THE UNIVERSITY OF MELBOURNE

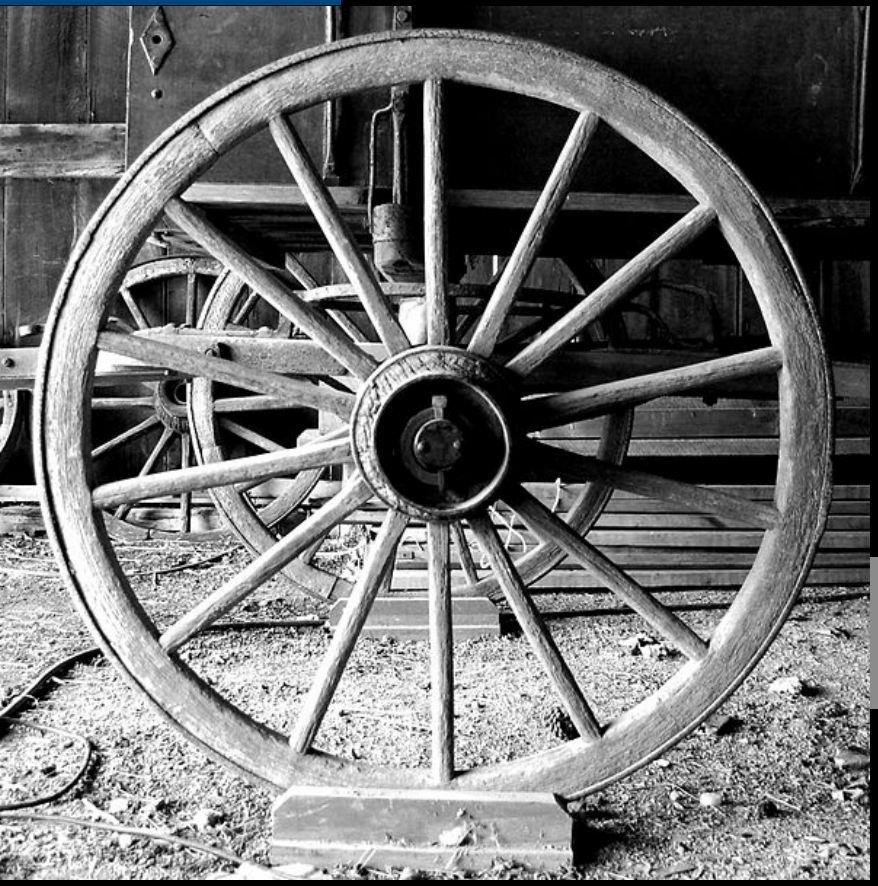


Image: Wikimedia Commons

GEOM90007

SPATIAL VISUALISATION

SENCING – PERCEPTION

LAST LECTURE

- Introduction
  - Definitions
  - Subject modules
- Intro to Graphical Excellence
  - How can graphics lie or exaggerate
  - Examples

THIS LECTURE

- Processing
  - Luminance, brightness and lightness
  - Colour vision
  - Perceptual processing
    - Pre-attentive and attentive
    - Implications for visualisation

"We can think of the world itself as an information display…

Every intricate surface reveals the properties of the material from which it is made…

If our extraordinary skill in perceiving the information inherent in the environment can be applied to data visualization, we will have gained a truly powerful tool."

(Ware, 2013)

Sensing with the Eye

HUMAN VISION

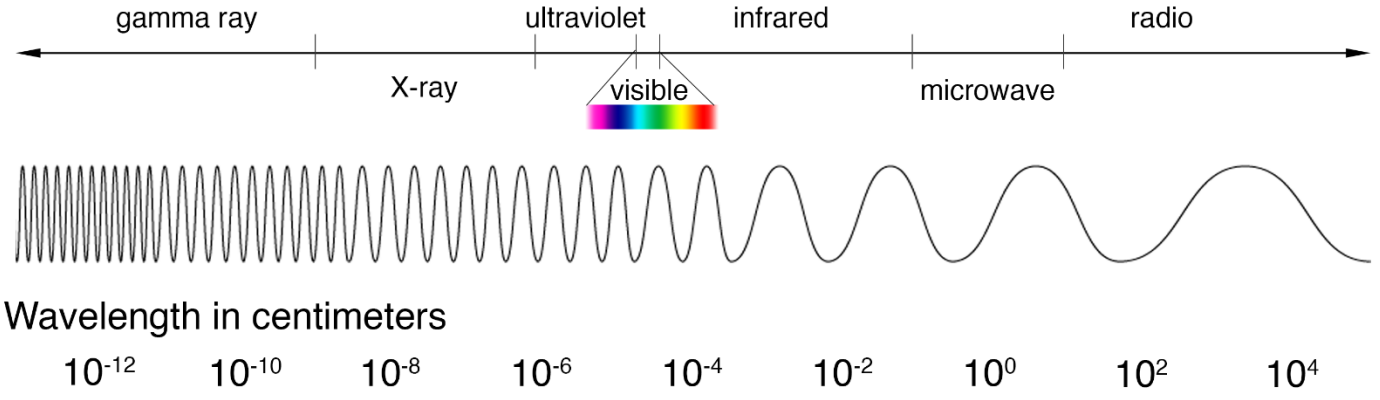
- Human vision is integral to visualisation:
  - How we see phenomena (e.g. colour)
  - How we represent phenomena (e.g., geometry)
  - How we design complex systems (e.g., HCI)

- Vision involves the gathering and recording of light scattered from **objects** in the environment (or scene)

- Light enters the eye to interact with very small photoreceptors
  - **Phototransduction** is when photons are converted into electrical signals

VISIBLE SPECTRUM

- Humans can only sense a very small 'visible' part of the electromagnetic spectrum



www.nasa.gov

- Colour (and total) blindness is the result of not responding to certain wavelengths (e.g., red λ)

- Note, energy of light depends on its wavelength and intensity

THE EYE

- The eye is the organ of vision
- Light is transmitted through space-time (which may be reflected from surfaces), enters the eye and various muscles perform **focusing** to allow us to 'look' at objects in the scene

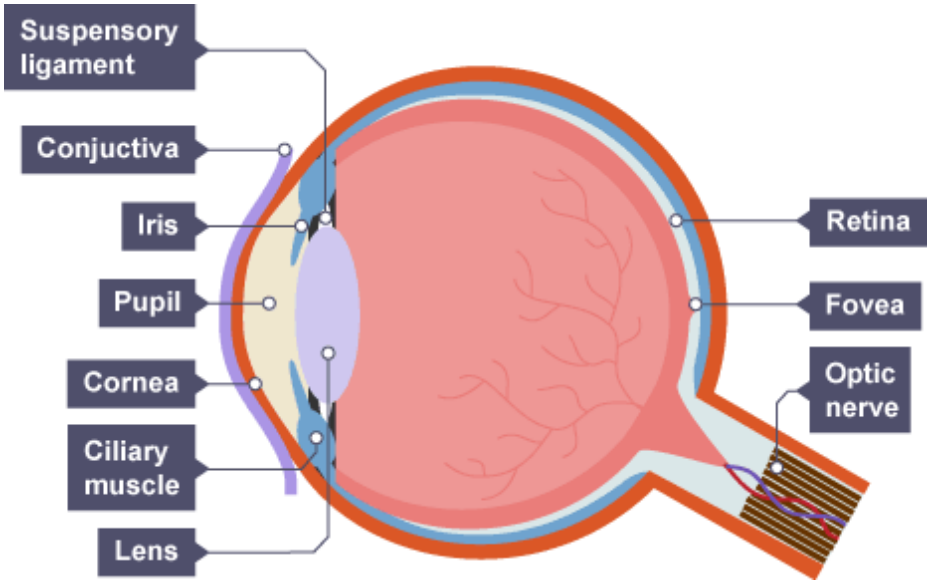
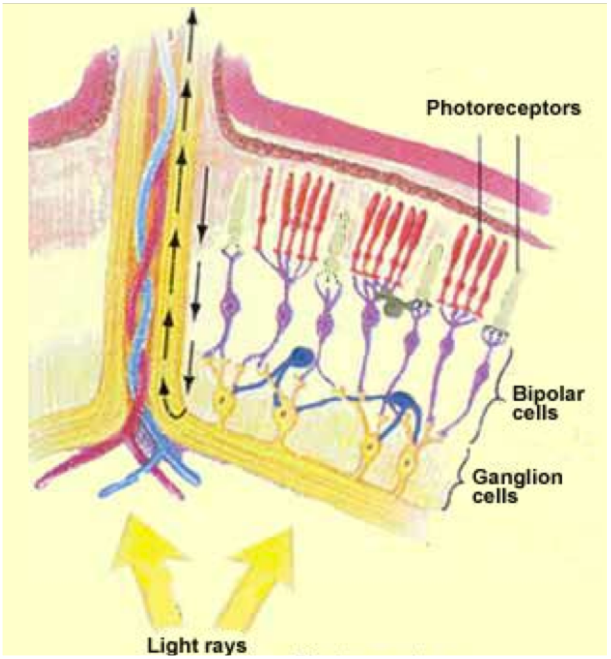


Image: BBC GCSE Bitesize

- Once oriented, light is projected onto a photoreceptive layer called the **retina**
- The **fovea** is the area (of the retina) with highest acuity (clarity)
- Retina (roughly) radially structured around the fovea.

RETINA

- Comprises three main layers of neurons (brain cells)
  - Photoreceptors (convert light to nerve impulses)
  - Bipolar neurons
  - Ganglion neurons (their axons — **optic nerve** — carry the nerve impulses to the visual relay in the brain)



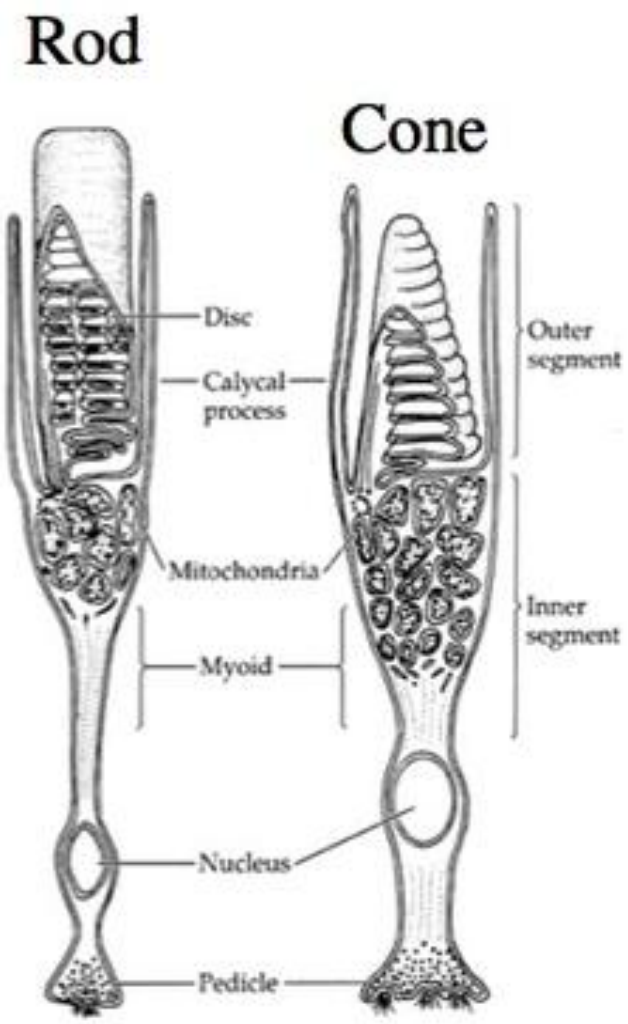
- Each of these neurons has a specific **receptive field**—the visual area over which a neuron responds to light
- Neurons are the basic circuits of information processing in the brain
  - Respond to fixed wavelength ranges
  - Fire discrete pulses of electricity with varying rates (↑**excited** — ↓**inhibited**)

Rods:

- ~100 million
- Associated with **scotopic** vision (low light)
- Low acuity
- 1 type, highly sensitive
  - Active 400 – 700nm
- Generally **achromatic** (without colour)

Cones:

- ~6 million
- Associated with **photopic** vision (day light)
- Higher acuity
- Typically 3 types with varying sensitivity:
  - Low wavelength (L), peak 420nm ~Red
  - Medium (M), peak 530nm ~Green
  - Short (S), peak 560nm ~Blue
- Together form **trichromatic** vision
- Variation may lead to vision deficiencies*



Photoreceptors

Image: Vision Eye Institute, Australia

RETINA

Distribution of rods and cones across the retina

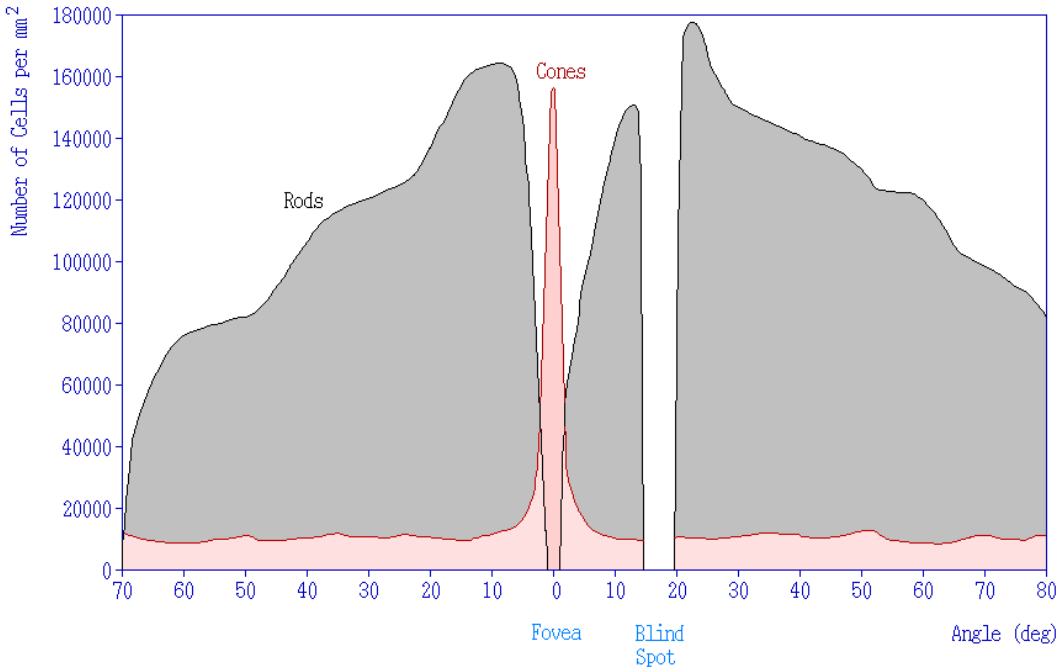
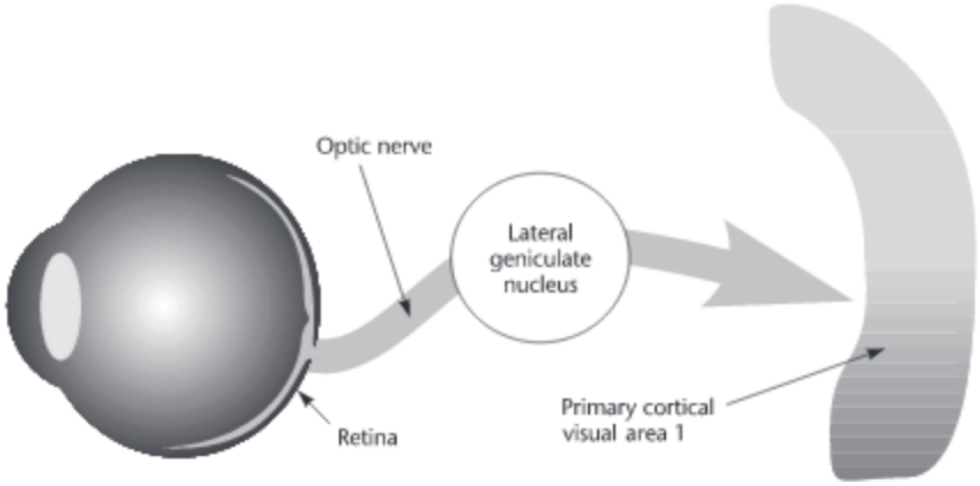


Image: Wikimedia Commons

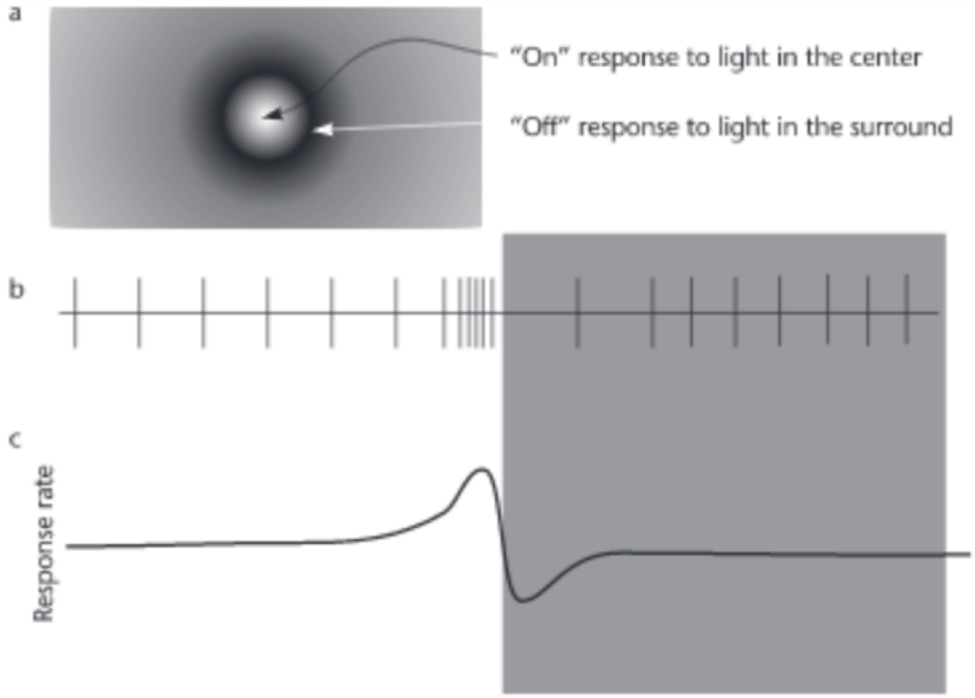
- Highest acuity at the **fovea** that subtends 1 to 2 degrees of visual angle.
- Where the optic nerve meets the retina, due to the lack of photoreceptors, a ***blind spot*** occurs.
- Limited number of photoreceptors mean the eye can manage only a certain amount of visual information at a given time frame.

FROM THE EYE TO THE BRAIN



- Photoreceptor connectivity with ganglion cells varies
  - In the fovea cone connections are typically 1:1
  - Outside, thousands of rods may share a single ganglion resulting in generalisation (compression) and data loss.
  - Optic nerve only contains ~1M fiber; thus, they eye performs a significant amount of processing (*image compression* and perhaps, *segmentation*) before transmitting information to the brain.
- Visual information is primarily processed in the visual cortex, the largest brain system
  - Five main regions V1 (primary), V2…V5
  - Tasks from object recognition to action – complex processing

RECEPTIVE FIELDS: ON- OR OFF-CENTER



a) Receptive field structure of an on-center cell

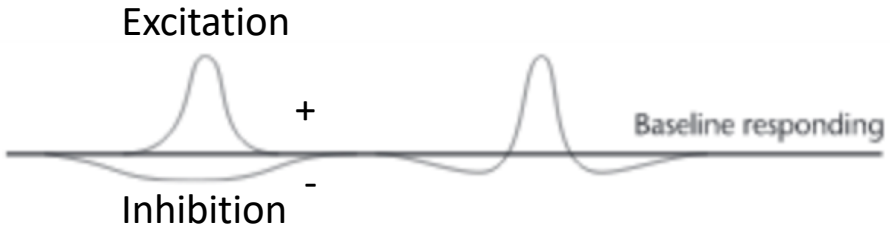
b) As the cell passes over from a light region to dark region, the rate of neural firing increases just to the bright side of the edge and decreases on the dark side

c) A smooth plot of the cell activity level

$$f(x) = \alpha_1 e^{-\left(\frac{x}{\sigma_1}\right)^2} - \alpha_2 e^{-\left(\frac{x}{\sigma_2}\right)^2}$$

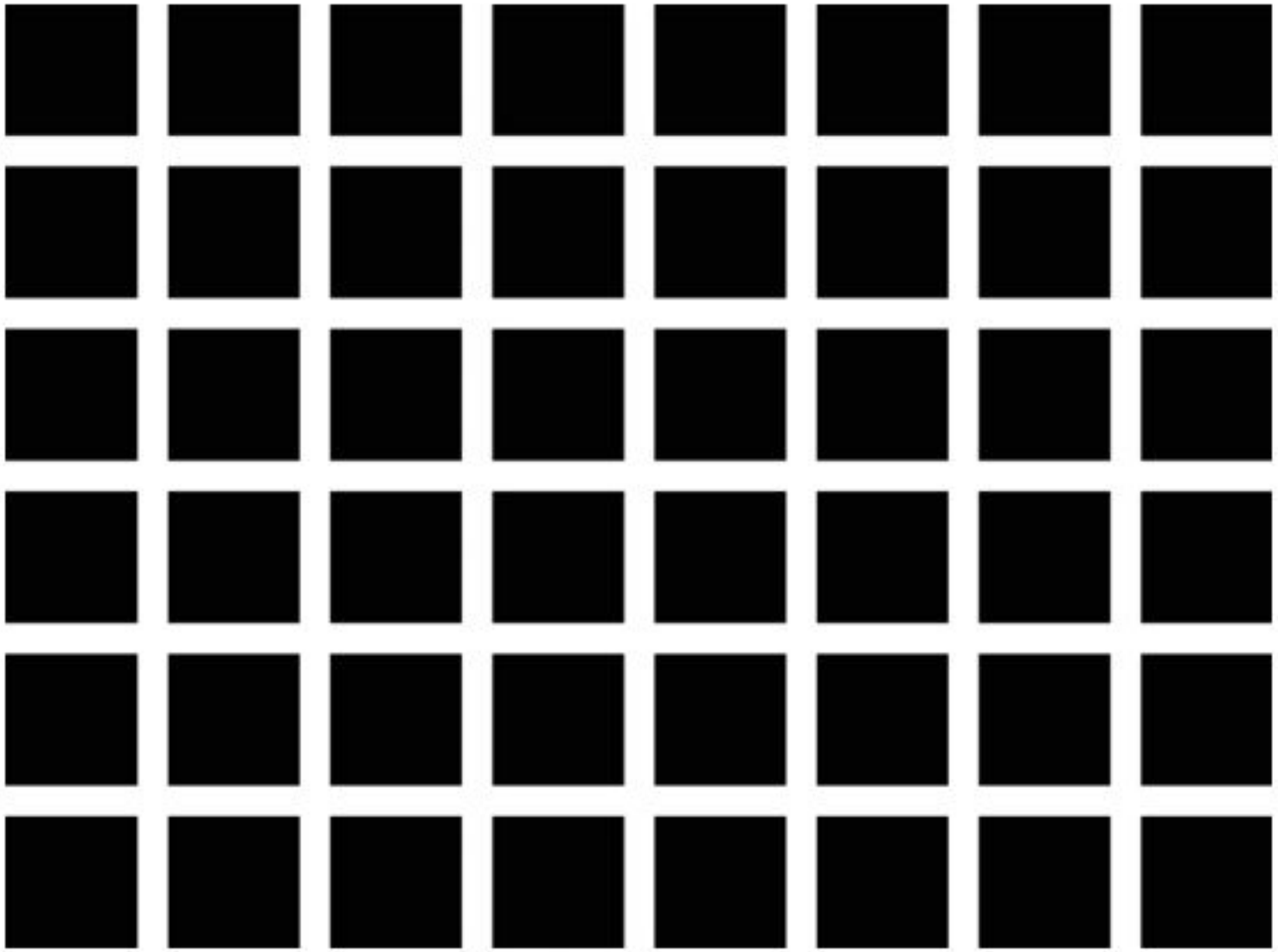
Difference of Gaussian (DoG) model

DoG model of a receptive field

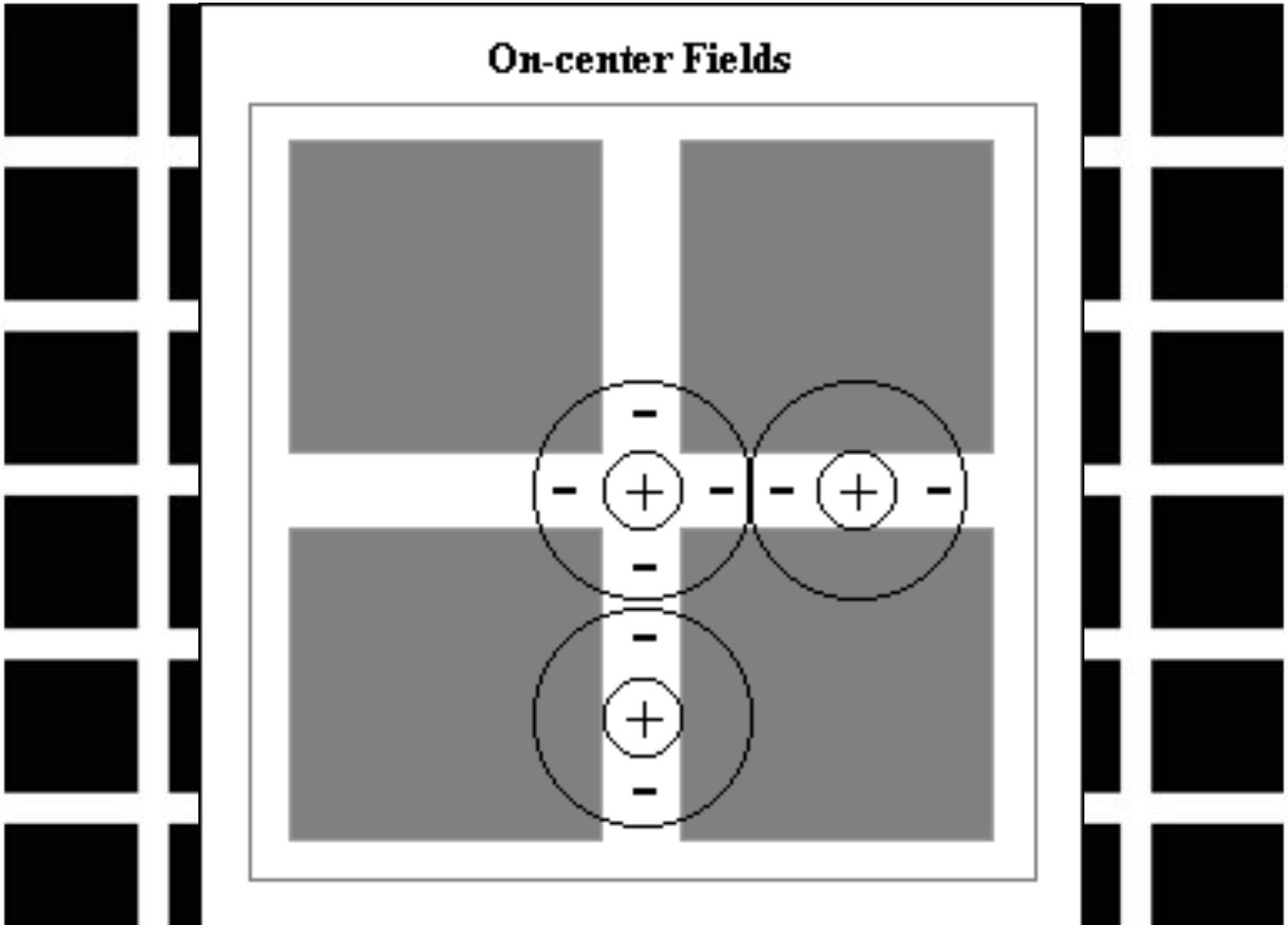


EXAMPLE: on-center retinal ganglion cells

Hermann grid



Hermann grid



THE EYE – KEY POINTS

- Retina develops from brain cells (neurons)
- Limited number of rods and cones
  - Can only handle a certain amount of information over any given time frame
- Non-uniform distribution leads to variation in vision
  - Decreased acuity in the periphery
- A ‘blind spot’ occurs at the optic nerve connecting to the brain (lacks photoreceptors)

VISUAL PROCESSING IN THE BRAIN

Signal processing is performed by neurons
Frequency-modulated pulses are exchanged

- **Retinal processing**
  - Signals pass through layers of neurons to reach rods and cones
  - Compression before transmission through optic nerve to the brain

- **Brain**
  - Optic nerves pass through optic chiasma
  - Left hemispheres generally* receives signals from right visual field (vice-versa)
  - Stereopsis and other post-processing

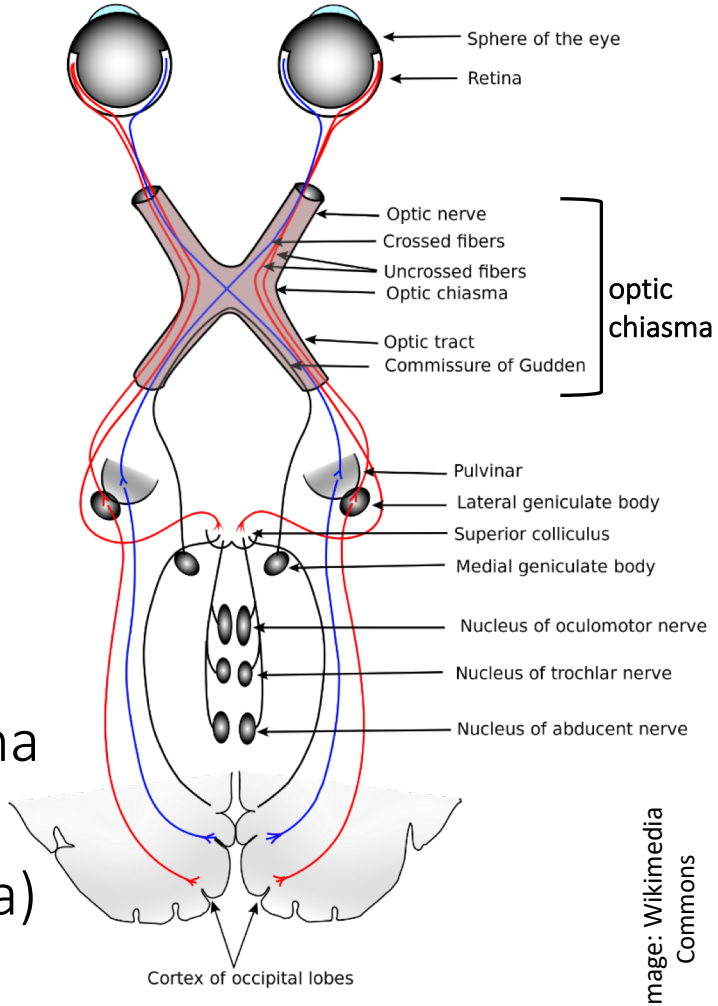


Image: Wikimedia Commons

VISUAL PROCESSING

- Four types of eye movement – critical to understanding scenes

1. Smooth pursuit movements
Both eyes move smoothly along the same line (conjugate movement)

2. Vergence eye movements
Convergence or divergence of view lines (disconjugate)

3. Saccadic eye movements
Rapid changes in point of fixation (eye moves up to 1000/s) e.g. REM

4. Saccadic masking
Gaps between rapid movements may be suppressed (smoother flow)

More information: Purves et al. (2001) Neuroscience, http://www.ncbi.nlm.nih.gov/books/NBK10991/

VISUAL PROCESSING

- Four ty critica es

  1. Sm
  Both ng the ovement)

  2. Ver
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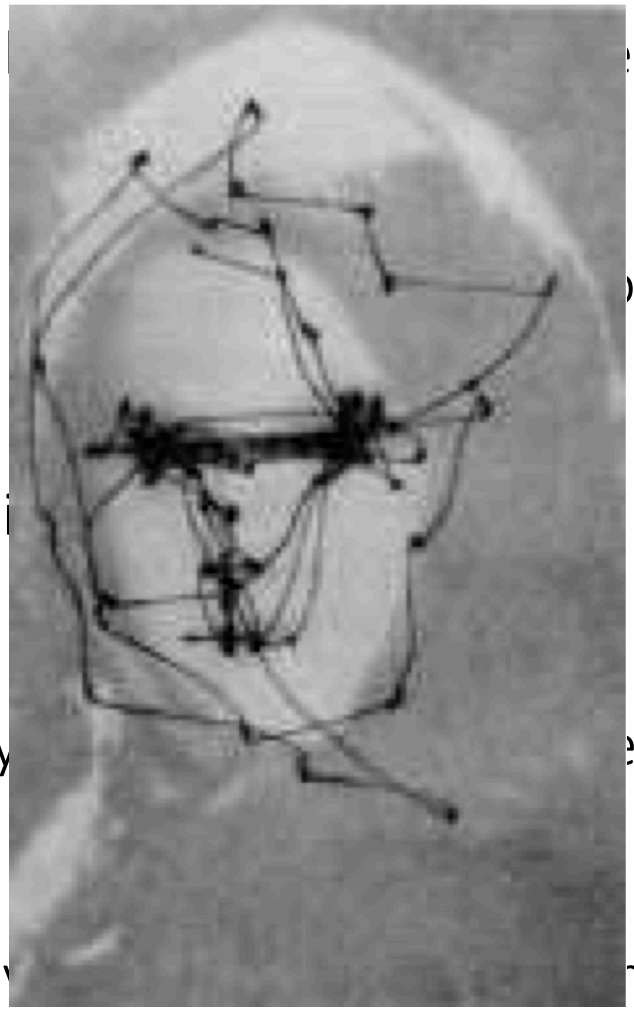

More information: Purves et al. (2001) Neuroscience, http://www.ncbi.nlm.nih.gov/books/NBK10991/

TESTING ACUITY

- Visual acuities are measurements of our ability to see detail.
- Acuities are **important in display technologies** because they give us an idea of the limits on the information densities that we can perceive
- For example, distinguishing between distinct features relies on the spacing of photoreceptors in the eye
- Superacuities (vernier and stereo)
  - Integrate input from many photoreceptors
- Using degrees (1/360 of a turn), mins (1/60 degree) and seconds (1/60 min)

TESTING ACUITY

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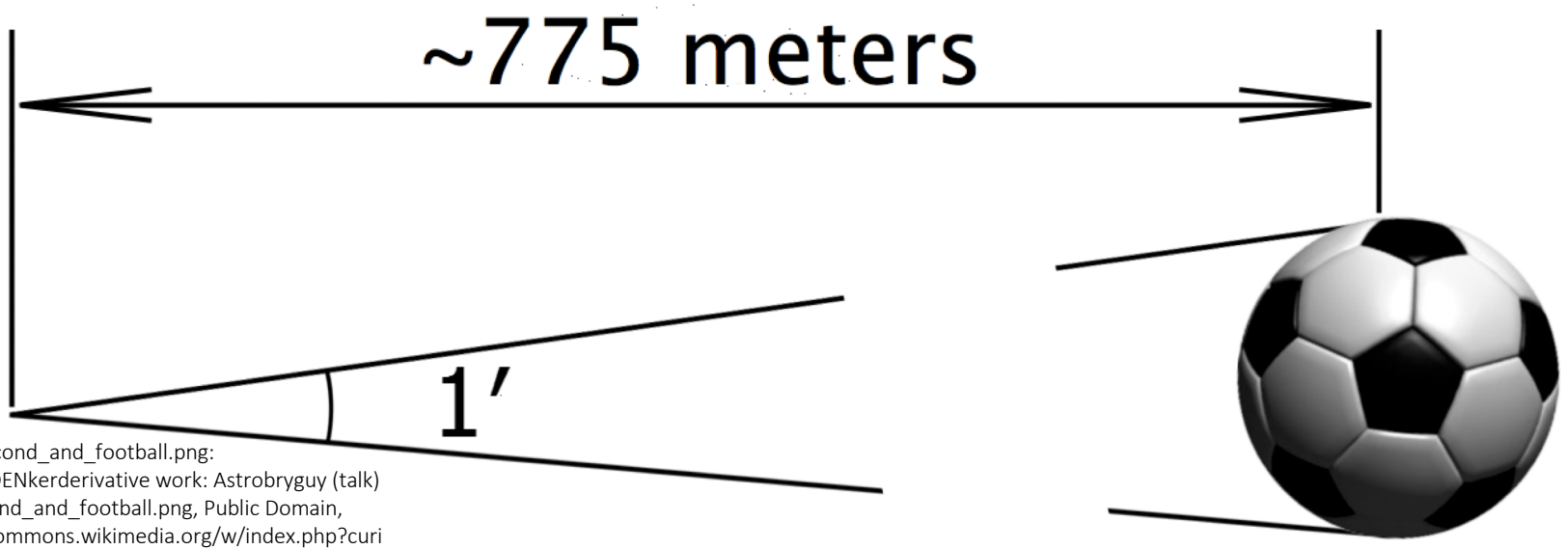


By Arcsecond_and_football.png: ru:User:DENkerderivative work: Astrobryguy (talk) - Arcsecond_and_football.png, Public Domain, https://commons.wikimedia.org/w/index.php?curid=16443304

  - Integrate input from many photoreceptors

- Using degrees (1/360 of a turn), mins (1/60 degree) and seconds (1/60 min)

Image: Ware (2013)

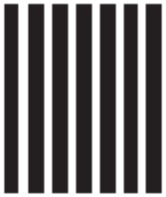
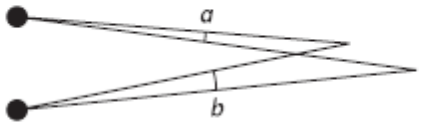
Point acuity (1 minute of arc) The ability to resolve two distinct point targets	
Grating acuity (1-2 minutes of arc). The ability to distinguish a pattern of bright and dark bars from a uniform gray patch.	
Letter acuity (5 minutes of arc). The ability to resolve letters. The Snellen eye chart is a standard way of meaning this ability. 20/20 vision means that a 5-minute letter target can be seen 90% of the time	
Stereo acuity (10 seconds of arc). The ability to resolve objects in depth. The acuity is measured as the different between two angles (a and b) for a just-detectable depth distance	
Vernier acuity (10 seconds of arc). The ability to see if two line segments are collinear.	

Image: NPS
www.nps.org.au

High contrast test

seconds (1/60 min)

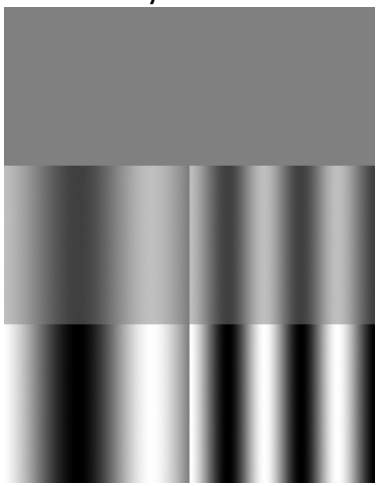
Image: Ware (2013)

TESTING CONTRAST SENSITIVITY

- The *measured amount of light,* $\boldsymbol{L}$*,* coming from a surface source (e.g. display)

- Contrast: difference in **luminance** of an object. Sensitivity can vary between individuals

- Contrast sensitivity function (CSF)
  Test pattern: Sine wave grating, with the following 5 variables:
  - Spatial Frequency (SF, # cycles per degree), Orientation (e.g. horizontal, vertical) Contrast (wave amplitude), Phase angle (displacement of pattern), Area of pattern
  - Usually uses *Michelson contrast* formula



Zero contrast

Medium contrast

High contrast

Low SF High SF

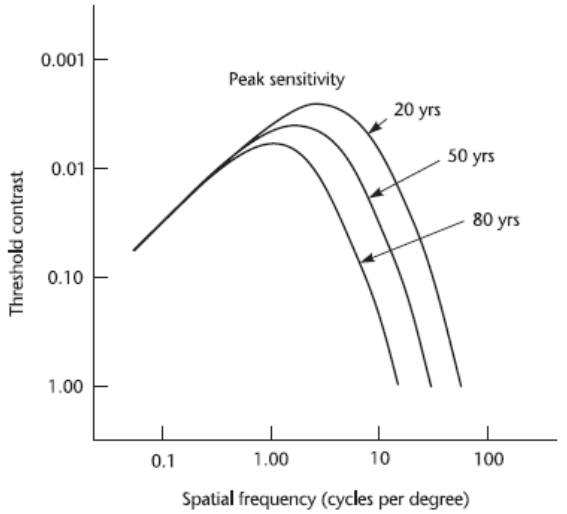


Image: Ware (2013)

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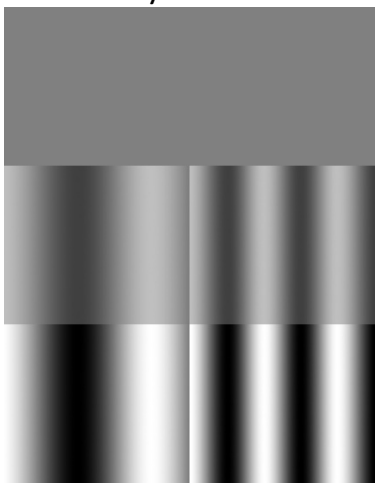

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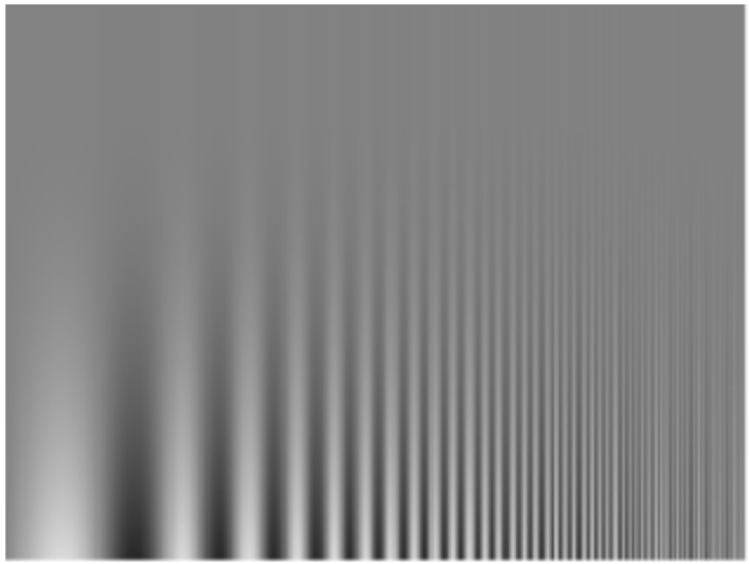

BINOCULAR AND FIELD OF VIEW

- Binocular vision
  - Improves acuity and contrast sensitivity

- Field of view
  - Monocular: ~160° (horiz)
  - Binocular overlap: ~120° (horiz)
  - Acuity is non-uniform over field
  - Impacts ability to use information displays and quickly analyse large information spaces (Koenig, 2010)

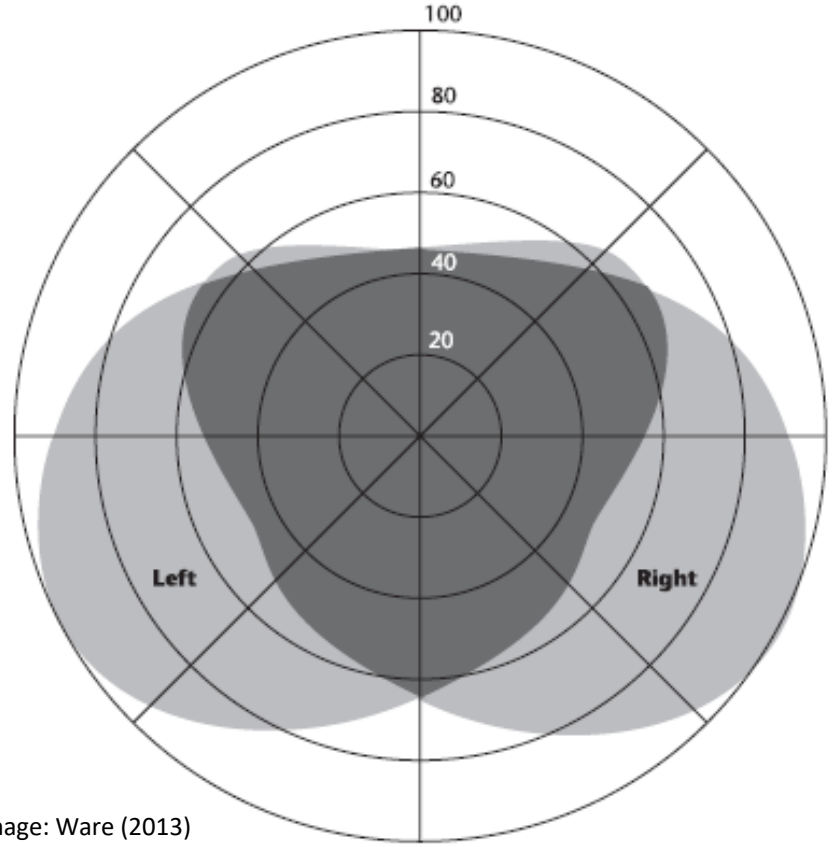

Image: Ware (2013)

BRAIN PIXELS VS SCREEN PIXELS

- The visual efficiency of a display: what screen size provides the best match of screen pixels to brain pixels (neurons in the eye)

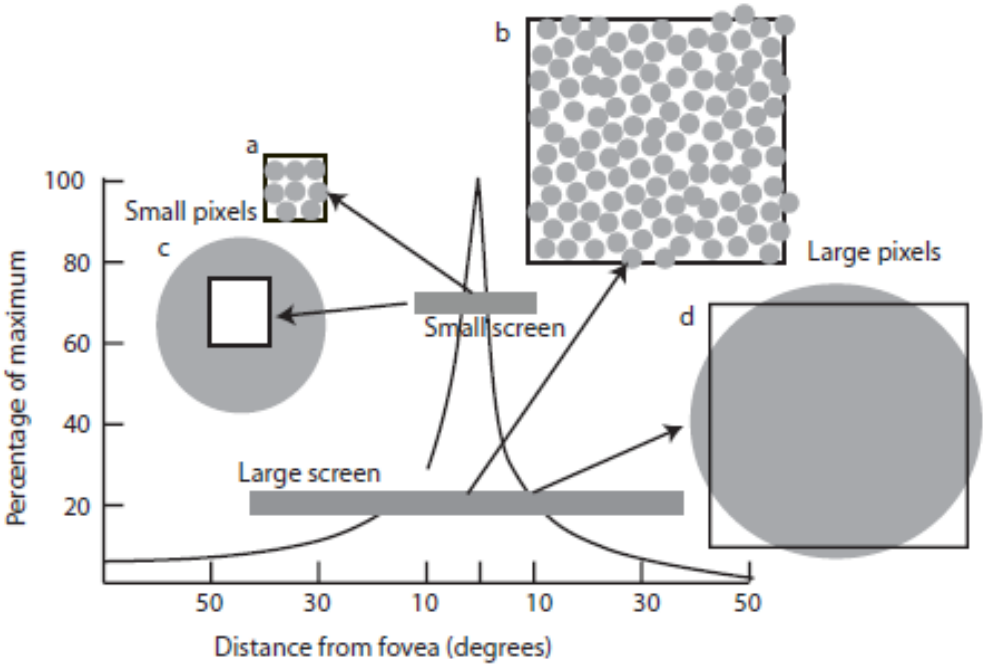

Image: Ware (2013)

- Small vs large screen
- Brain pixels vs screen pixels
- Periphery has compressed information
- Requires consideration of display dimensions and design (eff. communication)

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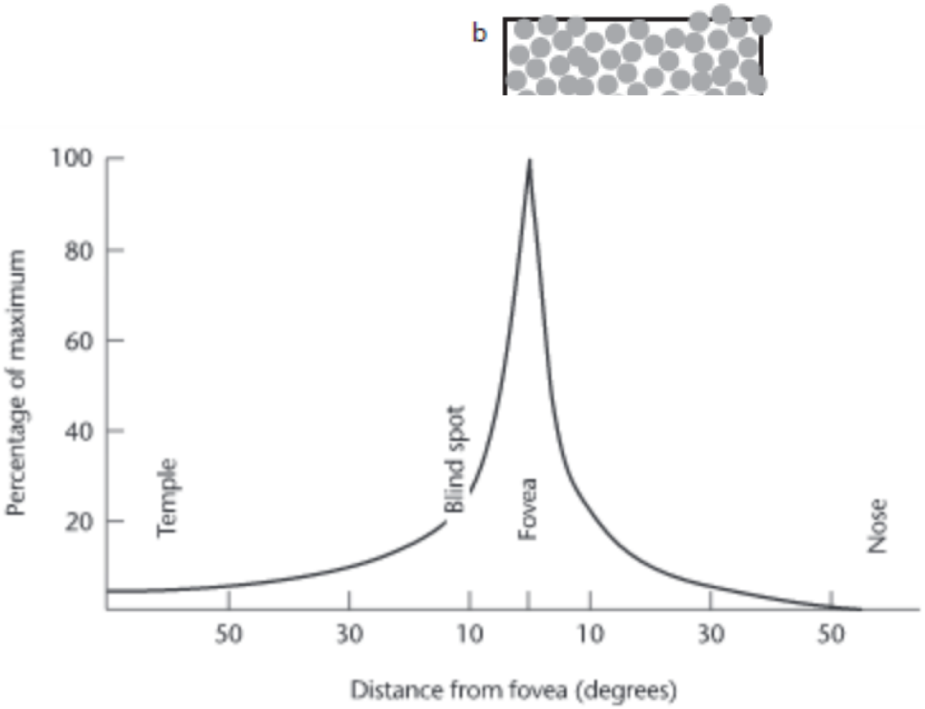

Image: Ware (2013)

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- Brain pixels vs screen pixels
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Light

INTERACTION WITH SURFACES

- Objects in nature are complex and varied
- Frequencies of visible light interacting with a surface may be (i) transmitted, (ii) absorbed or (iii) reflected
- The perceived colour of an object relates to the frequencies of light
  - we experience colour surfaces, not coloured light (*colour constancy)*
  - apparent overall reflectance of a surface *(lightness constancy)*
- Texture may cause irregular reflections, so reflected light can vary
- Light is complex from a modelling perspective with techniques to approximate its behaviour:

  diffuse (e.g. Lambertian), **ambient** and **specular** shading, impacting its reflection together with **shadowing**

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- Tex ary
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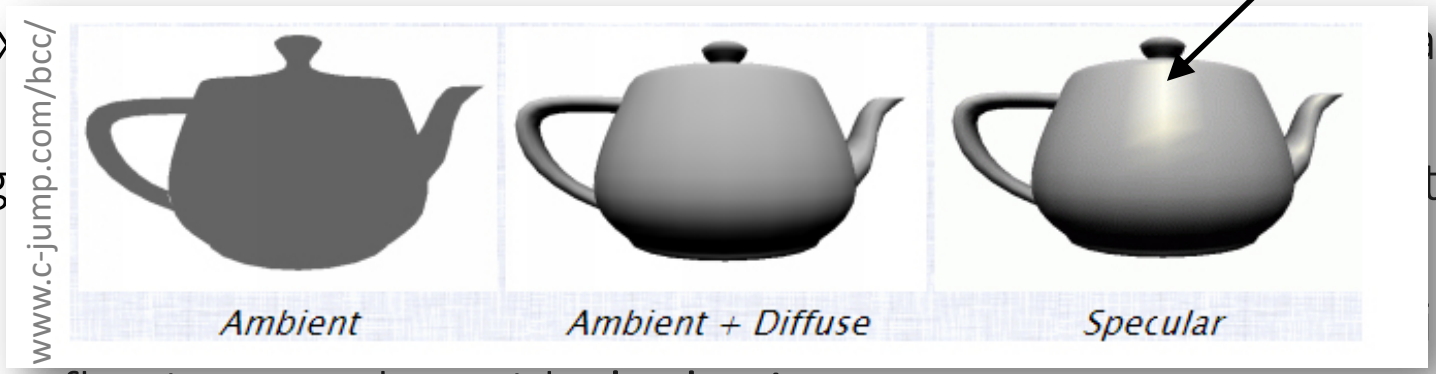
Luminance:
Intensity of light emitted from a surface in a particular direction (brightness)

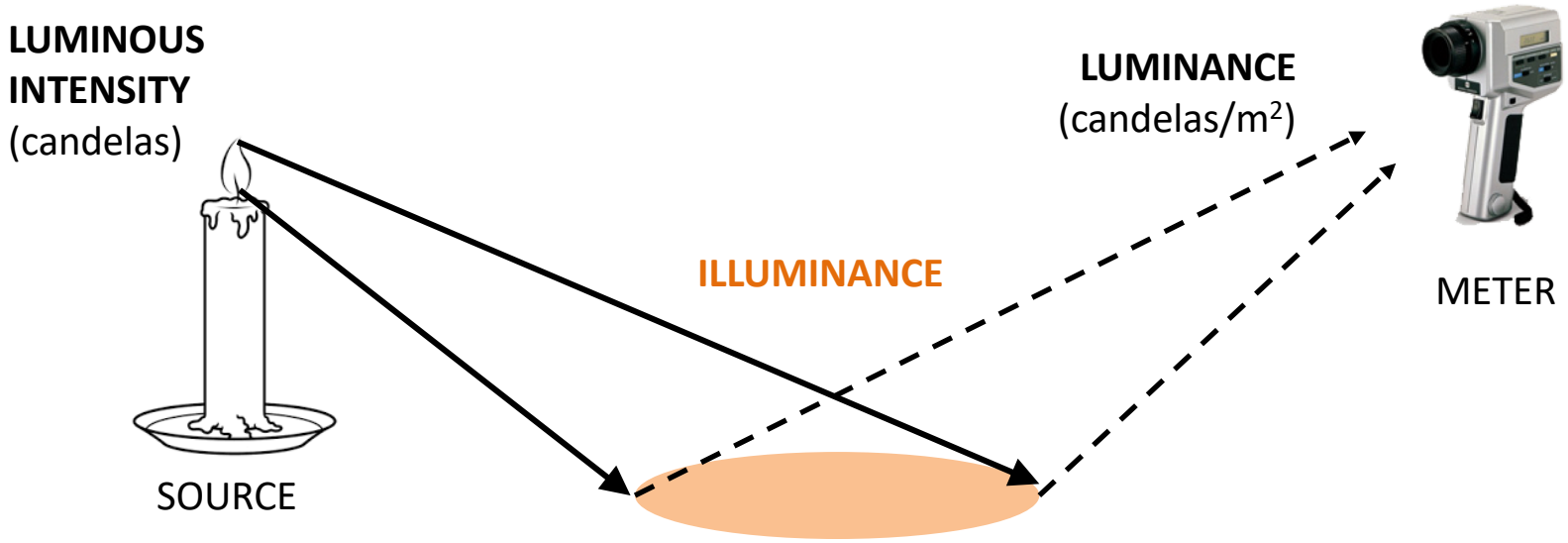


DESCRIBING LIGHT

- Different terms can be used to describe the quantity of light, depending on the perspective:
  - Luminance (physical variable)
  - Brightness (psychological variable)
  - Lightness (psychological variable)

DESCRIBING LIGHT

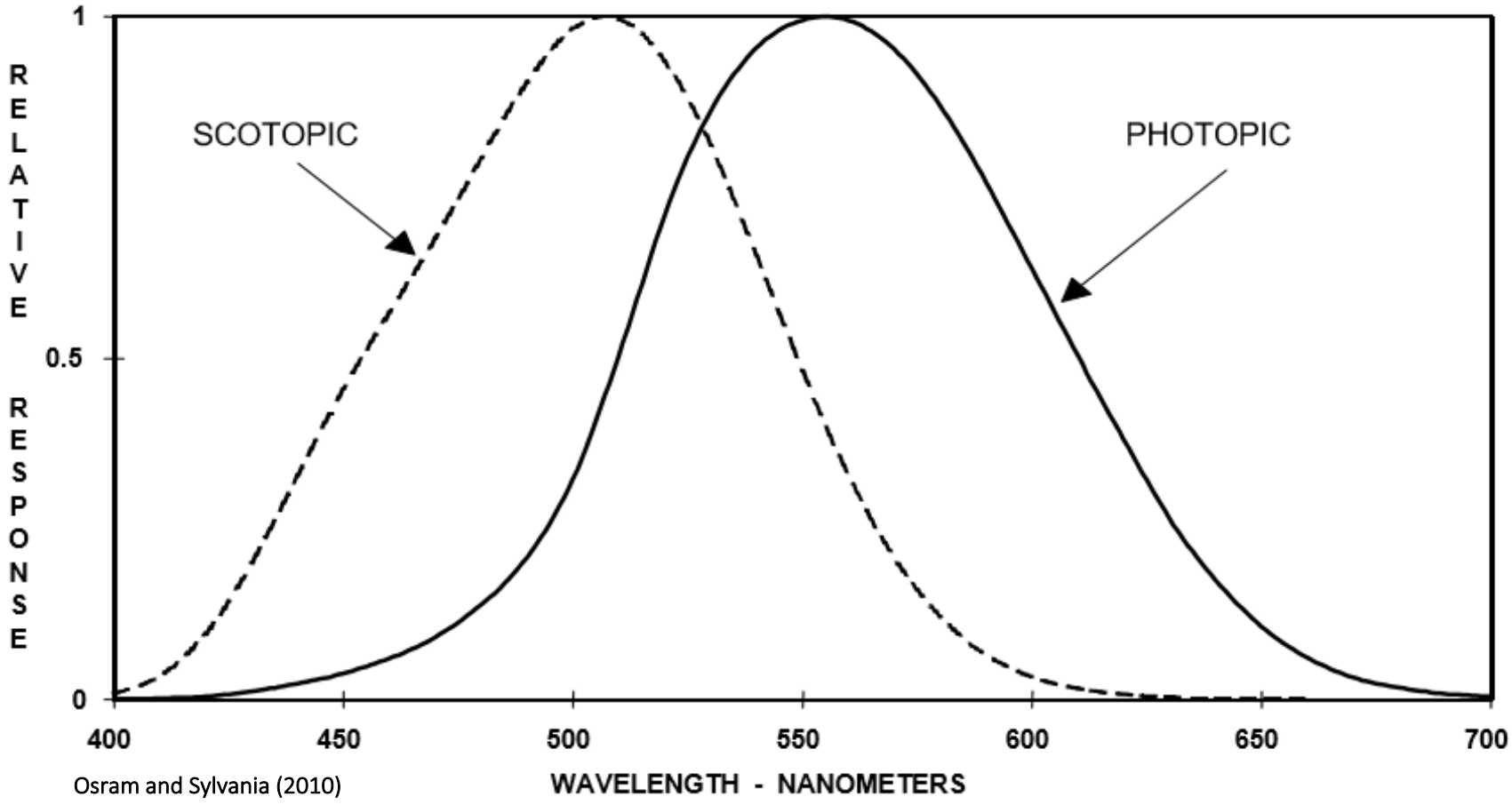
- Luminance
  - The *measured amount of light,* $\boldsymbol{L}$, coming from a surface source (e.g. display). Unit: candelas per square meter (cd/m^2)
  - Can be measured using a luminance meter (reads light incident from a specific angle)



REVIEWING PHOTORECEPTORS

- Photopic vision
  - High ambient conditions (day light), luminance $[10,10^6]$ cd/m^2
  - Max. sensitivity: ~550nm
  - Generally cone mediated
- Mesotopic vision, medium ambient conditions (dusk/dawn)
- Scotopic vision
  - Low ambient conditions (night), luminance $[0.001,10^{-6}]$ cd/m^2
  - Max. sensitivity: ~507nm
  - Generally rod mediated (colour is lost)

REVIEWING PHOTORECEPTORS



Osram and Sylvania (2010)

REVIEWING PHOTORECEPTORS

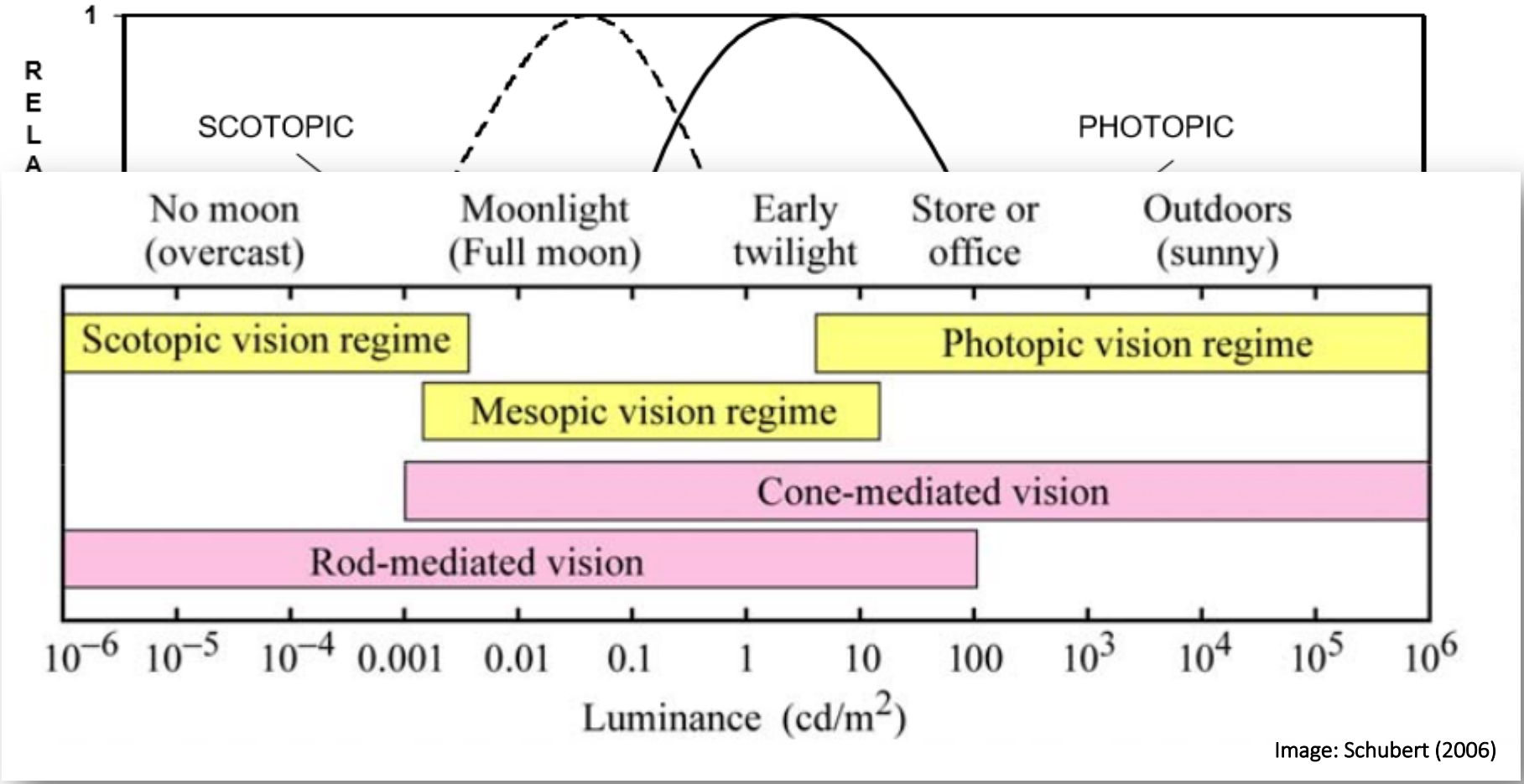


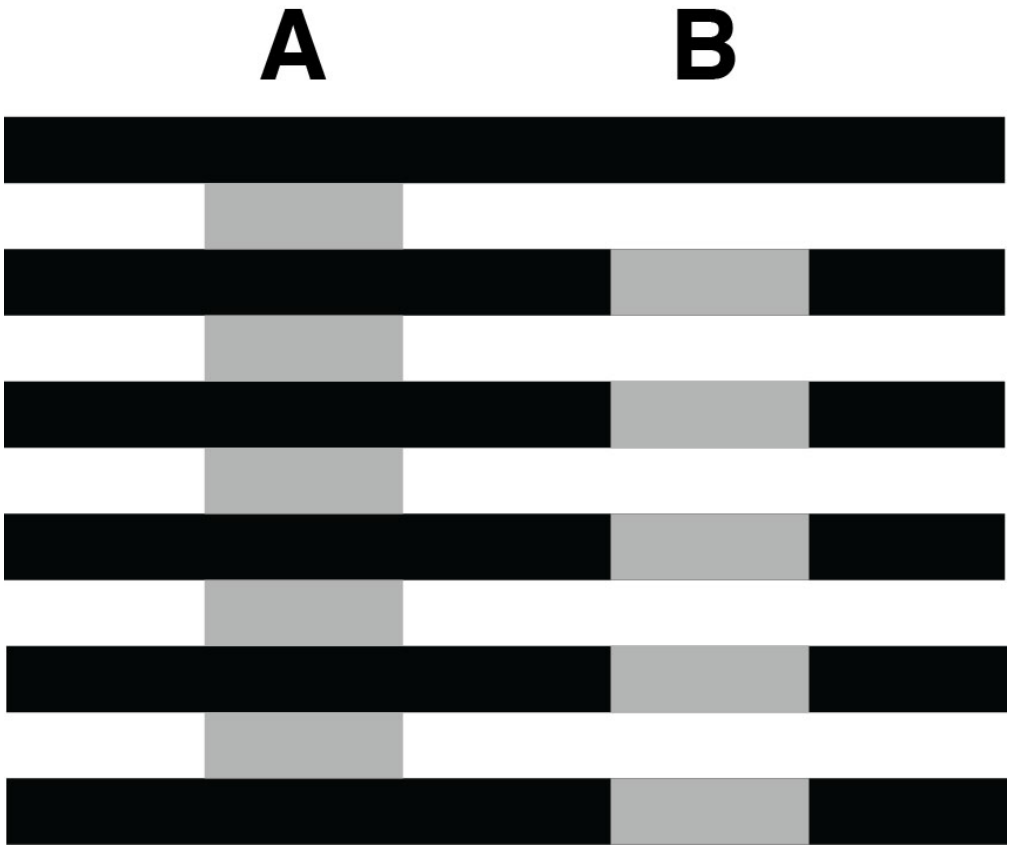
Image: Schubert (2006)

PROCESSING LIGHT

- **Brightness**
  - The *perceived* amount of light coming from self-luminous sources (e.g. viewing a display at night).
  - A non-linear function, $\boldsymbol{n}$ varies with the size of the patch of light
    General form: $Brightness = \boldsymbol{L}^{n}$
  - Be careful of context-dependent definitions where 'brightness' may be something completely different!

PROCESSING LIGHT

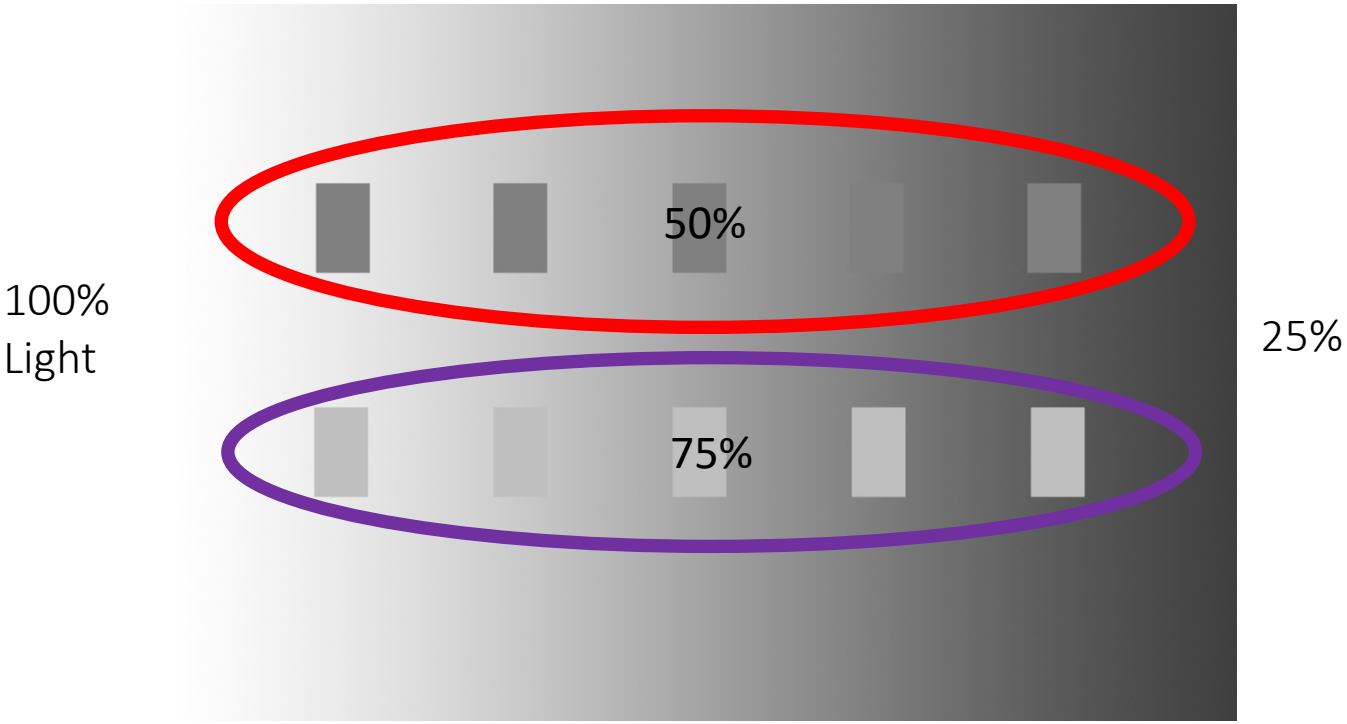
- White's Illusion
  - Different *perceived brightness* in different scenarios



Interactive White's Illusion: http://www.michaelbach.de/ot/lum-white/index.html

PROCESSING LIGHT

- **Simultaneous Brightness Contrast**
  - Recall: Contrast is the difference in luminance of an object



PROCESSING LIGHT

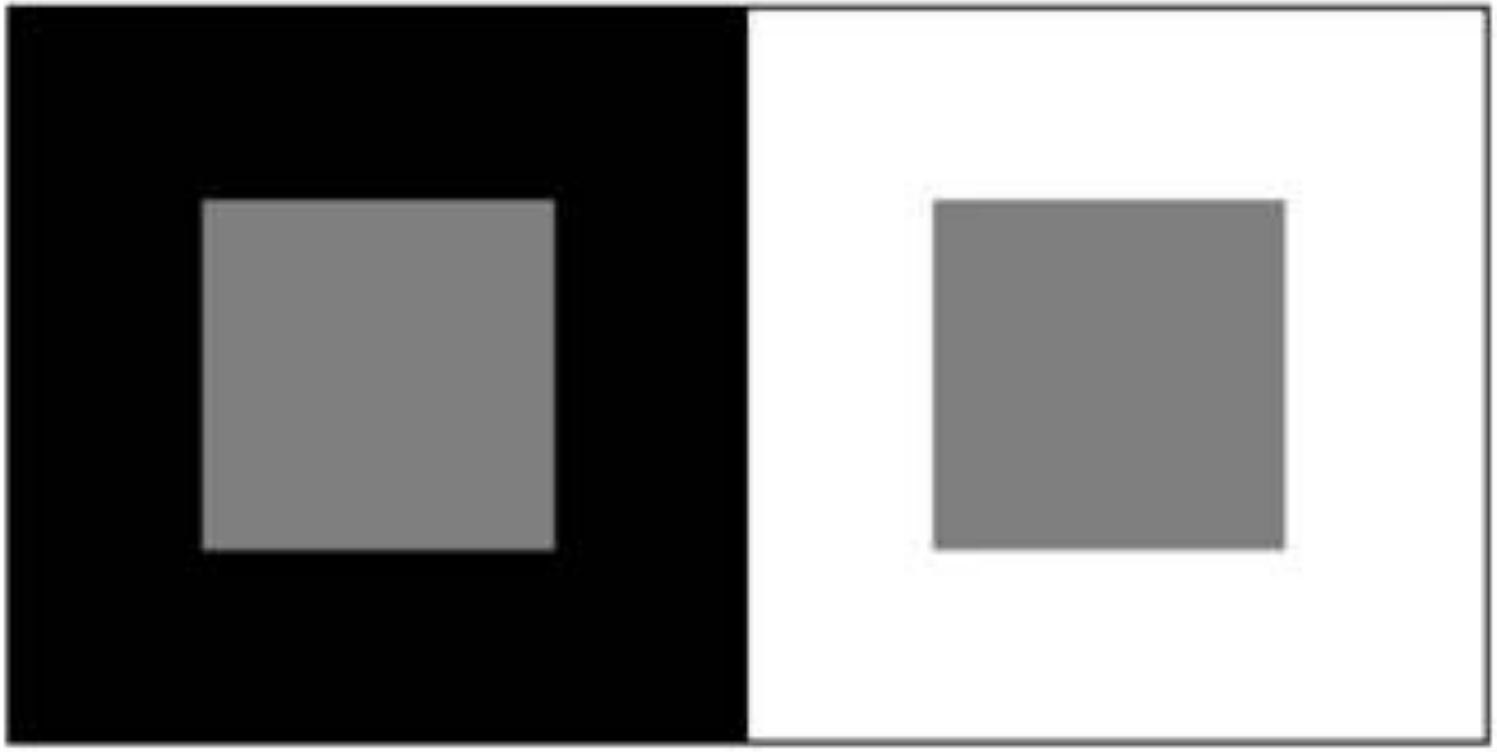
- **Simultaneous Brightness Contrast**
  - Recall: Contrast is the difference in luminance of an object

- "a grey patch placed on a dark background looks lighter than the same grey patch on a light background" (Ware, 2013)

- Simultaneous Brightness Contrast
  - A well known problem in graphics/map reading when using grey-scale. Values may be influenced by surroundings.

PROCESSING LIGHT

- Simultaneous Brightness Contrast
  - Recall: Contrast is the difference in luminance of an object



PERCEIVING LIGHT

Other brightness/Contrast issues for visualisation

- Text contrast
  - Minimum luminance ratio of 3:1 (ISO 9241-3)
    10:1 recommended (finer detail requires greater contrast)

- Steven's Power Law applies to **all** stimuli
  - Law states: Perceived sensation S is proportional to the stimulus intensity I raised to a power of n
  - $S = aI^n$

Table: Stevens (1975)

PERC

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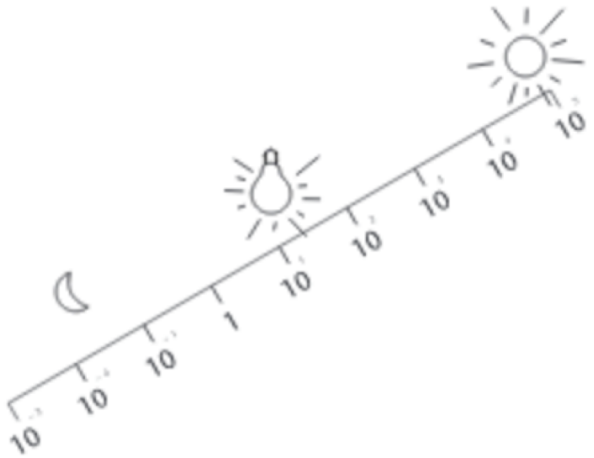
Continuum	Exponent	Condition
Loudness	0.67	3000 Hz tone
Brightness	0.33	In dark
Brightness	1.0	Point source brief flash
Lightness	1.2	
Length	1.0	Line feature
Area	0.7	Area feature
Taste	1.3	Sucrose
Taste	1.4	Salt
…		

st)

Table: Stevens (1975)

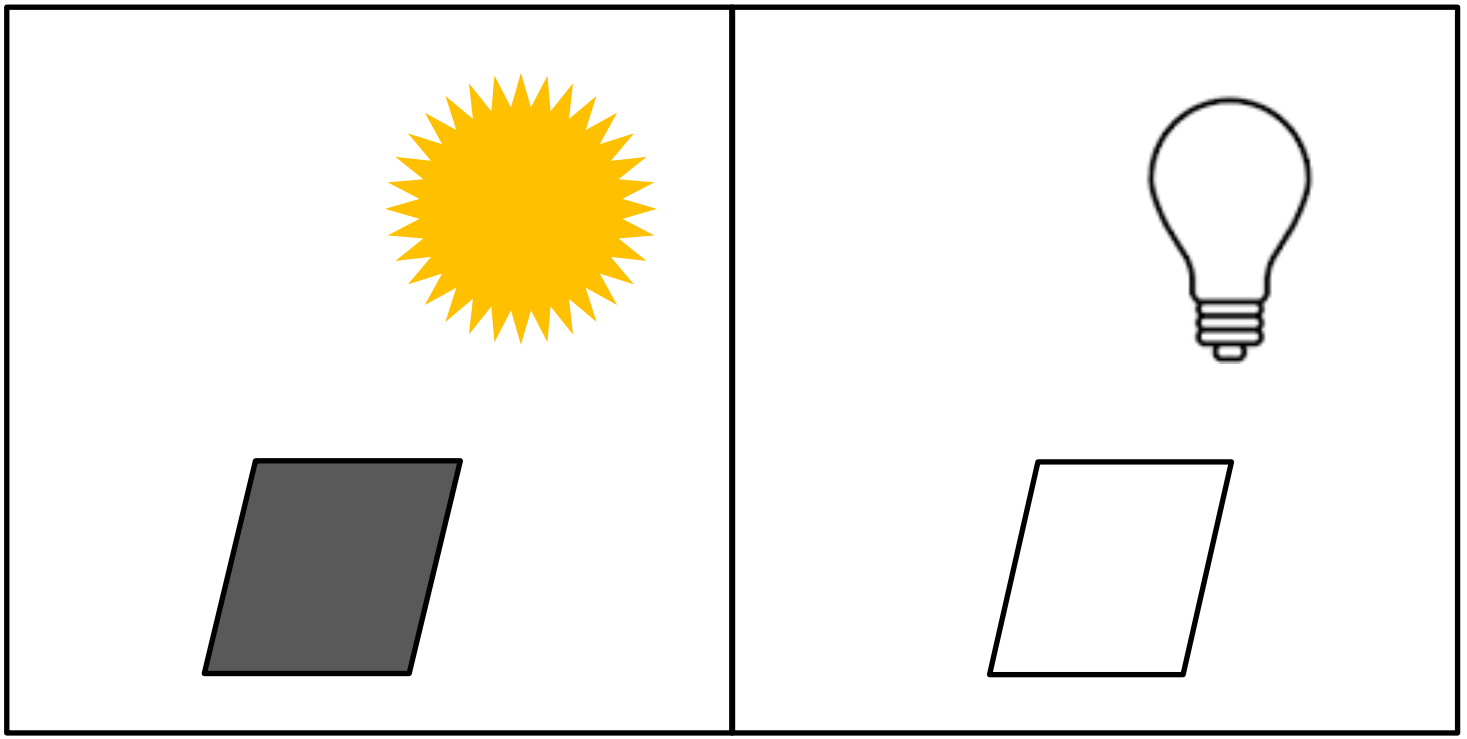
PROCESSING LIGHT

- Lightness
  - The *perceived reflectance of a surface*, e.g., white surface is 'light', black surface is 'dark'. Beware, various models exist.
  - Luminance is *completely unrelated* to perceived lightness or brightness
  - Lightness consistency is achieved in two stages: *adaptation* and *lateral inhibition*



REVISION QUESTION

- A4 black object (paper) in full sun vs. A4 white one in the office



Which would have higher luminance?
Which would have higher lightness?