# Perception and Presence

Lecture 2

RVAU - Realidade Virtual e Aumentada - EIC0070

2019/2020 - 1S

Filipe A. Rodrigues

Jorge A. Silva

(adaptado de slides Rui Nóbrega, A. Augusto Sousa)

# Overview

- Presence in VR
- Perception and VR
- Human Perception

# PRESENCE

# Presence ..

*"The subjective experience of being in one place or environment even when physically situated in another"*

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and virtual environments*, *7*(3), 225-240.

# Immersion vs. Presence

- *Immersion:* the extent to which technology delivers a vivid illusion of reality to the senses of a human participant.
- *Presence:* a state of consciousness, the (psychological) sense of being in the virtual environment. A perceptual and cognitive consequence of immersion.
- So Immersion produces a sensation of Presence
- Goal of VR: Create a high degree of Presence
  - Make people believe they are really in Virtual Environment

Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators and virtual environments*, *6*(6), 603-616.

# How to Create Strong Presence?

Suggestions on how to create strong Presence?

# How to Create Strong Presence?

- Use Multiple Dimensions of Presence
  - Create rich multi-sensory VR experiences
  - Include social actors/agents (narratives?) that interact with user
  - Have environment respond to the user
- What Influences Presence
  - Vividness – ability to provide rich experience (Steuer, 1992)
  - Using Virtual Body – user can see themselves (Slater, 1993)
  - Internal factors – individual user differences (Sadowski, 2002)
  - Interactivity – how much users can interact (Steuer, 1992)
  - Sensory, Realism factors (Witmer, 1998)

# Different Levels of Immersion (1/2)

1. Challenge-induced immersion
   - *"The feeling of presence that is at its most powerful when one is able to achieve a satisfying balance of challenges and abilities."*

     *(Ermi and Mäyrä, 2005)*

2. System and perceptual response
   - Properties of a media - **to which degree** a **system** (or platform) is **capable** of **reproducing natural perception** through multisensory displays, tracking systems and multimodal artificial *stimuli*.

# Different Levels of Immersion (2/2)

3. Narrative

- Immersion in response to a narrative, the characters of the world or the setting of the world itself.

  M.L. Ryan proposed 3 sub-categories of narrative immersion:

  - Temporal: desire to know what will happen next
  - Spatial: response to the depicted scene, environment or location
  - Emotional: emotional investment and attachment to the fate of certain characters

Ryan, M. L. (2003). Narrative as virtual reality: Immersion and interactivity in literature and electronic media. The Johns Hopkins University Press.

# Example: UNC Pit Room

- Key Features
  - Training room and pit room
  - Physical walking
  - Fast, accurate, room scale tracking
  - Haptic feedback – feel edge of pit, walls
  - Strong visual and 3D audio cues
- Task
  - Carry object across pit
    - Walk across or walk around
  - Dropping virtual balls at targets in pit

- http://wwwx.cs.unc.edu/Research/eve/walk_exp/

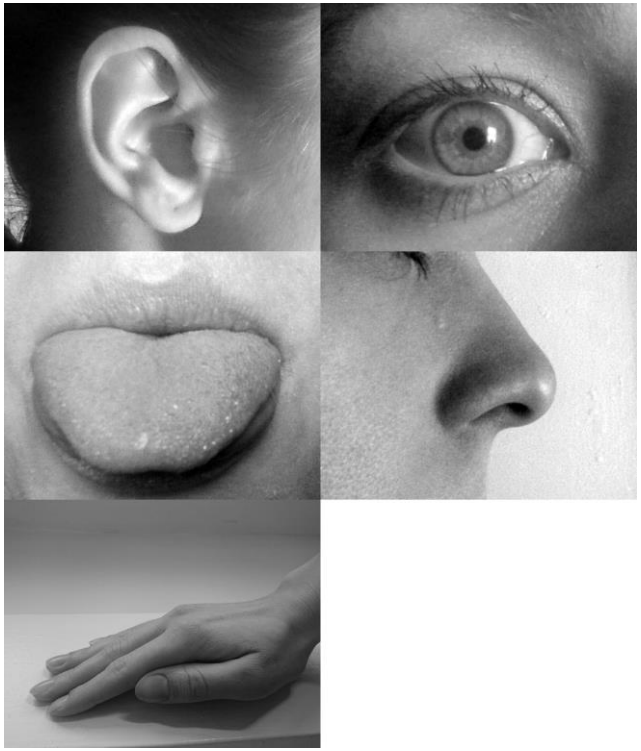
# Typical Subject Behaviour

- Note – from another pit experiment
- https://www.youtube.com/watch?v=VVAO0DkoD-8

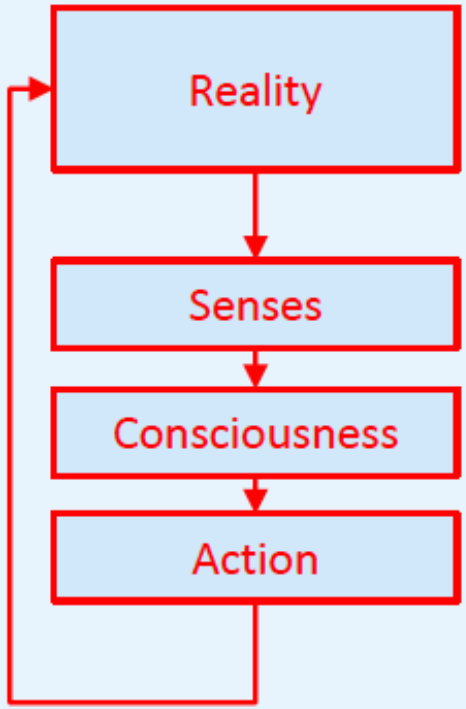
# PERCEPTION AND VR

# How do We Perceive Reality?

- We understand the world through our senses:
  - Sight, Hearing, Touch, Taste, Smell (and others..)
- Two basic processes:
  - Sensation – Gathering information
  - Perception – Interpreting information

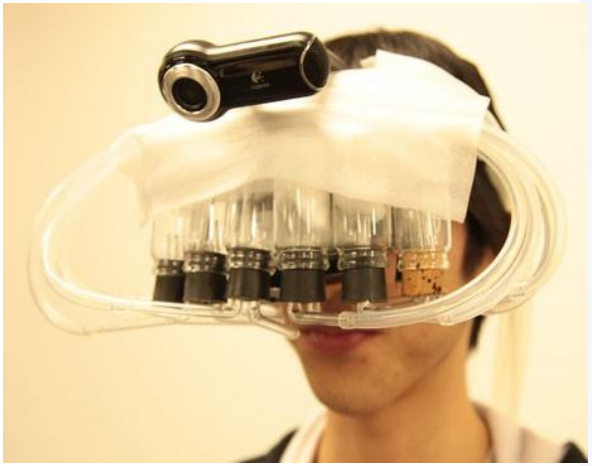


# Simple Sensing/Perception Model

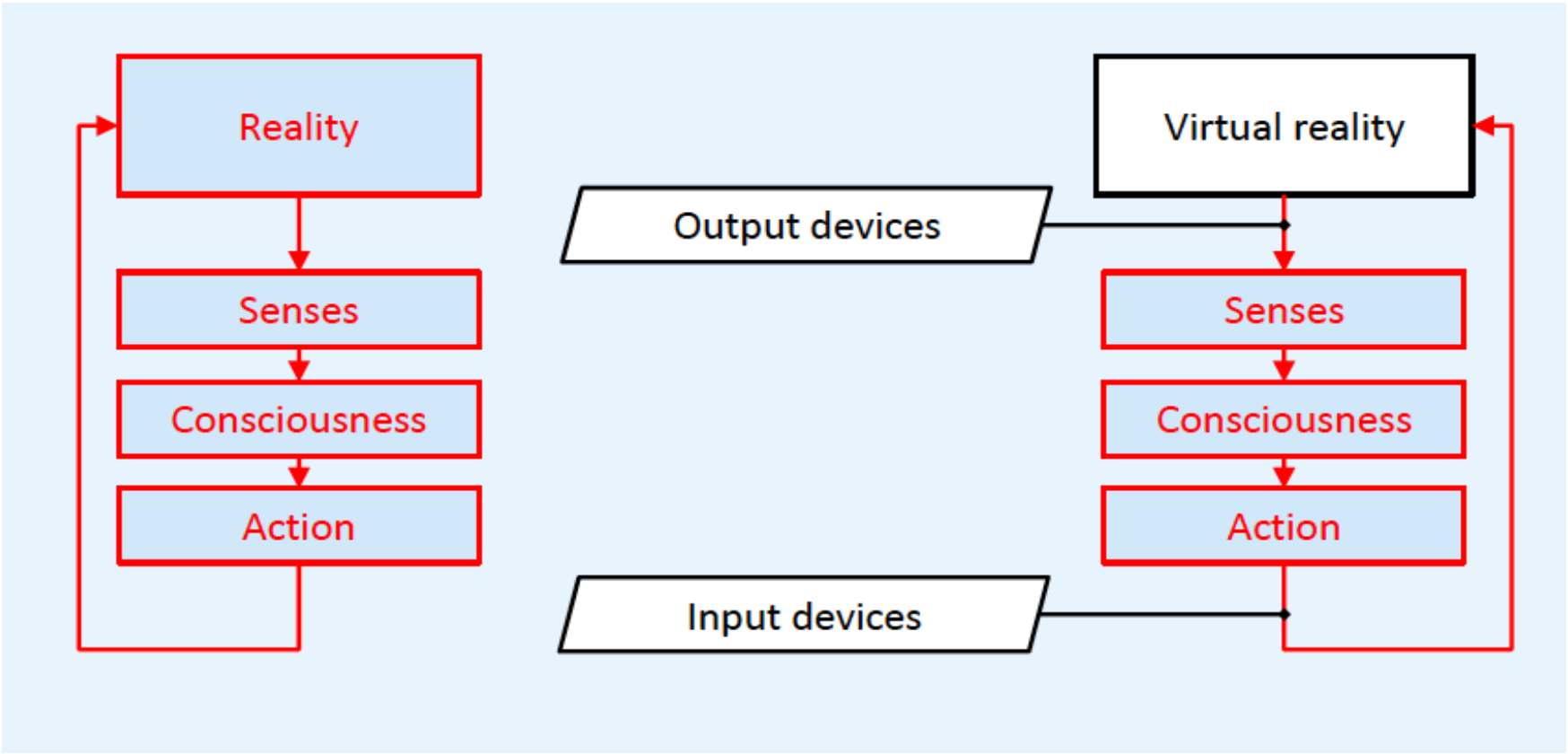


# Creating the Illusion of Reality

- Trick the human perception by using technology to generate artificial sensations
  - Computer generated sights, sounds, smell, haptics, etc…

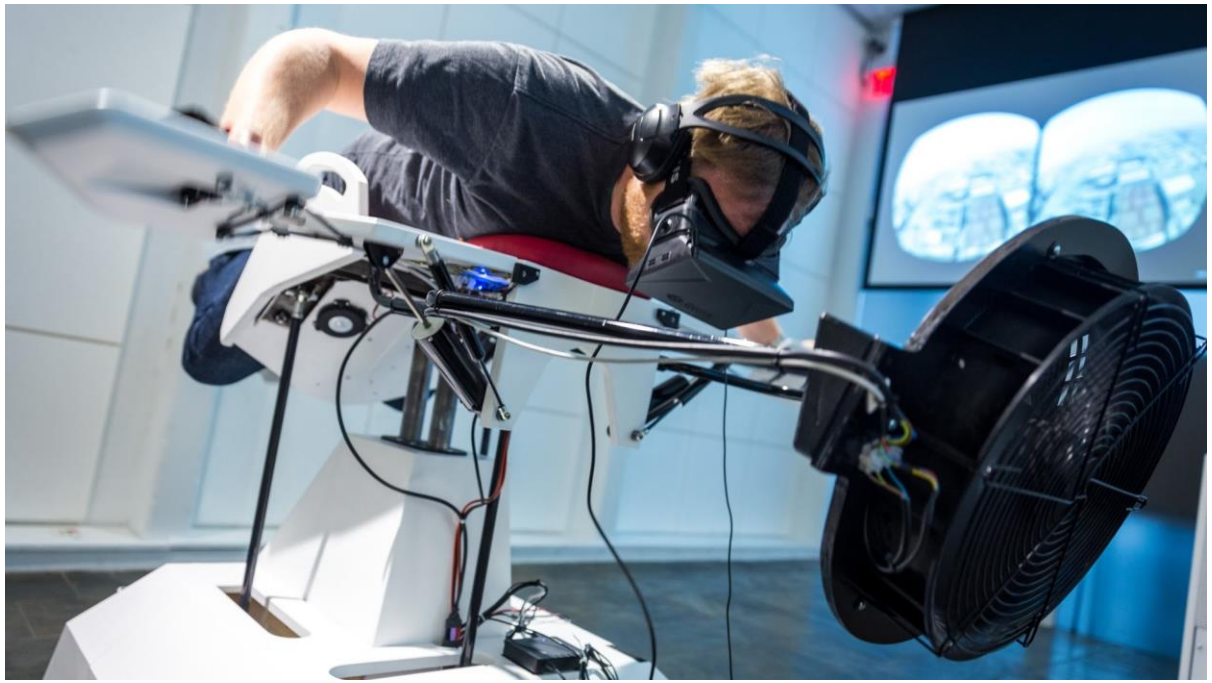


# Reality vs. Virtual Reality




- In a VR system there are input and output devices between human perception and action

# Example Birdly - http://www.somniacs.co/



- Create illusion of flying like a bird
- Multisensory VR experience
  - Visual, audio, wind, haptic

# Birdly Demo


- https://www.youtube.com/watch?v=gHE6H62GHoM

# Measuring Presence

- Questionnaires:
  - Witmer & Singer 1998
    https://nil.cs.uno.edu/publications/papers/witmer1998measuring.pdf
  - Portuguese version: Silva et al. 2016
    Silva et al. 2016 questionnaire for measuring presence in virtual environments: factor analysis of the presence questionnaire and adaptation into Brazilian Portuguese, in Virtual Reality

# HUMAN PERCEPTION

# Physiology and Perception in Virtual Reality Environments

(based on slides by Professor A. Augusto de Sousa (FEUP / DEI))

# Motivation

- Virtual Environments (VE):
  - Human Factors
  - Engineering Requirements

Hard to dissociate...

# Summary

- Physiology of Visual Perception
- Auditory Perception Physiology
- Haptic Perception Physiology
- Virtual Presence

*The Science of Virtual Reality and Virtual Environments*
Roy Kalowsky
Addison Weslley, 1994 (1ª Edição)

# Physiology of Visual Perception

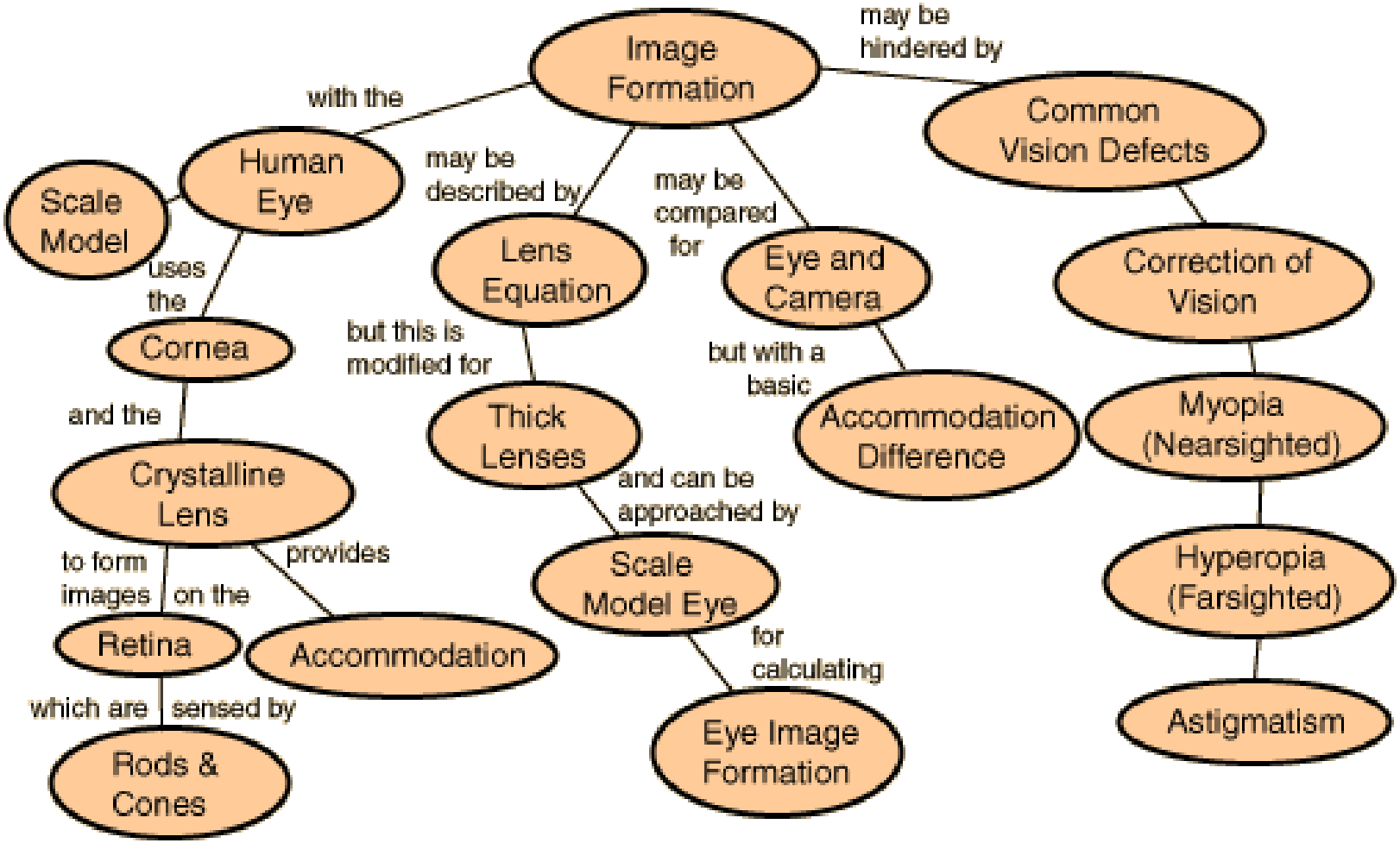
1. Human eye
2. Field of vision
3. Stereoscopy (binocular vision)
4. Visual perception of movement
5. Temporal resolution
6. Spatial resolution
7. Visual perception of space
8. Color perception

# Physiology of Visual Perception

- “Visual Channel ”
  - Most important interface in an VE
  - Extremely sensitive to anomalies in an image
  - Much more so when there is animation:
    - Any imperfections become apparent
      - Known process?
        - No, far from it...

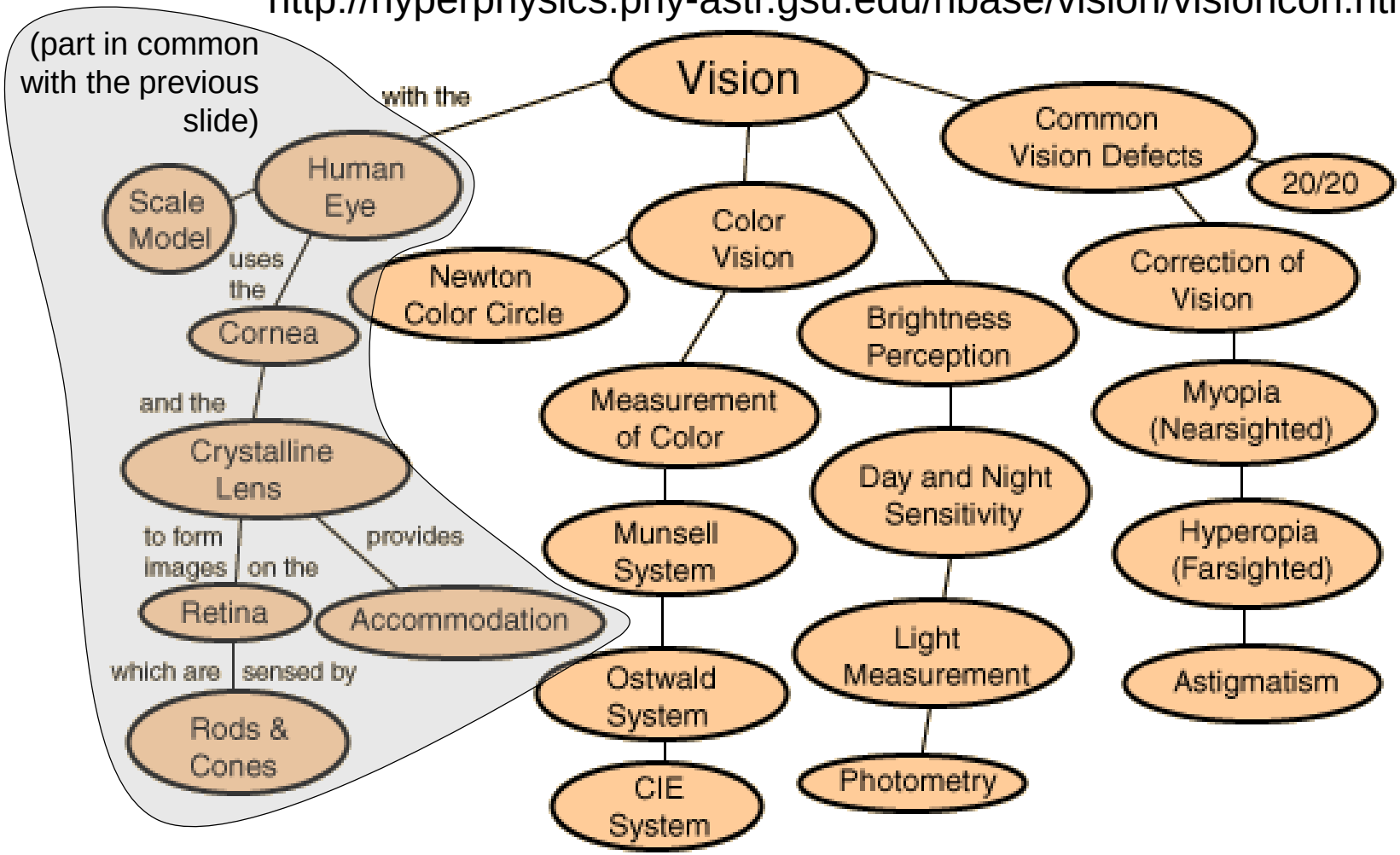
# Image Formation

http://hyperphysics.phy-astr.gsu.edu/hbase/vision/imagformcon.html



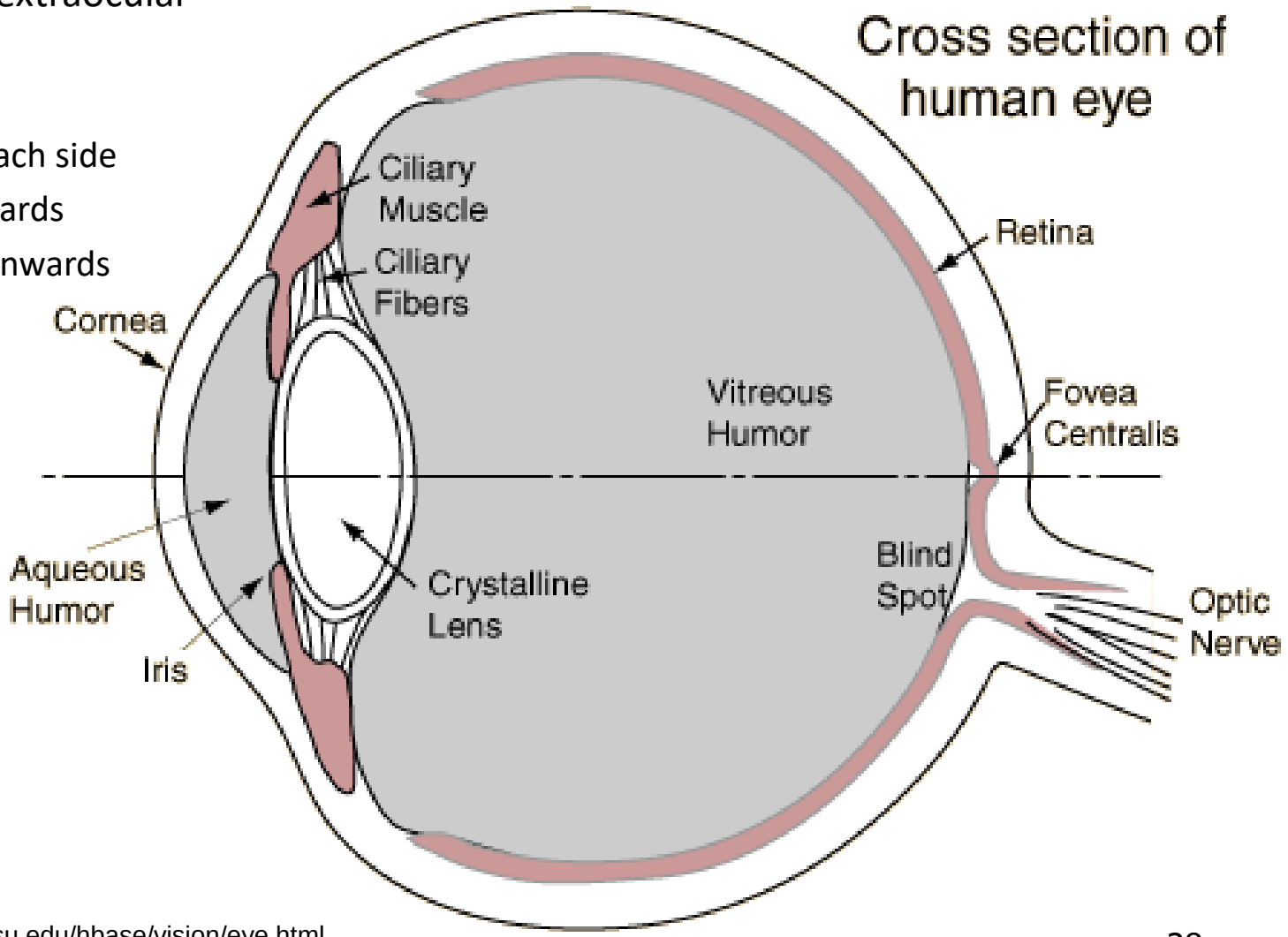
# Eyesight

http://hyperphysics.phy-astr.gsu.edu/hbase/vision/visioncon.html



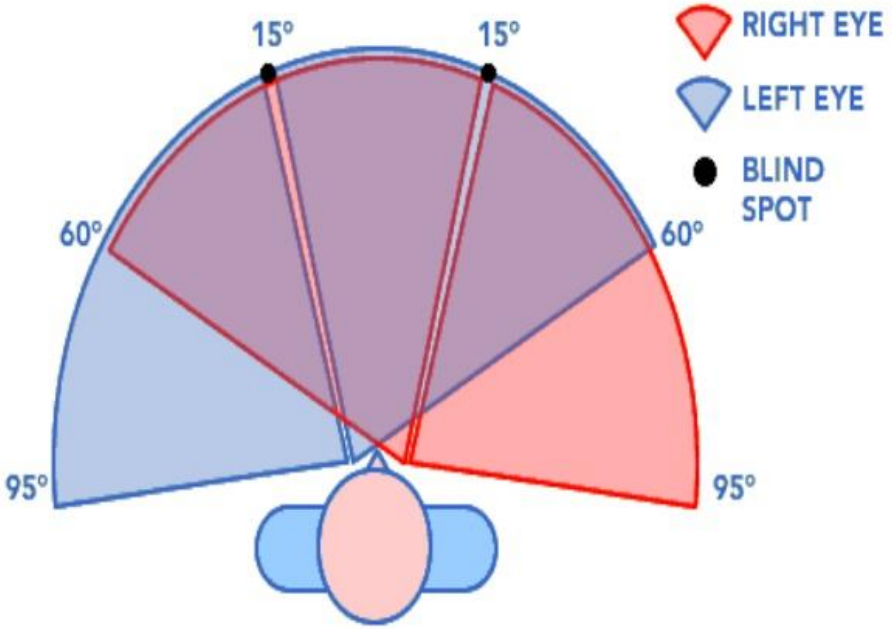
# 1. The Human Eye

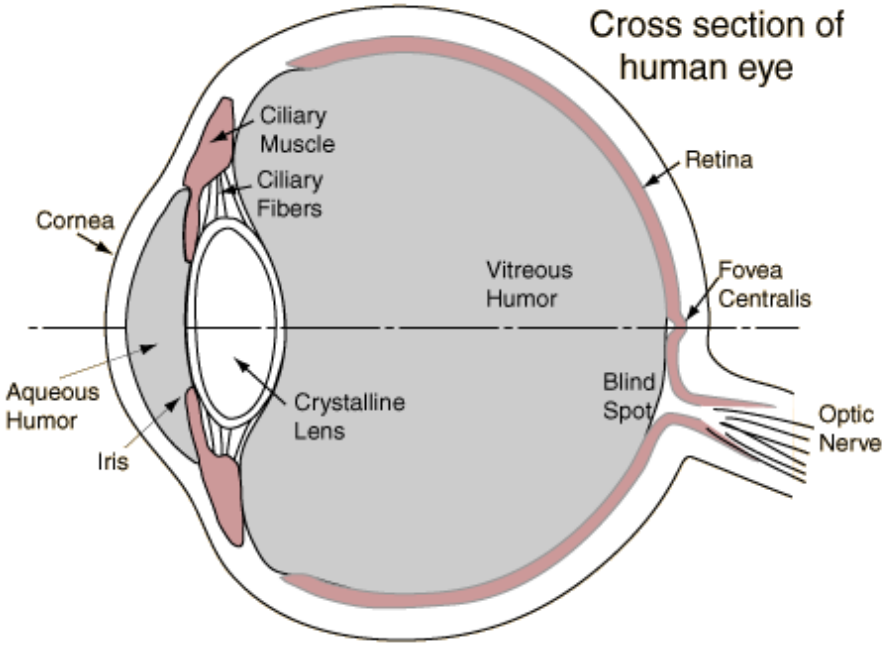
- Supported by 6 extraocular muscles
  - Movements:
    - 50º to each side
    - 40º upwards
    - 60º downwards




http://hyperphysics.phy-astr.gsu.edu/hbase/vision/eye.html

# 1. The Human Eye



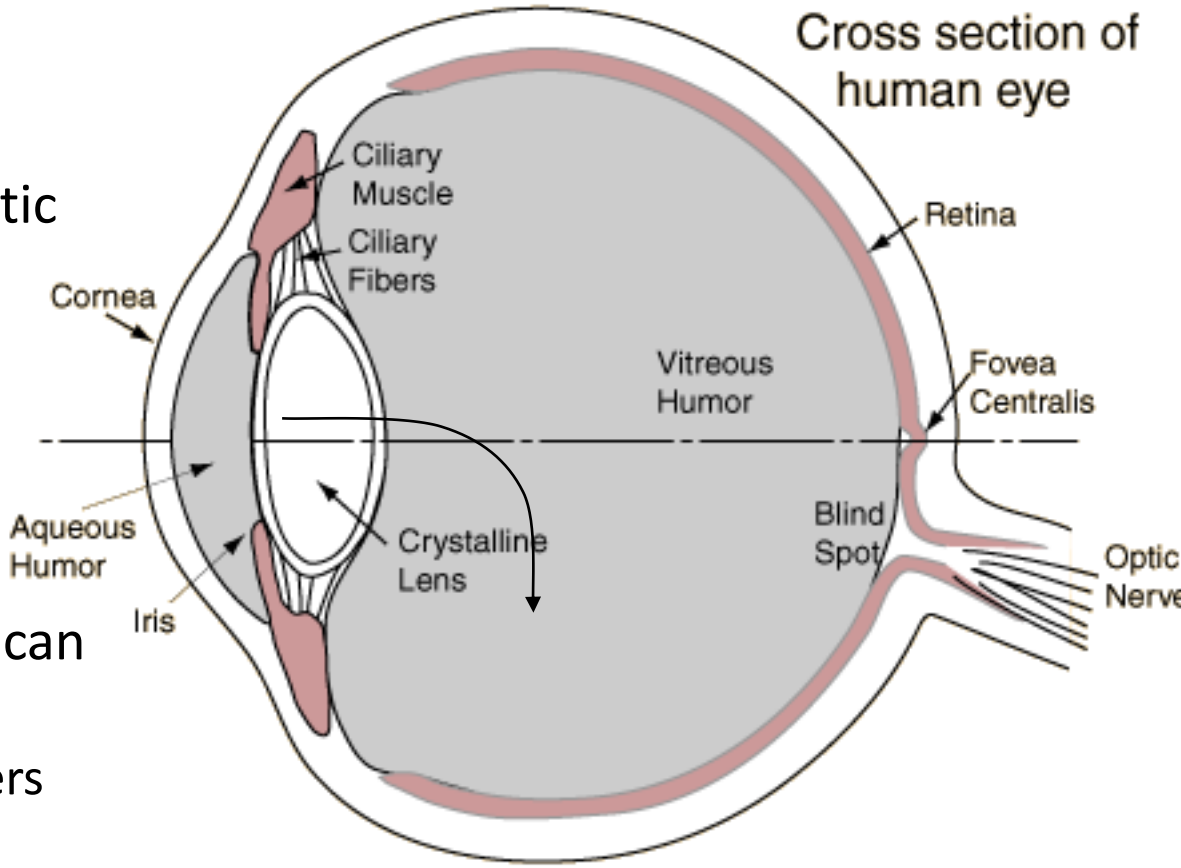




- Find the blind spot:
  - Try at home: https://io9.gizmodo.com/why-every-human-has-a-blind-spot-and-how-to-find-your-5804116

http://hyperphysics.phy-astr.gsu.edu/hbase/vision/eye.html

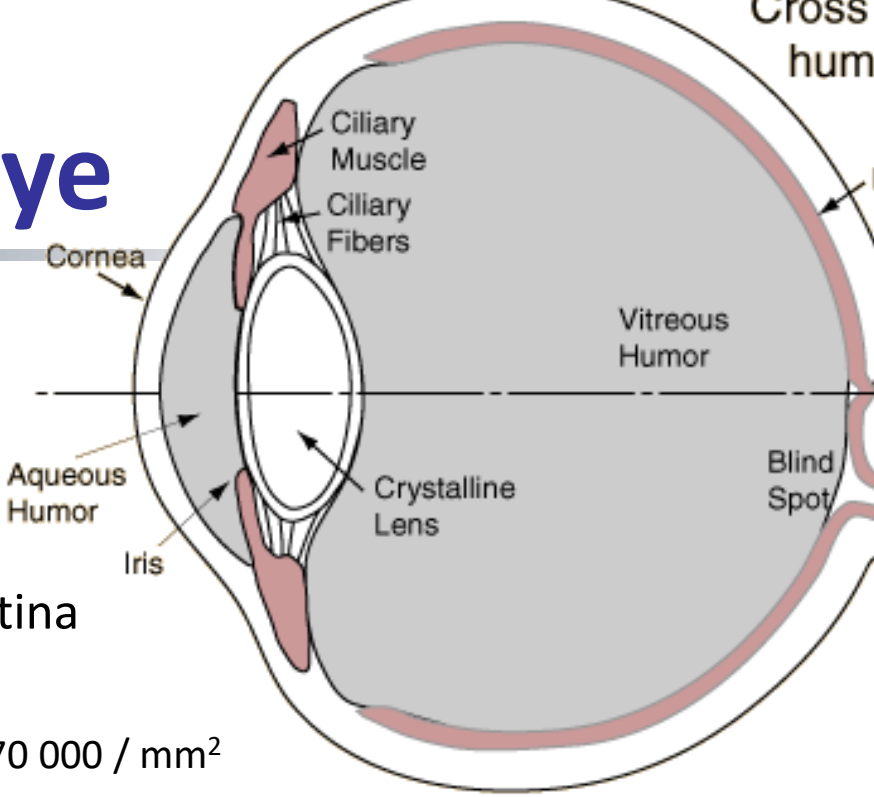
# 1. The Human Eye

- Retina
  - Converts electromagnetic radiation to nerve impulses
  - Composition: 10 layers can be identified
    1. Photosensitive Receivers
    2. Neuronal connections
    3. Etc…



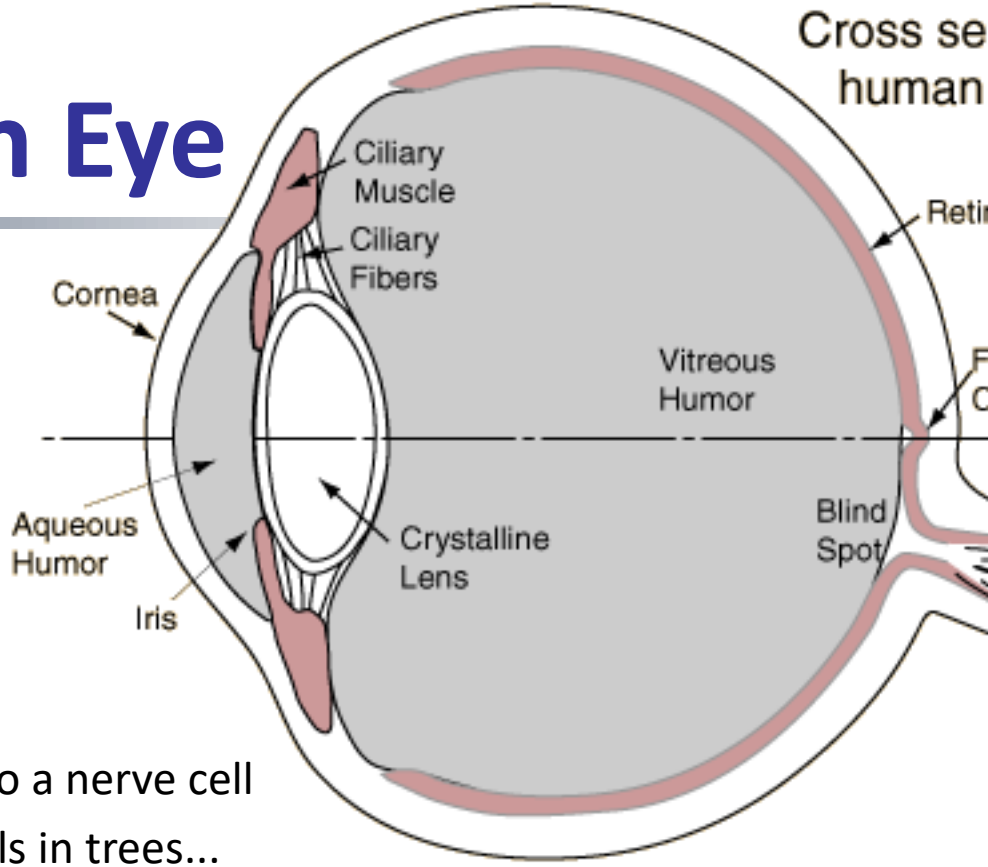

- Receivers:
  - Rods
  - Cones

# 1. The Human Eye



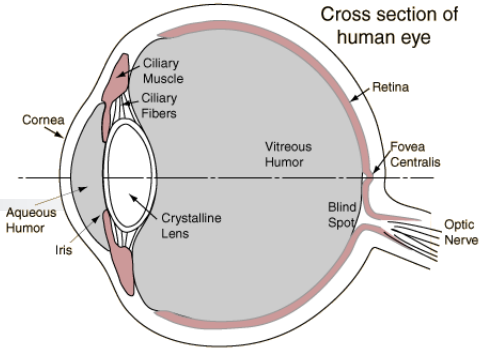

- Rods
  - 120 Million per retina
  - Non homogeneous distribution along retina
    - Absent from Fovea
    - Maximum density at 20º of the fovea: 170 000 / $mm^2$
  - High sensitive to low intensity light
    - Think Black & White vision
    - Need adaptation to darkness (30 min. for maximum sensitivity)

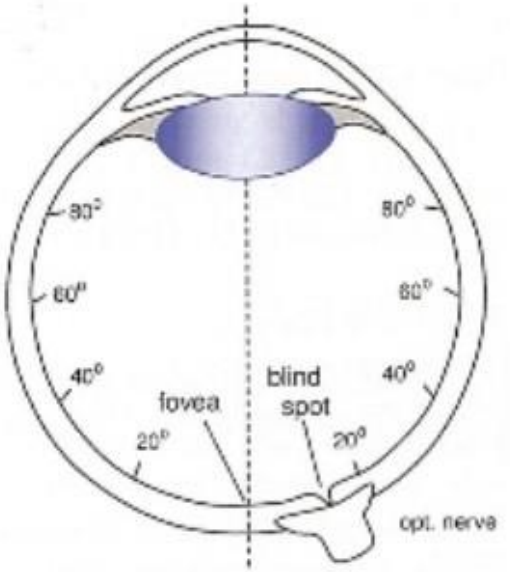
# 1. The Human Eye

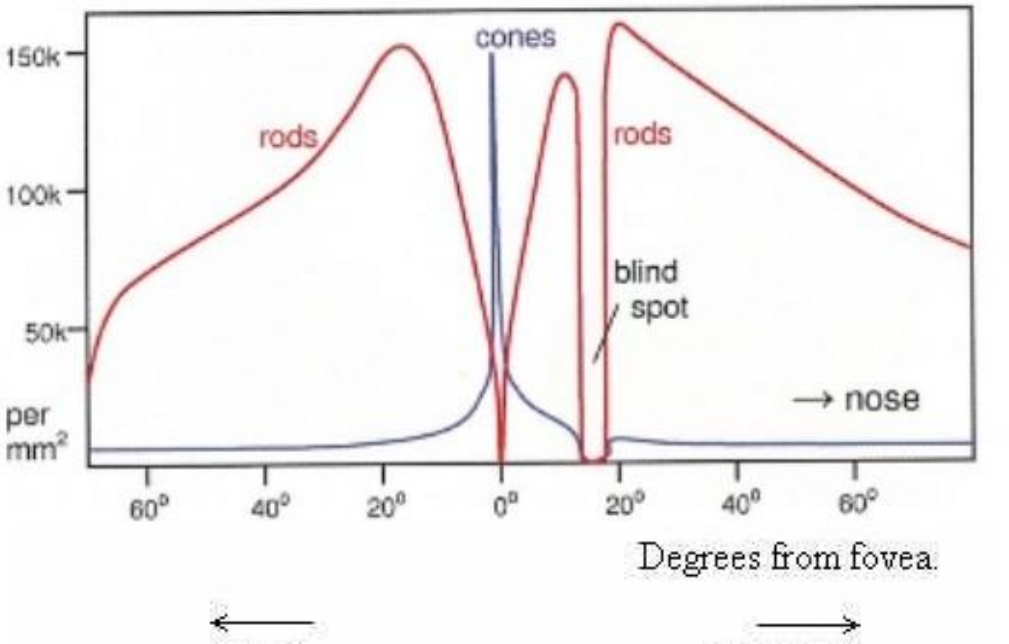



- Cones
  - 6 Million per retina
    - Center of fovea: 150 000 / $mm^2$
    - Outside fovea: 16 300 / $mm^2$
  - Links:
    - In Fovea: each cone is connected to a nerve cell
    - Outside: they connect to nerve cells in trees...
  - High sensitive to bright intense light
    - Color detection
    - Image sharpness (visual acuity)

# 1. The Human Eye



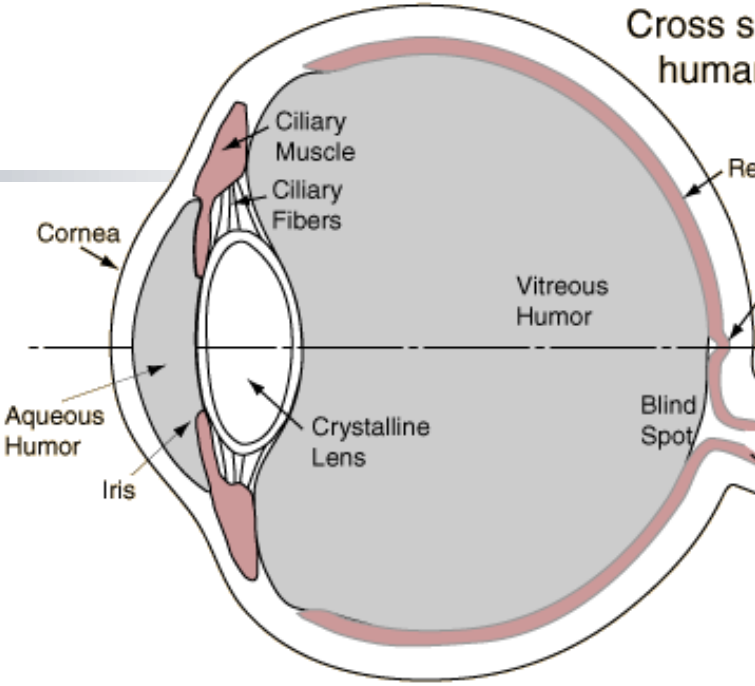



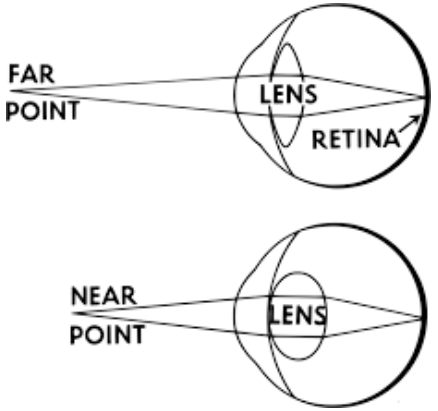

Temporal

Nasal

# 1. The Human Eye

- Human Eye Adaptation:
  - High sensitivity to slight light variations
  - Maximum dynamic range $10^{13}$
    - No comparable artificial sensors...
  - Depth of field:
    - It varies with light intensity
    - <u>Accommodation:</u>
      - Ability of the eye to change its focus from distant to near objects
      - Crystalline acts as lens (ciliary muscles)



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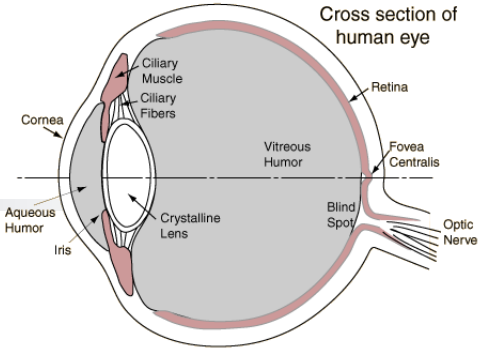
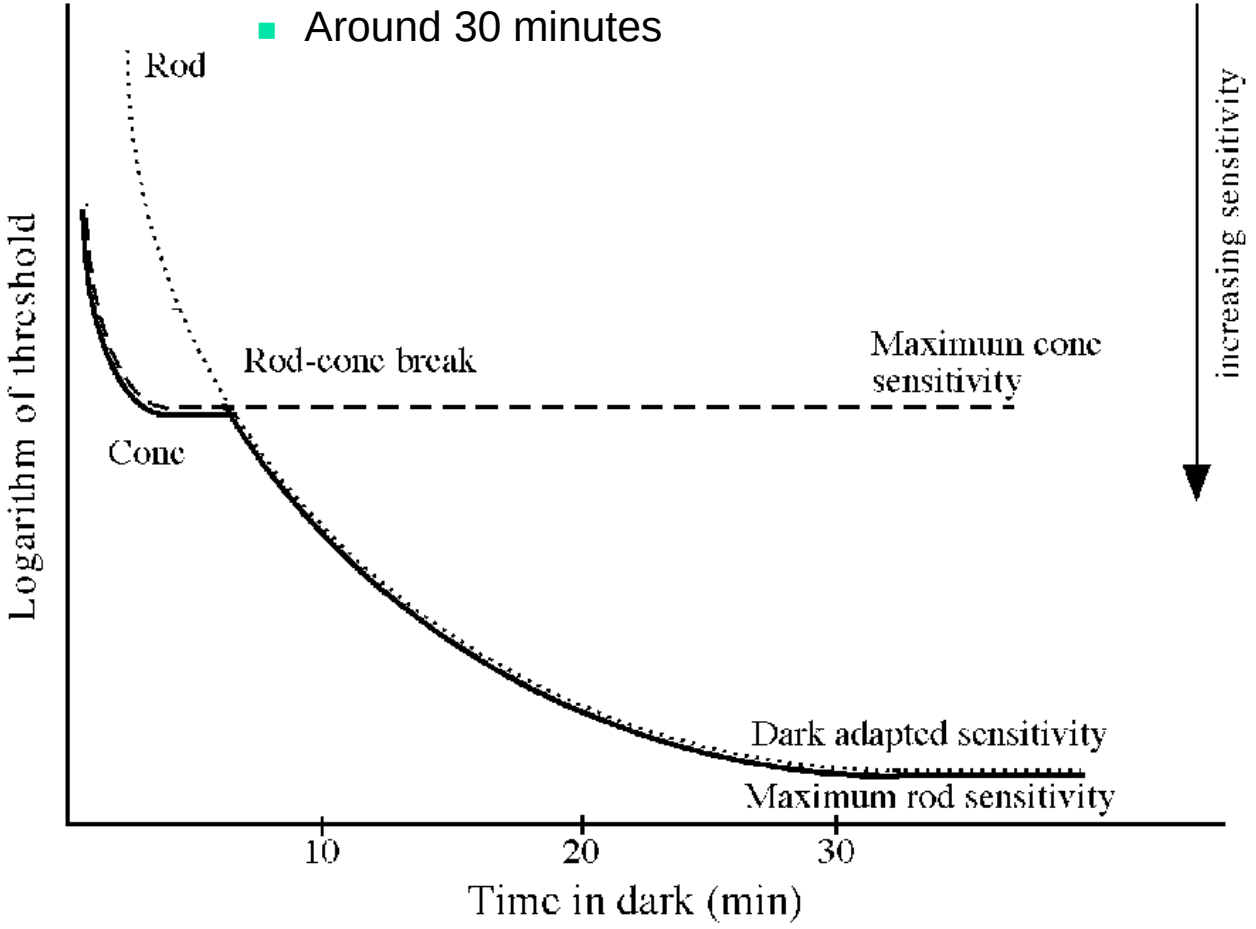
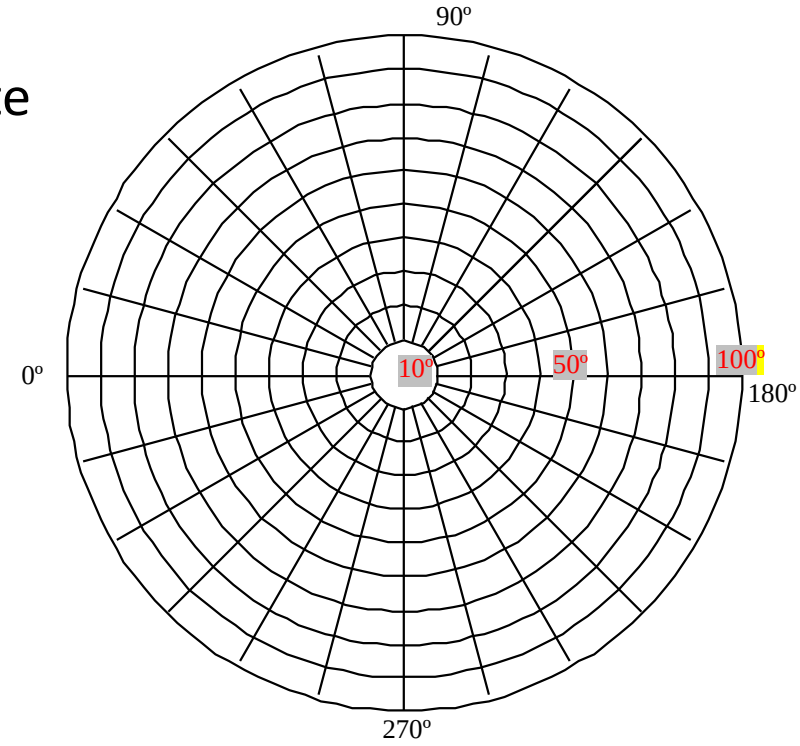



- Adaptation to the light
  - *Absolute Visual Threshold*
    - Around 30 minutes



# 2. Field of Vision

- Importance:
  - Ex: masks and protection goggles create obstacles and decrease:
    - Field of View
    - Capability of motion detection in the peripheral vision

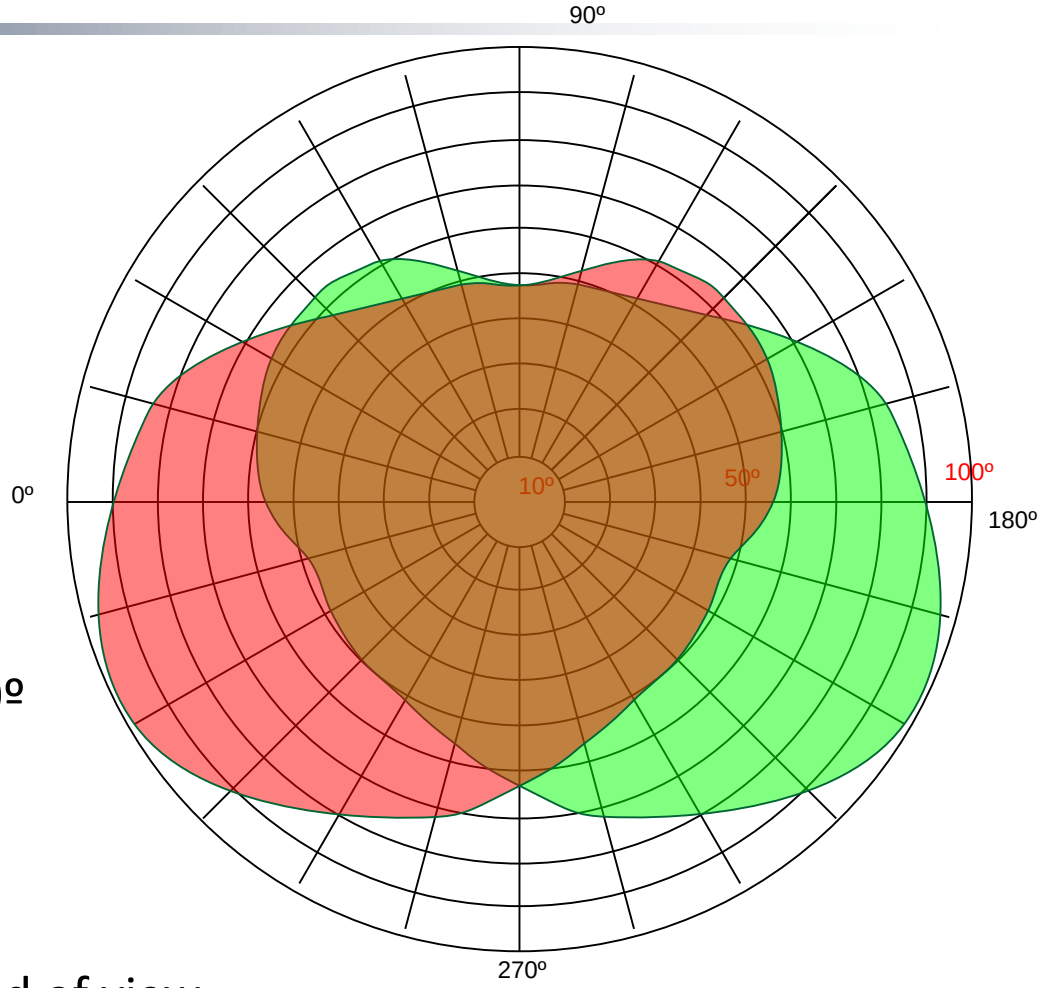



- Several graphs to depict it
  - "*Polar Plot*" or "*Perimeter Charts*"

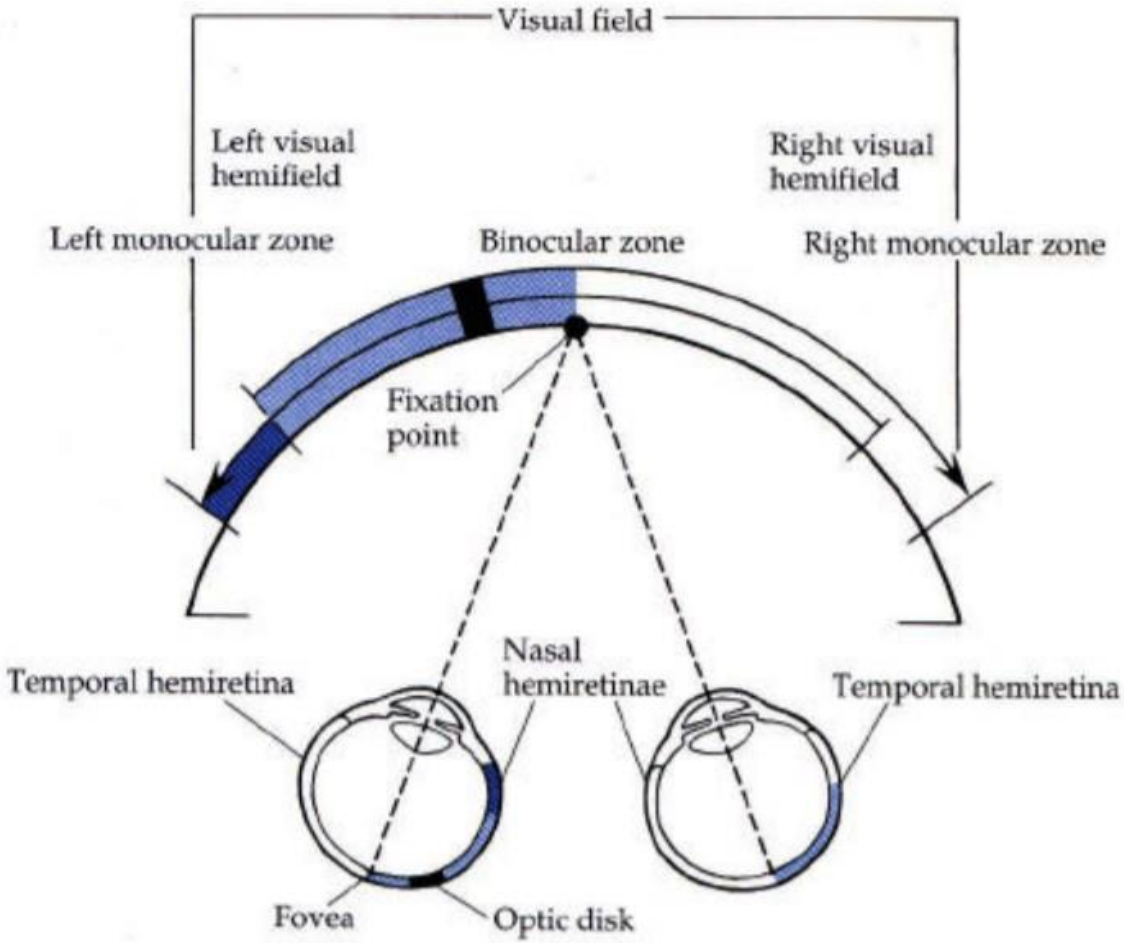
http://webeye.ophth.uiowa.edu/ips/PerimetryHistory/3-perimeter.htm

# 2. Field of Vision

- Monocular Field:
  - V=120º; H=150º
  - Temporal side: 100º
  - Nasal side: 60º
- Two eyes:
  - V=120º; H=200º
  - Binocular overlay: 120º
    - → Stereoscopic zone
- Acuity:
  - It varies across the field of view



# 2. Field of Vision

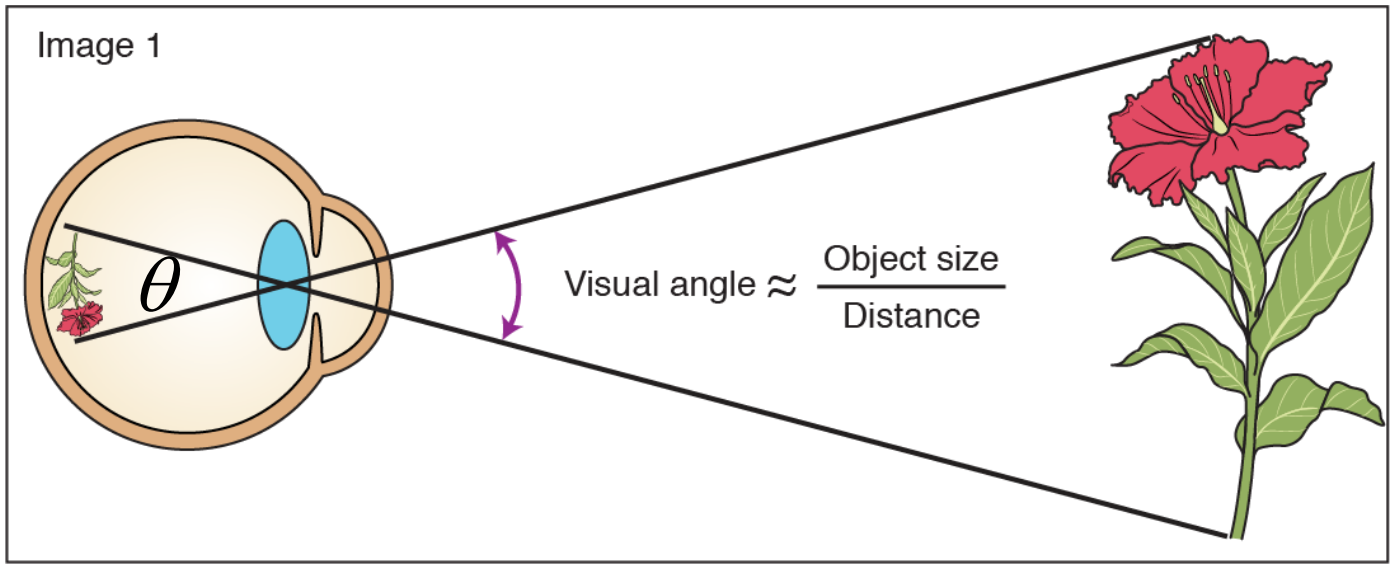


# 2. Field of Vision

- Field of View and Technology
  - Field of View of Head Mounted Displays / Glasses
    - Smaller than the observer's
  - Increase field of view on equipment:
    - Lower resolution, especially in the fovea area…

# 2. Field of Vision

- Visual Angle
  - Instead of distances of object dimensions




$$\theta = \tan^{-1}\left(\frac{s}{d}\right)$$

# 3. Stereoscopy (binocular vision)

- Binocular Vision (stereopsis):
  - Is a result of:
    - **Neuronal and physiological interaction** of both **eyes** in the **overlay region**
  - Important:
    - Two visual channels
    - <u>But only one sensory system</u>

# 3. Stereoscopy (binocular vision)

- Depth perception
  - By alternative methods...
    - Motion parallax
    - Different object sizes
    - Texture gradient (distortion)

Depth differences are detected from:
- 0.05mm at a distance of 0.5m
- 4mm at distances of 5m

- Binocular Rivalry
  - Phenomenon occurs when <u>each eye</u> receives a <u>different image</u> (diplopia)
    - By differences in size, brightness, color ...
  - More likely with synthetic images than real ones

# 3. Stereoscopy (binocular vision)

- Binocular Rivalry Effects
  - Failure to focus
  - One of the two images is deleted
    - At any moment one image (dominant) is visible, while the other is invisible (surpressed)
  - One eye tends to be dominant
    - When image perceived longer

# 3. Stereoscopy (binocular vision)

- Rivalry with the HMD when:
  - One image brighter than the other
  - Some vision from the “outside world”:
    - Convergence angles different from the ones in image
  - Misalignment of the images
    - More at the borders of monocular images
- Rivalry is higher on *Raster* than *Vector*
  - ...so, it is higher in images than drawings

# 3. Stereoscopy (binocular vision)

- Detecting “Clues” for depth perception
  - Lateral disparity of image in the retina
  - Motion parallax
  - Different object sizes
  - Texture gradients

    - Depth differences are detected from:
      - 0.05mm at a distance of 0.5m
      - 4mm at distances of 5m

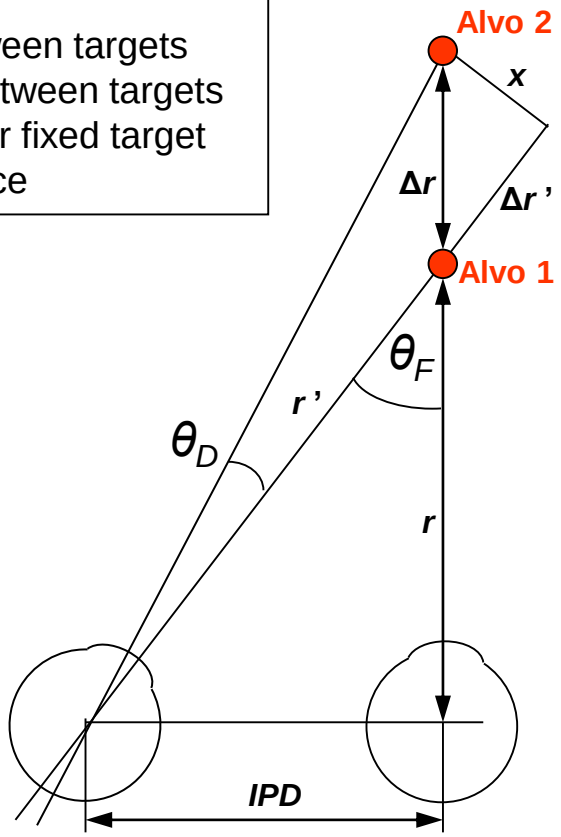
# 3. Stereoscopy (binocular vision)

$$x = \frac{IPD}{r'} \cdot \Delta r \qquad (1)$$

$r$ : Distance to fixed target
$\Delta r$ : Depth difference between targets
$\theta_D$ : Angular separation between targets
$\theta_F$ : Convergence angle for fixed target
$IPD$ : Interpupillary distance

Since $\theta_D$ is too small:

$$\theta_D \approx \frac{x}{r'+\Delta r'} \qquad (2)$$




And suppose that:

$$r >> IPD$$

We have:

$$r'+\Delta r' \approx r + \Delta r$$

$$r' \approx r$$

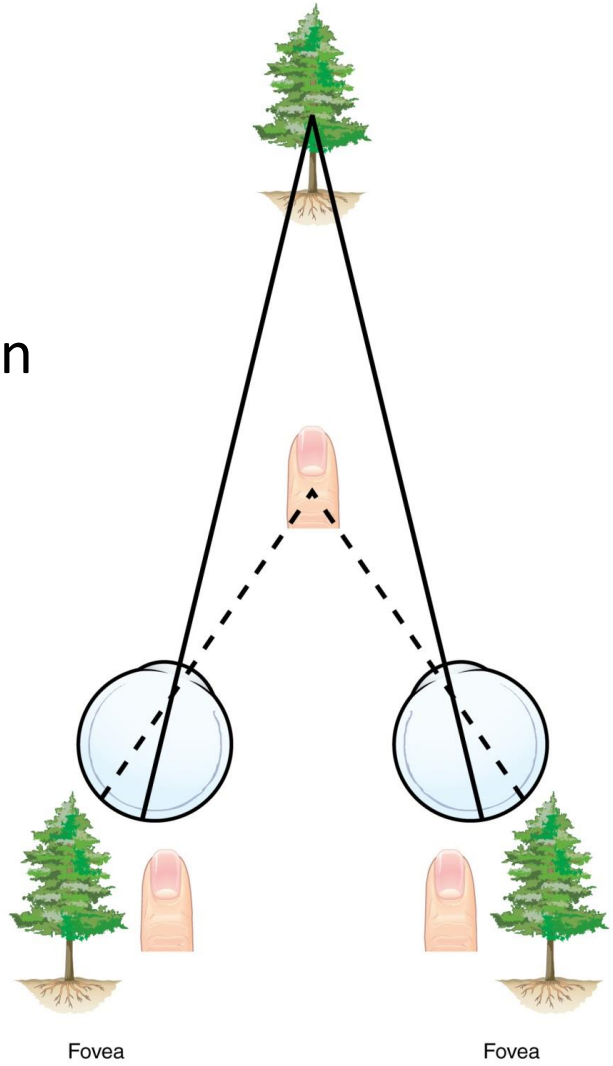
Where, from (1) and (2):

$$\theta_D \approx \frac{IPD}{r} \cdot \frac{\Delta r}{r + \Delta r}$$

**Lateral Disparity**

# 3. Stereoscopy (binocular vision)

- Lateral disparity (δ) of the image in the retina
  - The **relative difference** in the image **position** of an **object** on the retina **in function** to the **position of vergence**




http://txliblms.test.calstate.edu/mymoodle/pluginfile.php/467/mod_resource/content/2/mobile_pages/6-BIO1680417.html

# 3. Stereoscopy (binocular vision)

| | | |
|---|---|---|
| $\delta$ : Disparity | d : Depth | $D$ : Distance |
| $\theta_1, \theta_2$ : Binocular Parallax | $\delta_L+\delta_R=\theta_2-\theta_1$ : **Binocular Disparity** | |

Replacing, in the previous expression:

$$\delta = \theta_D$$

$$d = \Delta r$$

$$D = r$$

Results:

$$\delta = \frac{IPD \cdot d}{D^2 + d \cdot D}$$

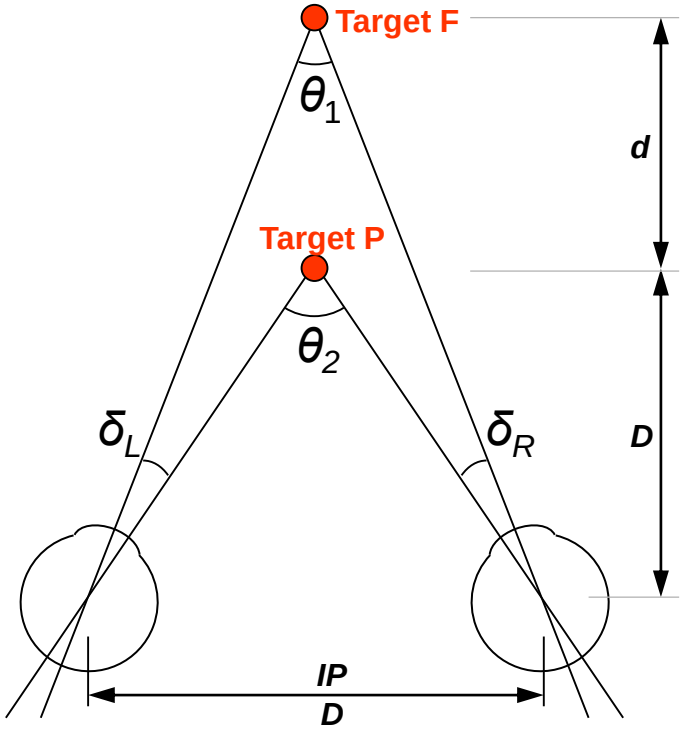
Where:

$$\delta \cdot D^2 + \delta \cdot d \cdot D = IPD \cdot d$$

$$d \cdot (IPD - \delta \cdot D) = \delta \cdot D^2$$

And, finally:

$$d = \frac{\delta \cdot D^2}{IPD - \delta \cdot D}$$ **Depth**



# 3. Stereoscopy (binocular vision)

- **Vertical disparity** of the image in the retina
  - Causes *diplopia*...
  - Does not translate depth perception
  - Really hard to compensate with eye movements
    (low vertical movement capability)
  - It is possible to adapt, but... readaptation to “normal”

  - **<u>Must be avoided</u>**
    - Causes:
      - Errors in the display devices
      - An object that is really closer to an eye; this one will see a larger object

# 3. Stereoscopy (binocular vision)

- Misalignment by rotation
  - Causes diplopia
  - More sensitive to simple lines
  - Can be tolerated, but with discomfort

- Disparity by different magnification on each image (*aniseikonia*)
  - Enhances any of the previous disparities
  - Affects depth perception

    (more problematic on nearby objects)

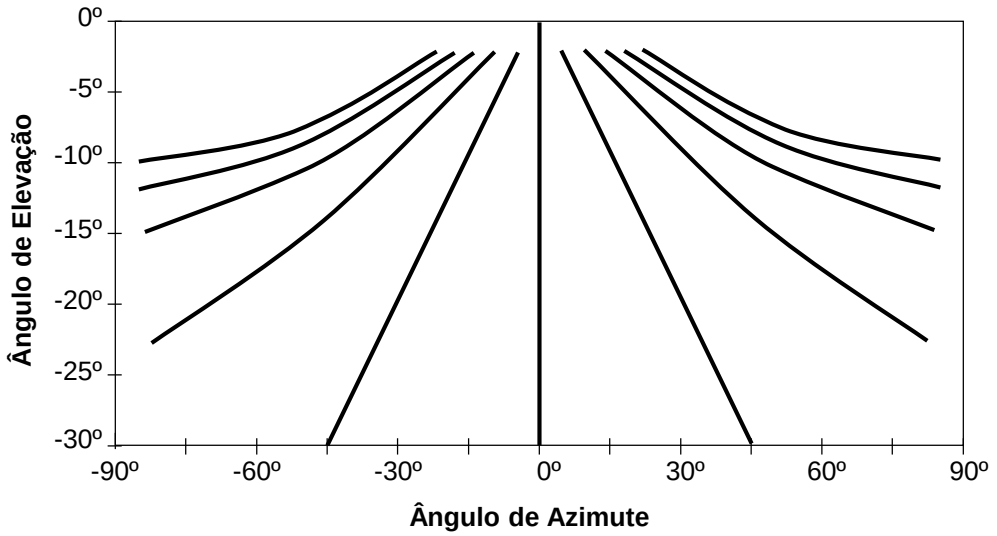
# 3. Stereoscopy (binocular vision)

- Stereoscopic acuity
  - Ability to solve small depth differences between two objects
  - Increases with illumination up to 3cd/$m^2$
    - In low light, the cones are poorly sensitive ...
  - Reaches the maximum with:
    - Objects in the center of the fovea
    - Vertical lines

* cd/$m^2$ : candela per square meter

# 4. Visual perception of movement

- Not correctly interpreted by most people in VR environment
  - Visual flow cues are not natural
    - Ex: rectilinear paths of equidistant objects generate non-rectilinear optical paths (in a real enviroment)

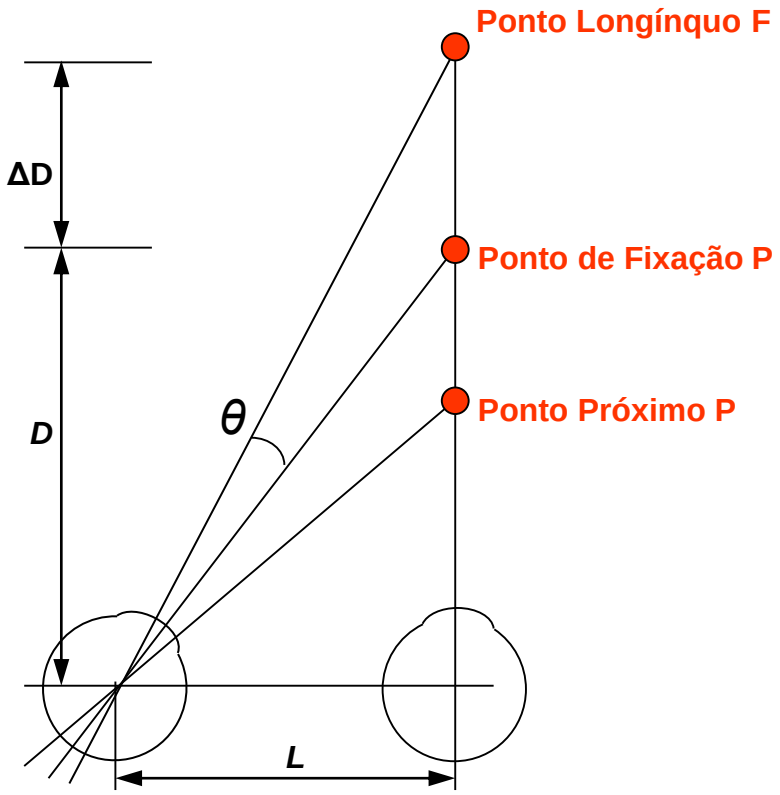


# 4. Visual perception of movement

- Motion Parallax
  - Relationship between objects in the FoV as they move
  - Aids the perception of stereoscopy over long distances
    - At over 500m, the lateral disparity is not enough…
  - Moving the head is a way of producing parallax
    - Good clue for depth perception
    - Works with just one eye
    - It complements the motion parallax

# 4. Visual perception of movement

- Motion Parallax




Resuming the angular separation:

Doing:

$$IPD = L;\ r = D;\ \Delta r = \Delta D$$

$$com\ \ D >> \Delta D$$

We have:

$$\theta \approx L \cdot \frac{\Delta D}{D^2}$$

Finally:

$$\omega = \frac{d\theta}{dt} \approx \frac{L \cdot \Delta D}{D^2 \cdot dt}$$

# 4. Visual perception of movement

- Motion Parallax
  - Previous expression results in low values
  - This suggests that the visual system also compares relative movements between objects
    - Meaning:
      - Motion parallax **provides** information about **direction** and **depth of field** in relation to a fixed point

# 5. Temporal Resolution

- The Retina is an efficient mechanism:
  - Rods:
    - Great sensitivity to low light
    - High latency (habituation...)
    - Slow monochrome exposure
  - Cones:
    - Lower sensitivity to low light
    - Lower latency (faster image changes)
    - Fast Color exposure

# 5. Temporal Resolution

- *Flicker* perception
  - **CFF – Critical Flicker Frequency**
  - It is defined as the frequency at which an **intermittent light appears** to be **steady** to the human **eye**
    - Is affected by:
      - Display brightness
      - Field of View
      - Image position at the retina

        (reduces outside the fovea, influenced by the rods)
    - Ferry-Porter Law:
      - States that the CFF is directly proportional to the logarithm of the light intensity

# 6. Spatial Resolution

- Is a term that refers to the number of pixels that are used to construct a digital image
  - The **matrix** structure **influences perception**
  - But it is **not the pixel resolution**
  - It refers to the ability to differentiate two objects

- Evaluations:
  - PSF – Point Spread Function:
    - Function that represents the blurring
  - MTF – Modulation Transfer Function:
    - Describes how well the display/optical system reproduces the frequency components of a point or line in the image
    - Frequency components are expressed in cycles per millimeter or (at a fixed distance) in cycles per degree of visual angle

# 6. Spatial Resolution

Image at left has a higher *pixel count* than the one to the right, but is still of worse spatial resolution.

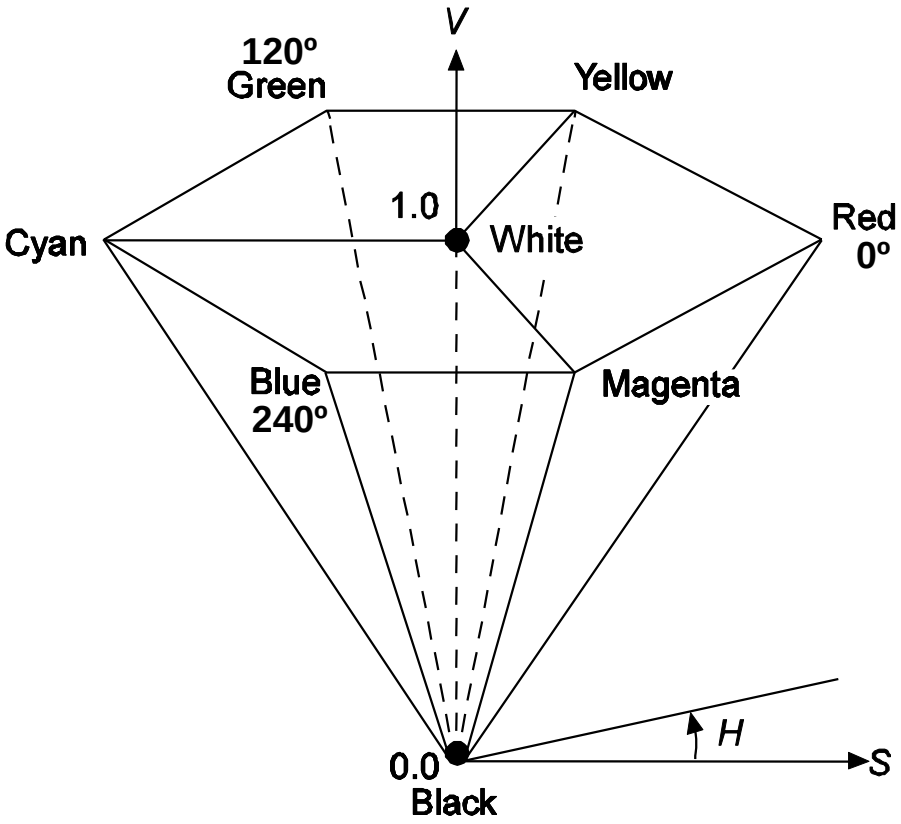
https://en.wikipedia.org/wiki/Image_resolution#Spatial_resolution

# 7. Perception of the Visual Space

- Space Perception: Depth
  - Binocular Disparity: already seen...
  - Interposion of another objects:
    - “z is beyond x with y in the middle”
  - Motion Parallax:
    - Probably the most powerfull clue
  - Perspective:
    - The relative difference in object dimensions
- Important: Scale consistency
  - Keep the objects scale consistent to each other

# 8. Color Perception

- Color Attributes:
  - Hue:
    Color description by name
  - Saturation:
    Color purity (white = impure)
  - Brightness/Intensity:
    from black to “maximum” color



# 8. Color Perception

- Response types
  - Achromatic response:
    - Light without dispersing into its constituent colors
    - Behavior covering a wide range of wavelengths
    - Hence the term “white light response”

  - Monochromatic response:
    - Behavior over a narrow range of wavelengths (e.g. red)
    - Wrong to talk about “black and white”

# 8. Color Perception

- Complexity:
  - The color of an object is a set of components with different wavelengths.
  - Two objects can look like they have the same color...
    - But they have different spectral components
    - They are influences by the color of the light
      - With compensation
  - Two individuals may have very different perceptions
    - Responsability of the cones (400nm to 700nm)
    - Photoreceptors with different spectral absorption characteristics

# 8. Color Perception

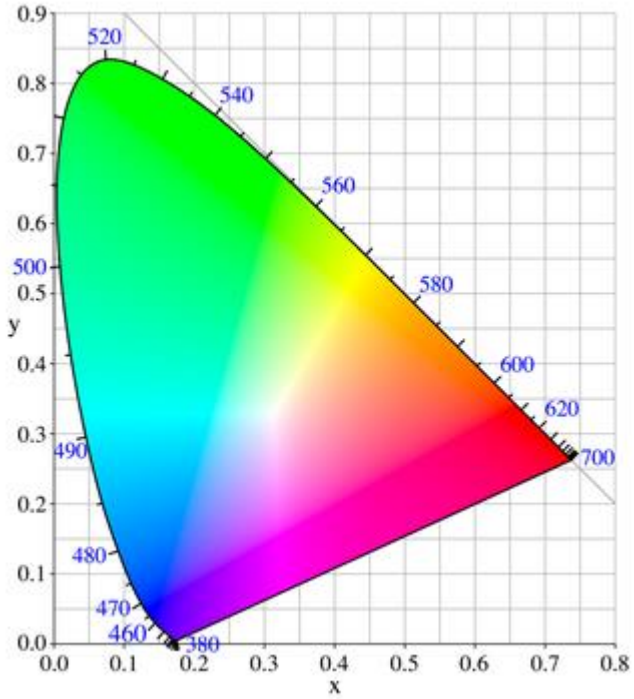
- Color perception dependencies
  - Chromatic adaptation
    - The ability to adjust to changes in illumination and preserve the object colors
    - White background / colors above 490 nm (warm colors)
      - Chromatic detection deteriorates
    - White background / colors below 490 nm (cold colors)
      - Chromatic detection improves

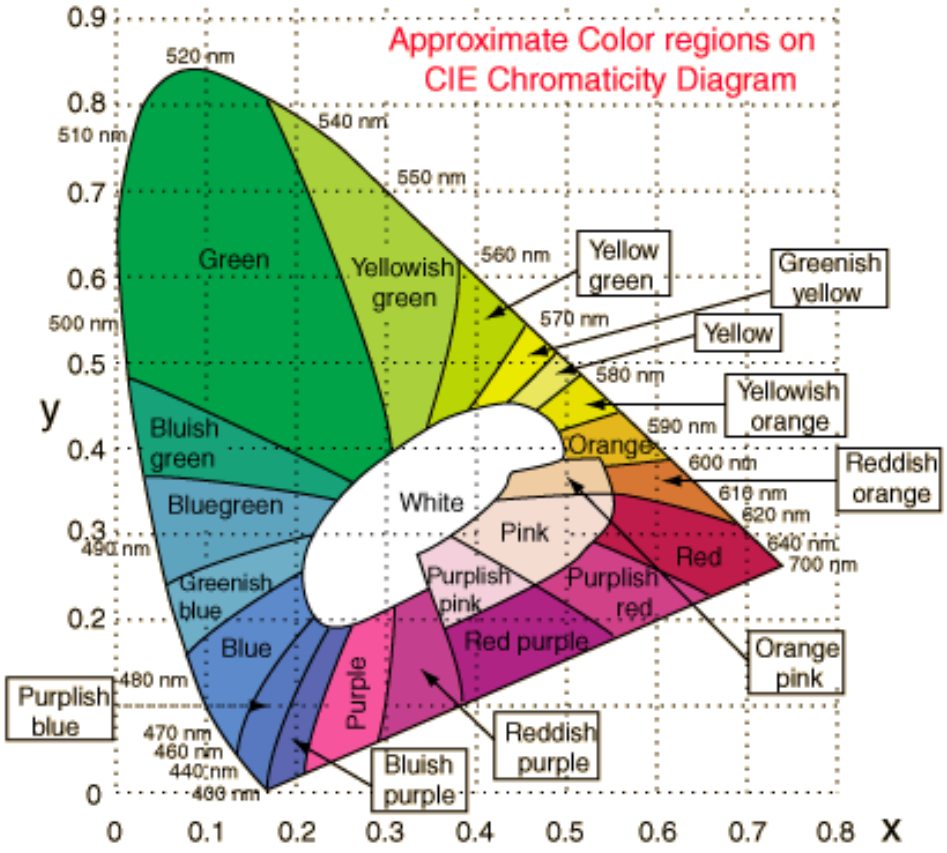
# 8. Color Perception

- Color perception dependencies (continuation)
  - Luminance (cones…)
    - **Perception reduces** significantly when **Lumin decreases** (< 3.5 cd/m$^{2)}$
    - Noticeable color only above 0.001 cd/m2
  - Retinal position
    - At **Fovea** the **colors** are more **saturated**
  - Duration of exposure
    - More time, better perception of color...

# 8. Color Perception

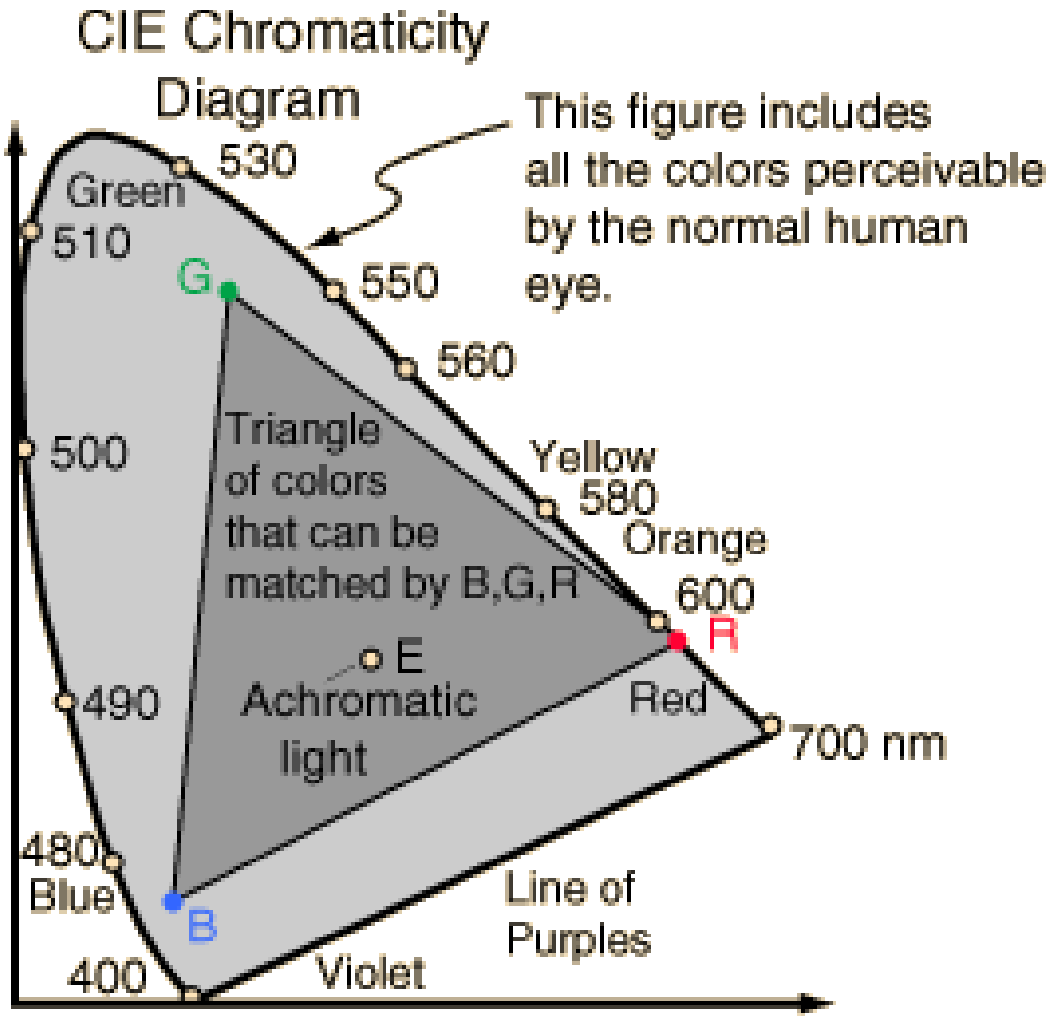
**CIE** specification accurately **represent** every single **color** the human eye can perceive



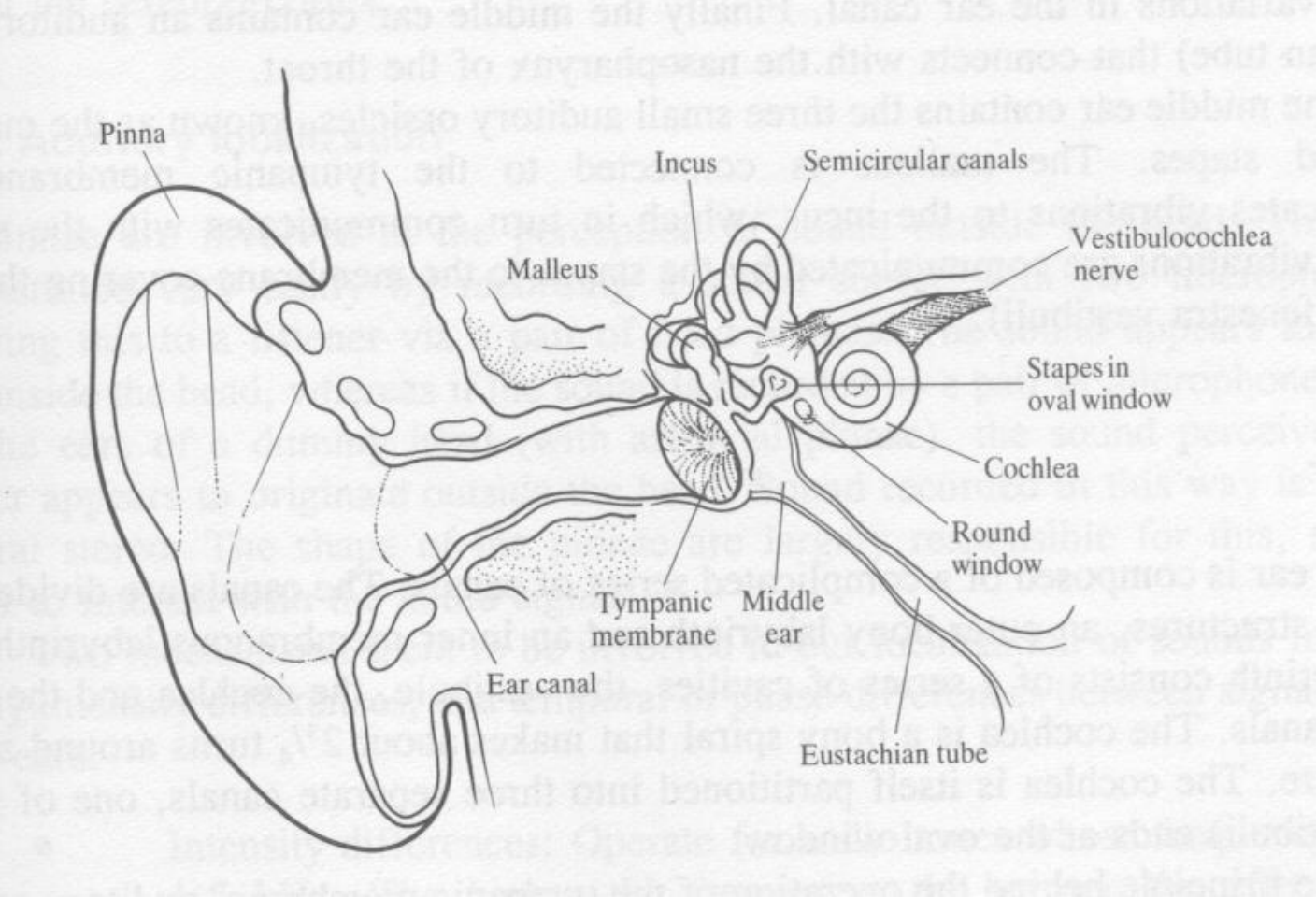




http://hyperphysics.phy-astr.gsu.edu/hbase/vision/cie.html

# 8. Color Perception



# Auditory Perception



# 1. Hearing Location

- Two mechanisms
  - Intensity differences
    - Audio masking
      - From: audio noise or reflections from the original source
      - Works above 1.5KHz frequency
  - Time differences
    - 650ms is enough for precise location

# 1. Hearing Location

- Echo/Reverb
  - The same sound reaches the ears:
    - After countless reflections
    - From various directions
    - The auditory system “isolates” the first one that is detected
      - (within small time differences)

# 1. Hearing Location

- Greater accuracy in continuous sounds
  - Hiss: higher accuracy
  - Click: lower accuracy
- Head movement
  - Search for “best position”

# 3. Frequency Analysis

- Frequency distinction (Ohm Acoustic Law)
  - Frequencies that compose a sound must be minimally separated
    - Otherwise, they will be perceived as a single component

-> The ear works like a series of narrow filters

# 4. Tone Detection

- 20-64Hz Zone
  - Barely noticeable
- 1-5KHz Zone
  - Most sensitive
- 16-20KHz Zone
  - Very poor discrimination...

# Touch and Strength Perception

1. Skin Sensitivity / Touch
2. Skin Anatomy
3. Kinasthesia

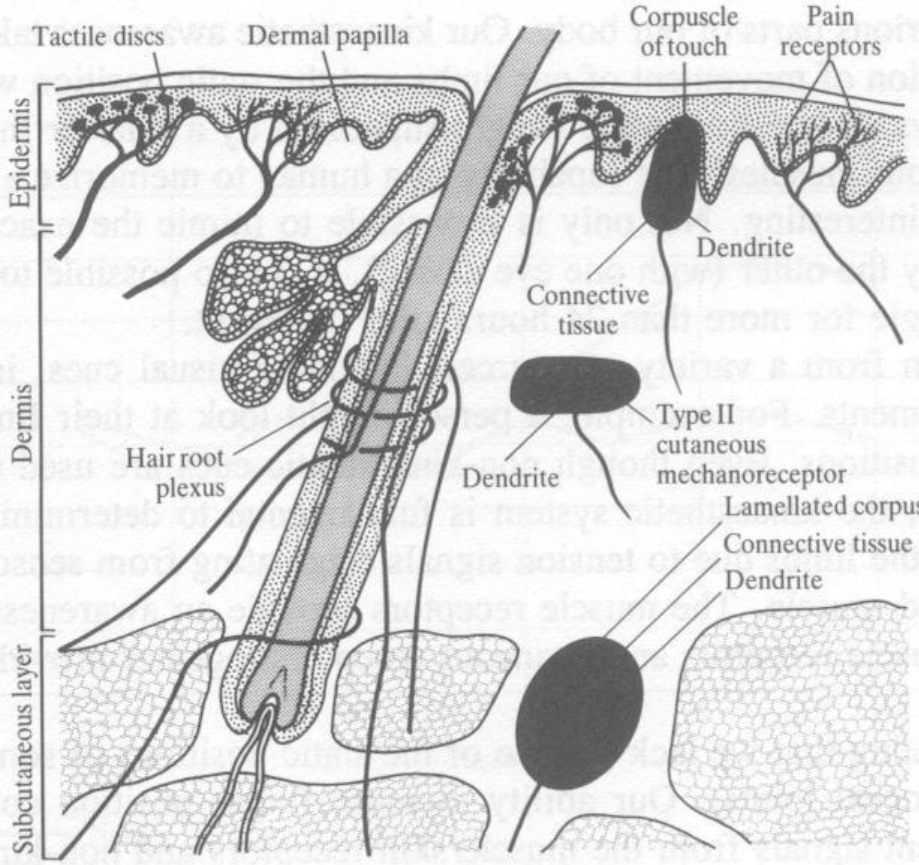
# 1. Skin Sensitivity / Touch

- Mechanical contact with the skin ...
  - Contact, vibration, rough sense, pressure, etc ...
  - Temperature is not tact but it is hard to distinguish
- Sensitivity depends, among other causes, on skin location

# 2. Tact

- Types of mechanical stimuli
  - Step
    - Displacement of the skin over an extended time period
  - Impulse
    - Quick displacement of the skin (~ ms)
  - Periodical
    - An Impulse that repeats regularly

# 2. Skin Anatomy




- Root Hair Plexus
  - Body **surface movements**
- Nerve endings
  - **Pain, continuous contact**
- Corpuscles of touch (by Meissner)
  - More **numerous** on **fingertips** and **palms**
  - High sensitive **discriminatory tact**
- Tactile discs (by Merkel)
  - **Aids** the **discriminatory tact**
- Type II Mechanoreceptors
  - **Deep in the dermis**
  - They **detect heavy** and **continuous touch** sensations
- …

# 3. *Kinaesthesia*

- Ability to **recognize** our own body:
  - **Movements**
  - **Relative positions of various parts**
    - The “amount” of movement
    - And direction of movement

# 3. *Kinasthesia*

- Information comes from various sources
  - Mechanoreceptors are really important in this context
  - Visual Clues
  - Fingers: no position is detected, but the movement is (relative position)