CIS 4930-001: Introduction to Augmented and Virtual Reality

Human Perception

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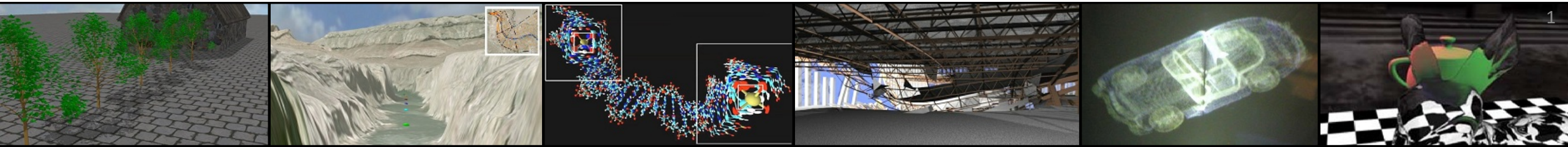
Some slides from: Anders Backman, Mark Billinghurst, Doug Bowman, David Johnson, Gun Lee, Ivan Poupyrev, Bruce Thomas, Geb Thomas, Anna Yershova, Stefanie Zollman



How do We Perceive Reality?

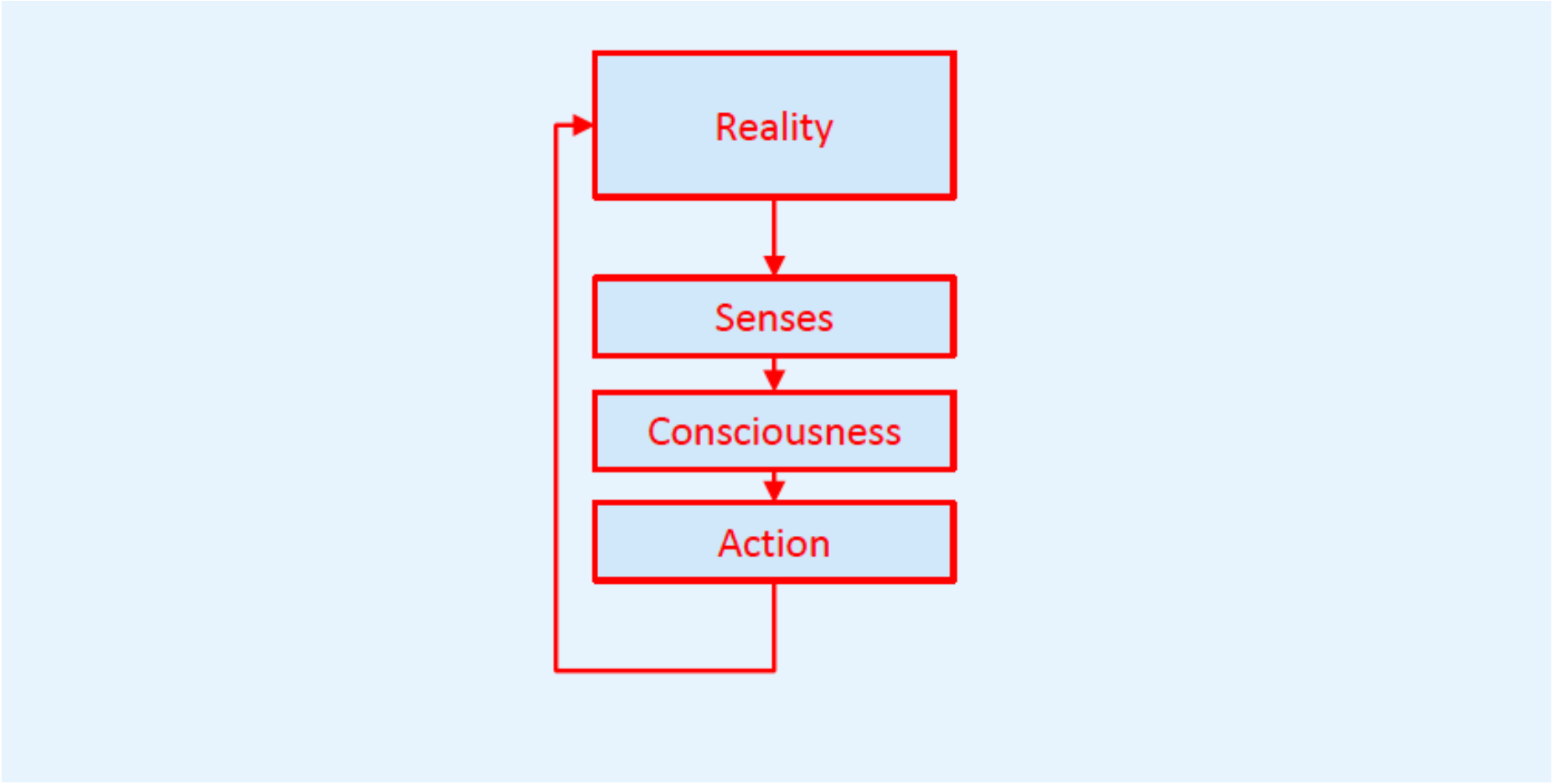
We understand the world through our senses:

- Sight, Hearing, Touch, Taste, Smell (and others..)

Two basic processes:

- Sensation – Gathering information
- Perception – Interpreting information

Simple Sensing/Perception Model



Goal of Virtual Reality

".. to make it feel like you're actually in a place that you are not."

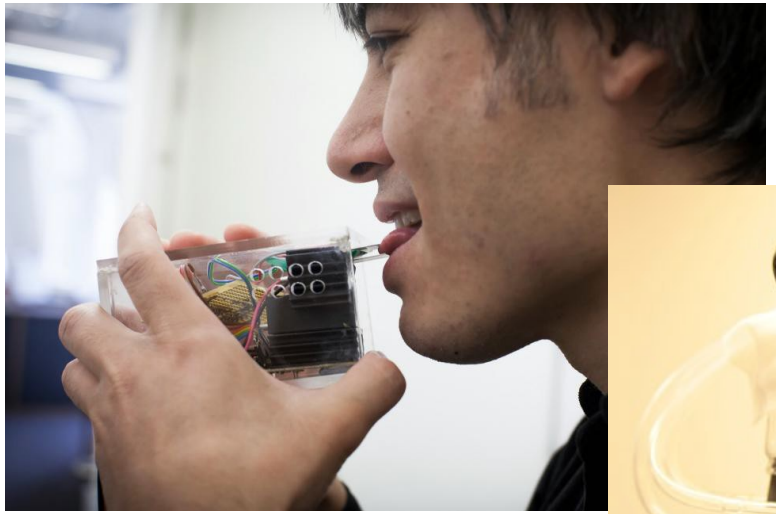
Palmer Luckey

Co-founder, Oculus

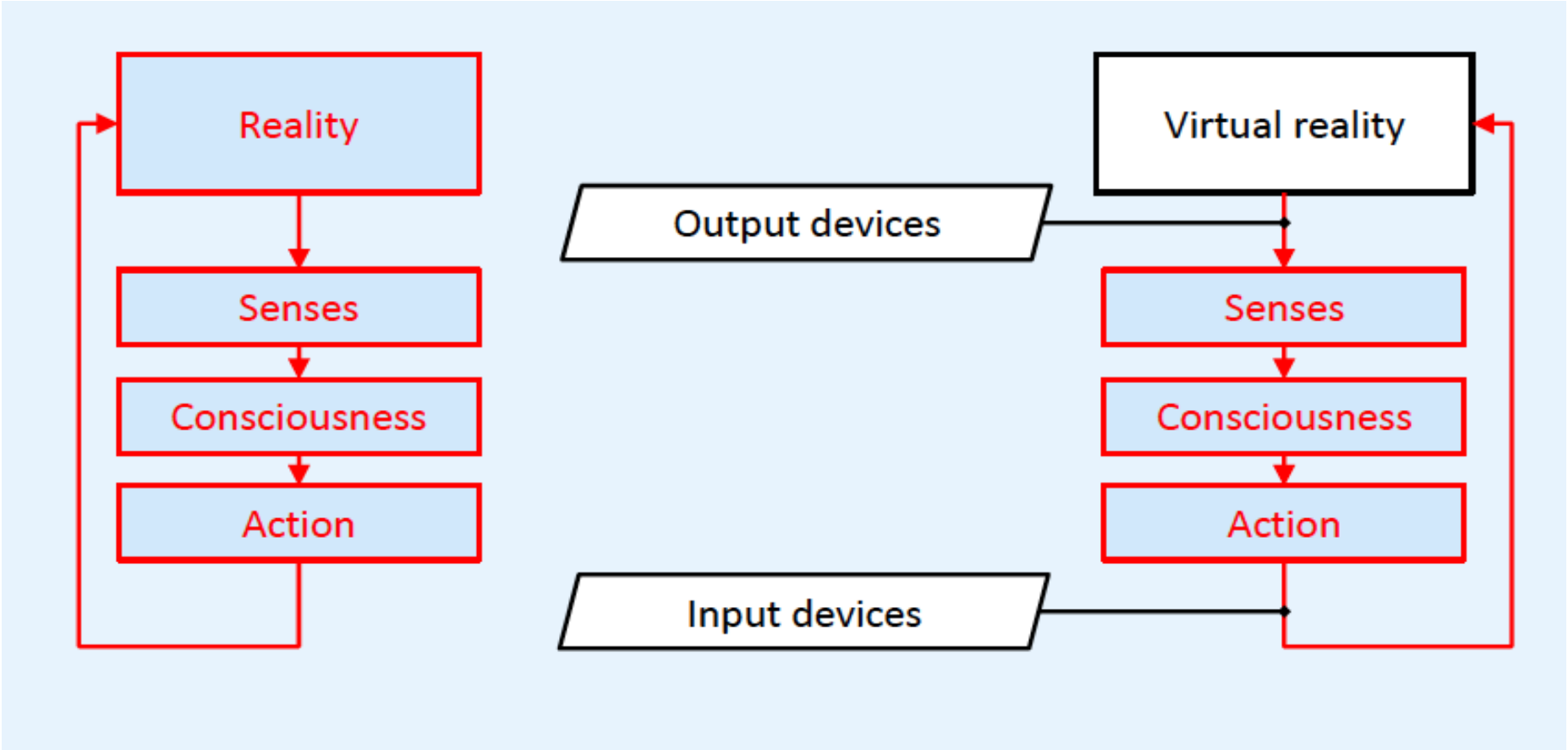
Creating the Illusion of Reality

Fooling human perception by using technology to generate artificial sensations

- Computer generated sights, sounds, smell, etc.



REALITY VS. VIRTUAL REALITY



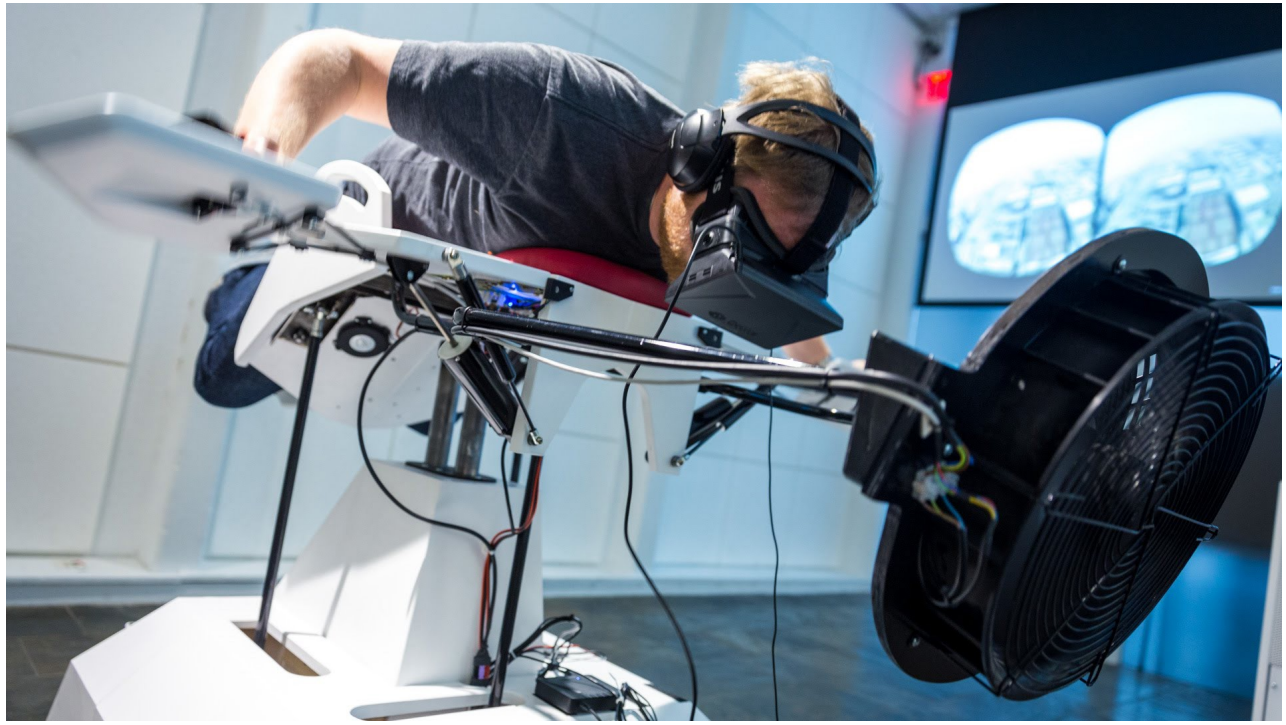
In a VR system there are input and output devices between human perception and action

Example Birdly

Create illusion of flying like a bird

Multisensory VR experience

- Visual, audio, wind, haptic

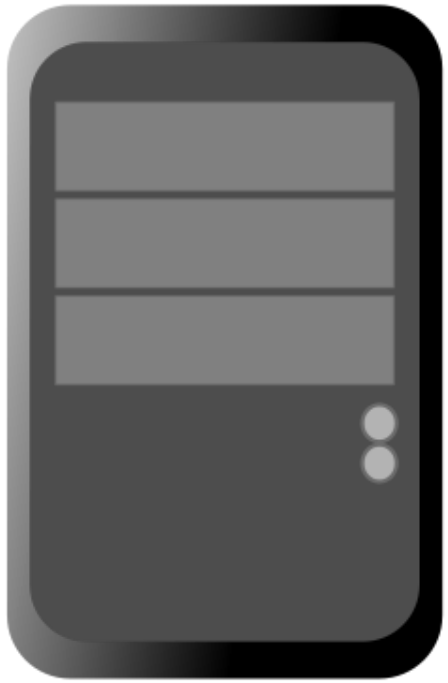


Birdly Demo

https://youtu.be/gHE6H62GHoM

Simulation

Understanding



Software

Hardware

Us

Visual Bandwidth

Bandwidth of vision is probably greater than other sensory modalities

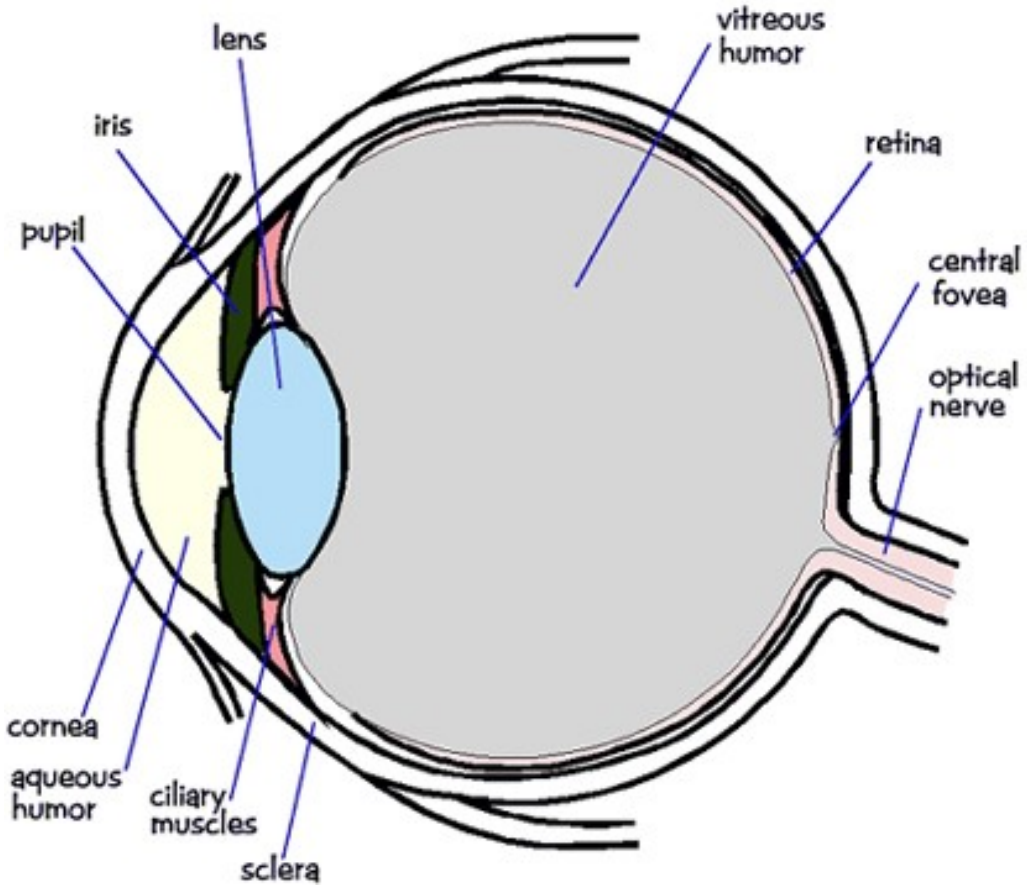
- Retina bandwidth ~10 Mbits/sec
- Most important sense for VR?
  - IMAX movie of rollercoaster can induce sensation of motion
  - Images can induce sensations of taste/smell

Why Study Basis of Vision?

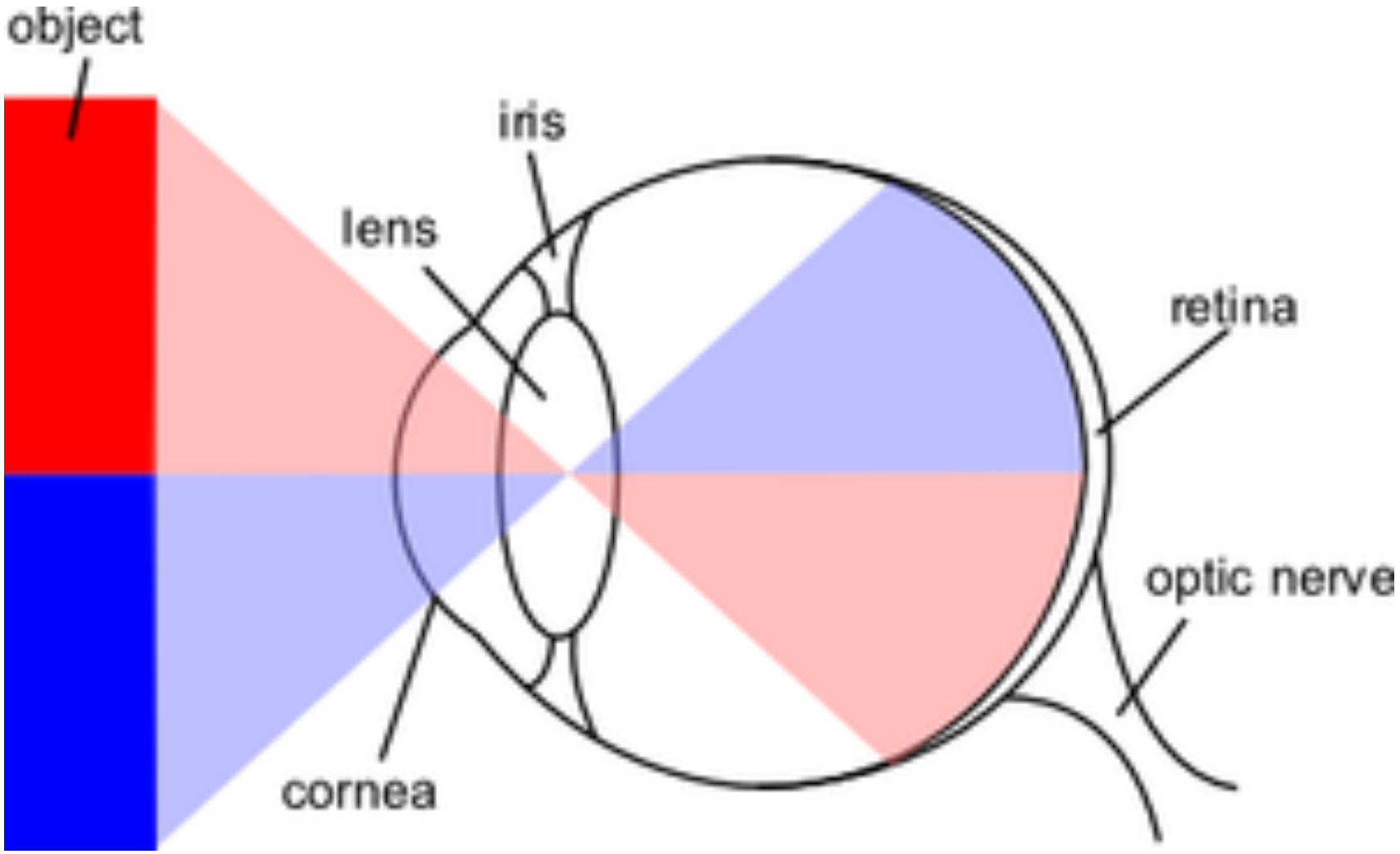
If a display can match human capabilities, we are done

If the display can't, nice to know where to concentrate resources.

Anatomy of Vision



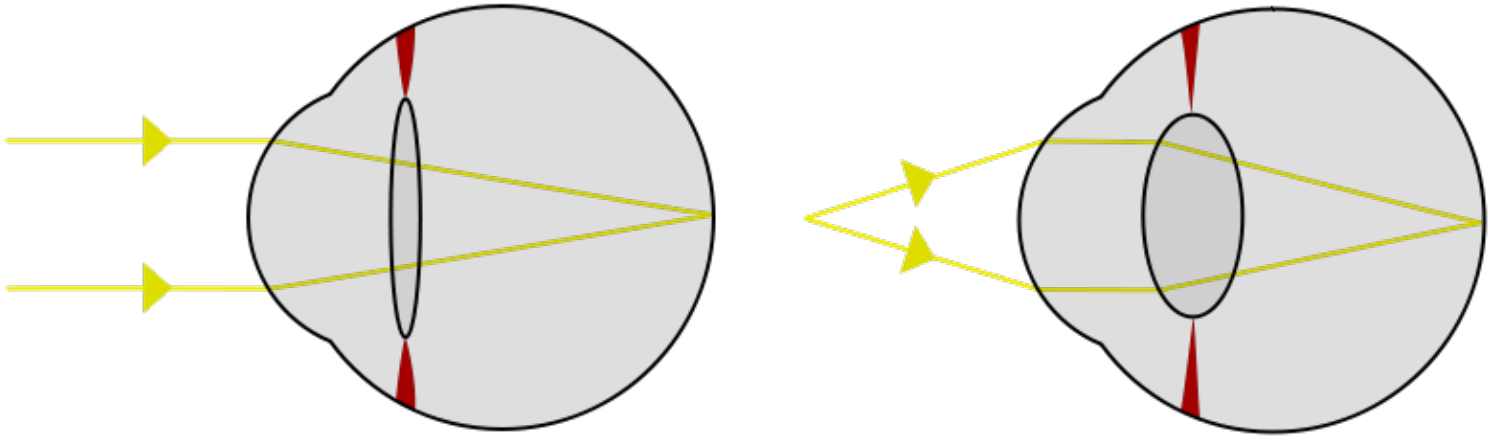
Eye Optics



ACCOMMODATION

Change in curvature of lens

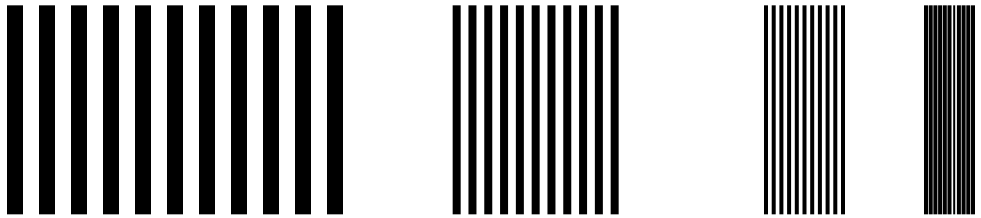
- Rest focus from 6m to infinity



VISUAL ACUITY

Cycles per degree (similar to angular resolution)

- Humans can resolve 0.93mm spacing at 1m



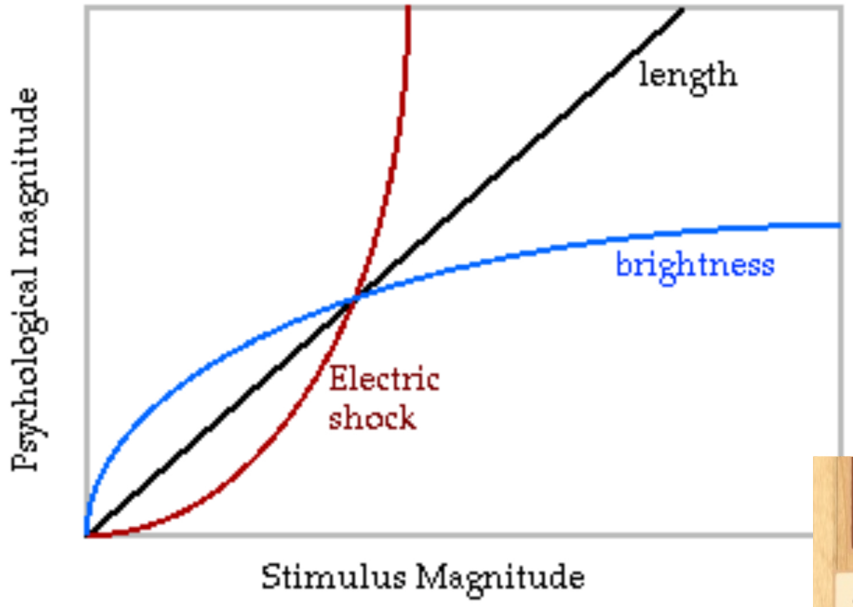
Fovea is about 1 Mpixel

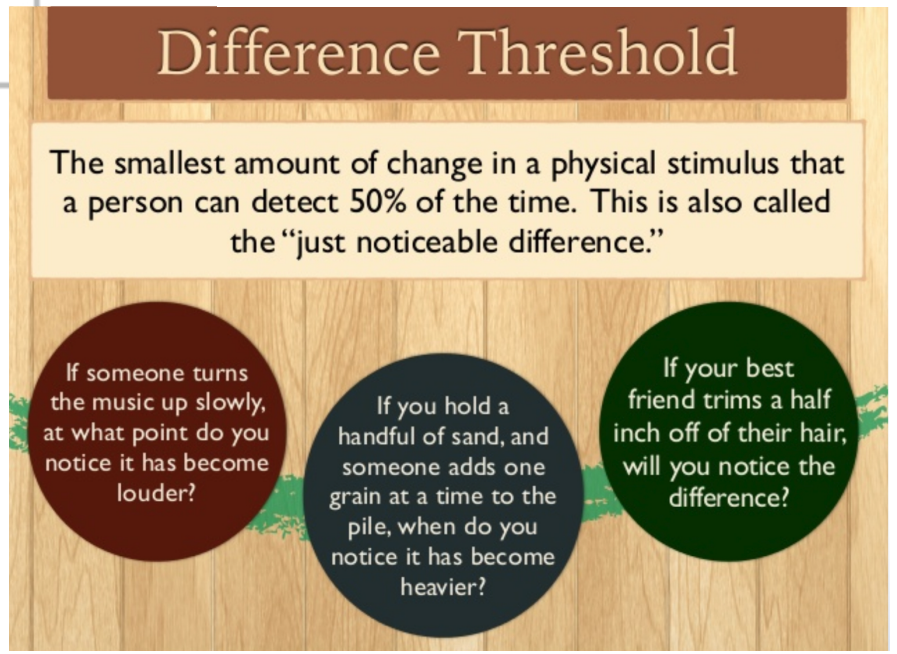
- 1 arc minute at fovea (1/60 degree)
  - 20/20 vision letters are 5 arc minute letters (strokes 1 arc minute)
- Around 24K x 24K over field of view

Retina is (dynamically) sensitive to light levels over 10^13 range

PSYCHOPHYSICS

Stevens' Power Law





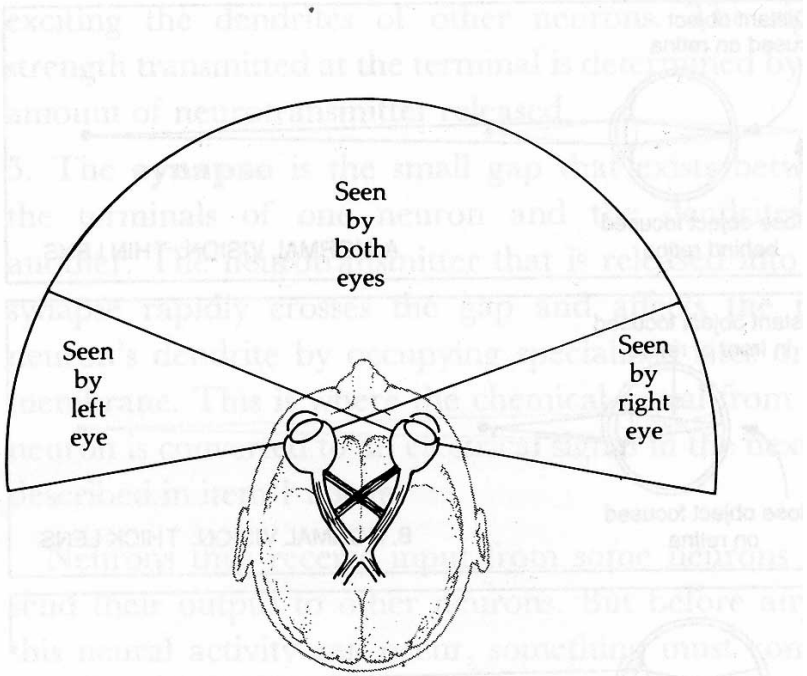
Visual Field

Monocular (one eye)

- 120° vertically and 150° horizontally
  - 60° to nose; 90° to side
  - 50° up; 70° down

Binocular (both eyes)

- 200° horizontal
- Eye can rotate about 50°
- Humans have 120° binocular overlap
- 2 x 40° monocular regions

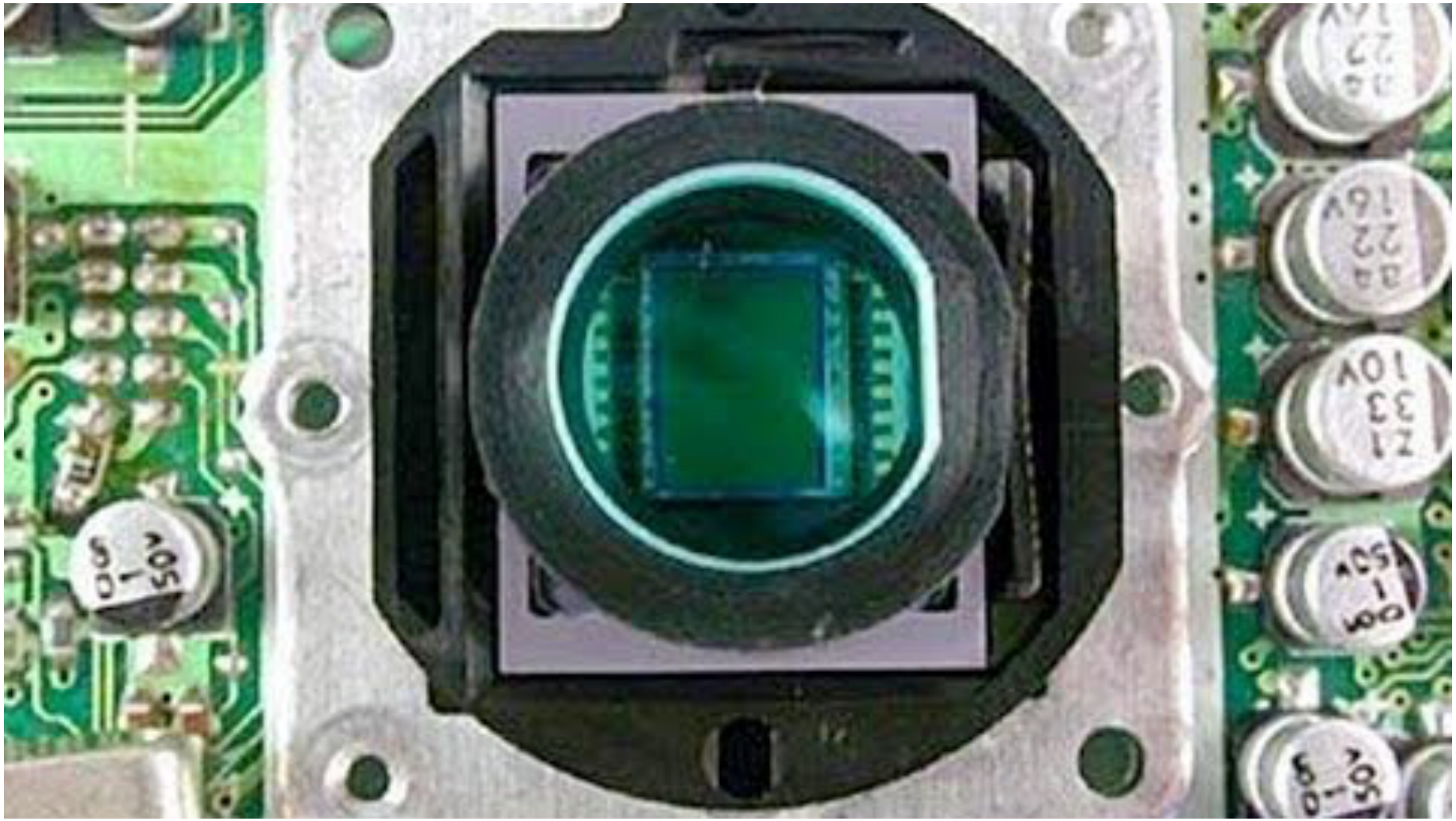


Frame rate

60Hz frame rate is generally considered important

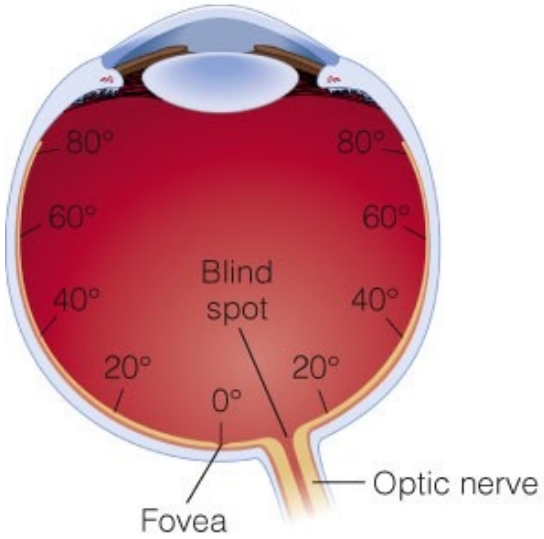
Old video games & movies at low rates but people weren't sensitized to it

FRAME RATE



https://youtu.be/buSaywCF6E8

BLIND SPOT



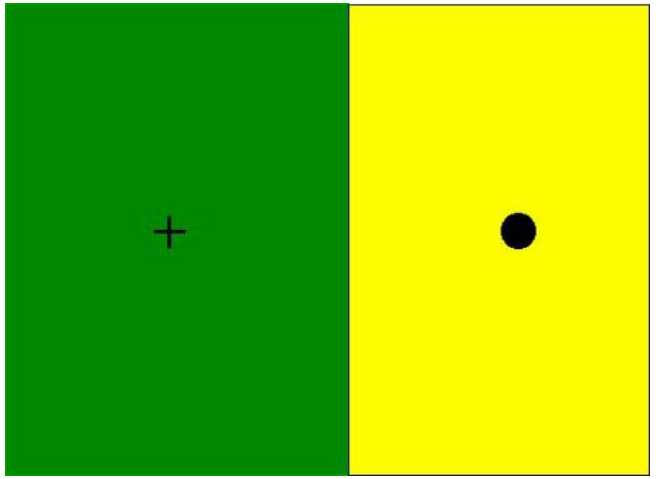
+ ●

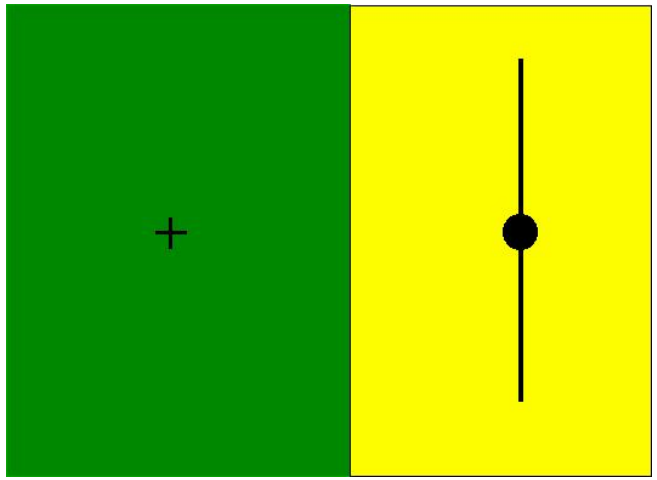
Close **left** eye

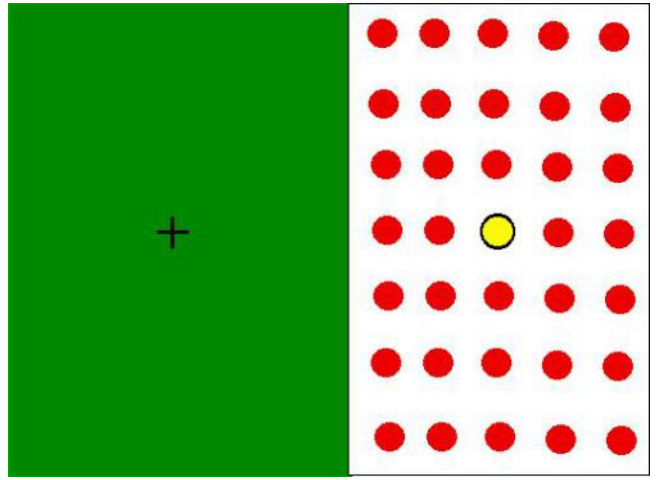
Stair at **+**

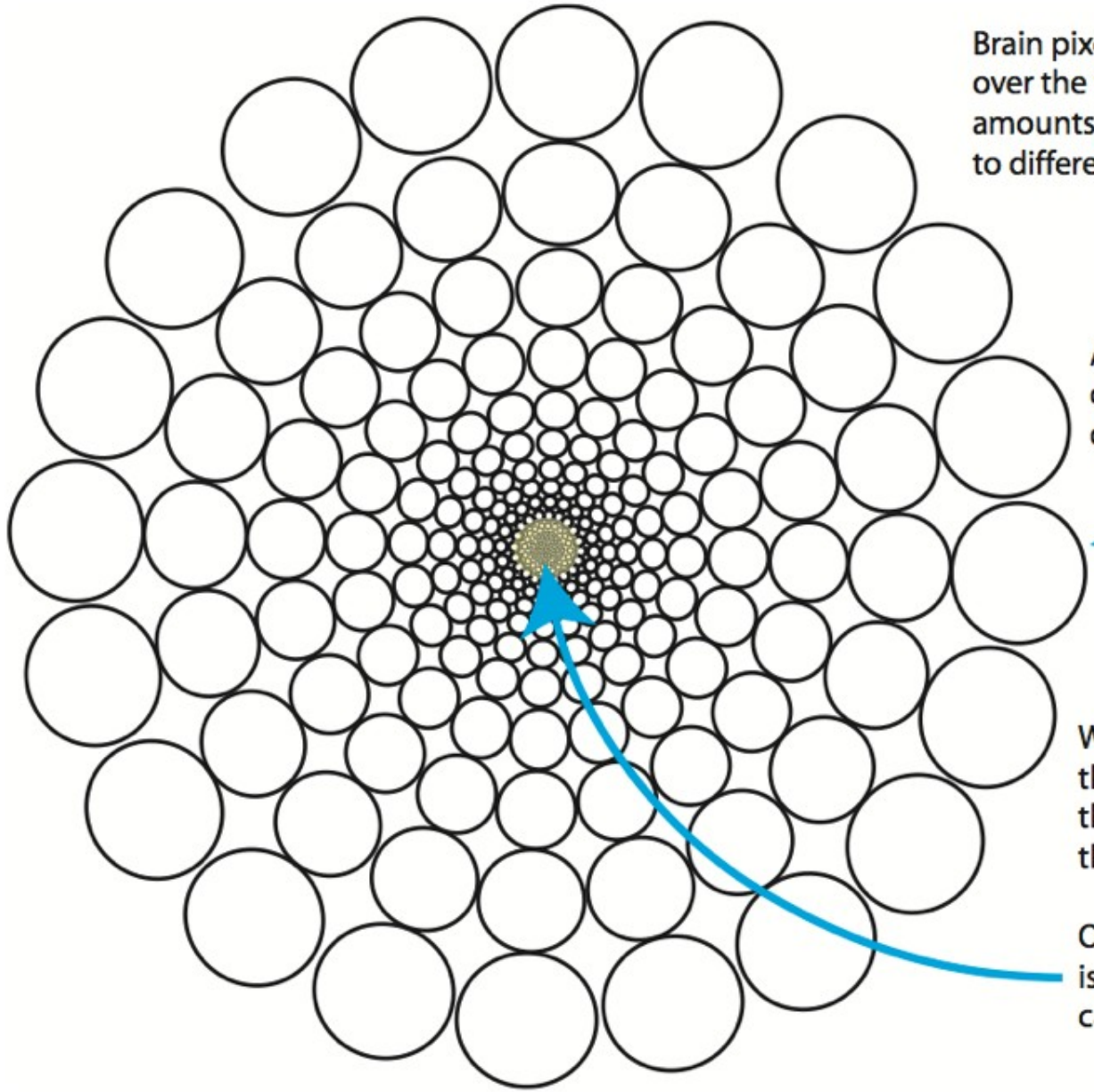
Move forward and backward until ● disappears

BLIND SPOT









Brain pixels vary enormously in size over the visual field. This reflects differing amounts of neural processing power devoted to different regions of visual space.

At the edge of the visual field we can only barely see something the size of a fist at arm's length.

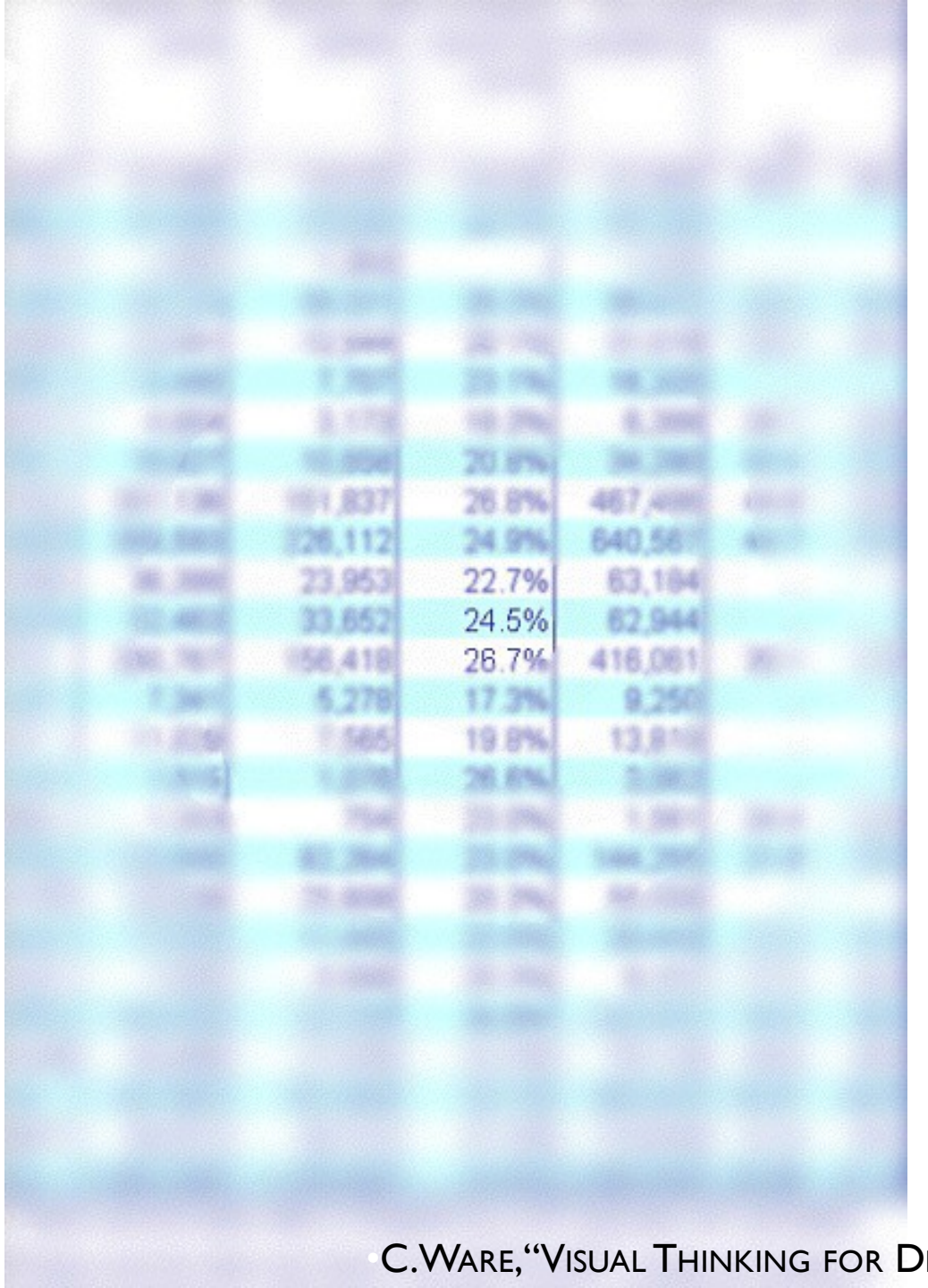
We can resolve about 100 points on the head of a pin held at arm's length in the very center of the visual field called the fovea.

Over half of our visual processing power is concentrated in a slightly larger area called the parafovea.

FOVEATION IS RELATIVELY EASY TO SEE

The key to recognizing the phenomenon is to *stair at a single word* on the printed page.

Then, without moving your gaze, note the blurriness of the surrounding text.



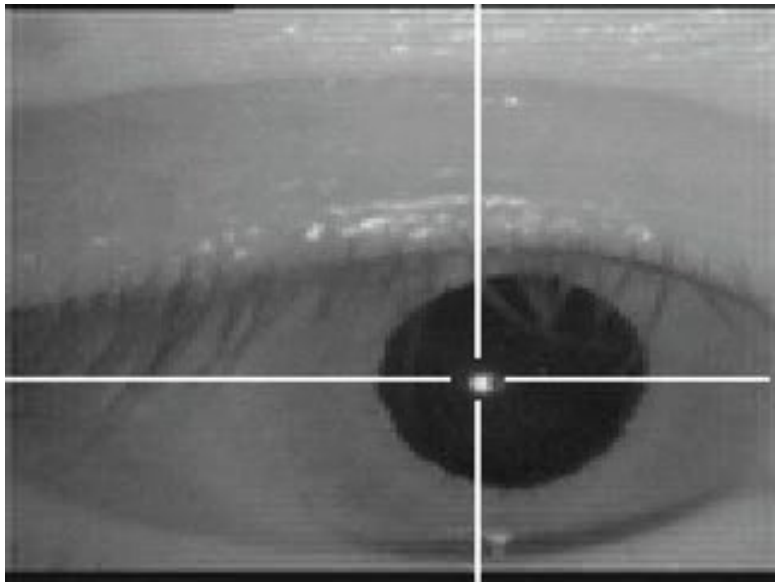
C. WARE, "VISUAL THINKING FOR DESIGN"

SACCADIC EYE MOVEMENTS

rapid involuntary eye movements

moving: 20-100 ms

fixations: 200-600 ms



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Other Eye Motion

Vergence - the motion of the eye to maintain binocular vision

- 'Cross-eyed' when focus in close

Version – eye movement in the same direction

Duction – motion of one eye

Eye makes compensatory motions when head moving

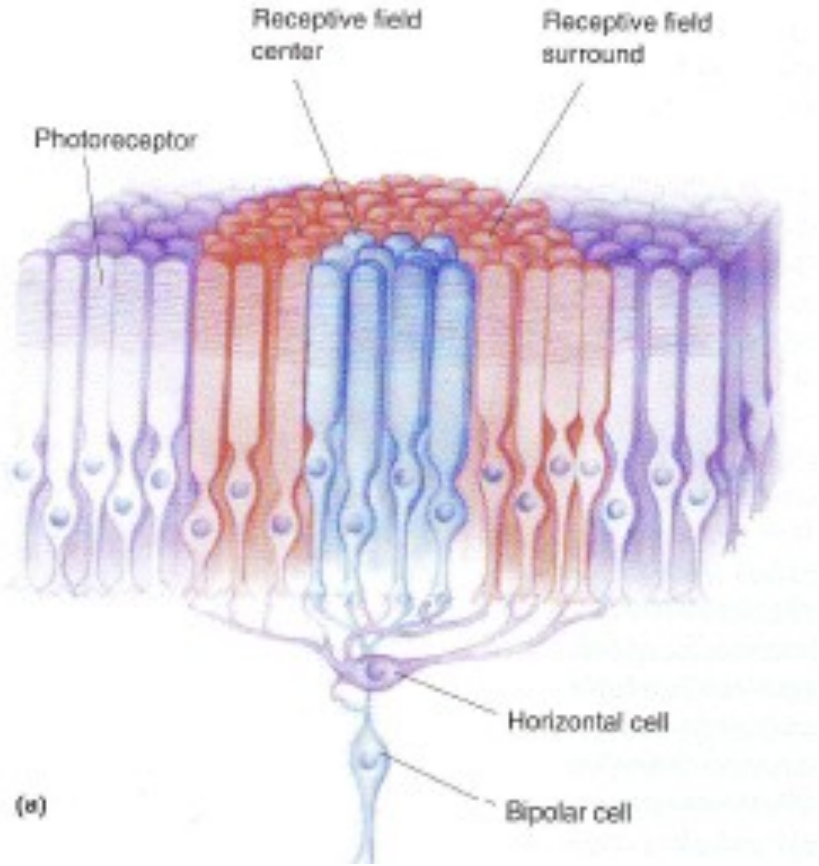
- Shake hand vs. shake head

Saccades – eye movement to use fovea more

Microsaccades – imperceptible motions to maintain excitation of rods and cones

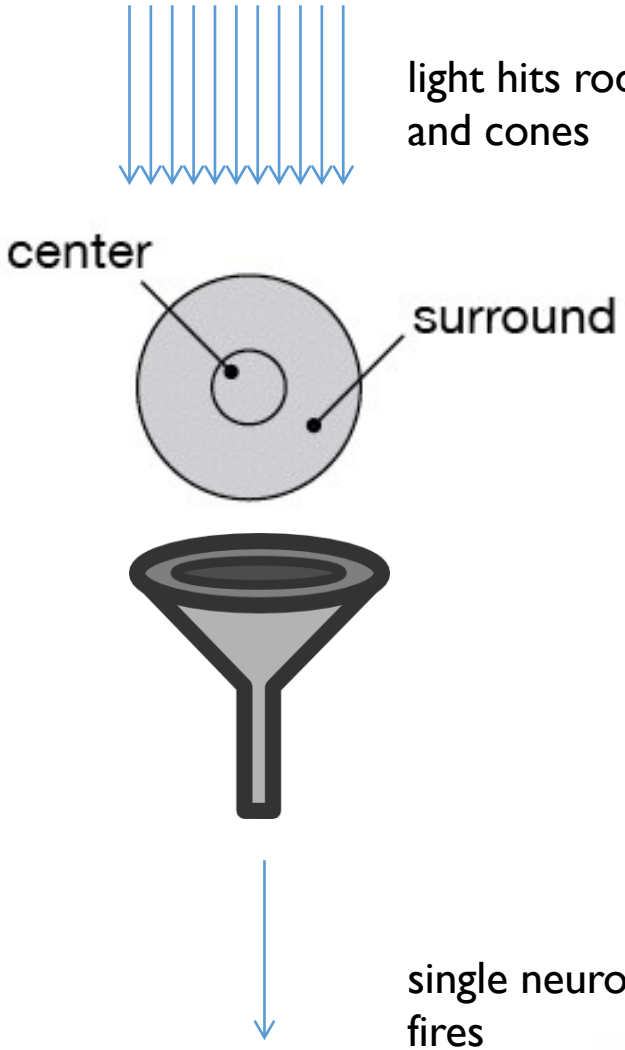
EDGE DETECTION

RECEPTIVE FIELD

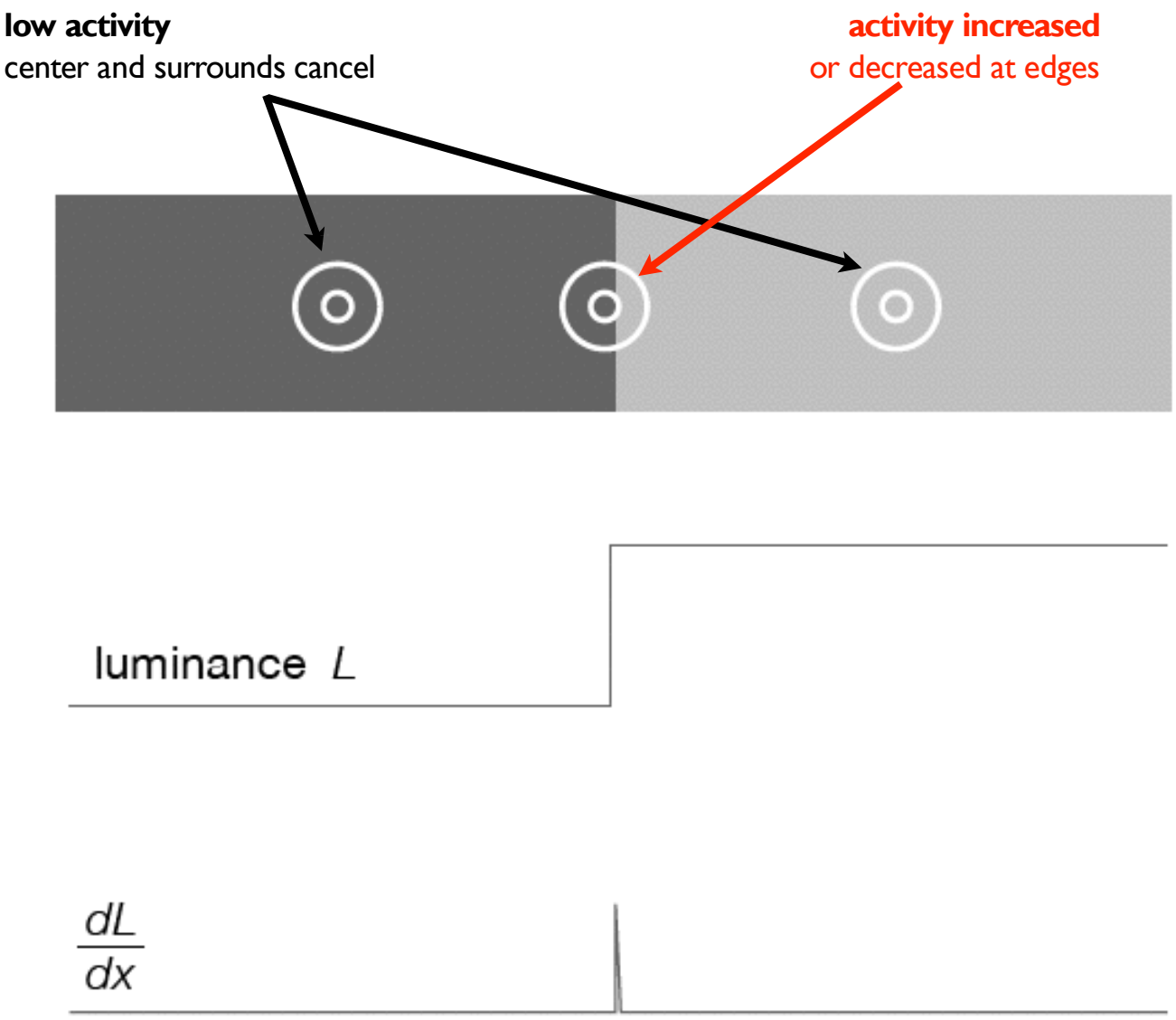


100M rods and cones

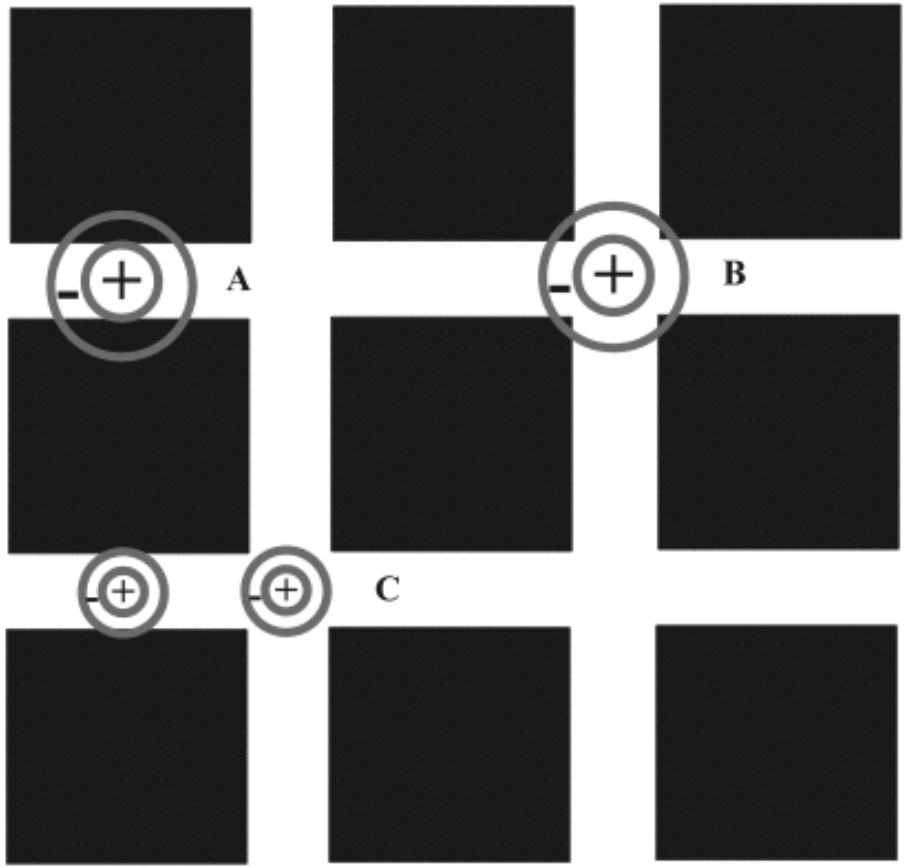
1M ganglion cells

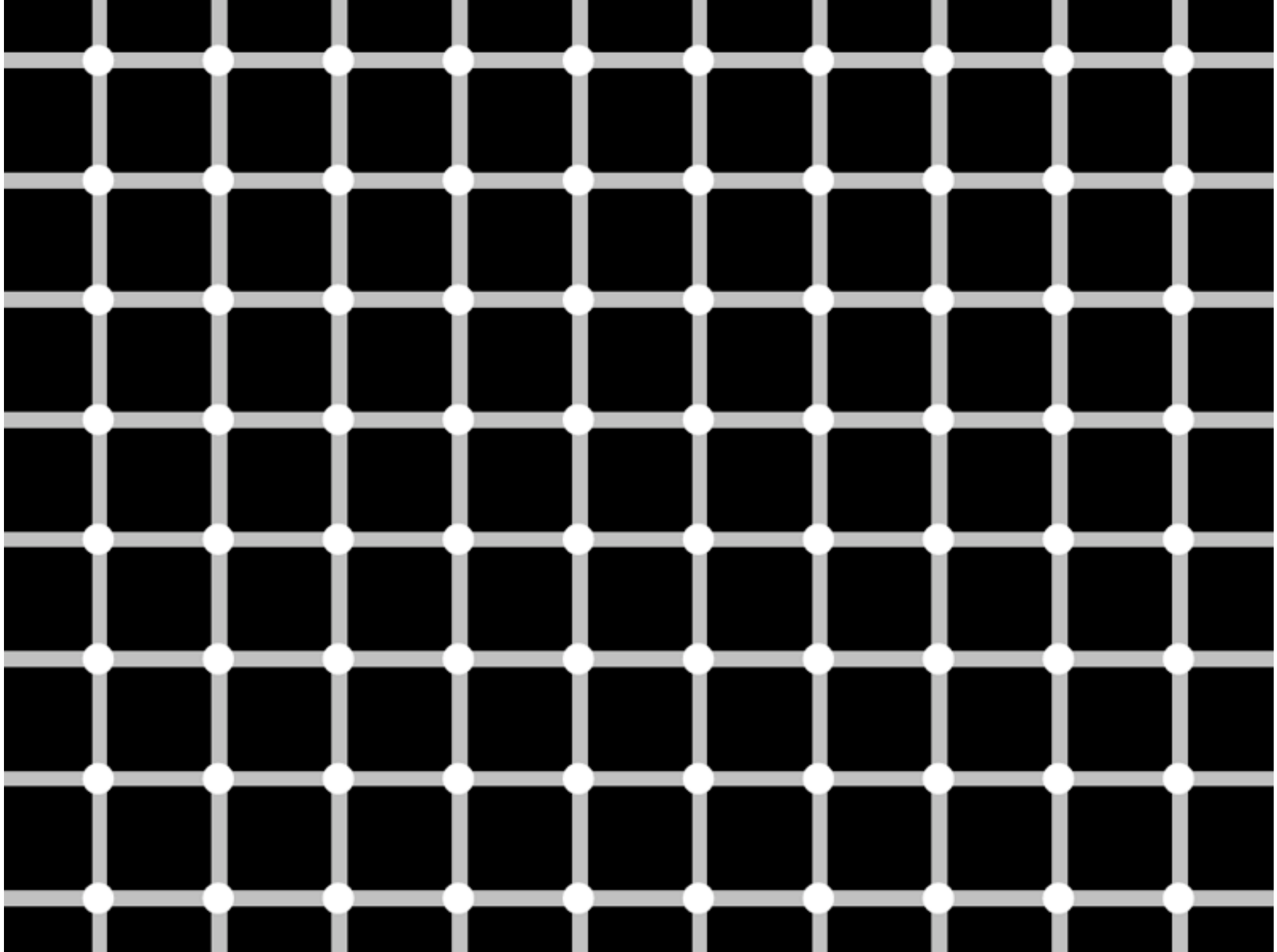


BEAR, CONNORS, PARADISO, "NEUROSCIENCE"


low activity
center and surrounds cancel
activity increased
or decreased at edges
luminance L
dL
dx

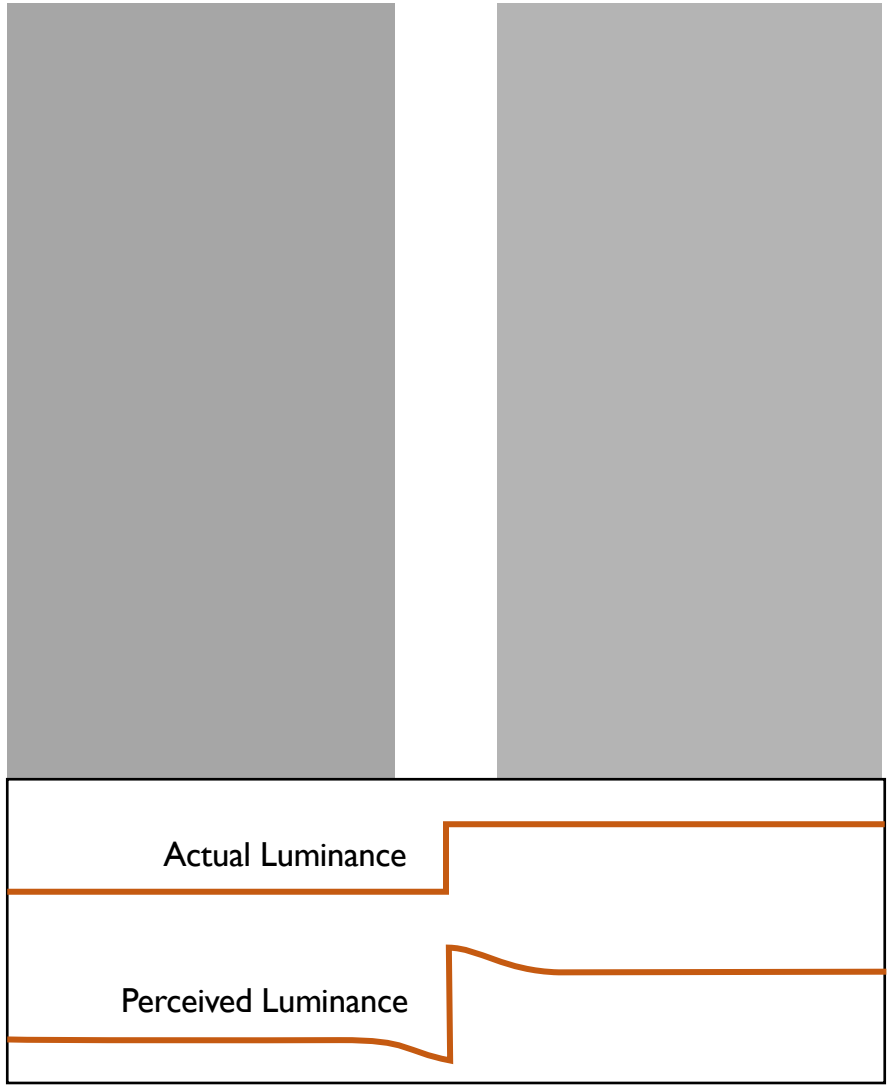
HERMANN GRID EFFECT





CONSEQUENCES OF EDGE EXTRACTION

Cornsweet Illusion



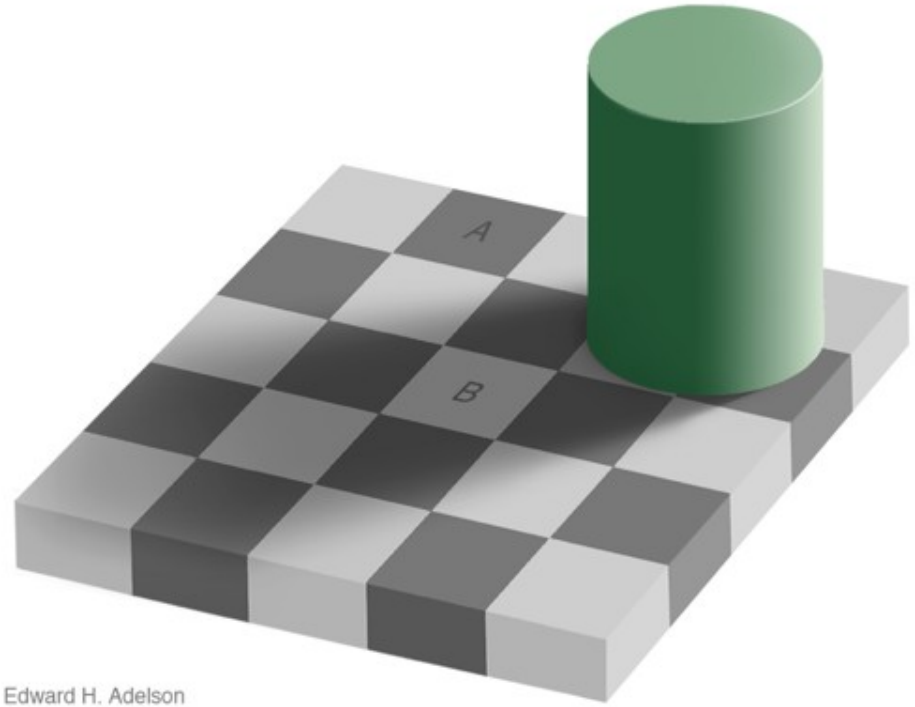
Cornsweet Illusion

D. Purves and R. B. Lotto

Mach Banding

SIMULTANEOUS CONTRAST

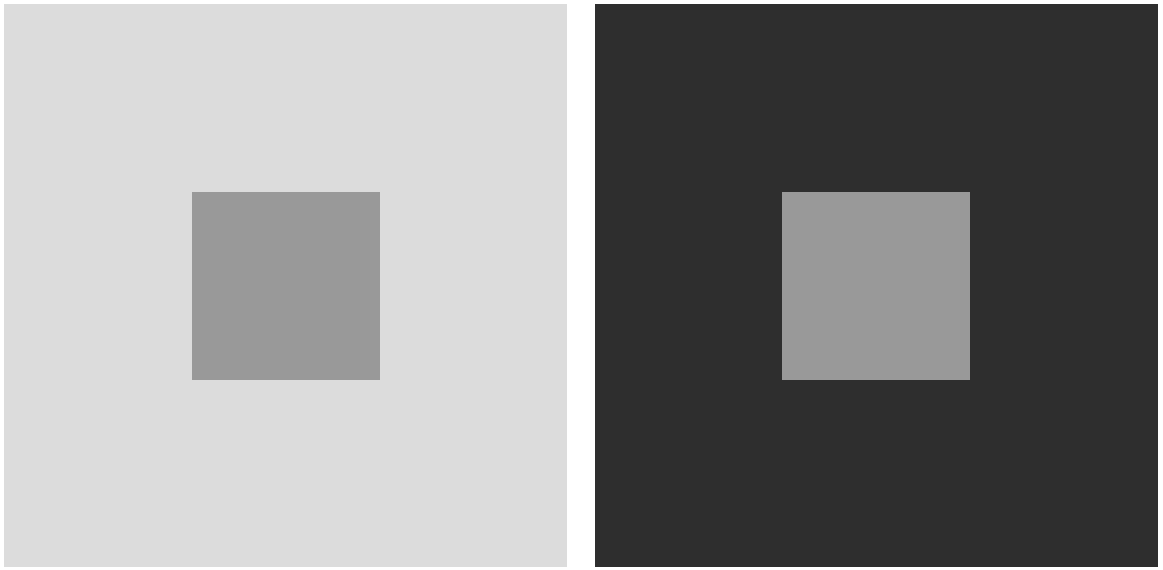
SIMULTANEOUS CONTRAST



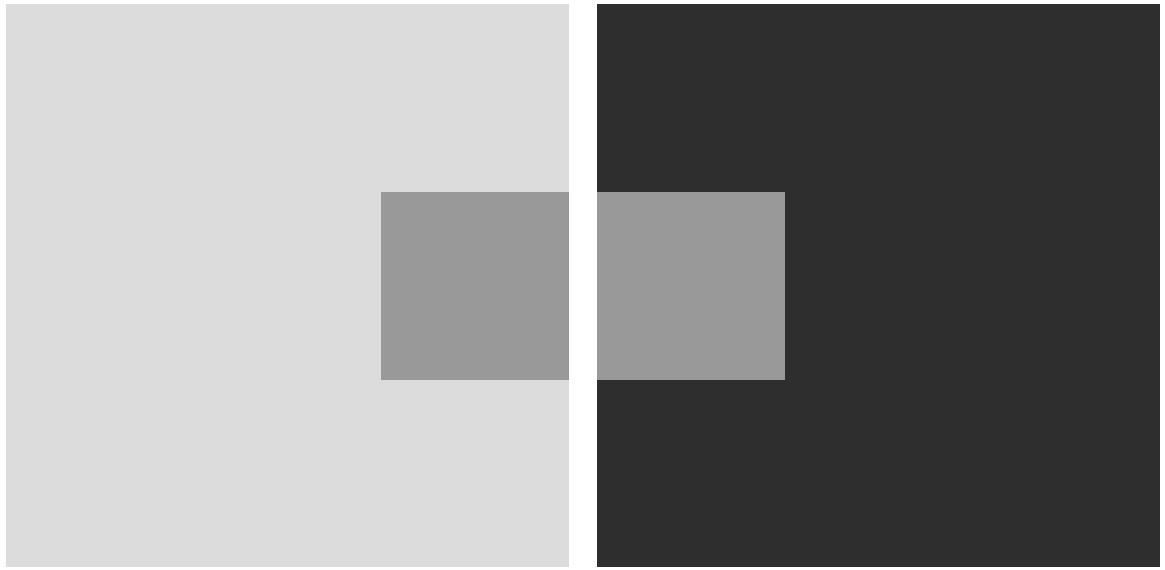
Edward H. Adelson

HTTP://PERSCI.MIT.EDU/_MEDIA/GALLERY/CHECKERSHADOW_DOUBLE_FULL.JPG

SIMULTANEOUS CONTRAST

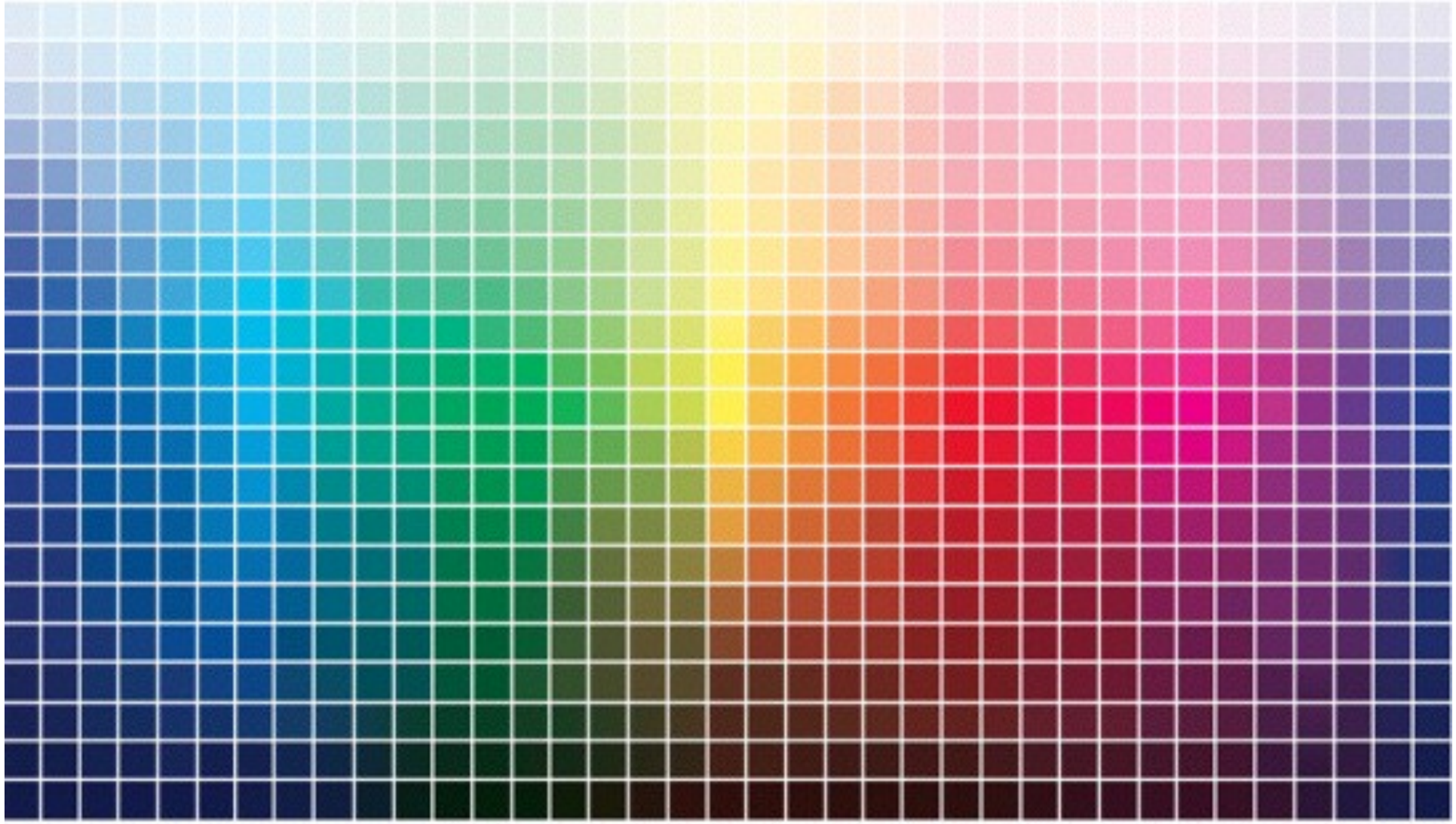


SIMULTANEOUS CONTRAST

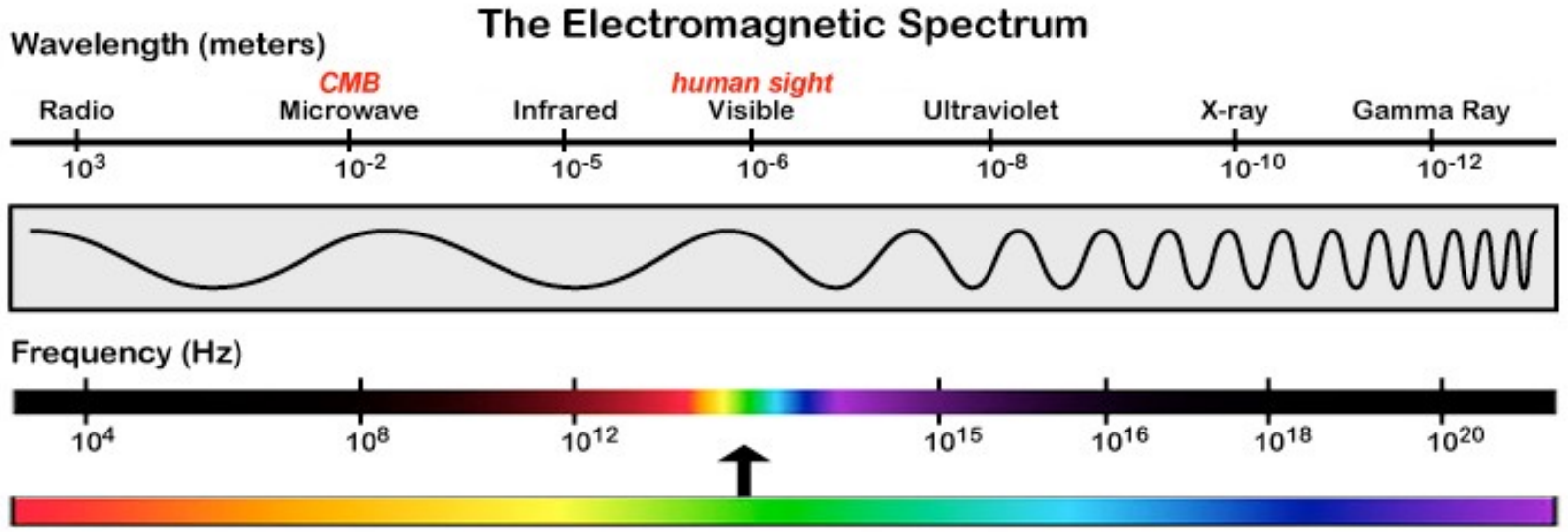


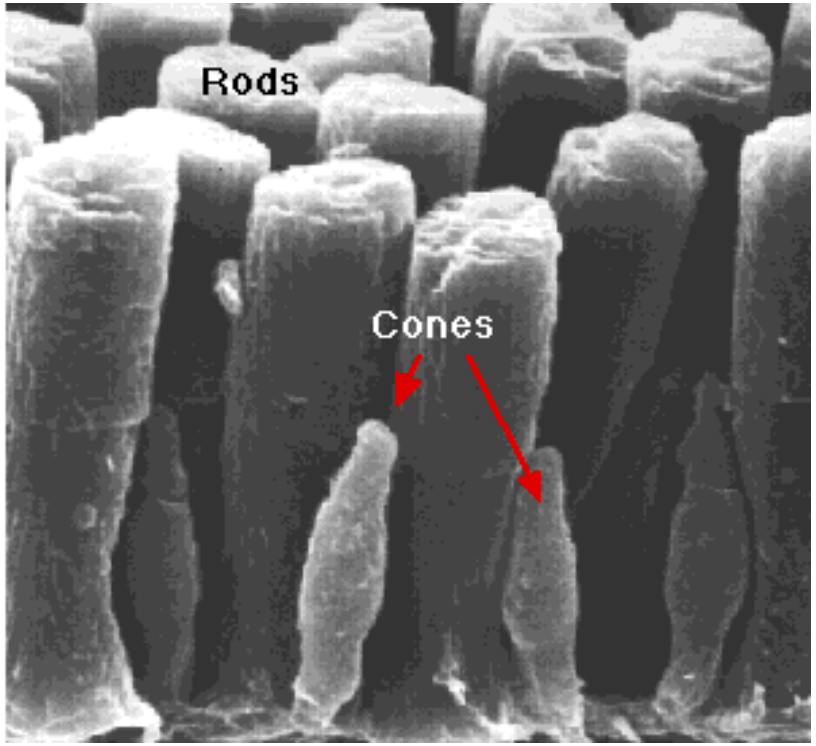
SIMULTANEOUS CONTRAST

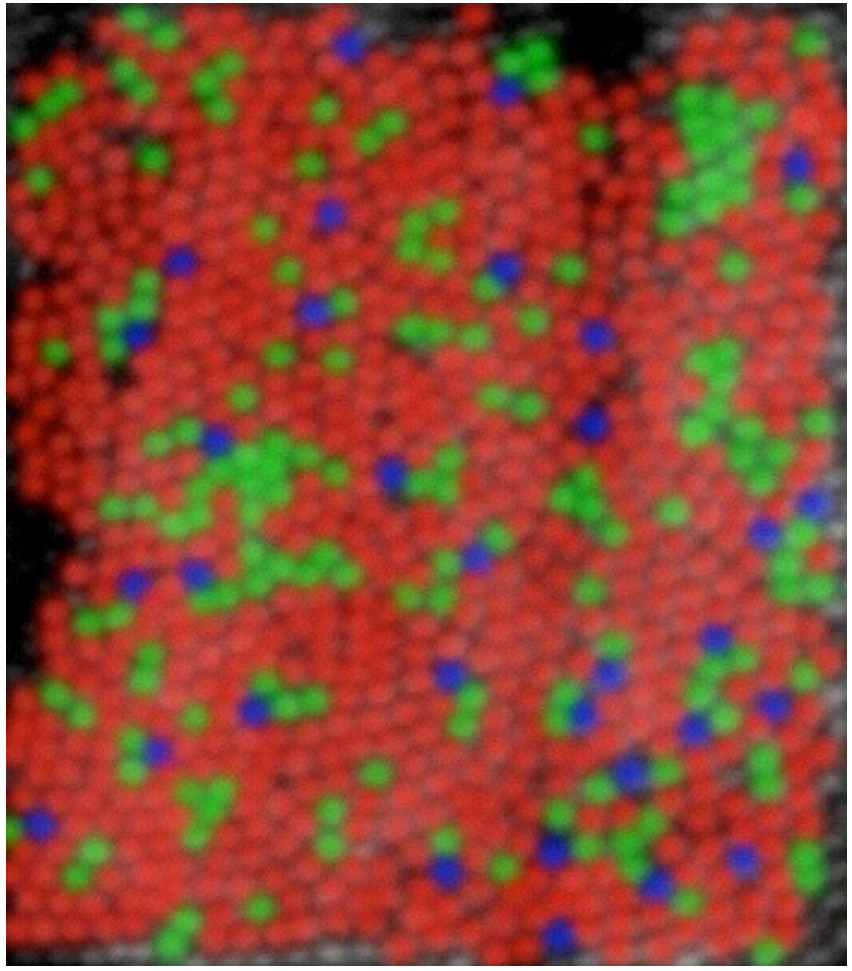
Color Perception



LIGHT


The Electromagnetic Spectrum
Wavelength (meters)
CMB
human sight
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^{3}
10^{-2}
10^{-5}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
Frequency (Hz)
10^{4}
10^{8}
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}

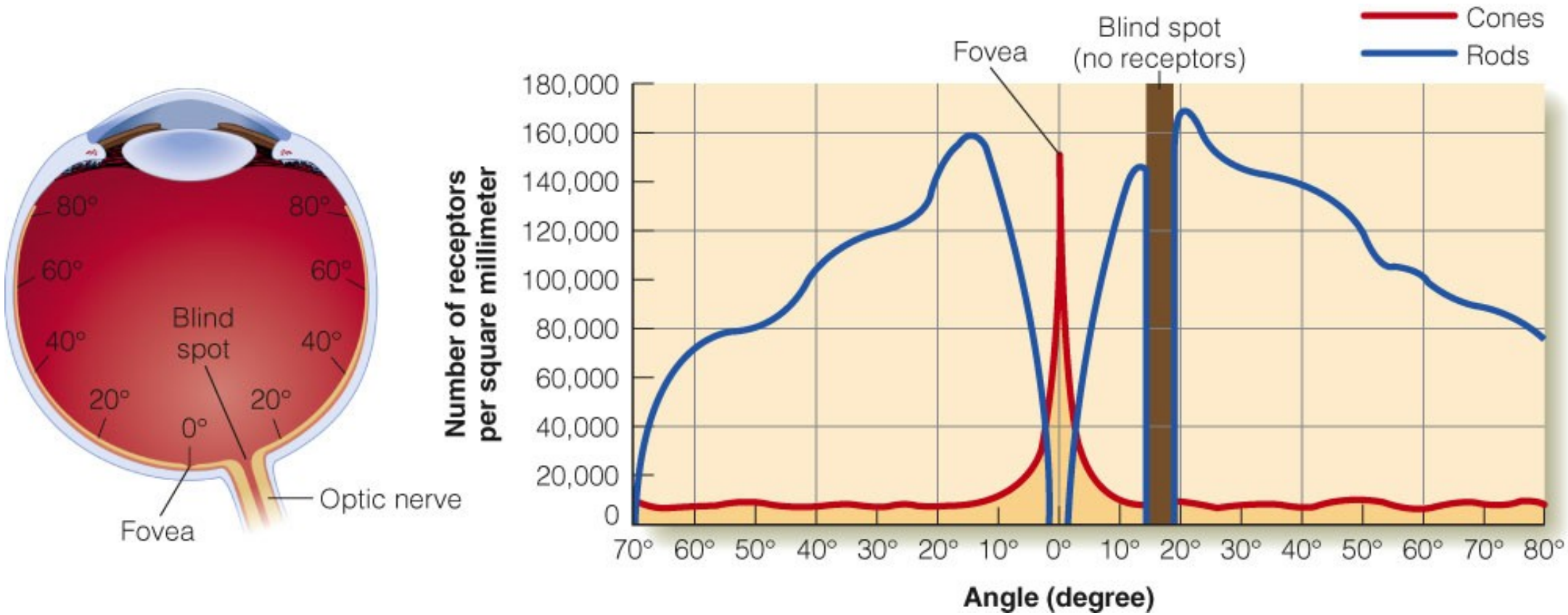




120 million rods

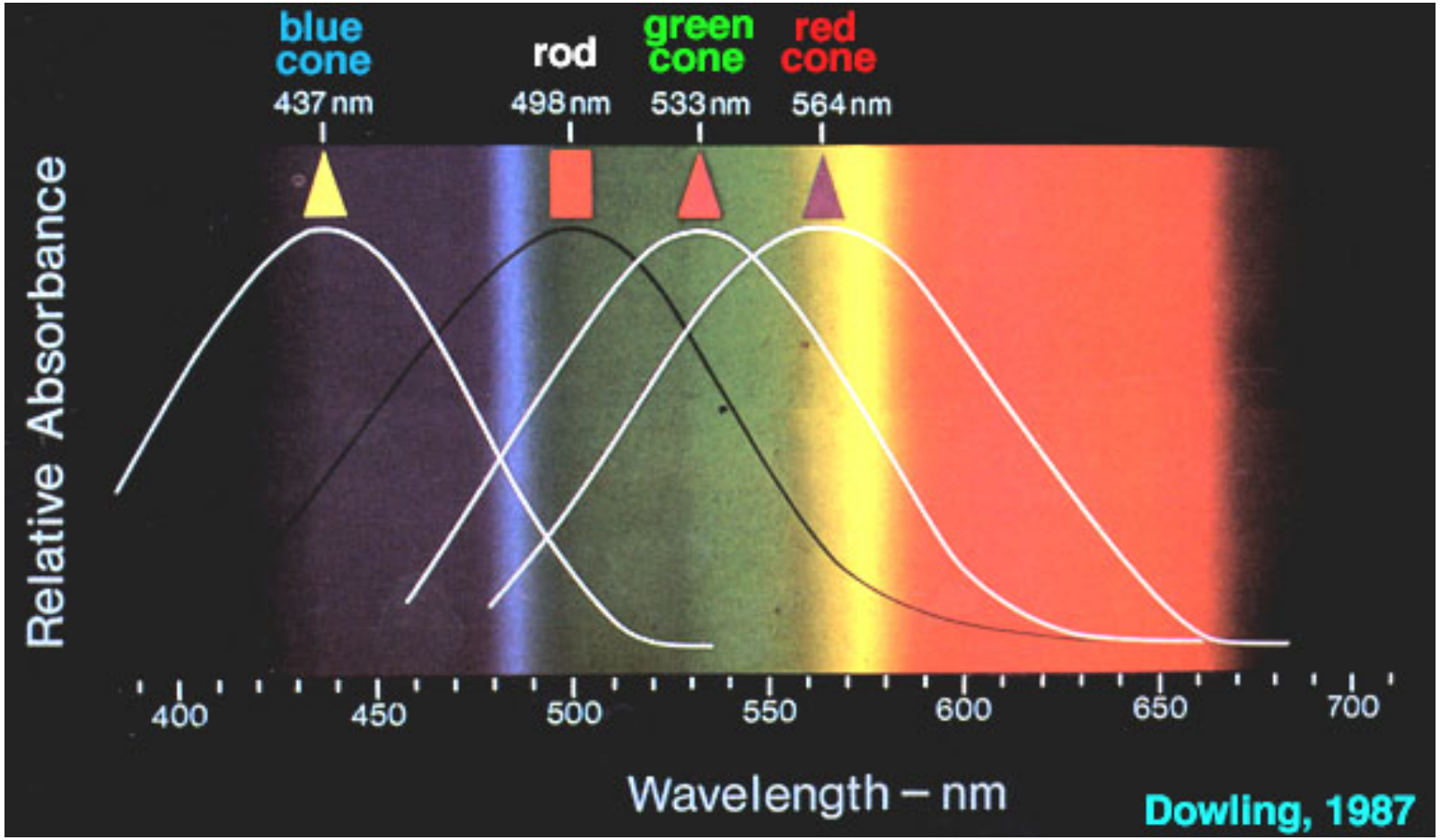
5-6 million cones

WANDELL, "FOUNDATIONS OF VISION" (LEFT) DAVID R. WILLIAMS, UNIV. OF ROCHESTER (RIGHT)



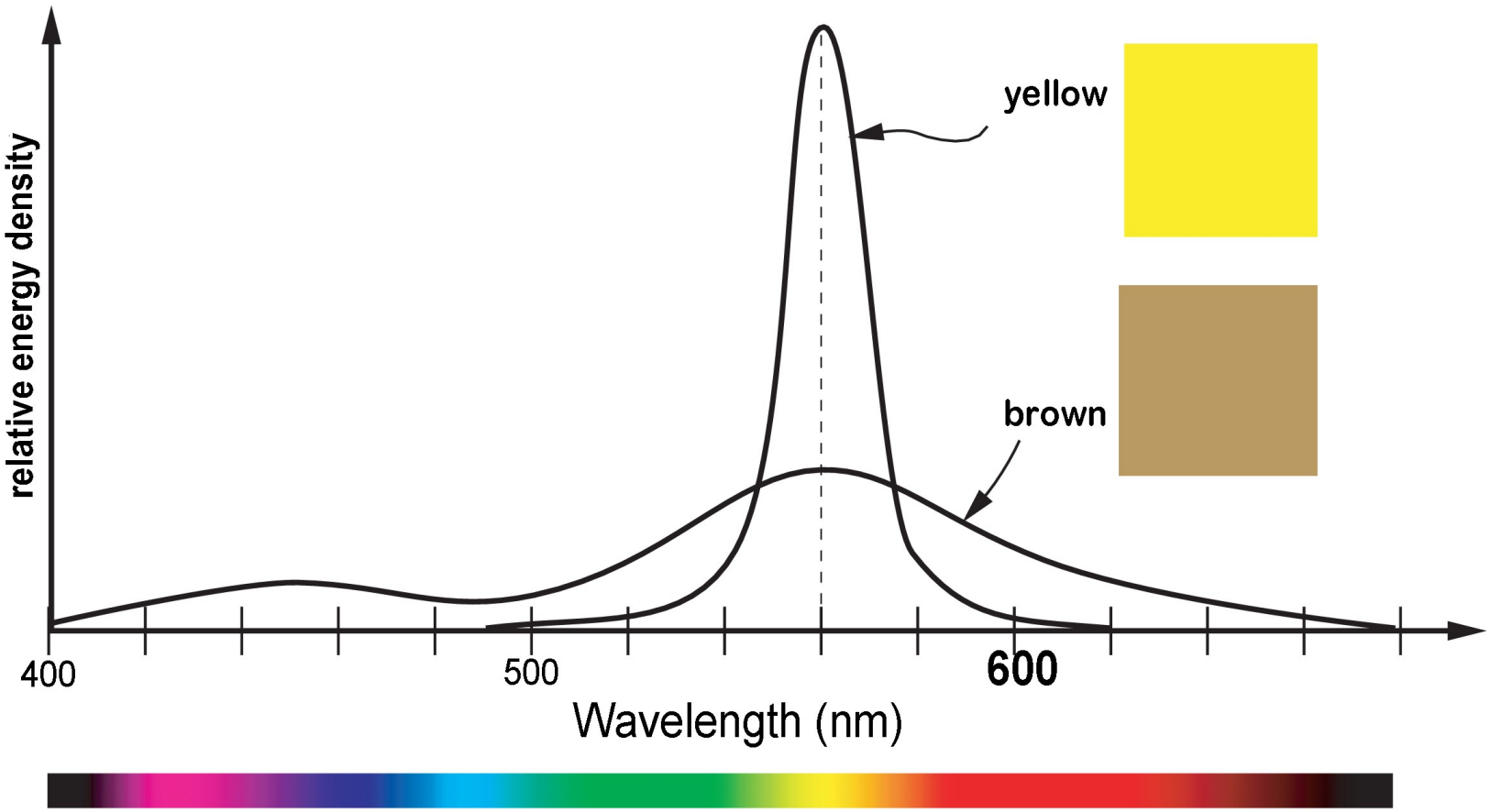
E. B. Goldstein "Sensation and Perception" (Adapted from Lindsay & Norman, 1977)

Cone Response



COLOR != WAVELENGTH

but rather, a combination of wavelengths and energy



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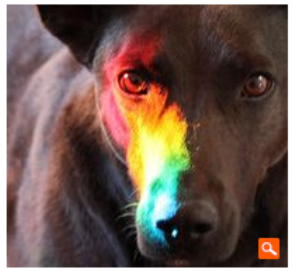

(jared/flickr/CC-BY-2.0)

We tear into this show with a dark scene from 1665. A young Isaac Newton, hoping to ride out the plague by heading to the country to puzzle over the deep mysteries of the universe, finds himself wondering about light. And vision. He wants to get to the bottom of where color comes from--is it a physical property in the outside world, or something created back inside your eyeball somewhere? **James Gleick** explains how Newton unlocked the mystery of the rainbow. And, as **Victoria Finlay** tells us, sucked the poetry out of the heavens.

Jonah Lehrer restores some of the lost magic by way of Goethe--who turned a simple observation into a deep thought: even though color starts in the

Latest Comments

What a fascinating story! I found it interesting as some aspects of it reminded me of the conflict in Gaza ...

Benny
on Fu-Go

The Most

Viewed | Listened | Commented

- Remembering Oliver Sacks
- American Football
- The Rhino Hunter
- Elements
- Shrink
- Colors
- Photos: Before and After Carlisle
- Looking Back With Dr. Sacks
- Antibodies Part 1: CRISPR
- The Poetry of "Elements"

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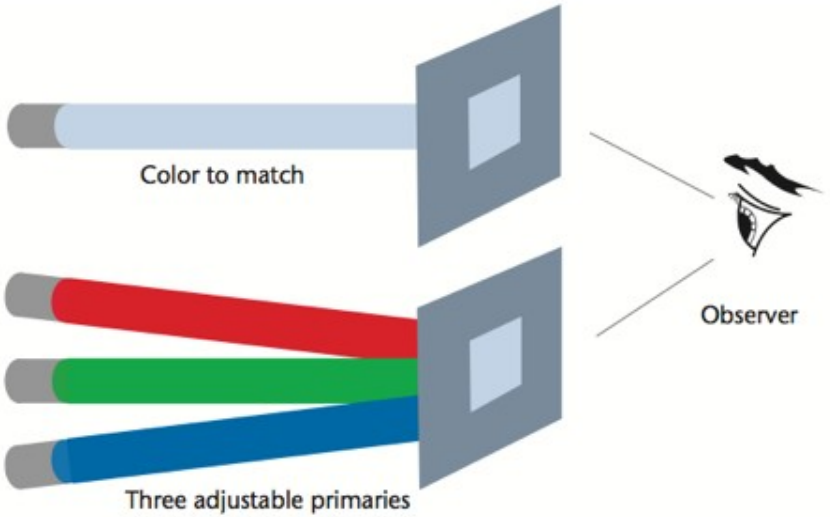
HTTPS://WWW.WNYCSTUDIOS.ORG/STORY/211178-RIP-RAINBOW

COLOR ABSTRACTION, REPRESENTATION



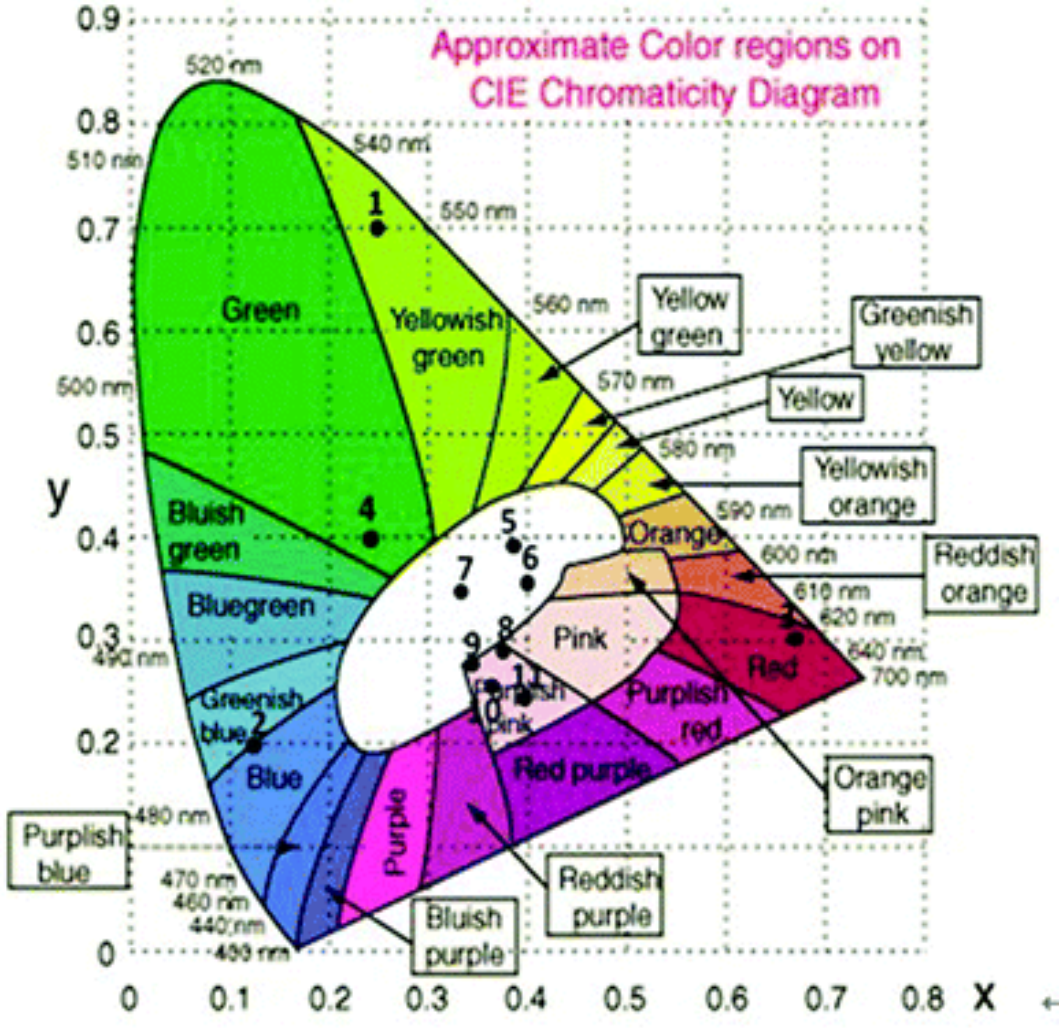
SPACE OF HUMAN COLOR

CIE (International Commission on Illumination)

- Standardized a set of color-matching functions that form the basis for most color measurement instruments

Experiments done in the 1920's and 1930's

Humans can mimic any pure (visible) light by addition and subtraction of three primary lights



ADDITIVE COLOR

(like we see in light)

primary: RGB

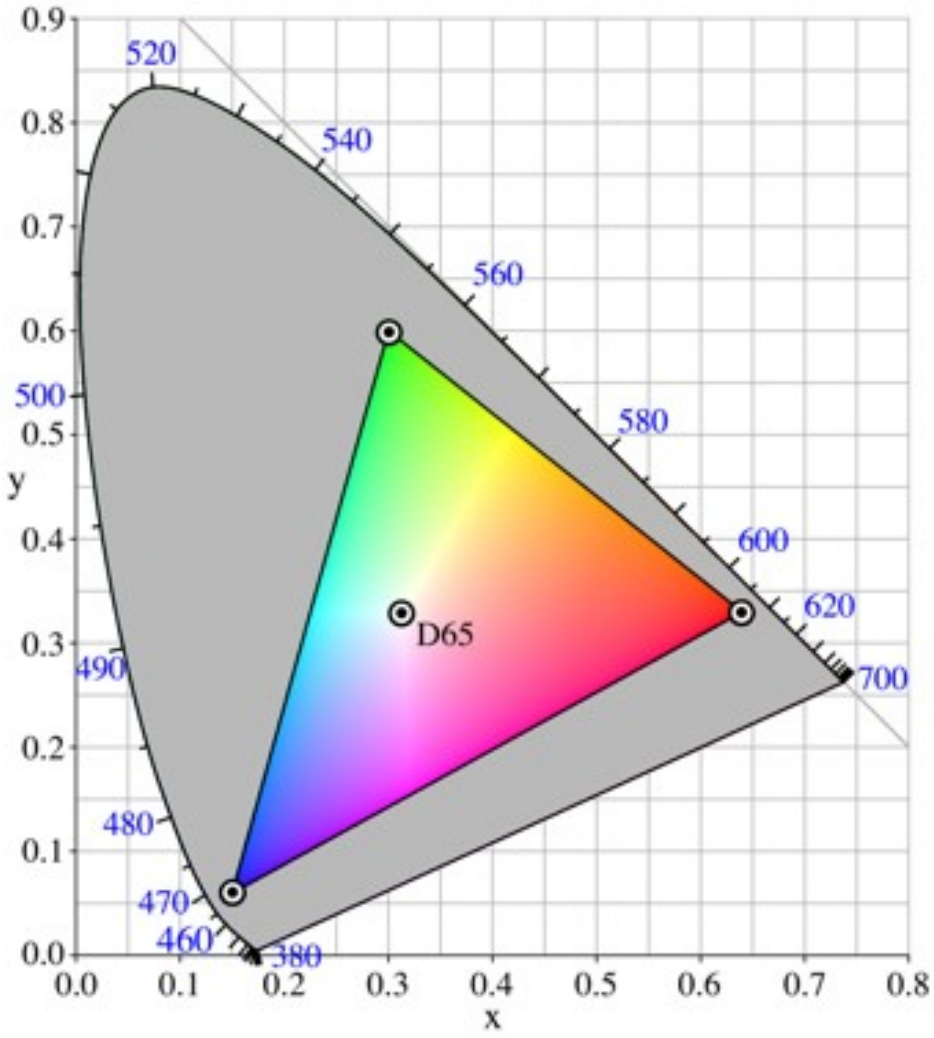
secondary: CMY

RGB COLOR SPACE

very common color space

not perceptually uniform

actual color is device-dependent



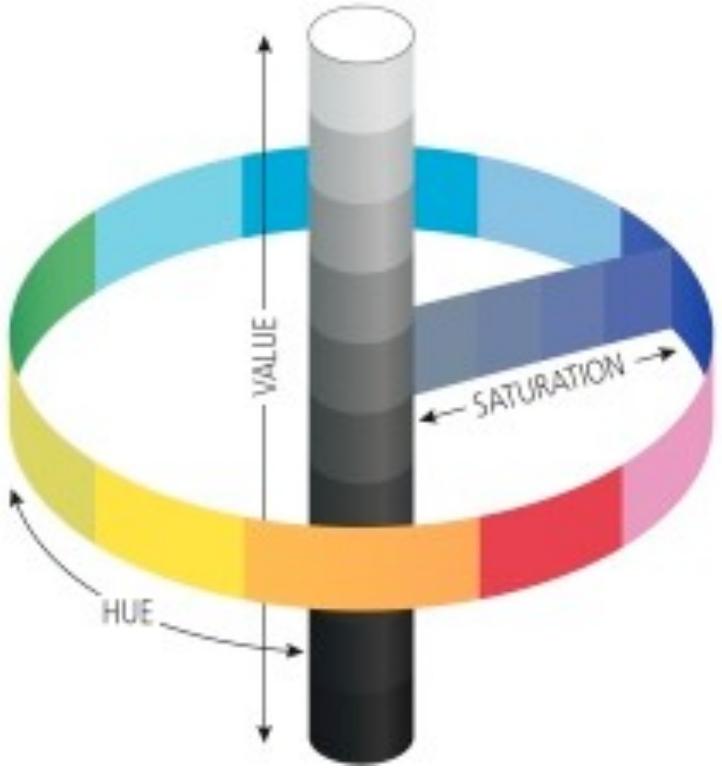
HSV [B, L, I] (ADDITIVE)

Hue, Saturation, [Value, Brightness, Lightness, Intensity]

polar coordinate representations of RGB space

Conical or cylindrical shaped space

More intuitive than RGB for color tuning



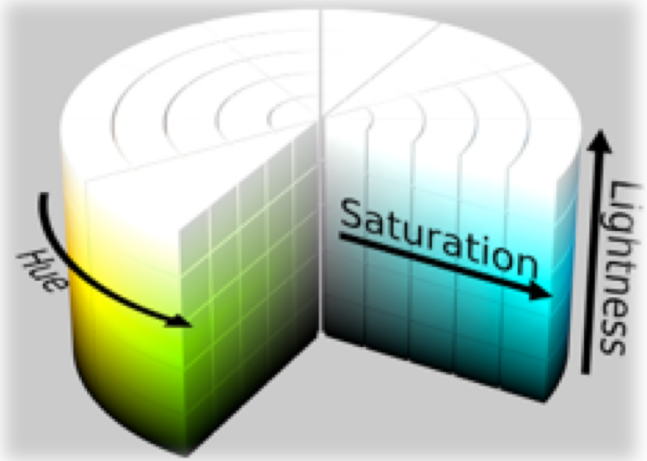
HSV [B, L, I] (ADDITIVE)

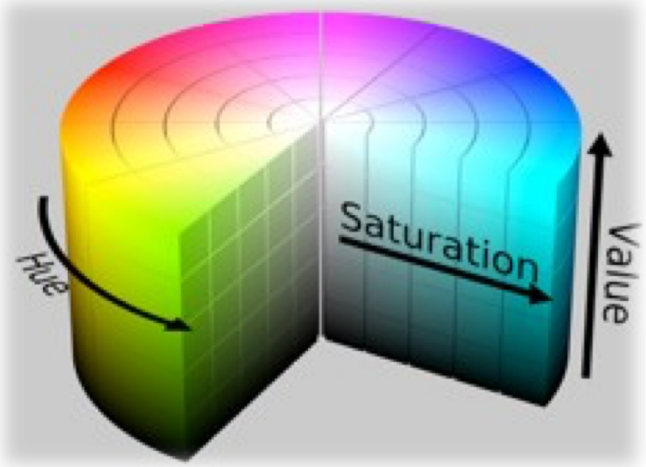
hue: what people think of as color

saturation: amount of white mixed in

luminance: amount of black mixed in

- lightness vs value (or brightness)
- intensity, in computer vision applications



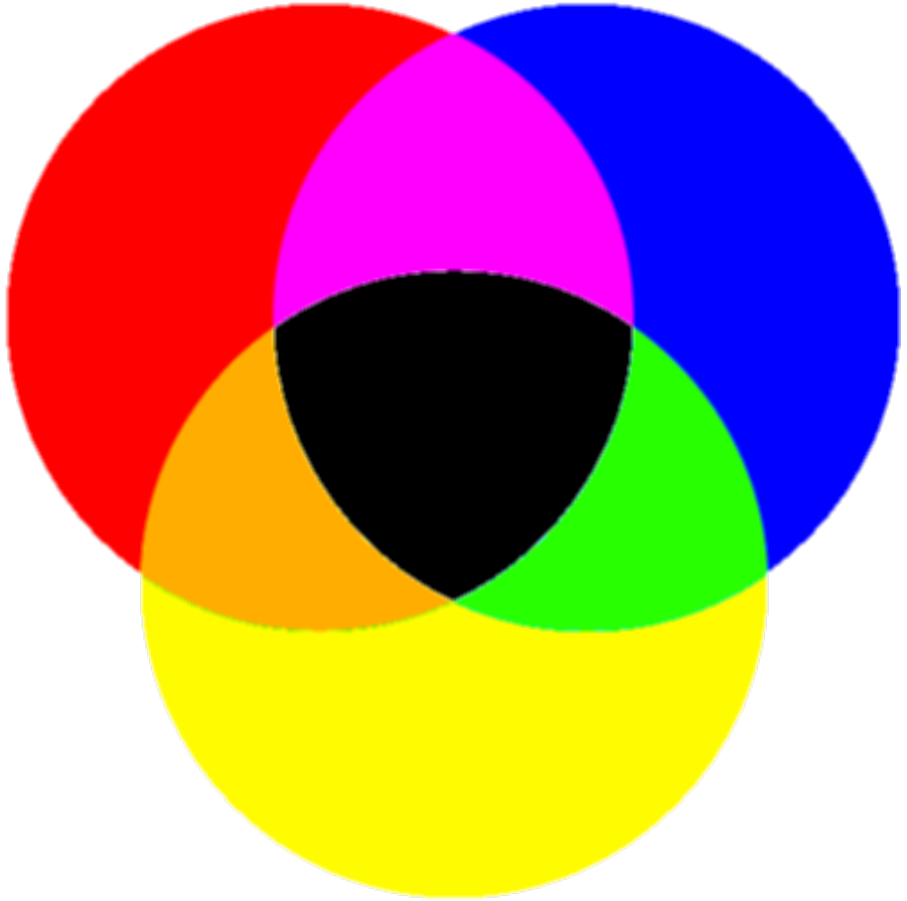


SUBTRACTIVE COLOR

(used in painting)

primary: RYB

secondary: OGV



SUBTRACTIVE COLOR

(used in print ink)

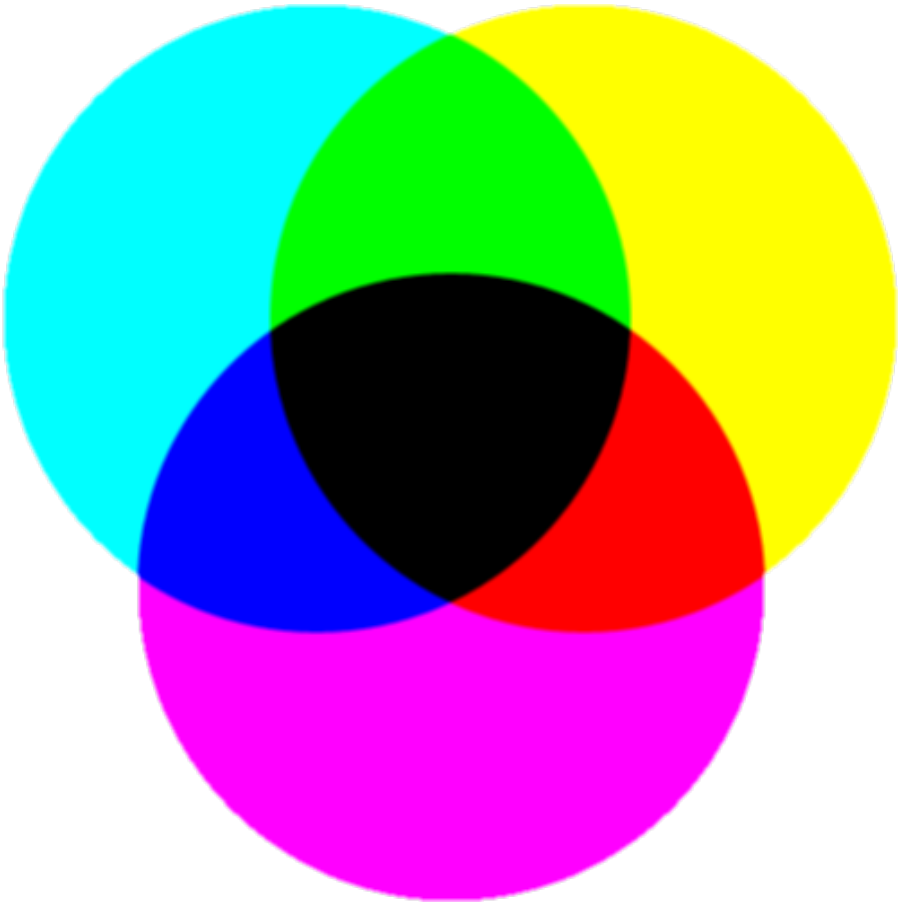
primary: CMY

secondary: RGB

approx black = C+M+Y

true black = C+M+Y+K

actual color is device-dependent



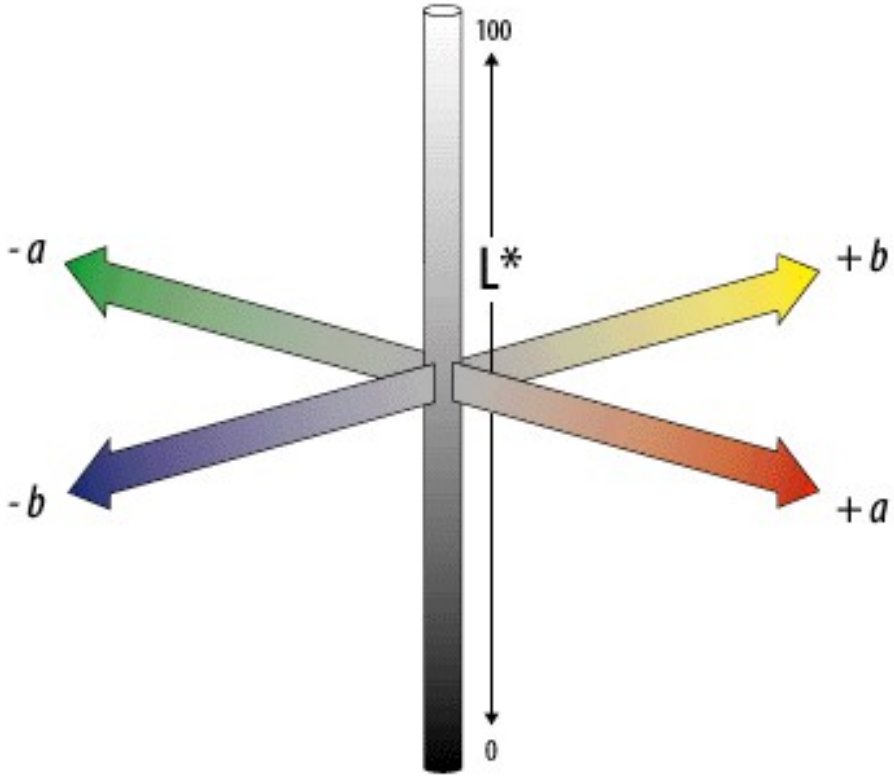
CIE LAB/LUV

mathematically defined & perceptually based to include all perceivable colors

a: red to green

b: yellow to blue

L*: lightness (black to white)



COLOR DEFICIENCIES & LIMITATIONS

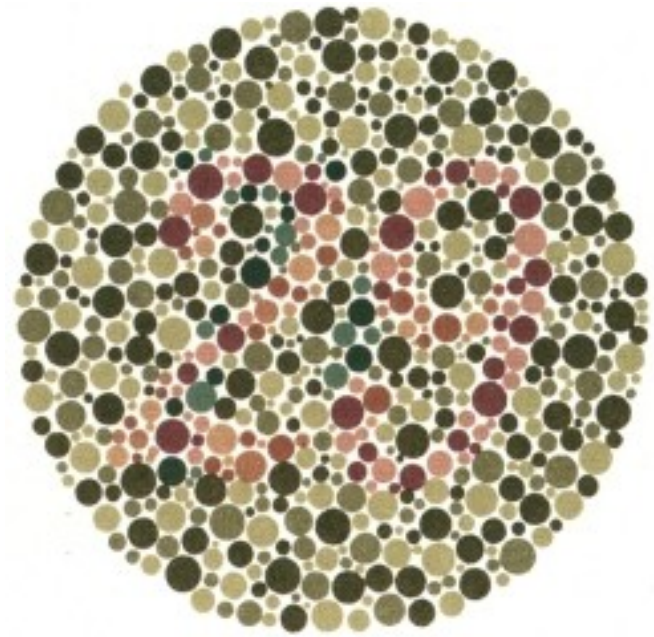
COLOR BLINDNESS

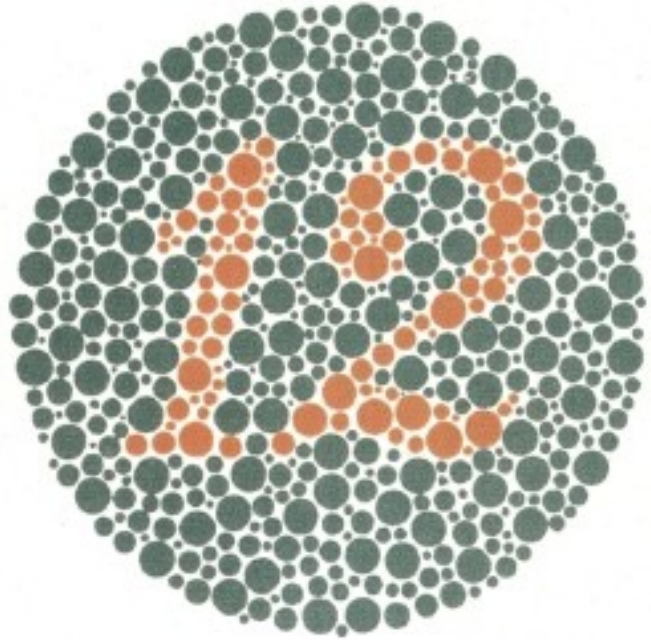
Deficiency in color vision

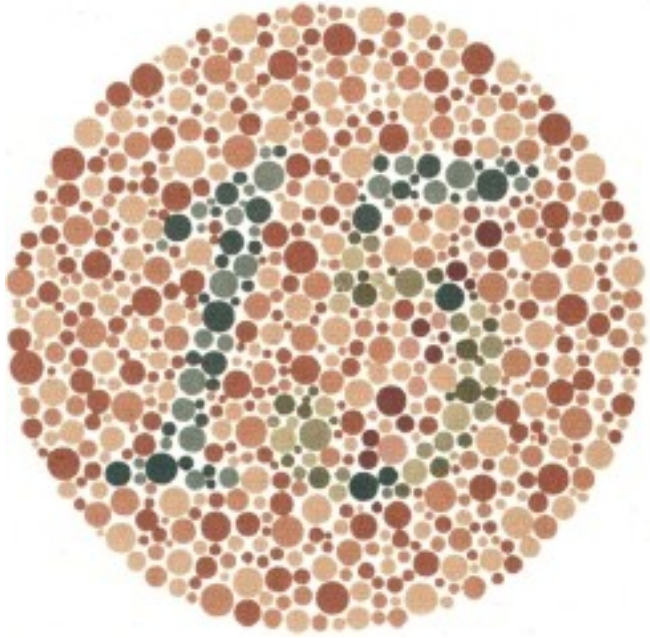
- Typically caused by faulty cone development

Found more in men than women

- Photopigment genes carried in x-chromosome
- 5-8% of men and 0.5% of women



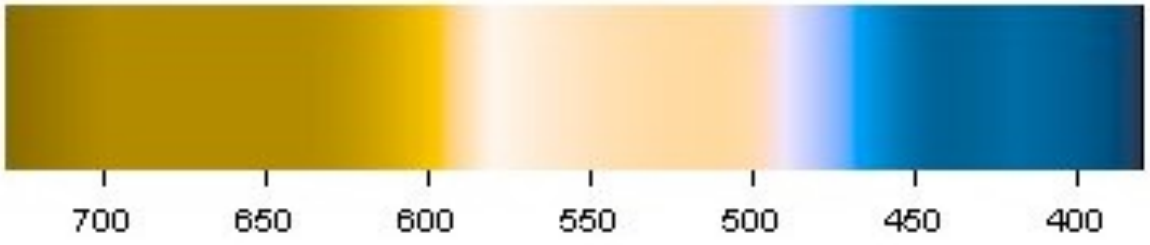




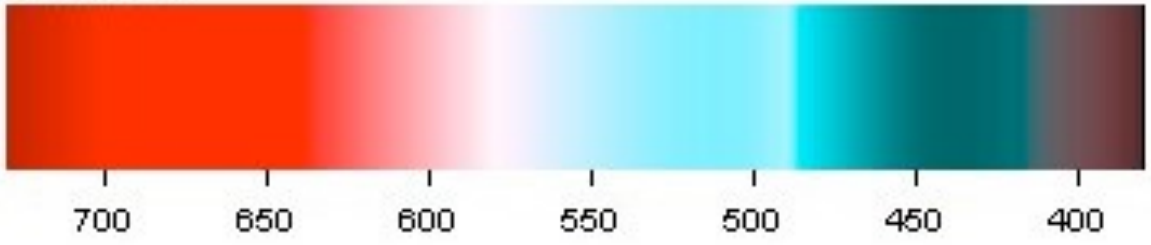
Normal

Protanopia

Deuteranopia



Tritanopia



MONOCHROMACY

total color blindness, very rare

- 1 dimensional color vision
- 2 or 3 cone pigments are missing

rod monochromacy: non-functioning or missing cones (achromatopsia)

cone monochromacy: multiple deficient cones

DICHROMACY

2 dimensional color vision

- 1 cone pigment is missing

protanopia: absence of red receptors

deuteranopia: absence of green receptors

tritanopia: absence of blue receptors

TYPES: TRICHOMACY

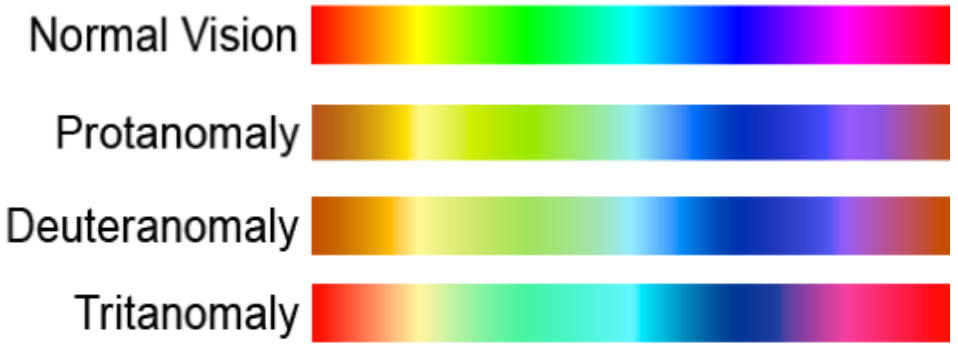
3 dimensional color vision

- 1 cone is altered in spectral sensitivity—impairment rather than loss

protanomaly: shift in red, poor red-green discrimination

deuteranomaly: shift in green, poor red-green discrimination (most common form of color deficiency)

tritanomaly: poor blue-yellow discrimination



The X-Rite Color Challenge and Hue Test

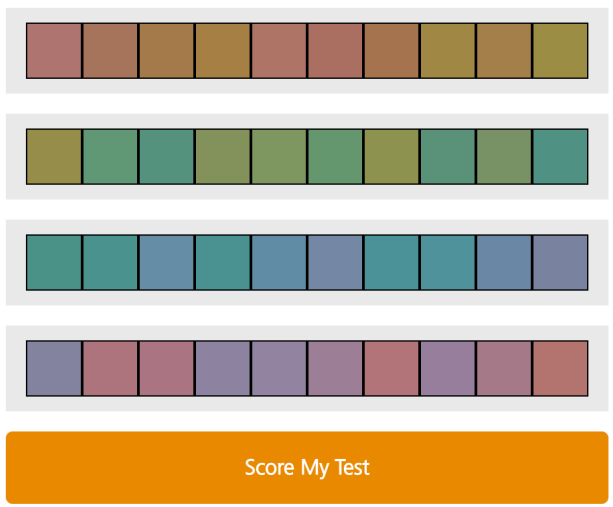
Are you among the 1 in 255 women and 1 in 12 men who have some form of color vision deficiency? If you work in a field where color is important, or you're just curious about your color IQ, take our online challenge to find out. Based on the Farnsworth Munsell 100 Hue Test, this online challenge is a fun, quick way to better understand your color vision acuity.

Just remember, this is not a replacement for the full test!

Directions:

1. The first and last color chips are fixed.
2. Drag and drop the colors in each row to arrange them by hue color.
3. Complete all four color tests.
4. Click 'Score My Test' to review results.

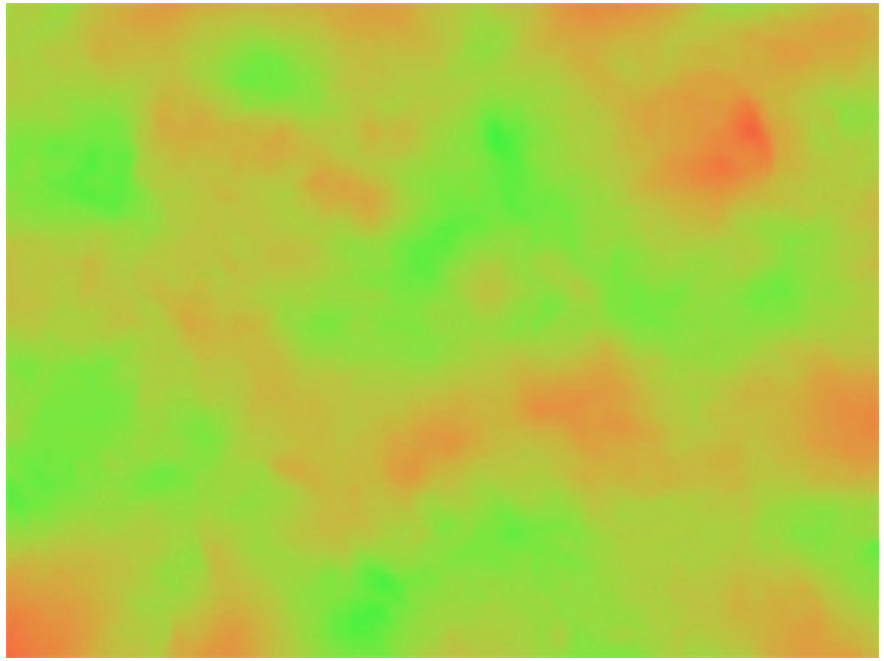
What's My Color IQ?



Score My Test

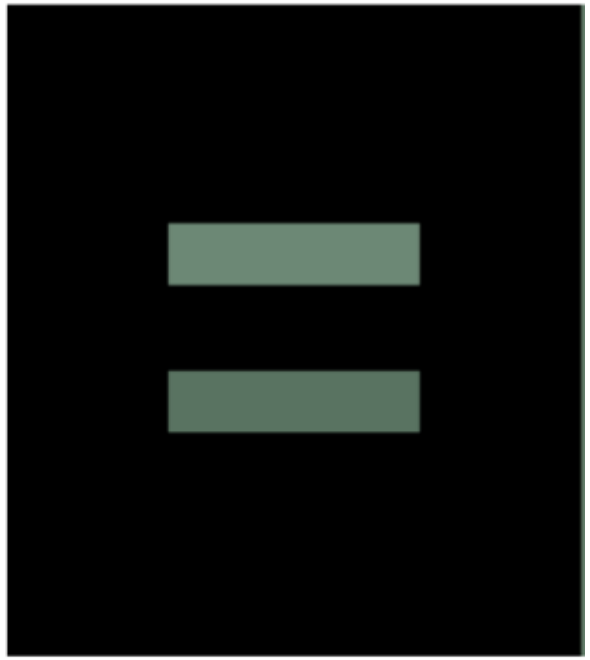
HTTPS://WWW.XRITE.COM/HUE-TEST

Contrast Sensitivity

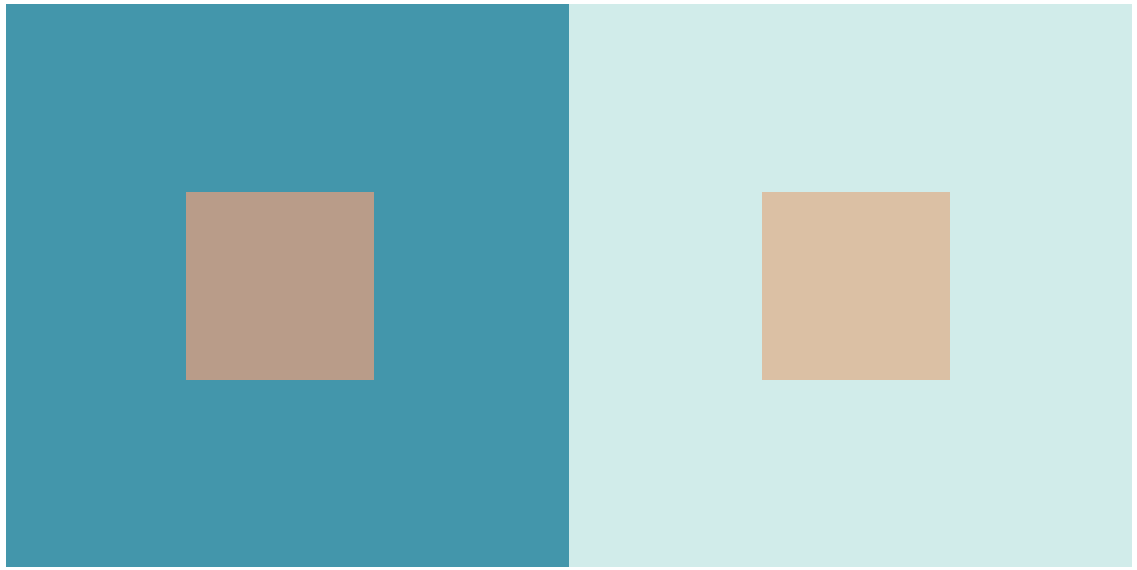


C. Ware, "Visual Thinking for Design"

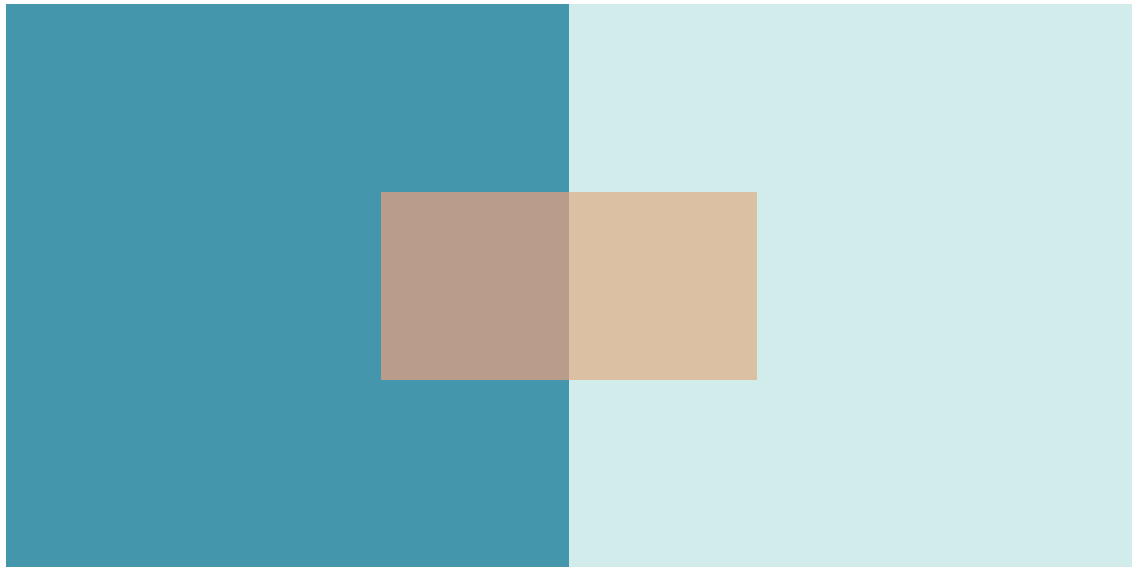
Color Relativity



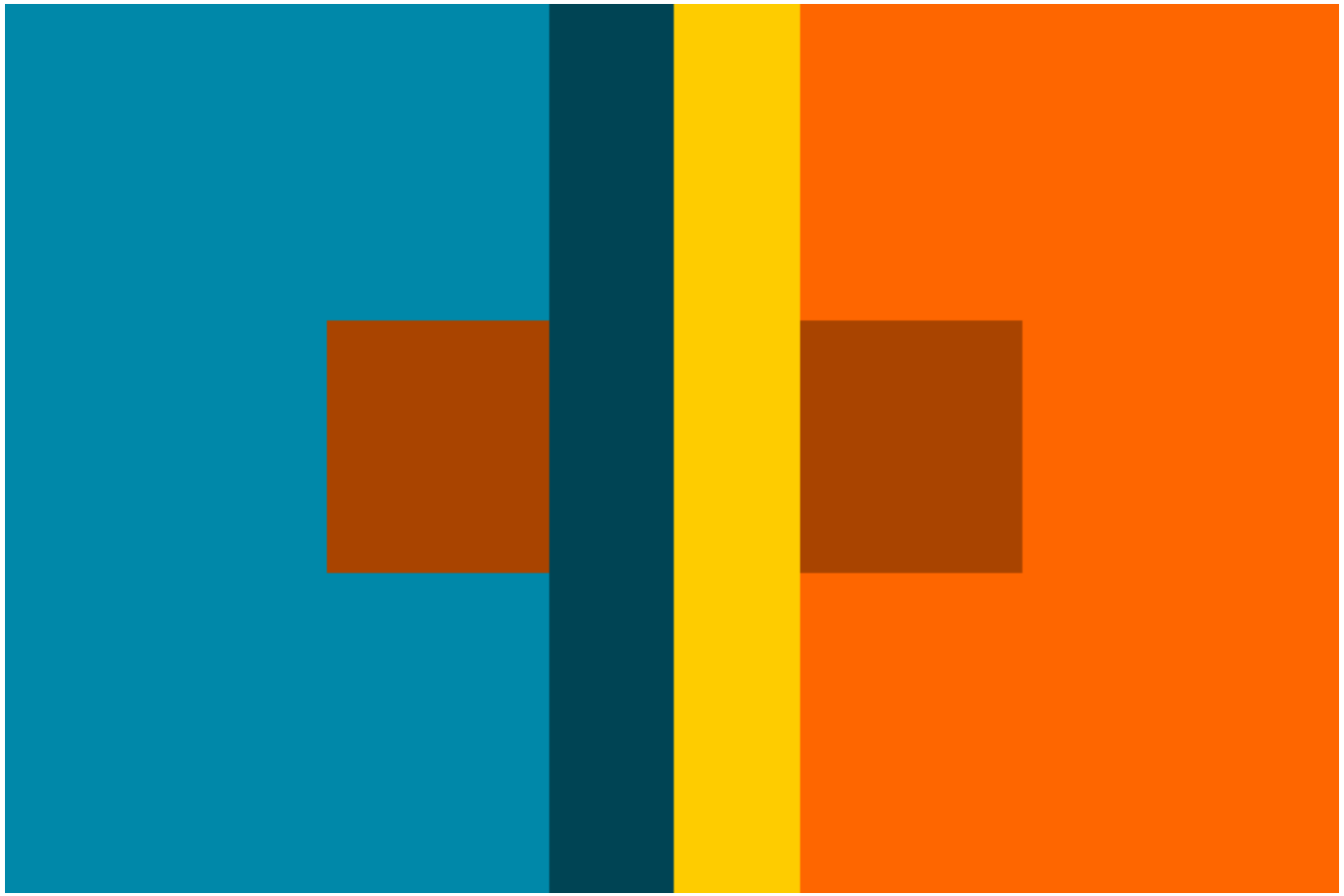
Color Relativity



Color Relativity



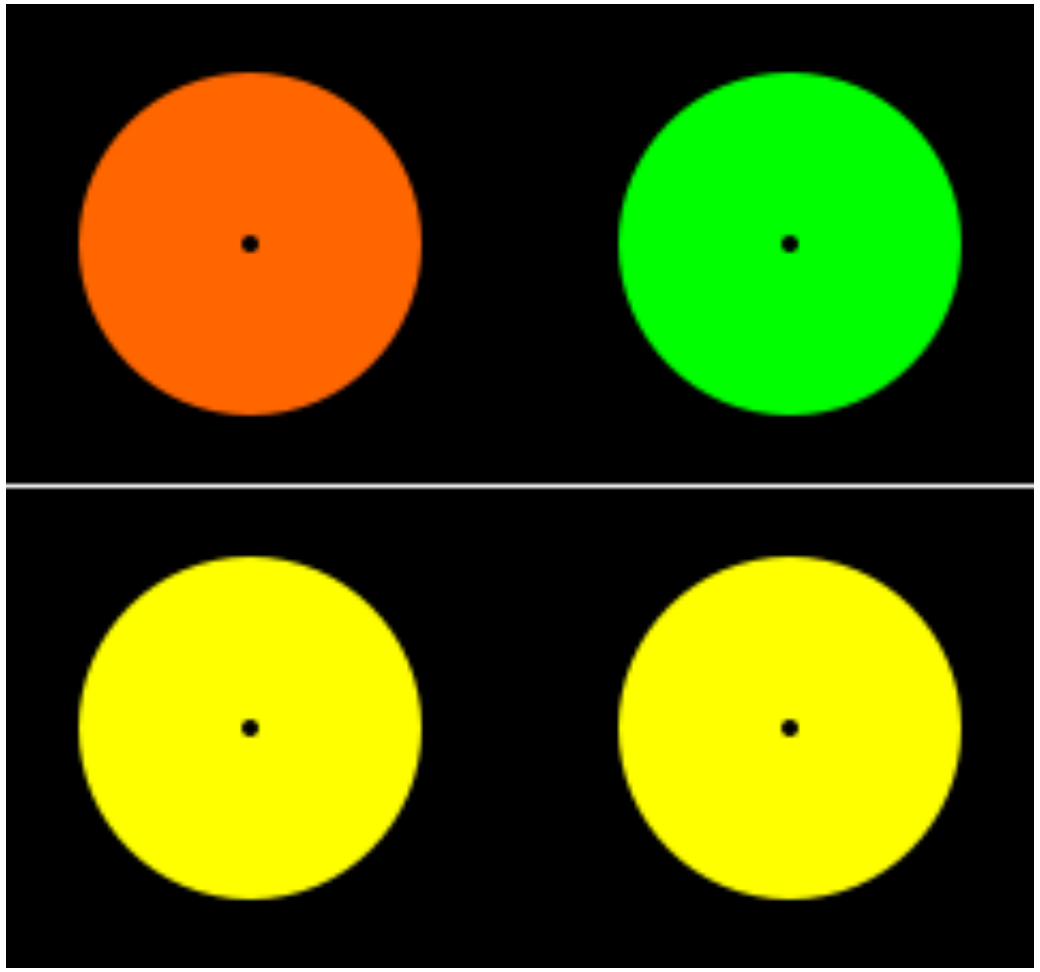
Color Relativity



Color Relativity

Color Relativity

SUCCESSIVE CONTRAST



look at a dot

then look at a dot

LUMINANCE CONTRAST

Showing small blue text on a black background is a bad idea.
There is insufficient luminance contrast.

Showing small blue text on a black background is a bad idea.
There is insufficient luminance contrast.

Showing small yellow text on a white background is a bad idea.
There is insufficient luminance contrast.

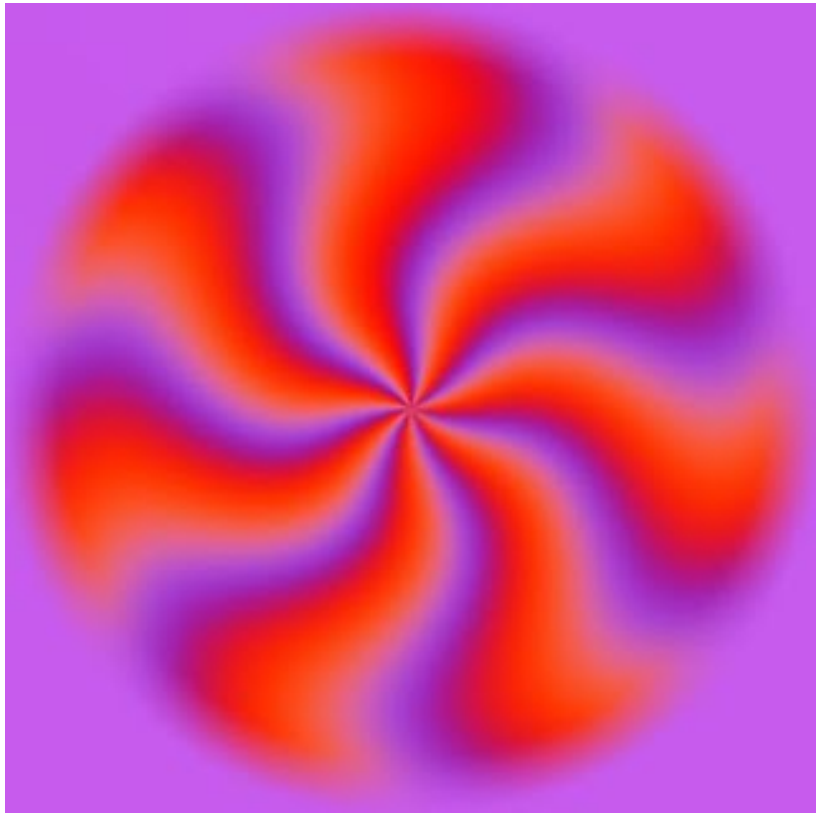
Showing small yellow text on a white background is a bad idea.
There is insufficient luminance contrast.

EQUILUMINANT COLORS

strong contrast: shapes seen by color sensitive cells

equiluminance: hides positions from light sensitive cells

flickering/movement caused by this disconnect



JUDGEMENT & PERCEPTION

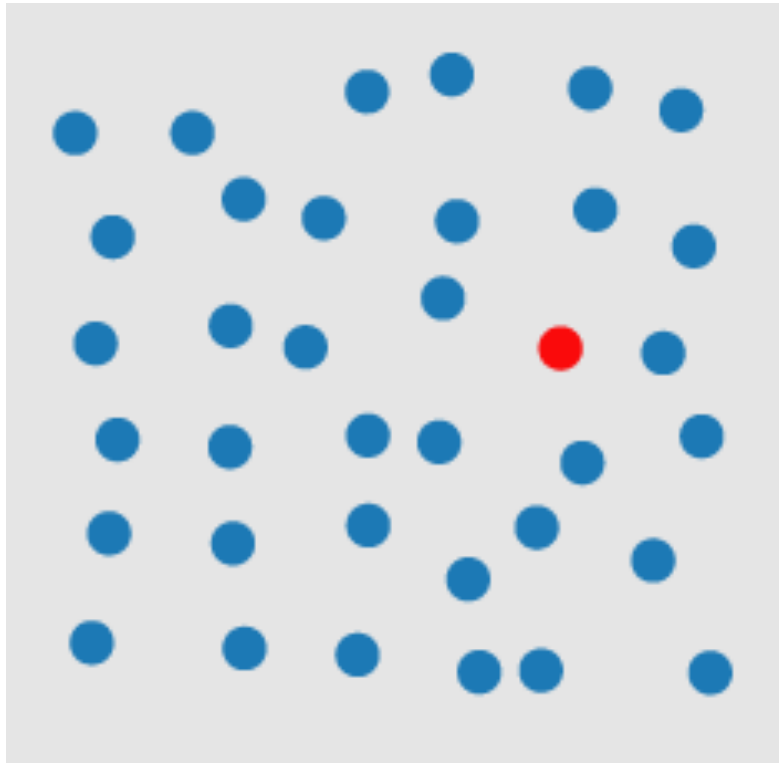
PRE-ATTENTIVE PROCESSING

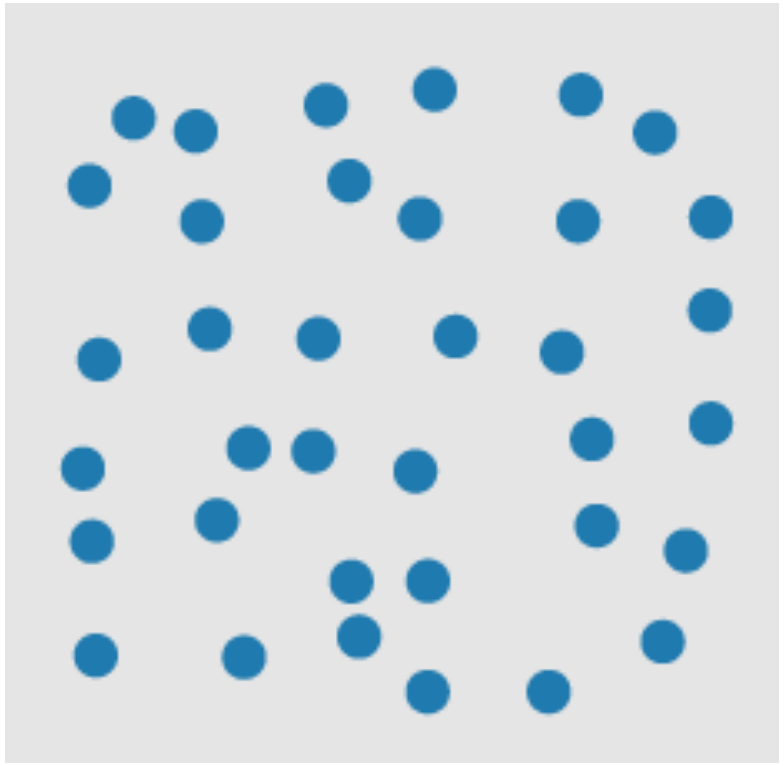
requires attention, despite name

very fast: <200 ms

what matters most is contrast between features

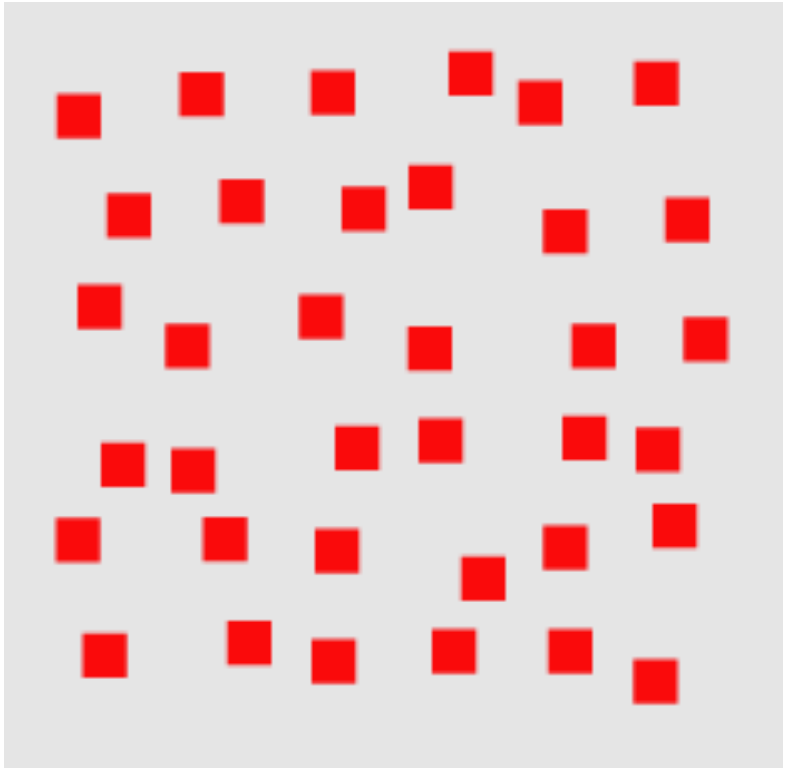
PICK THE OUTLIER

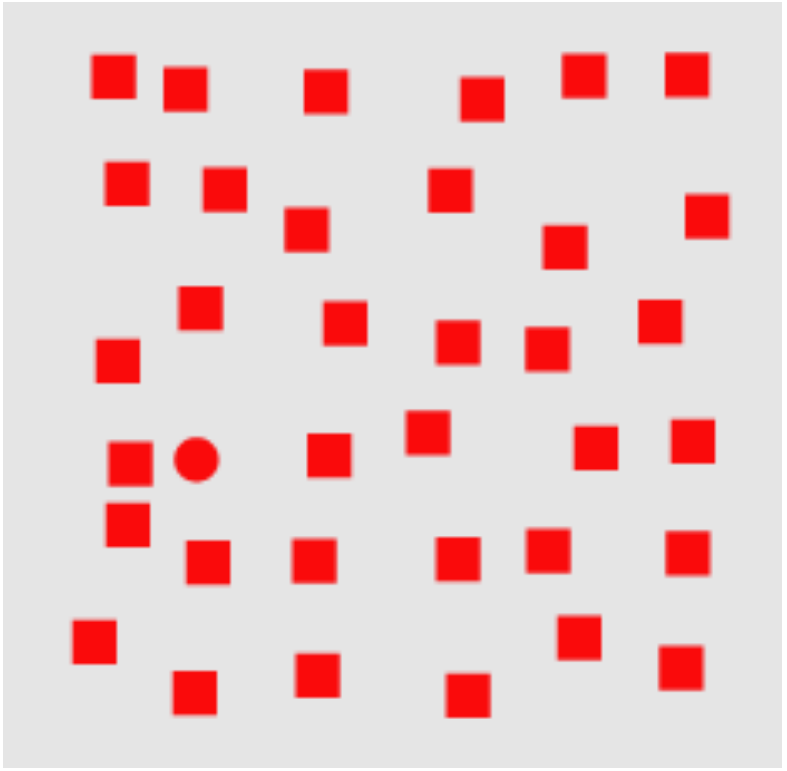




HEALY 2007

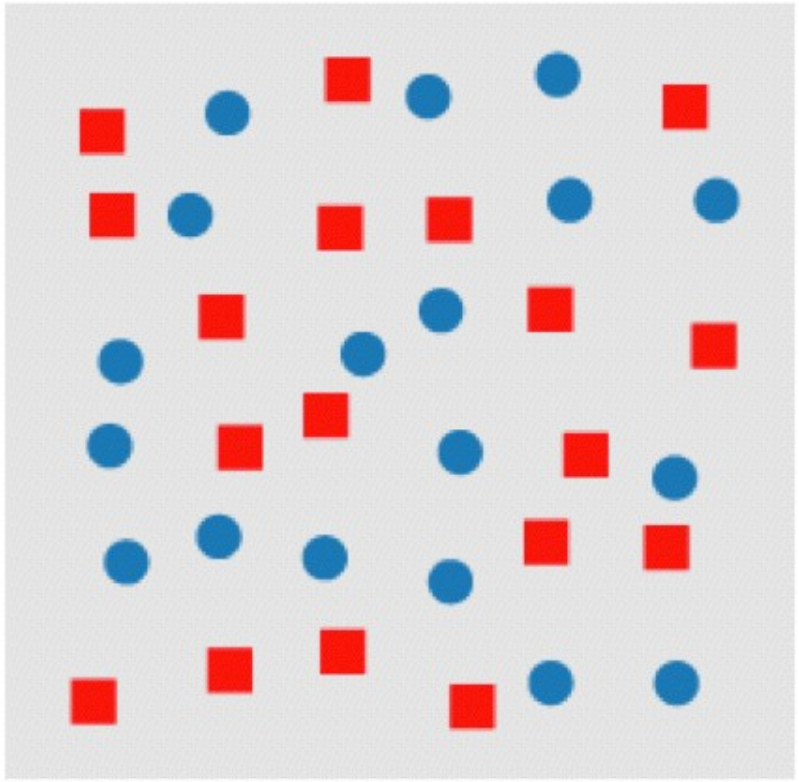
PICK THE OUTLIER

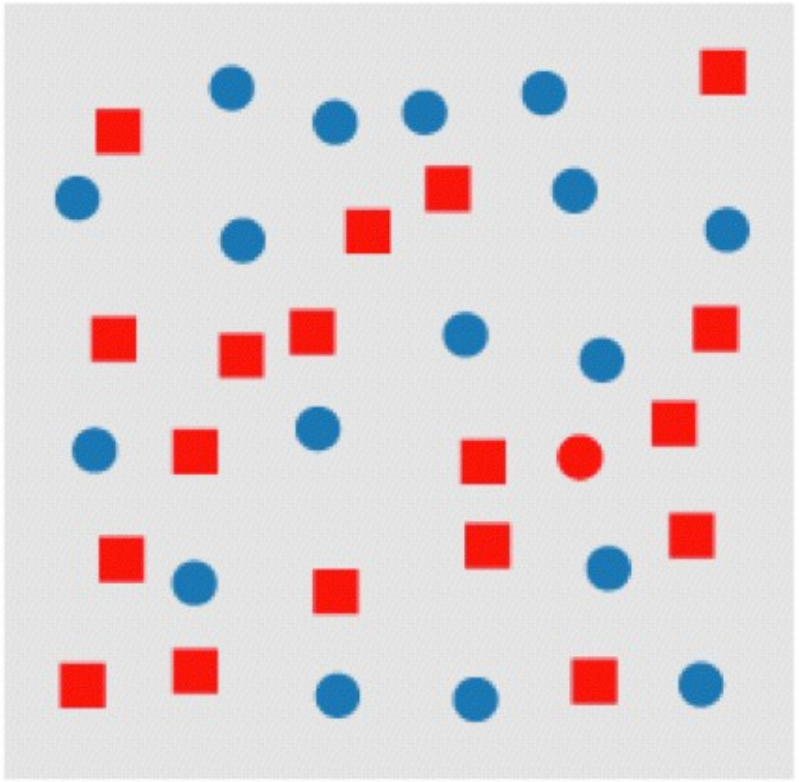




HEALY 2007

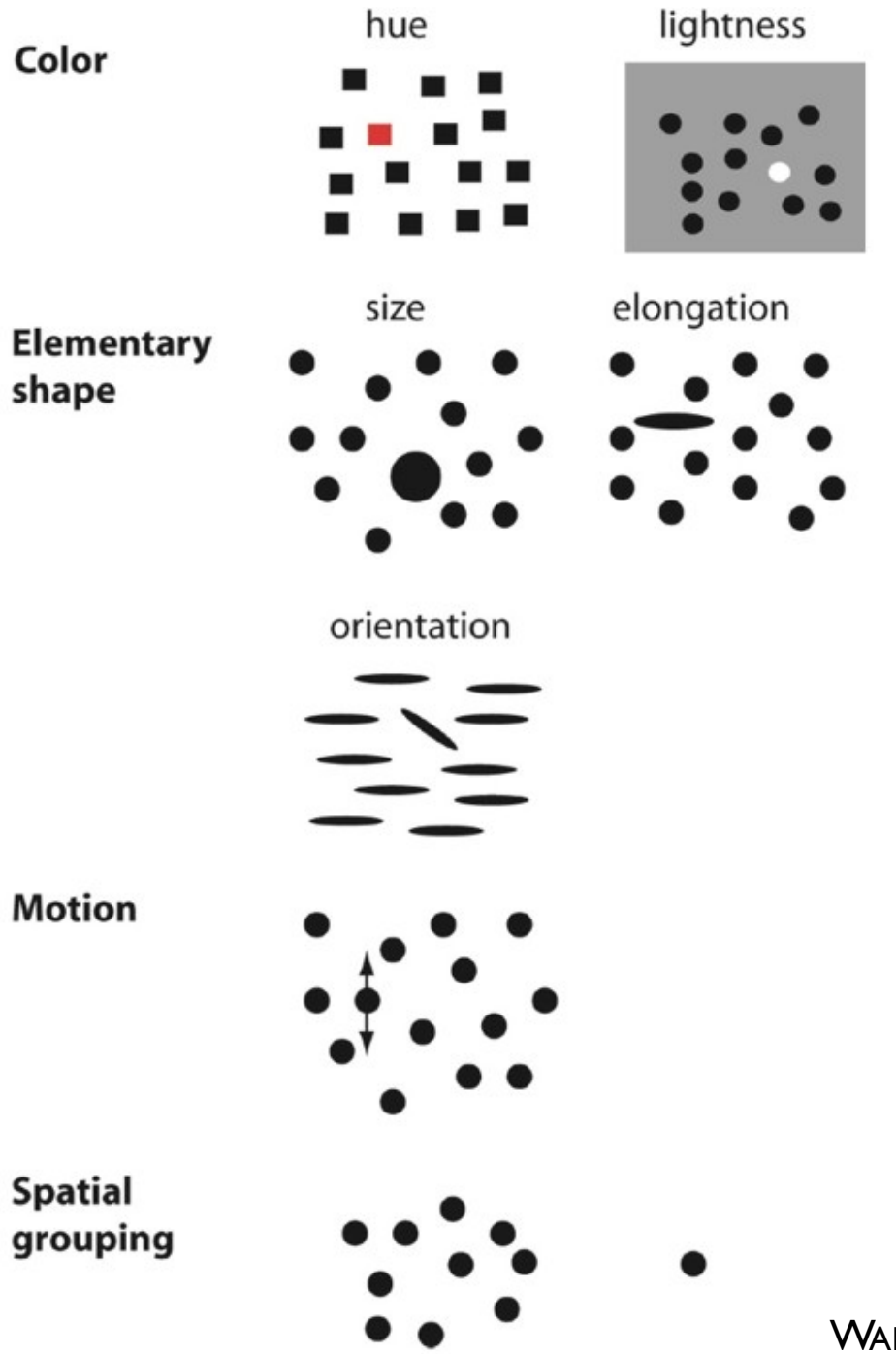
CONJUNCTION





HEALEY 2007

BASIC POPOUT CHANNELS

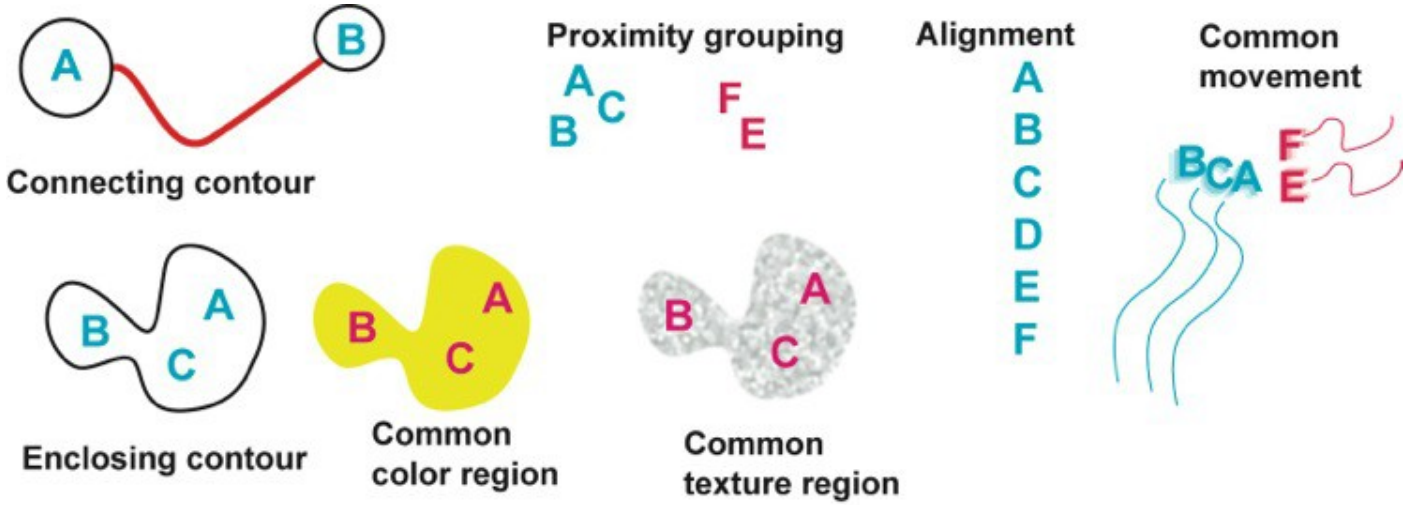


WARE 2008

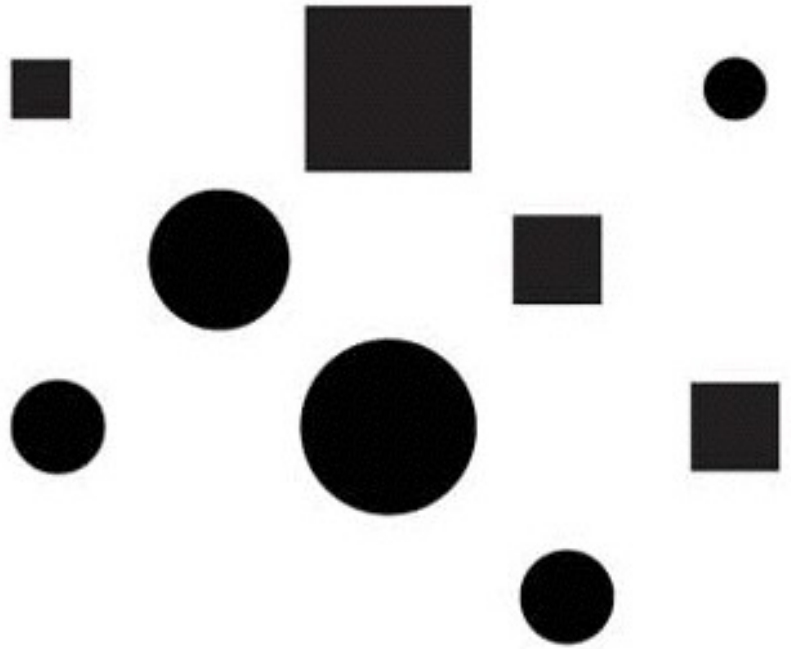
GESTALT PRINCIPLES

German: "Gestalt" = form

patterns transcend the visual stimuli that produced them

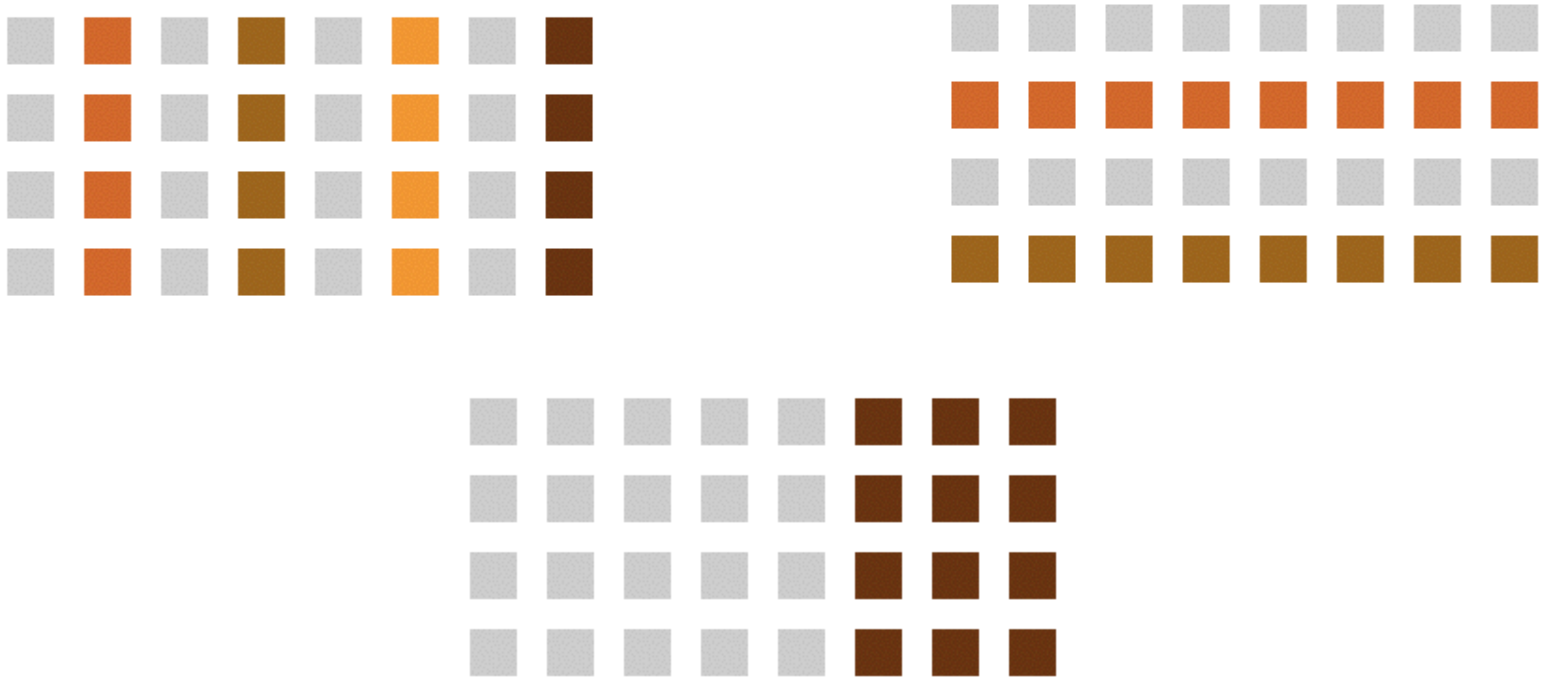


SIMILARITY



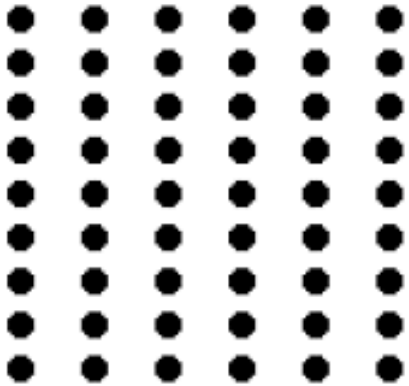
BANG WONG, "GESTALT PRINCIPLES, I", NATURE METHODS

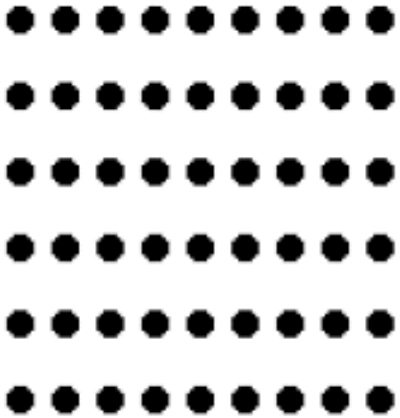
SIMILARITY

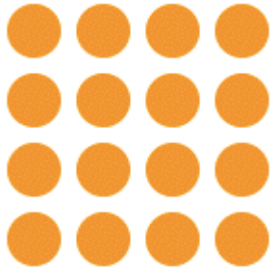


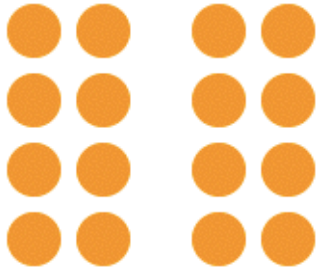
ANDY RUTLEDGE, "GESTALT PRINCIPLES OF PERCEPTION"

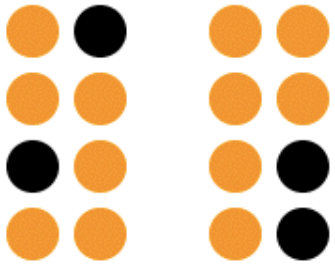
PROXIMITY





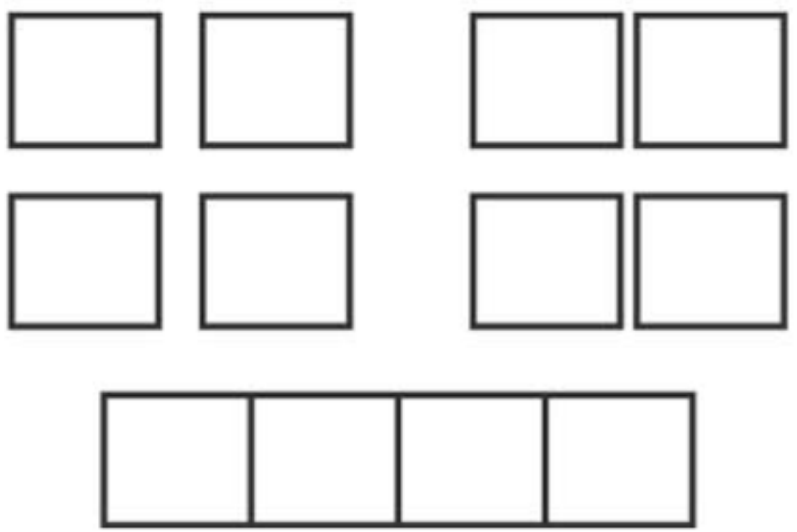






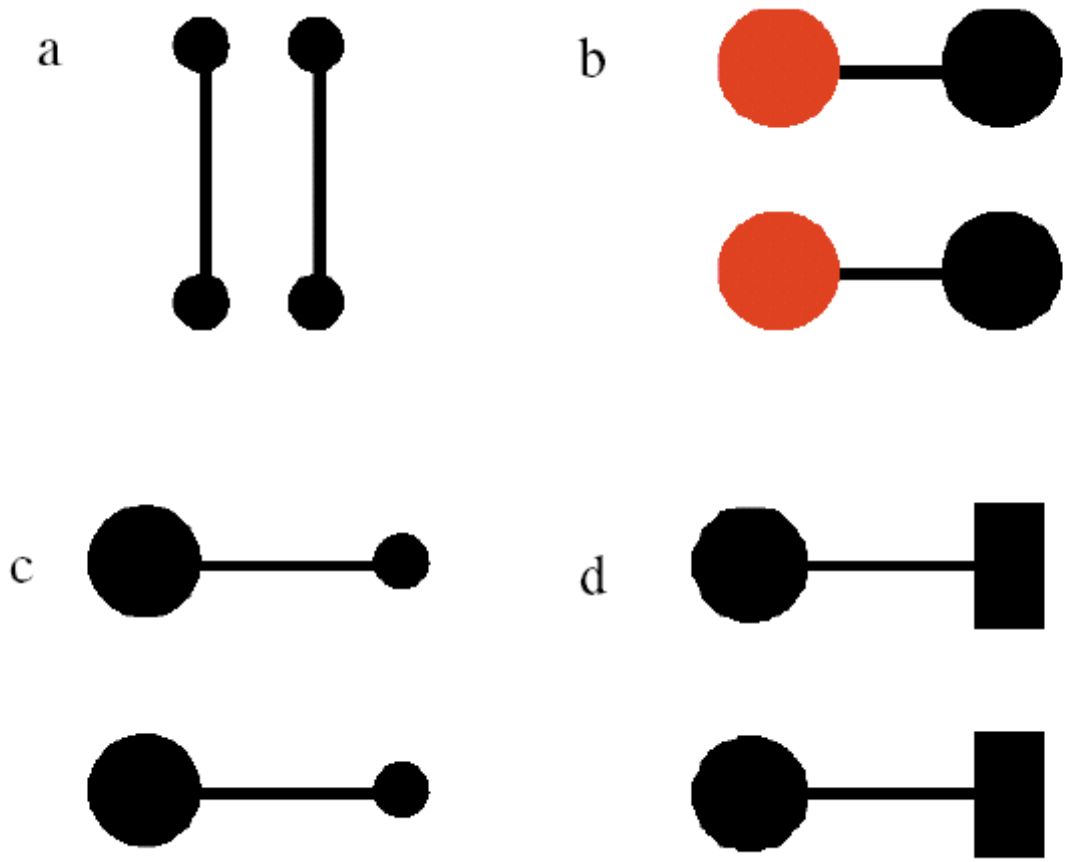
ANDY RUTLEDGE, "GESTALT PRINCIPLES OF PERCEPTION"

PROXIMITY



BANG WONG, "GESTALT PRINCIPLES, I", NATURE METHODS

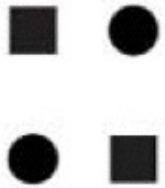
CONNECTEDNESS



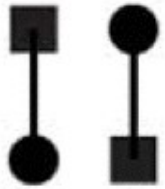
WARE, "INFORMATION VISUALIZATION"

GROUPING

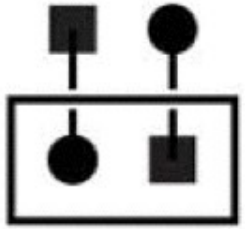
Similarity



Connection



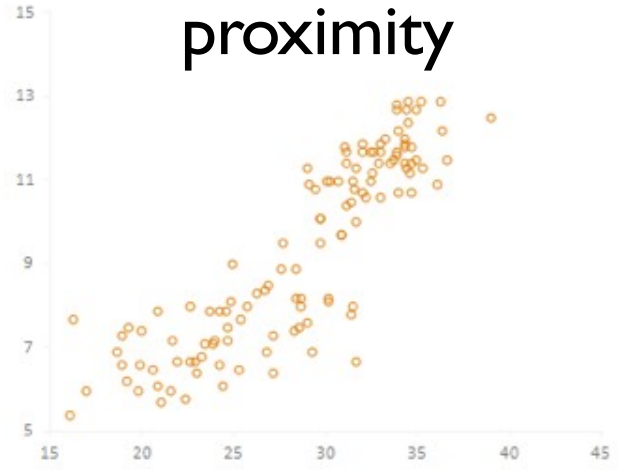
Enclosure



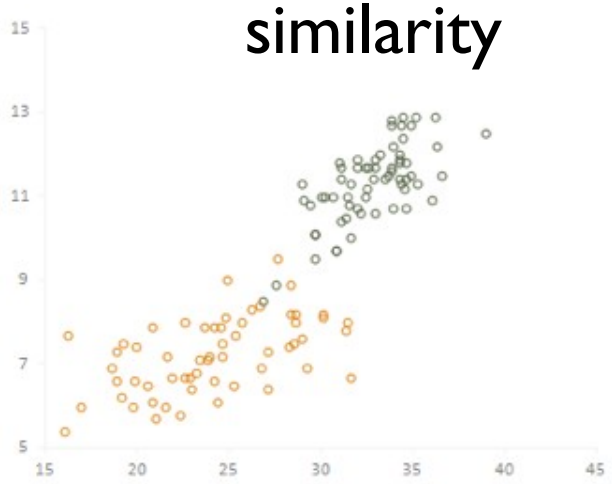
BANG WONG, "GESTALT PRINCIPLES, I", NATURE METHODS

GROUPING

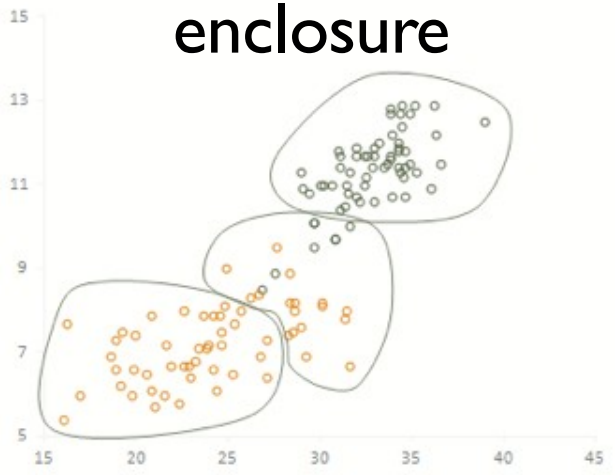
proximity



similarity

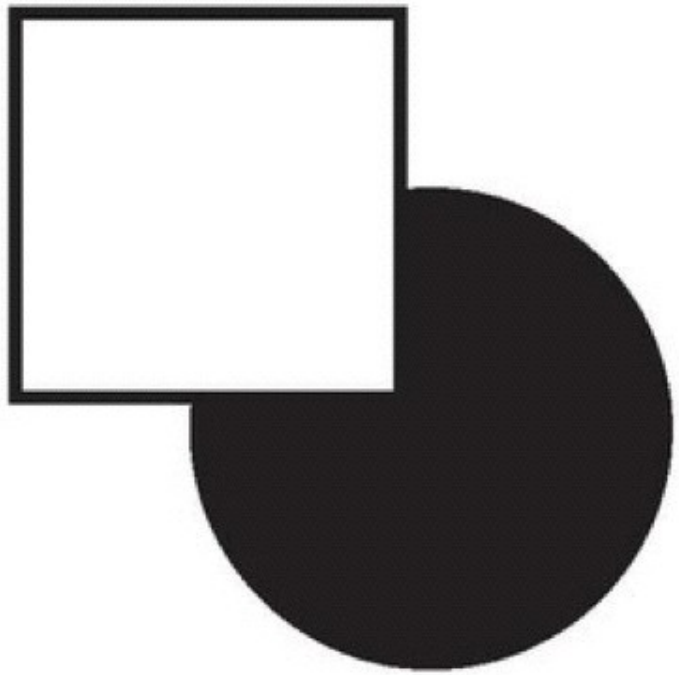


enclosure



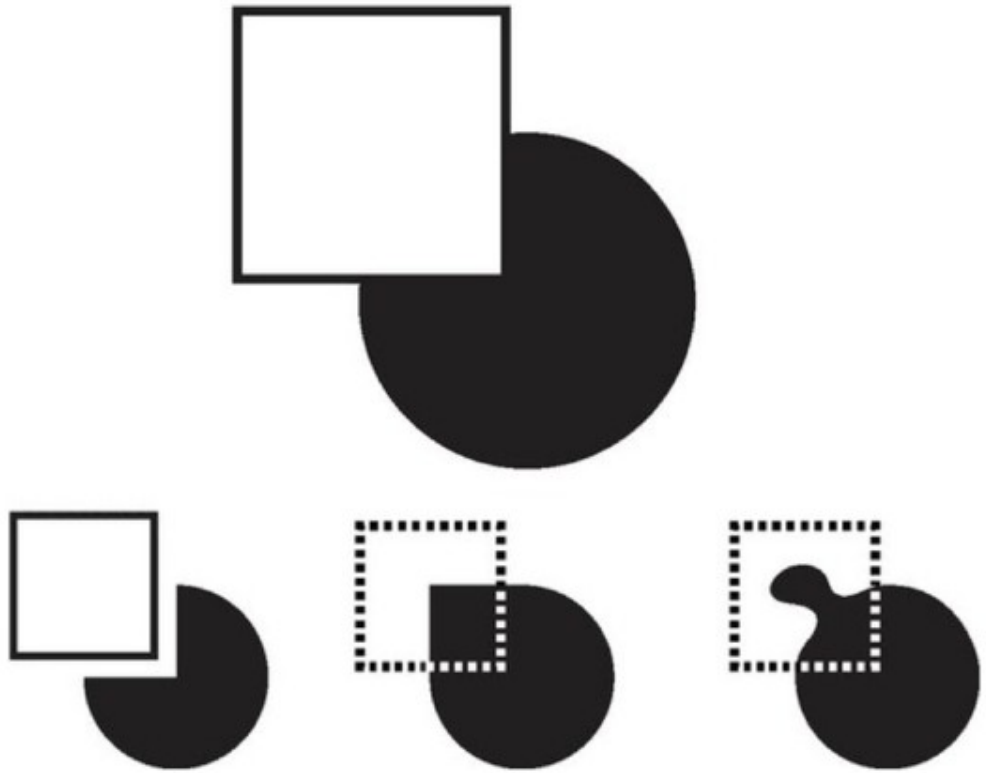
JORGE CAMOES

CONTINUITY



BANG WONG, "GESTALT PRINCIPLES, II", NATURE METHODS

CONTINUITY



BANG WONG, "GESTALT PRINCIPLES, II", NATURE METHODS

CLOSURE

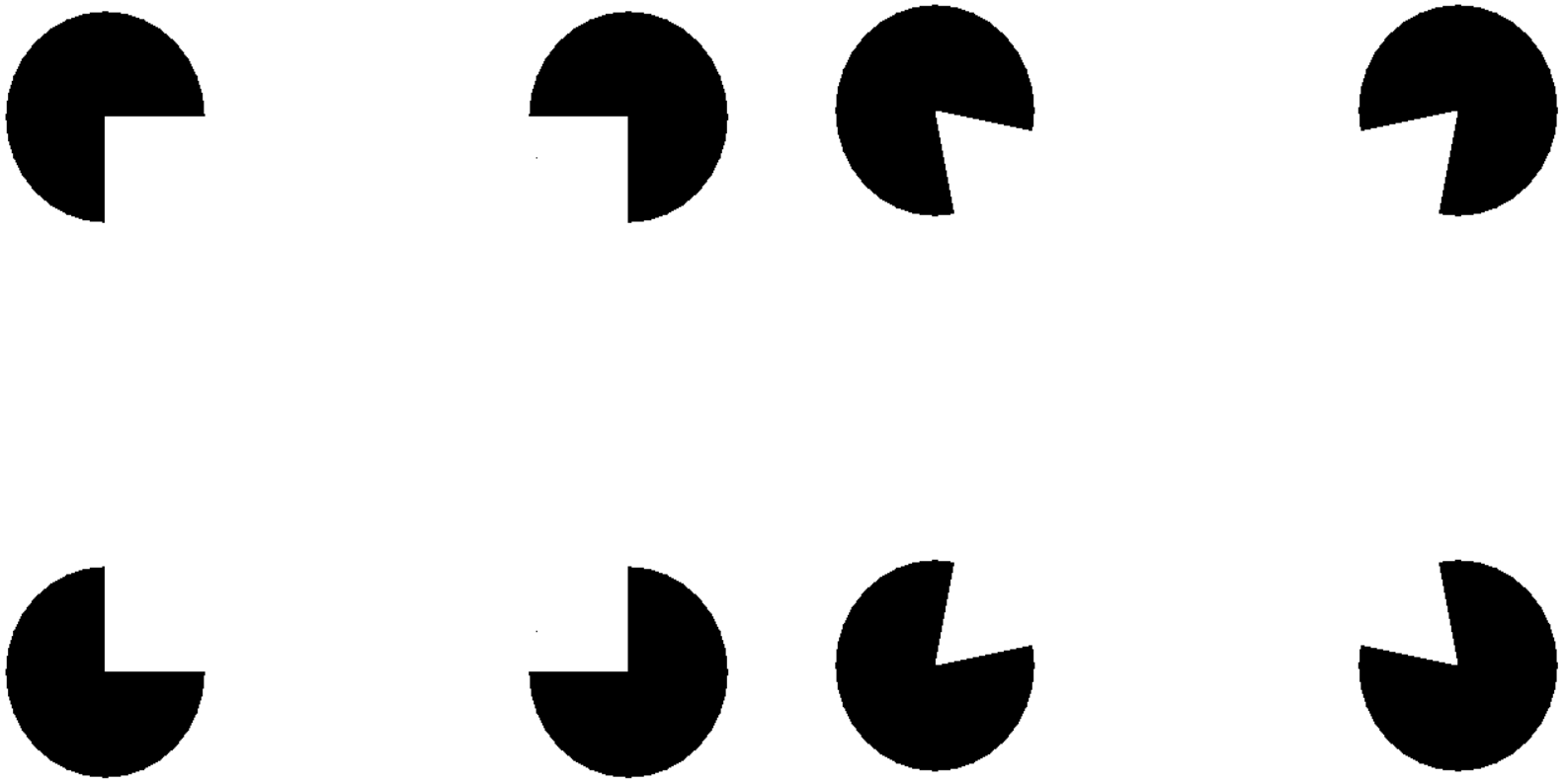
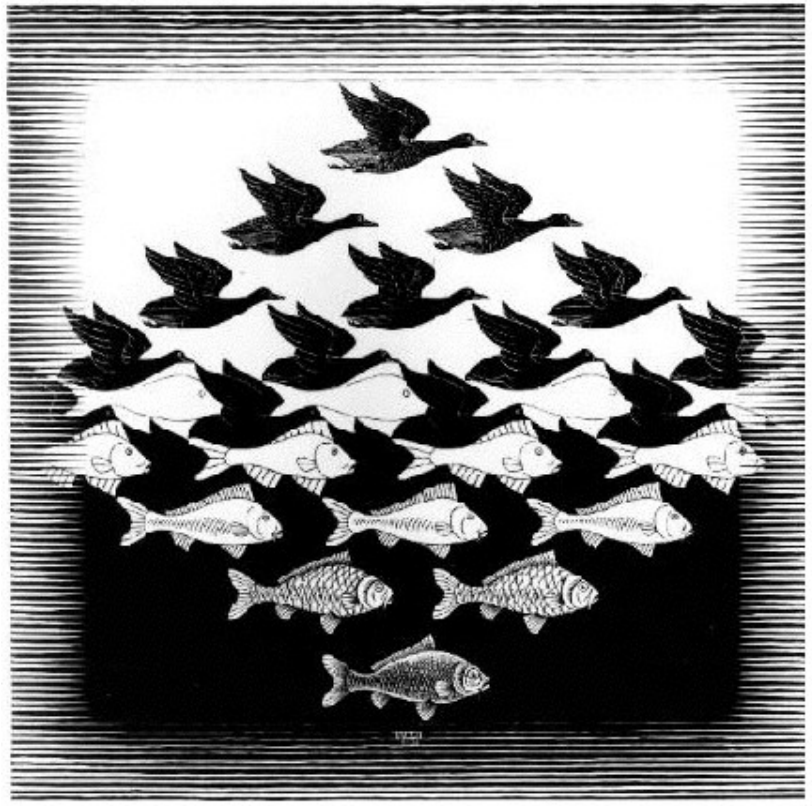


FIGURE / GROUND



M.C. Escher: *Sky and Water I* 1938 woodcut

COMMON FATE

GESTALT PRINCIPLES

similarity: things that look like each other (size, color, shape) are related

proximity: things that are visually close to each other are related

connection: things that are visually connected are related

continuity: we complete hidden objects into simple, familiar shapes

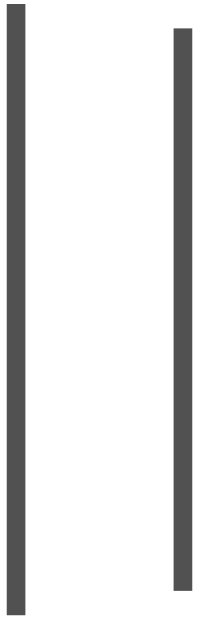
closure: we see incomplete shapes as complete

figure / ground: elements are perceived as either figures or background

common fate: elements with the same moving direction are perceived as a unit

AXIS OF ALIGNMENT

AXIS OF ALIGNMENT



ATTENTION

HTTPS://YOUTU.BE/VJG698U2MVO

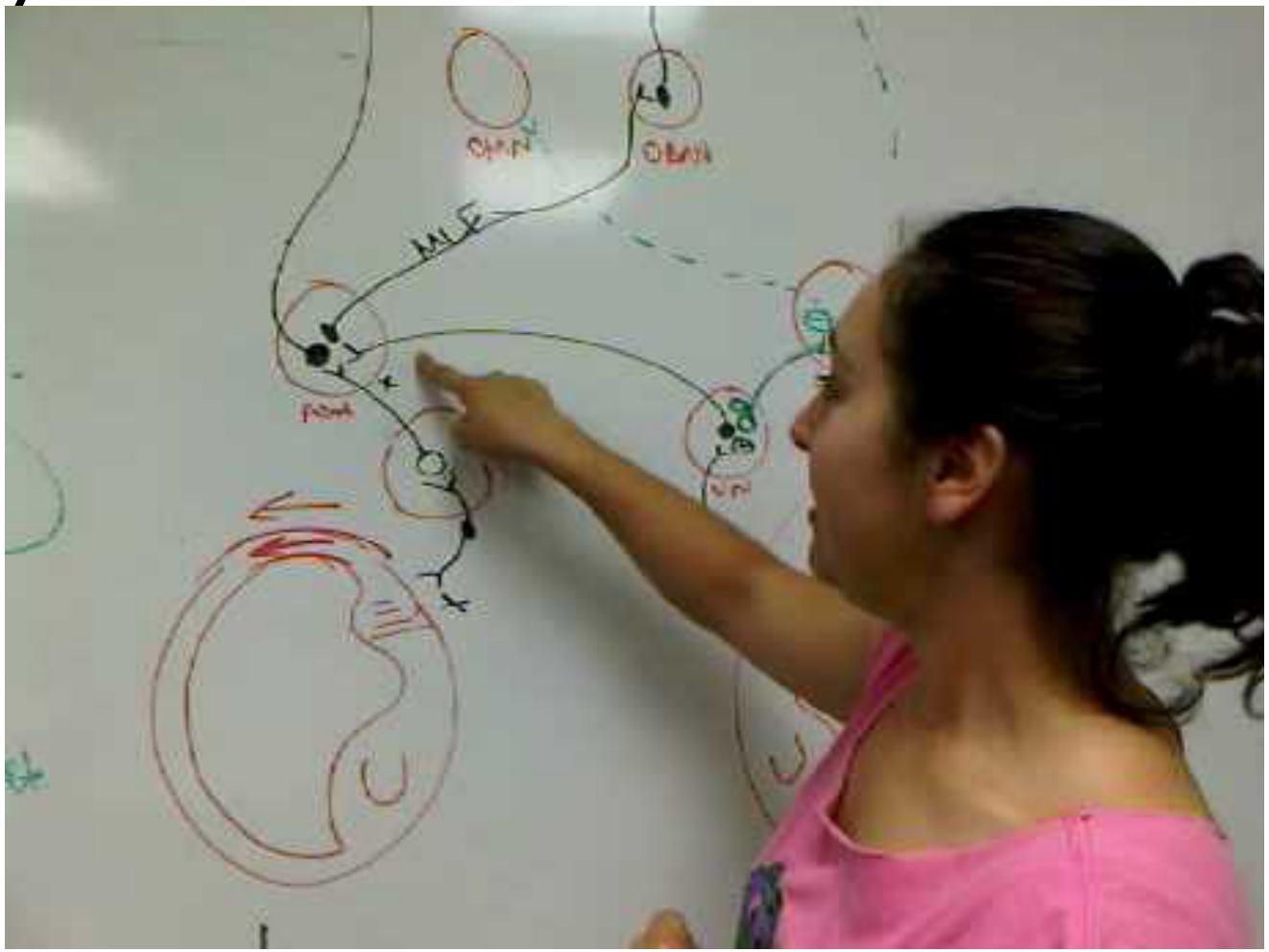
VECTION

Illusions of movement—motions in the display give the viewer a sensation that they have moved.

HTTPS://YOUTU.BE/61YMTX7OFEC

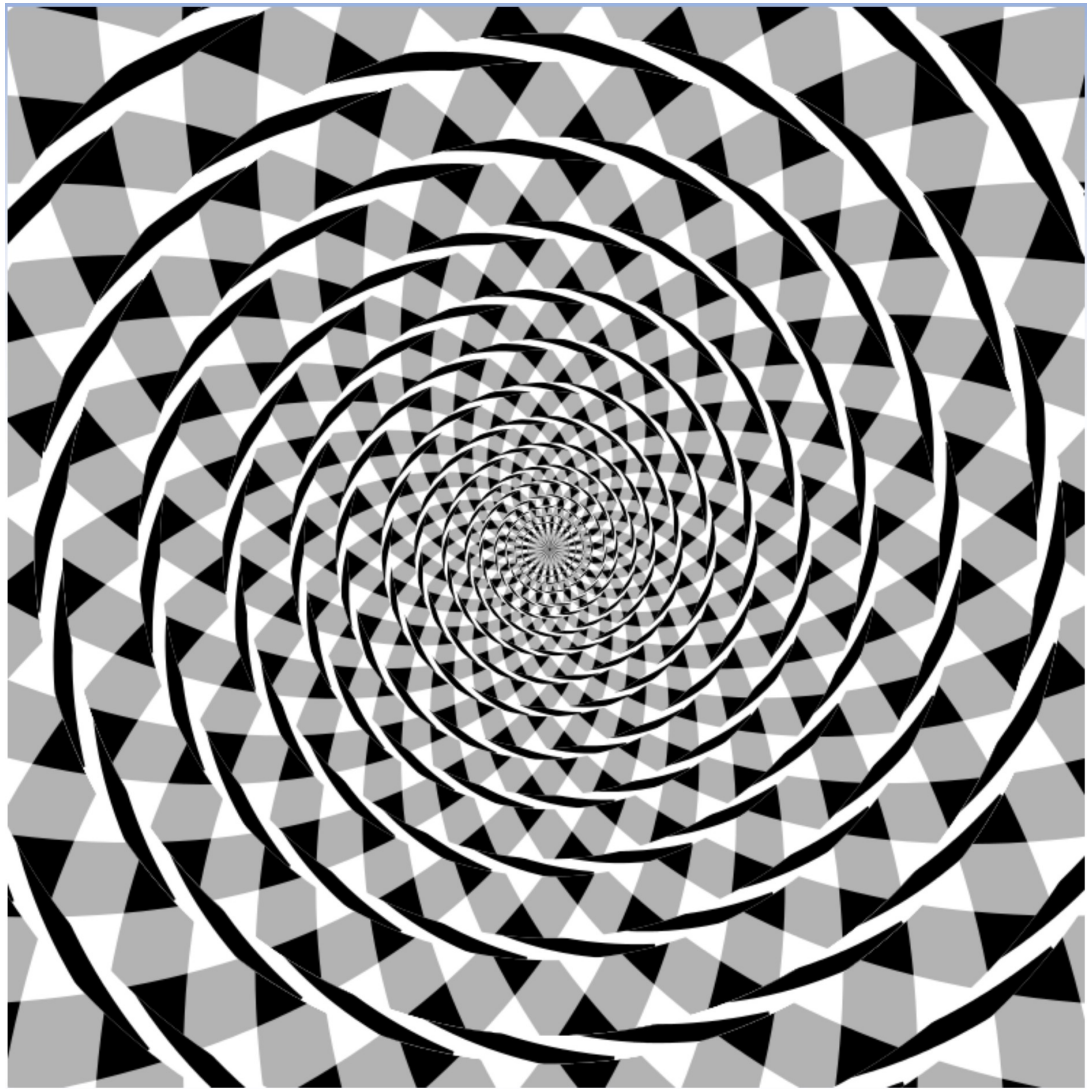
VESTIBULO-OCULAR REFLEX

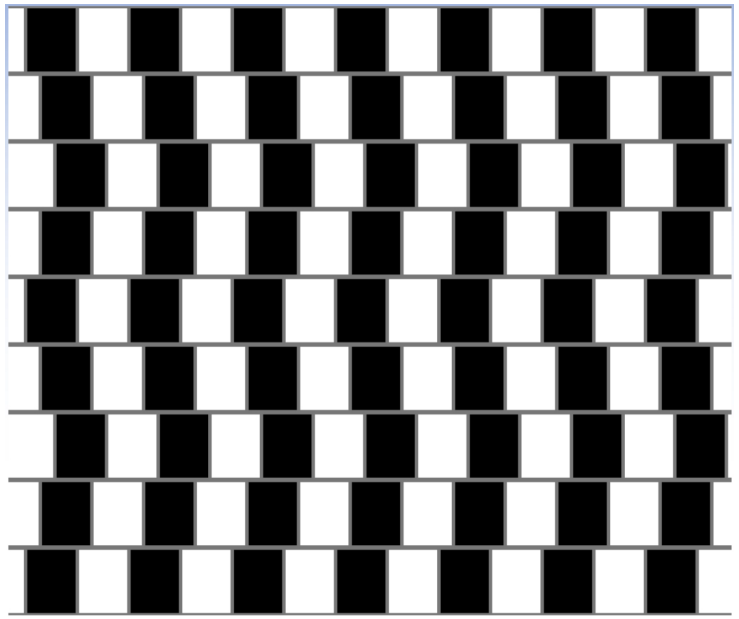
Reflex, where activation of the vestibular system of the inner ear causes eye movement

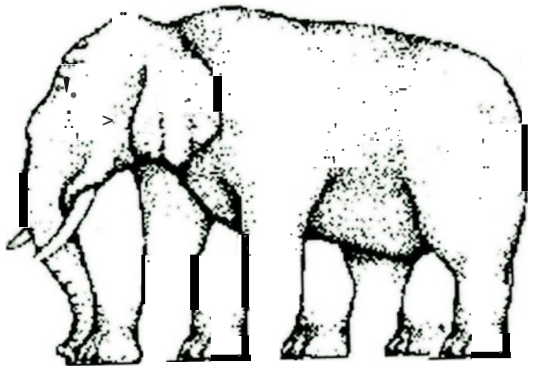


HTTPS://YOUTU.BE/MLBYNQ8KEDQ

More Optical Illusions







Depth Perception

More on this later

Other Processes

Sensory System	Modality	Stimulus Energy	Receptor Class	Receptor Cell Types
Somatosensory	Touch	Tap, flutter 5–40 Hz	Cutaneous mechanoreceptor	Meissner corpuscles
Somatosensory	Touch	Motion	Cutaneous mechanoreceptor	Hair follicle receptors
Somatosensory	Touch	Deep pressure, vibration 60–300 Hz	Cutaneous mechanoreceptor	Pacinian corpuscles
Somatosensory	Touch	Touch, pressure	Cutaneous mechanoreceptor	Merkel cells
Somatosensory	Touch	Sustained pressure	Cutaneous mechanoreceptor	Ruffini corpuscles
Somatosensory	Proprioception	Stretch	Mechanoreceptor	Muscle spindles
Somatosensory	Proprioception	Tension	Mechanoreceptor	Golgi tendon organ
Somatosensory	Temperature	Thermal	Thermoreceptor	Cold and warm receptors
Somatosensory	Pain	Chemical, thermal, and mechanical	Chemoreceptor, thermoreceptor, and mechanoreceptor	Polymodal receptors or chemical, thermal, and mechanical nociceptors
Somatosensory	Itch	Chemical	Chemoreceptor	Chemical nociceptor
Visual	Vision	Light	Photoreceptor	Rods, cones
Auditory	Hearing	Sound	Mechanoreceptor	Hair cells (cochlea)
Vestibular	Balance	Angular acceleration	Mechanoreceptor	Hair cells (semicircular canals)
Vestibular	Balance	Linear acceleration, gravity	Mechanoreceptor	Hair cells (otolith organs)
Olfactory	Smell	Chemical	Chemoreceptor	Olfactory sensory neuron
Gustatory	Taste	Chemical	Chemoreceptor	Taste buds

PROBLEMS

Mismatching Sensory information

- For example: Vision and acceleration is not matched in a flight-simulator. (Unless an advanced motion-platform is used).

Update frequency

- Due to simulation, scene complexity, etc.
- Frame rate (FPS), the rate of which the system can generate new images

PROBLEMS

Latency

- Due to simulation, graphic rendering of scene, device updates, etc. a latency is introduced.
- The time it takes for the system to react onto a users action

Using an HMD

- Eye convergence, fix focus

Simulator sickness (Cyber sickness) could be the result