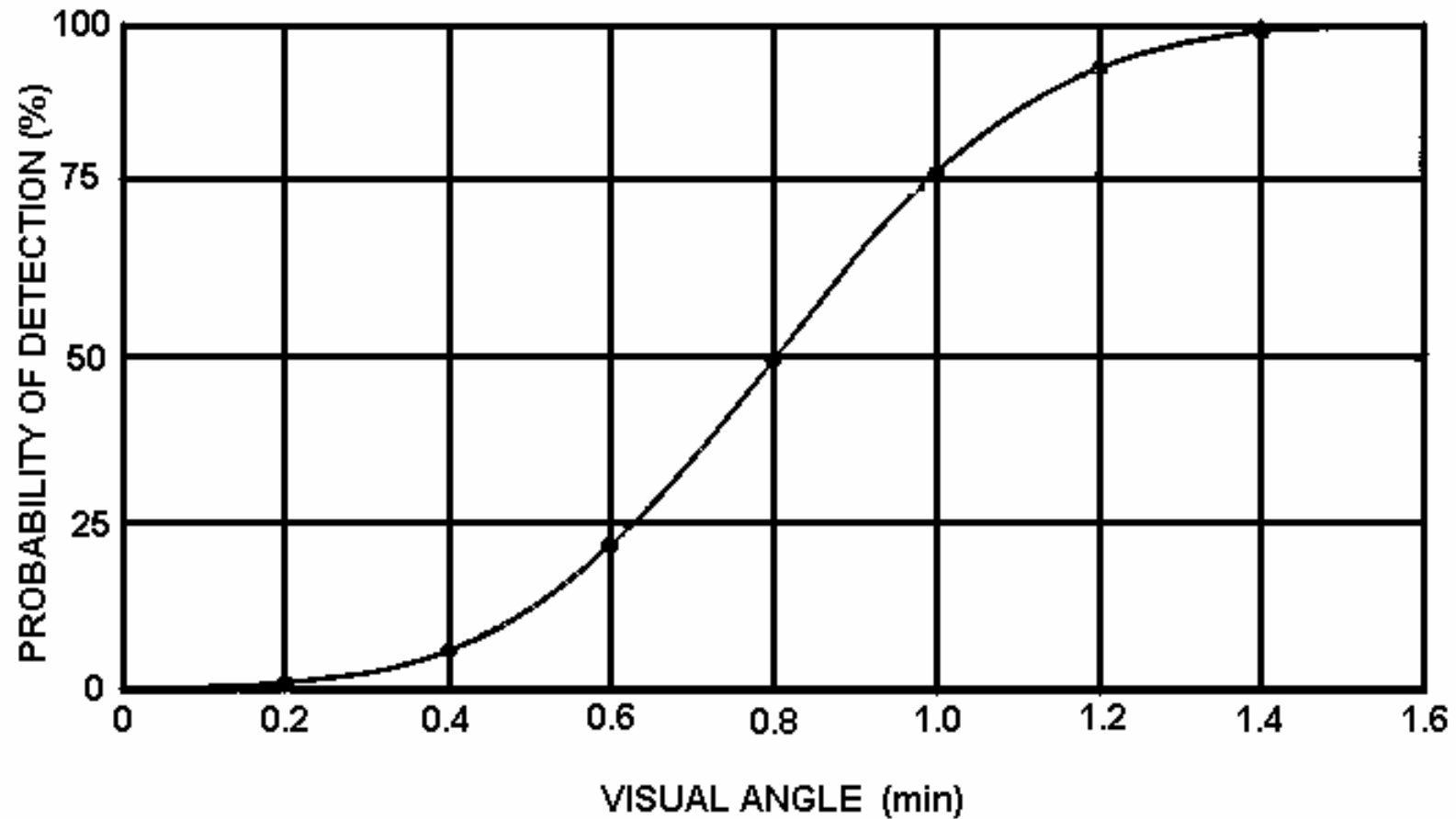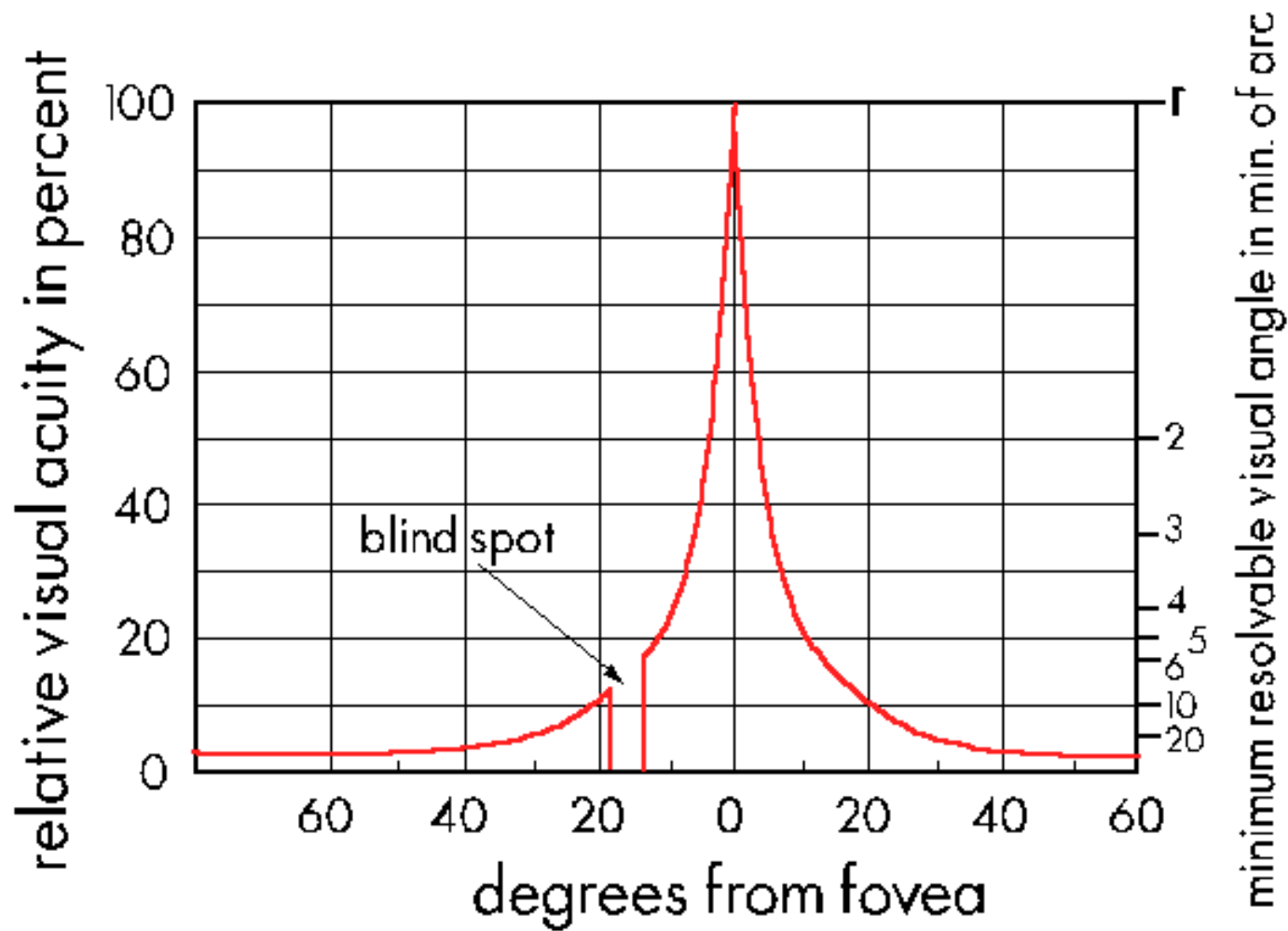
  3 - 4 levels

Visual Angle (minutes of arc)

Visual Angle = VA = $\dfrac{3438\ H}{D}$
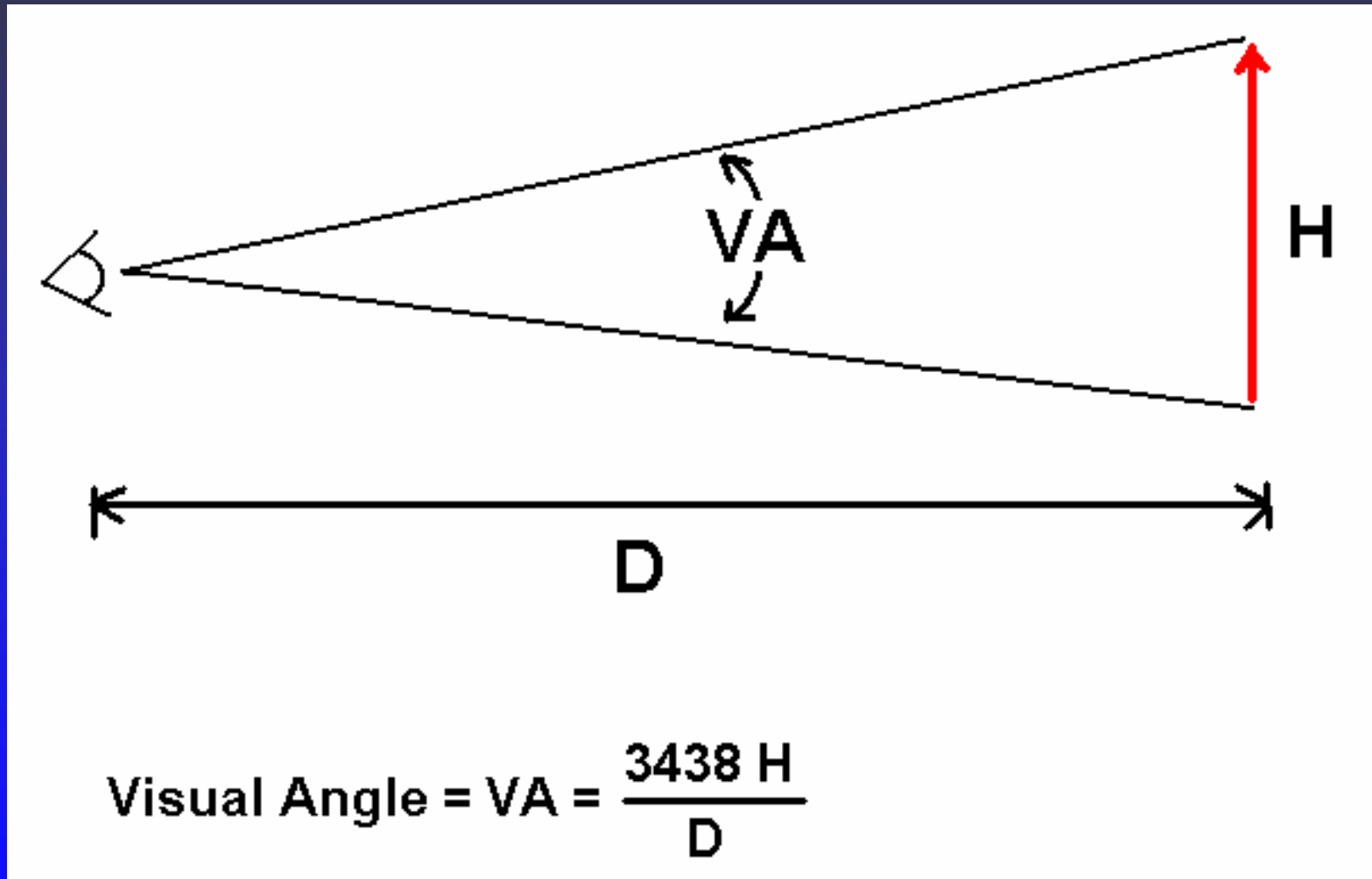
Visual Angle of Familiar Objects

Object	Distance	Visual Angle
Sun	93,000,000 mi	30'
Moon	240,000 mi	30'
Quarter	arm's length	2°
Quarter	90 yd	1'
Quarter	3 mi	1"
Lowercase pica type	reading distance	13'

Cumulative Probability of Detection

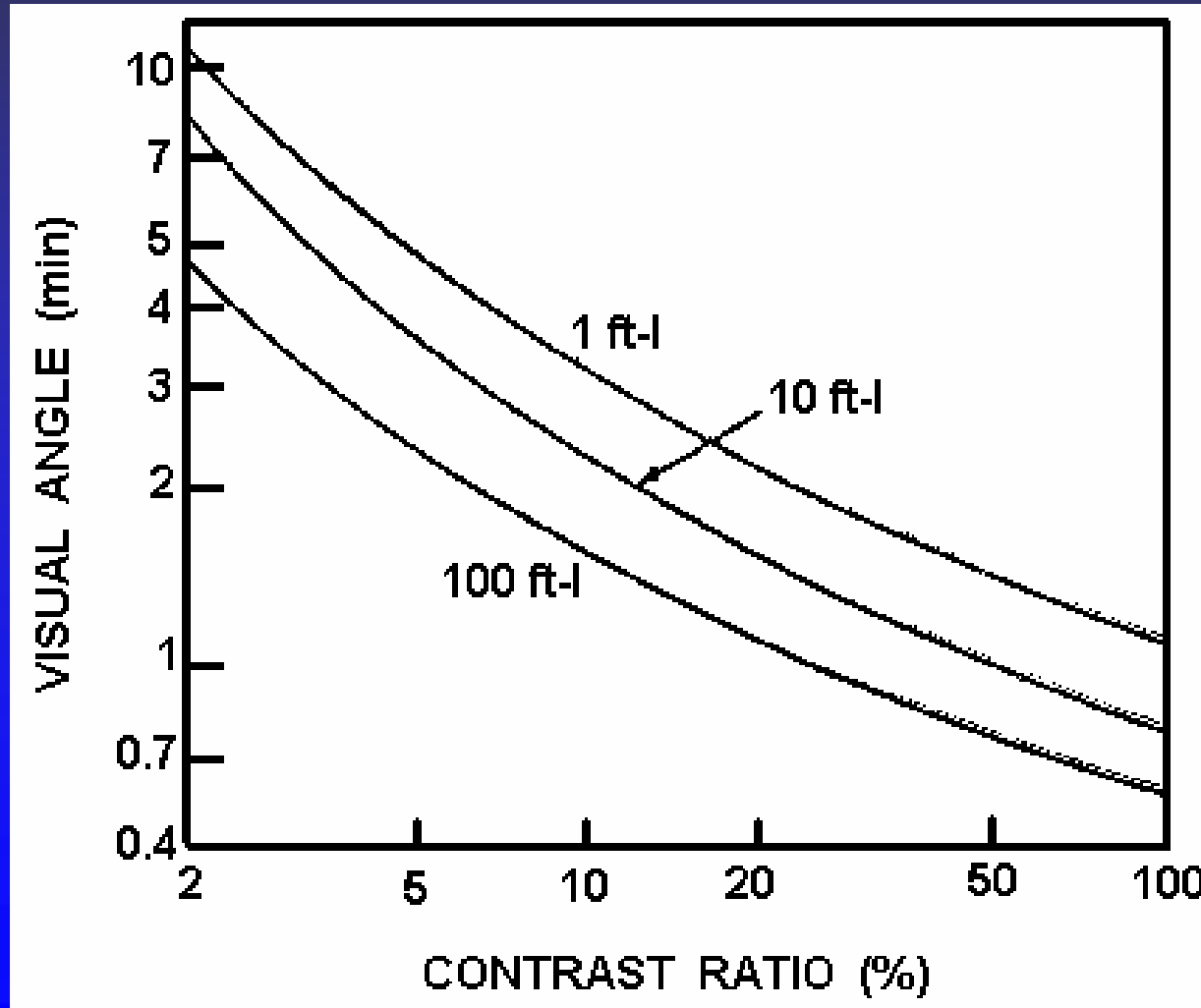Variation in Visual Performance Across the Retina

Minimum Separable Acuity

- Also called gap resolution
- Smallest space eye can detect between parts of a target (visual object).
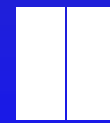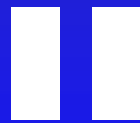
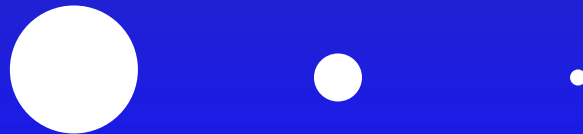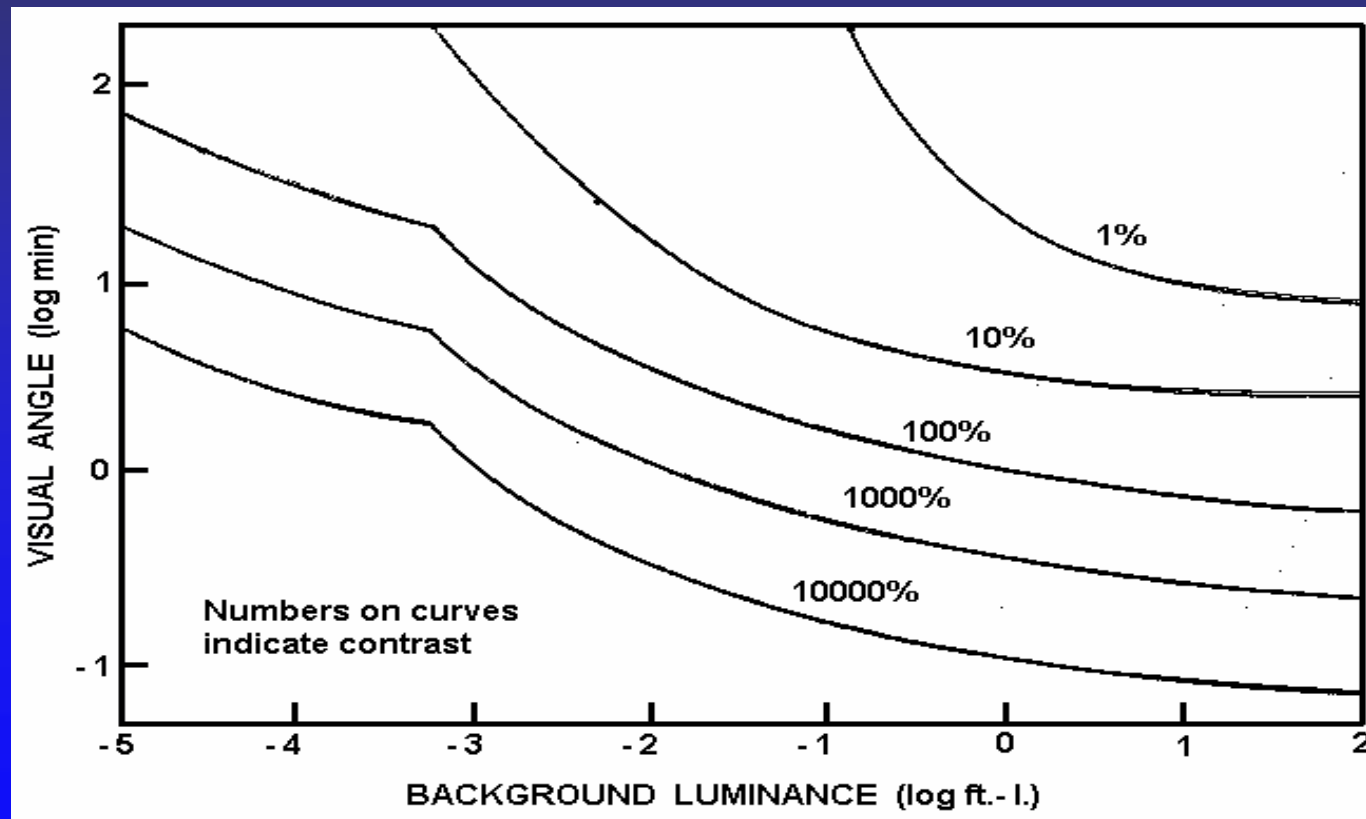# Minimum Separable Acuity as Function of Contrast

Minimum Perceptible Acuity

- Also called spot detection.
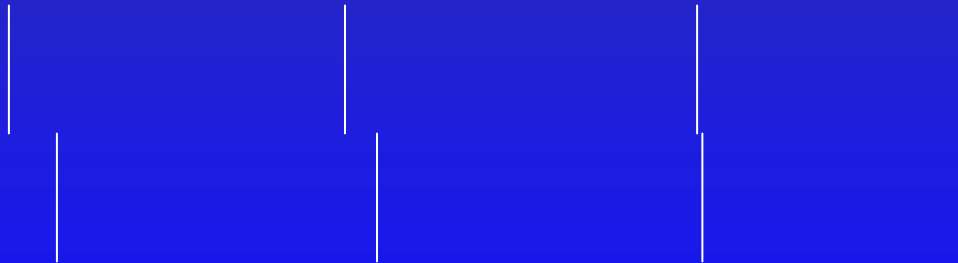- Eye's ability to detect smallest possible target.

Minimum Perceptible Acuity as Function of Contrast and Background Luminance

VISUAL ANGLE (log min)

1%

10%

100%

1000%

10000%

Numbers on curves indicate contrast
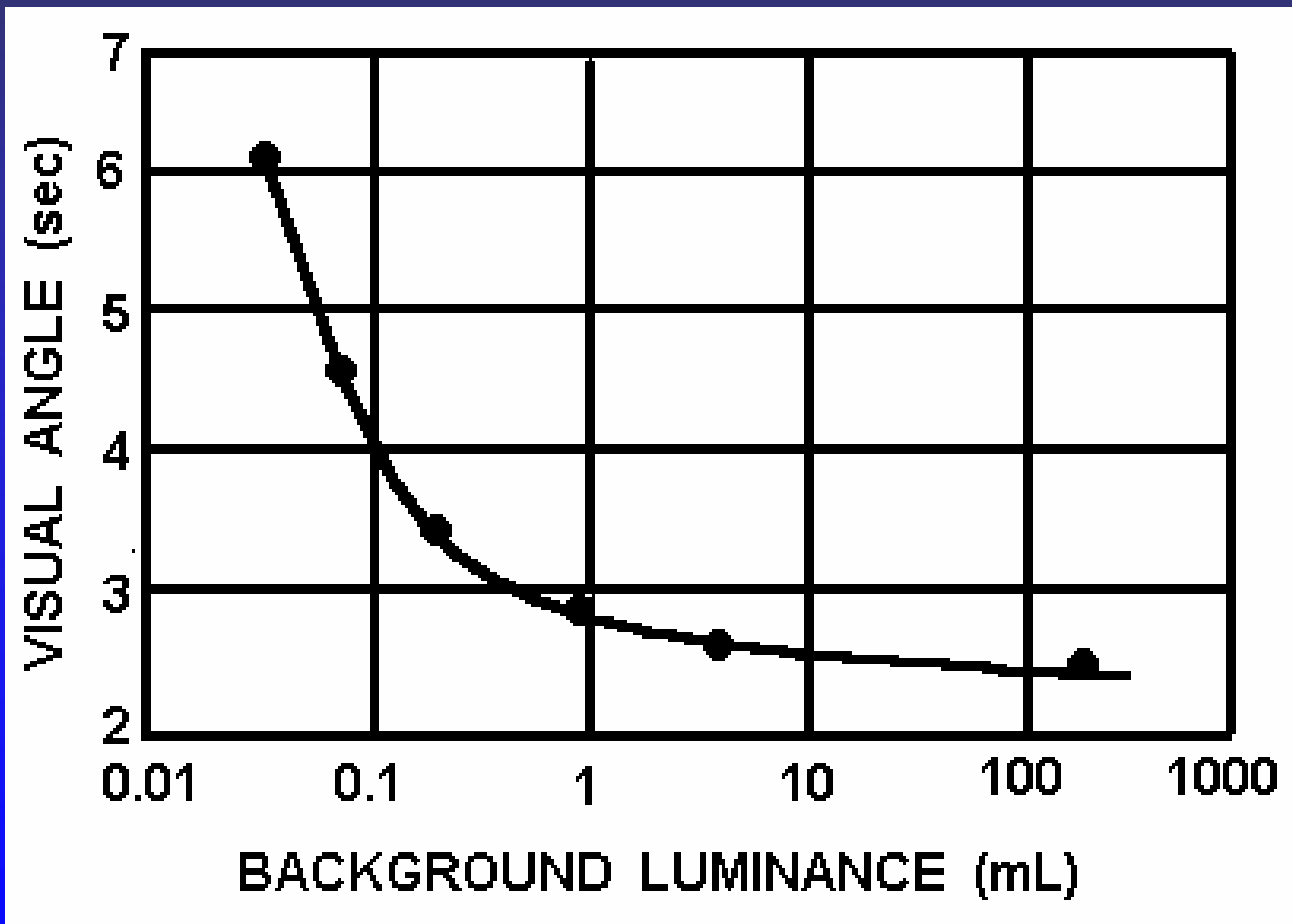
BACKGROUND LUMINANCE (log ft.- l.)

Vernier Acuity

- Smallest lateral displacement of one line from another that can be detected.

# Vernier Acuity as Function of Background Luminance

Color

- Attributes
  - hue: red, green, blue …
  - saturation: vividness of hue
  - brightness: luminance

- Relative discrimination
  - thousands of distinct colors

- Absolute discrimination
 - 24 distinct colors
  - recommended: 9

Color Spaces

- Each image is an array of 208 x 160 *pixels*
- Each pixel is a 3 dimensional value
  - Each dimension is called a *channel*
- There are multiple different possible color representations
  - RGB – R=red, G=green, B=blue
  - YUV – Y=brightness, UV=color
  - HSV – H=hue, S=saturation, V=brightness
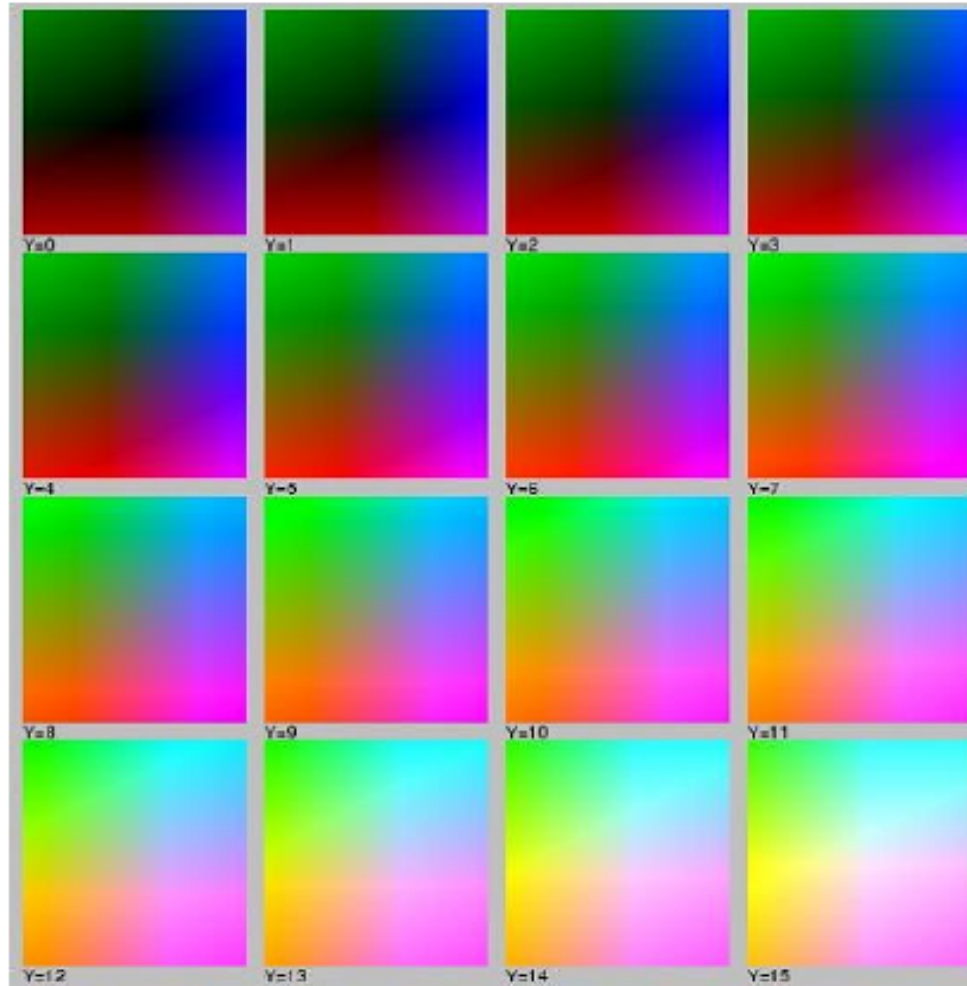- AIBO camera provides images formatted in the *YUV* color space
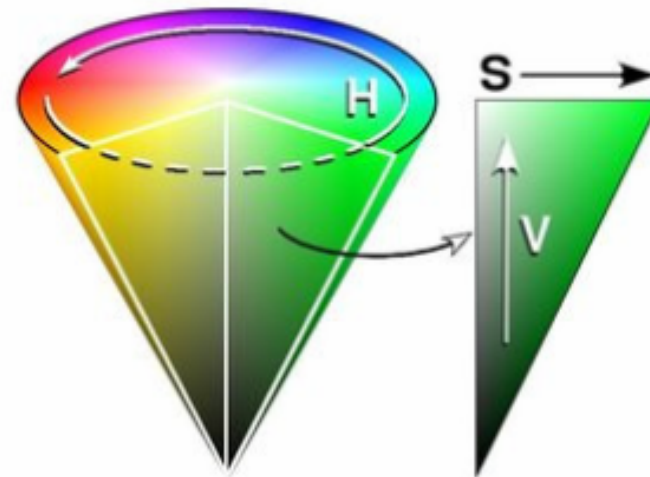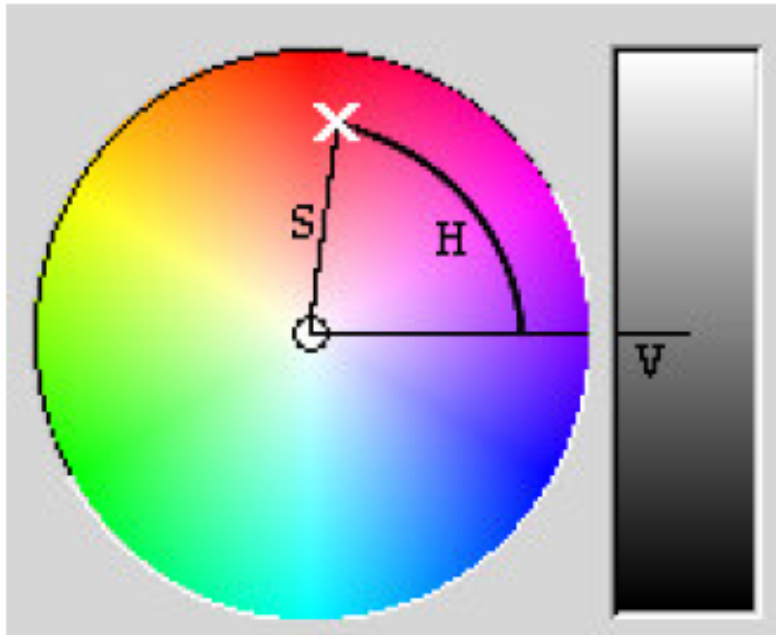
Color Spaces - RGB
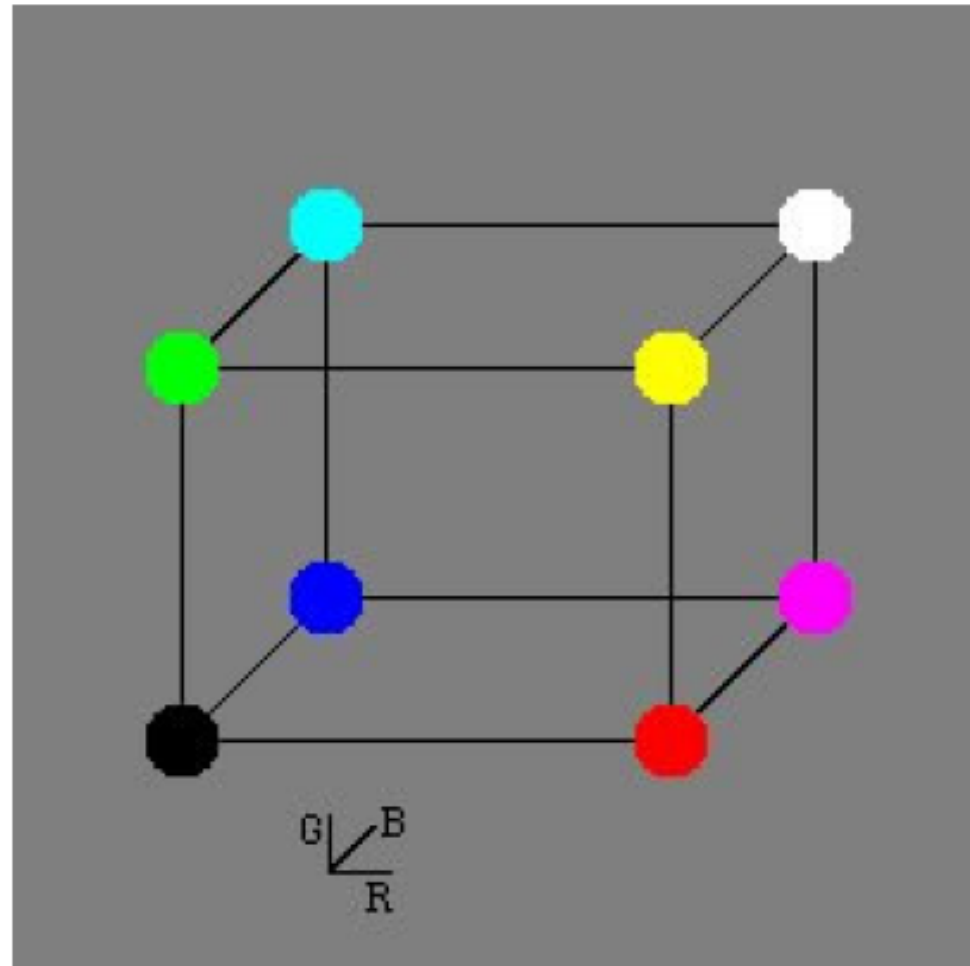
Color Spaces – YUV
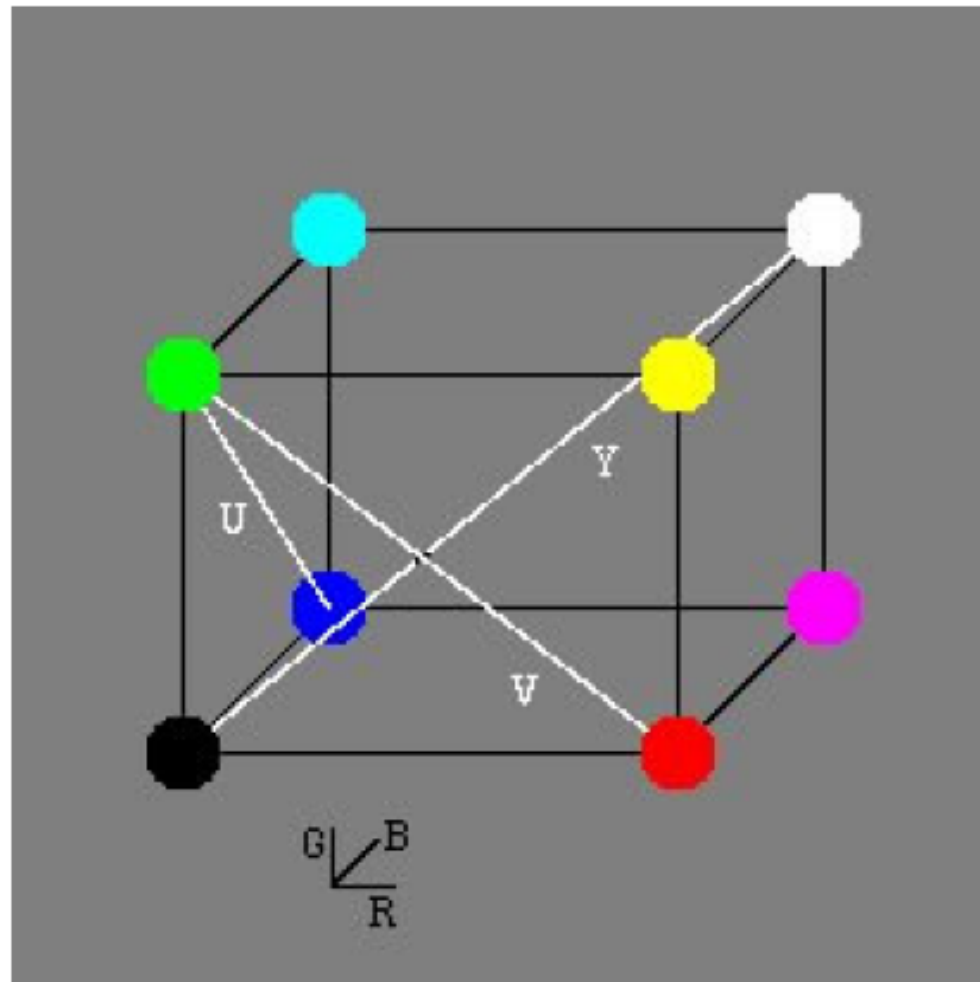
Color Spaces – YUV

Color Spaces – HSV

www.wordiq.com/definition/HSV_color_space

Color Spaces - Discussion

- RGB
  - Handled by most capture cards
  - Used by computer monitors
  - Not easily separable channels
- YUV
  - Handled by most capture cards
  - Used by TVs and JPEG images
  - Easily workable color space
- HSV
  - Rarely used in capture cards
  - Numerically unstable for grayscale pixels
  - Computationally expensive to calculate

Visual Field
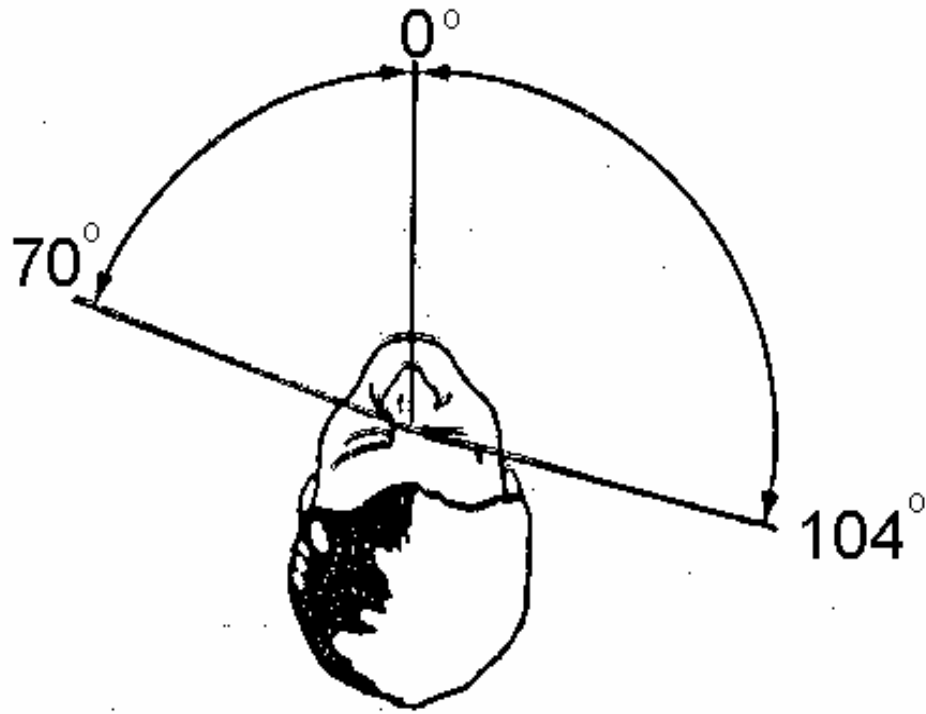
Monocular vision
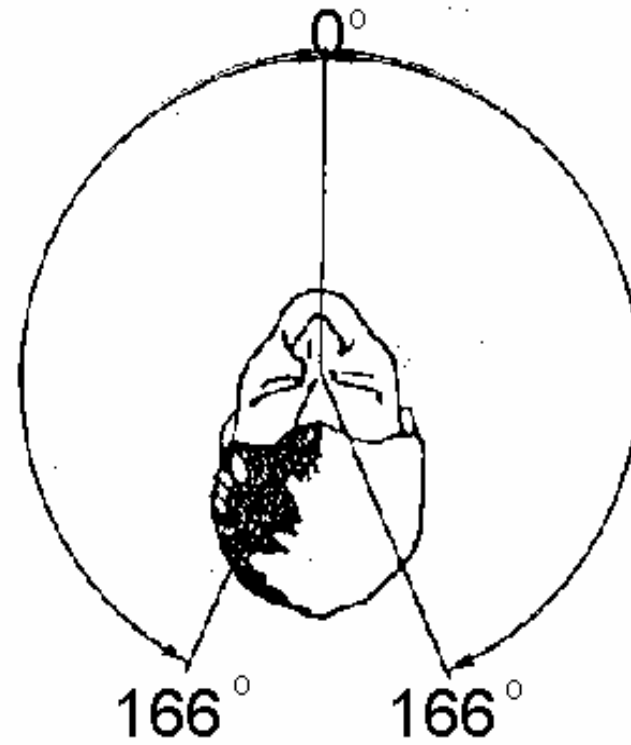
Binocular vision

Visual Impairments

Myopia :   Nearsightedness

Hyperopia :   Farsightedness

Presbyopia :   Loss of accommodation

Night Blindness :   Reduced rod vision

Color Blindness :   Inability to discriminate

Tunnel Vision :   Reduced field of view

Other Factors Affecting Visual Performance

- Contrast: optimum level exists

$$\text{Contrast} = \frac{B1 - B2}{B1} \times 100$$

- Illumination: optimum level exists

- Time: positive relationship

- Luminance Ratio: see contrast

Other Factors Affecting Visual Performance (2)

- Glare: negative relationship

- Movement: negative relationship

- Age: negative relationship

- Drugs: some drugs impair vision