nvidia

Visual Computing

2024/2025

Class 2

Visual Perception

deti departamento de electrónica, telecomunicações e informática

universidade de aveiro

Today’s Agenda

- A first (brief) look at Computer Graphics
- Why talk about Visual Perception?
- Visual Perception

What is Computer Graphics?

http://www.chilloutpoint.com/images/2009/07/the-most-fantastic-cg-landscapes/big/3d-cg-landscape-02.jpg

What is Computer Graphics?

The technology with which **pictures** are

- Captured or generated, and presented
- Manipulated and / or processed
- Merged with other, non-graphical application data

It includes:

- Integration with other kinds of data – Multimedia
- Advanced dialogue and interactive technologies

What is Computer Graphics?

Computer graphics generally means **creation, storage** and **manipulation** of **models** and **images**

Such models come from a diverse and expanding set of fields

- Physical, biological, mathematical, artistic, and conceptual / abstract structures

Computer Graphics deals with all aspects of ***creating*** images with a computer

- Hardware
- Software
- Applications

Why talk about Visual Perception?

http://youtu.be/TAZIvyAJfeM

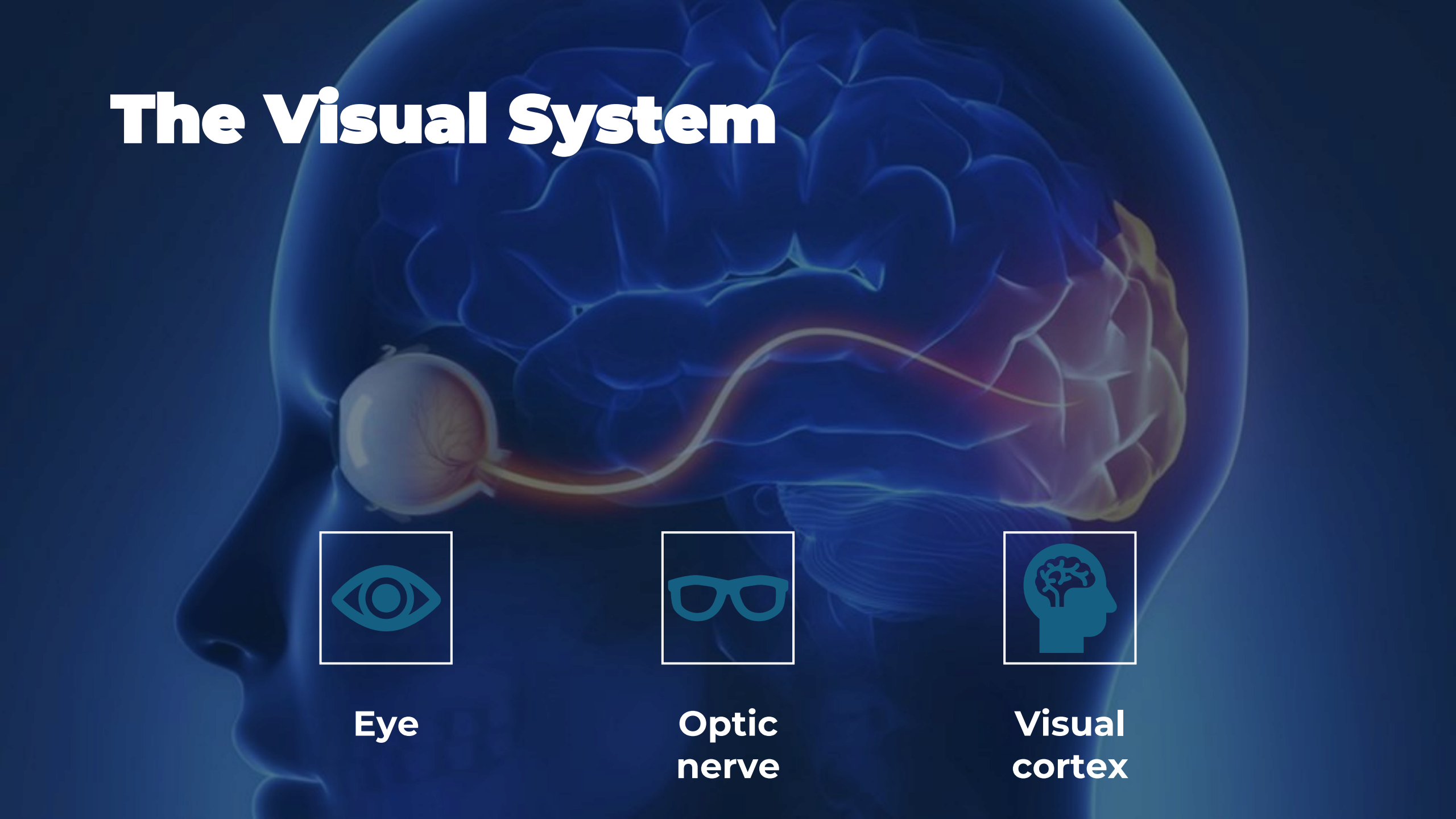
Visual Perception

and Computer Graphics

We’ll go for a hike and will see the mountain… …from afar

This is not intended as a very detailed account of visual perception, but a first glimpse at the range of aspects that may constitute grounds for understanding its importance

The Visual System



Eye

Optic nerve

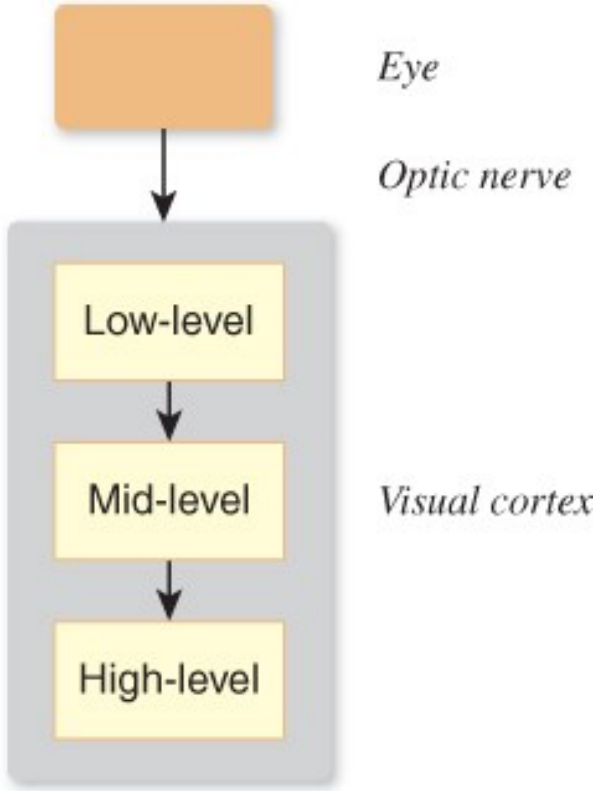
Visual cortex

The Visual Cortex

First stages (“early vision”) deal with low-level processing

- Sharp contrasts in brightness
- Changes in colour, orientation, spatial frequency

Detection is “local”, i.e., for regions that are close



The Visual Cortex

The remaining levels of processing deal with:

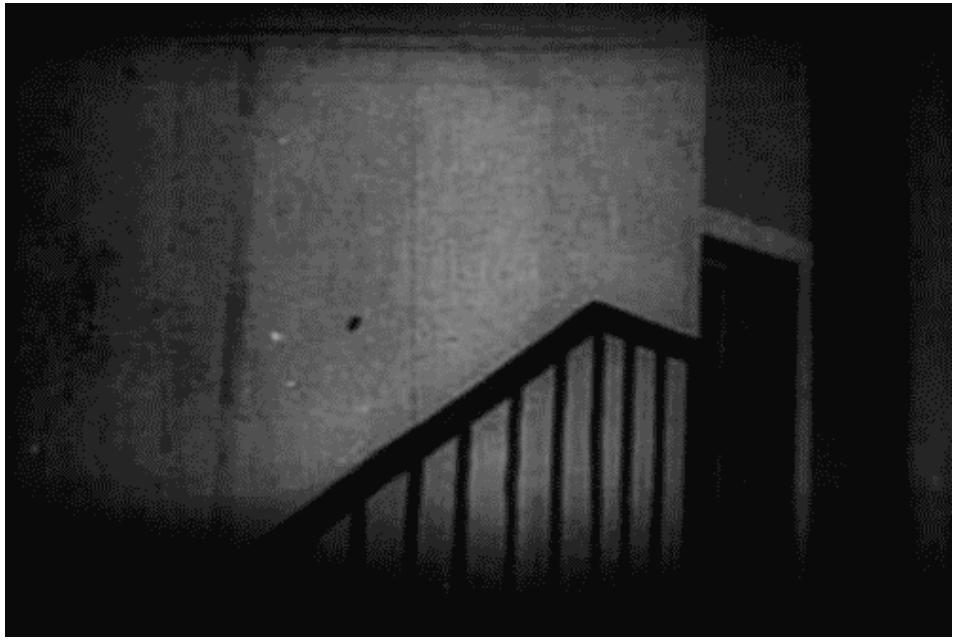
- Detecting motion, objects, shapes
- Handling attention
- Eye control (e.g., to act co-ordinately to follow an object)

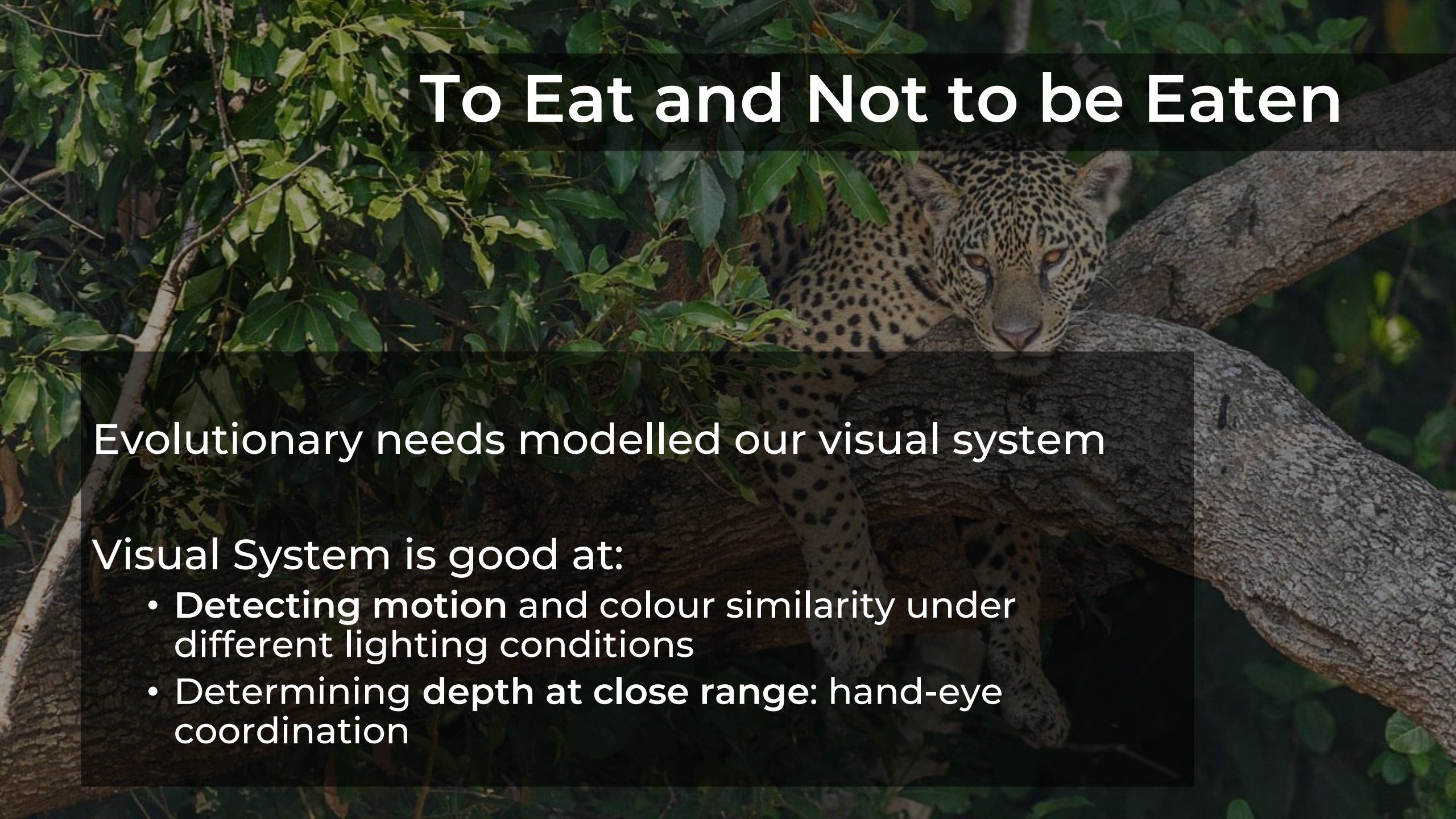
While we represent it as sequential it is substantially parallel processing

The visual system’s versatility

You can easily spot the black dot on this slide

And you can watch the movies on the right (full of grain) ignoring most of the noise beyond the central scene





To Eat and Not to be Eaten

Evolutionary needs modelled our visual system

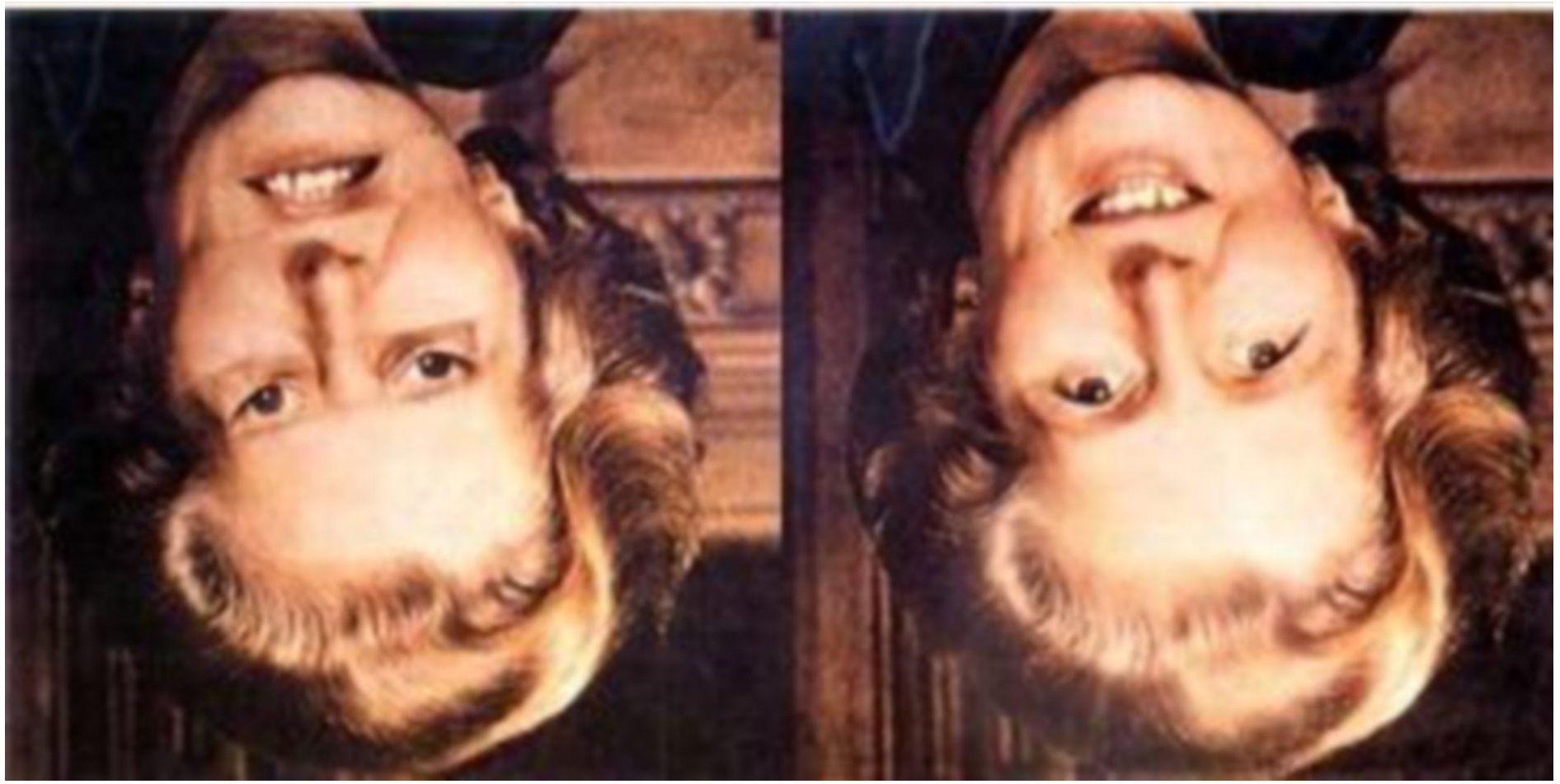
Visual System is good at:

- **Detecting motion** and colour similarity under different lighting conditions
- Determining **depth at close range**: hand-eye coordination


Spot something?


Spot something?

There is a lot going on at the visual cortex

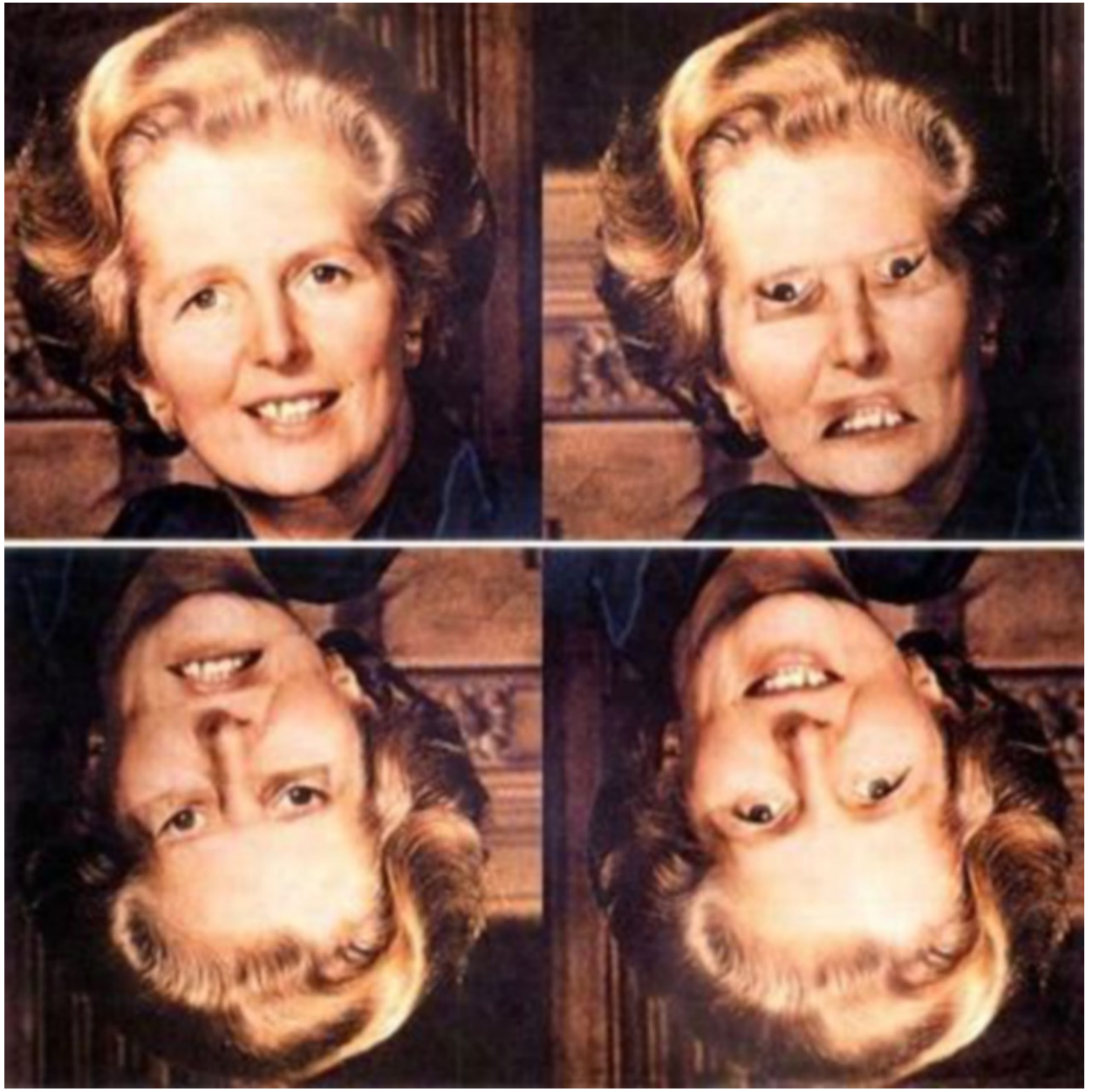


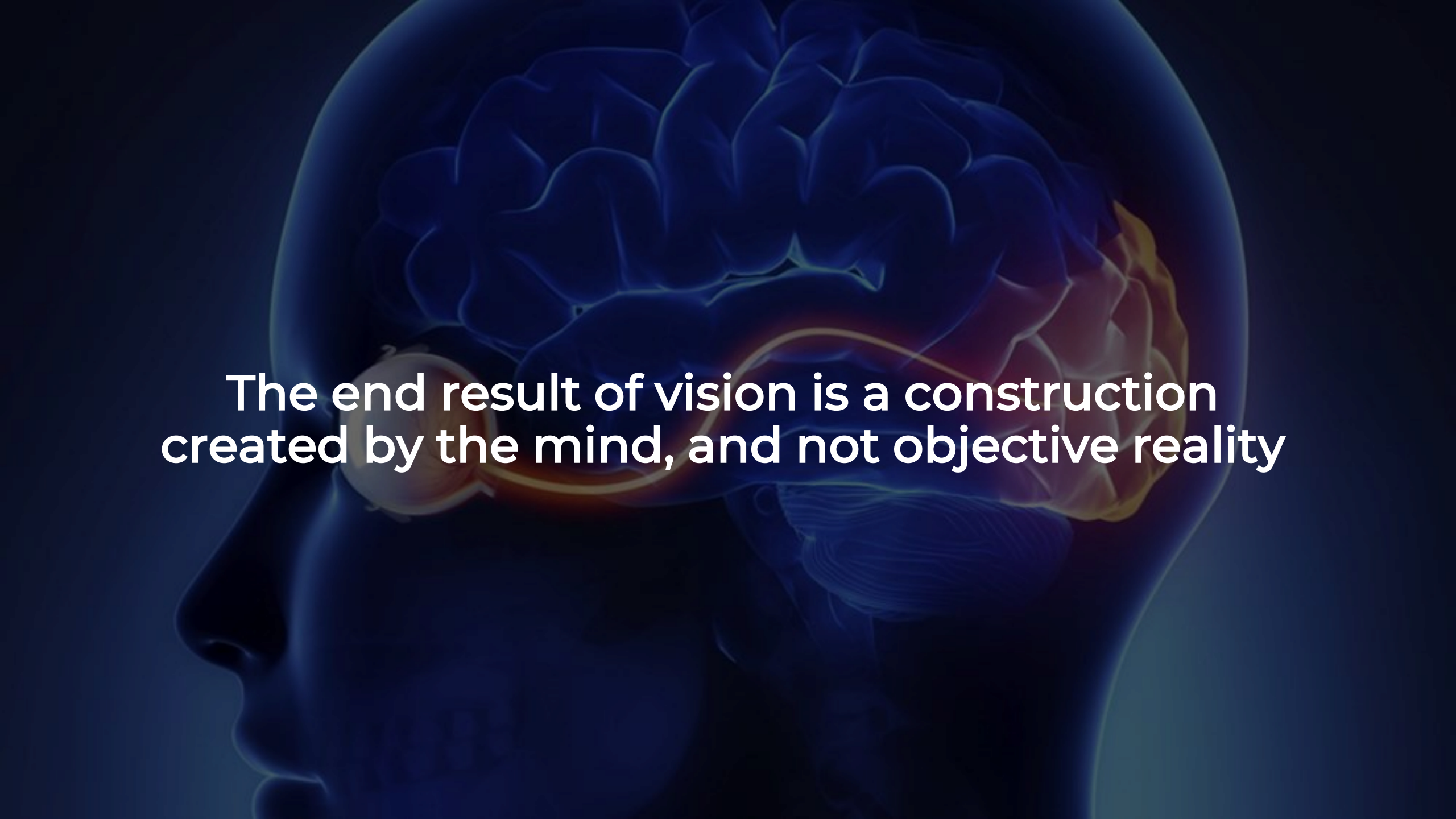
The Thatcher Effect

The Visual System is also very good at processing faces

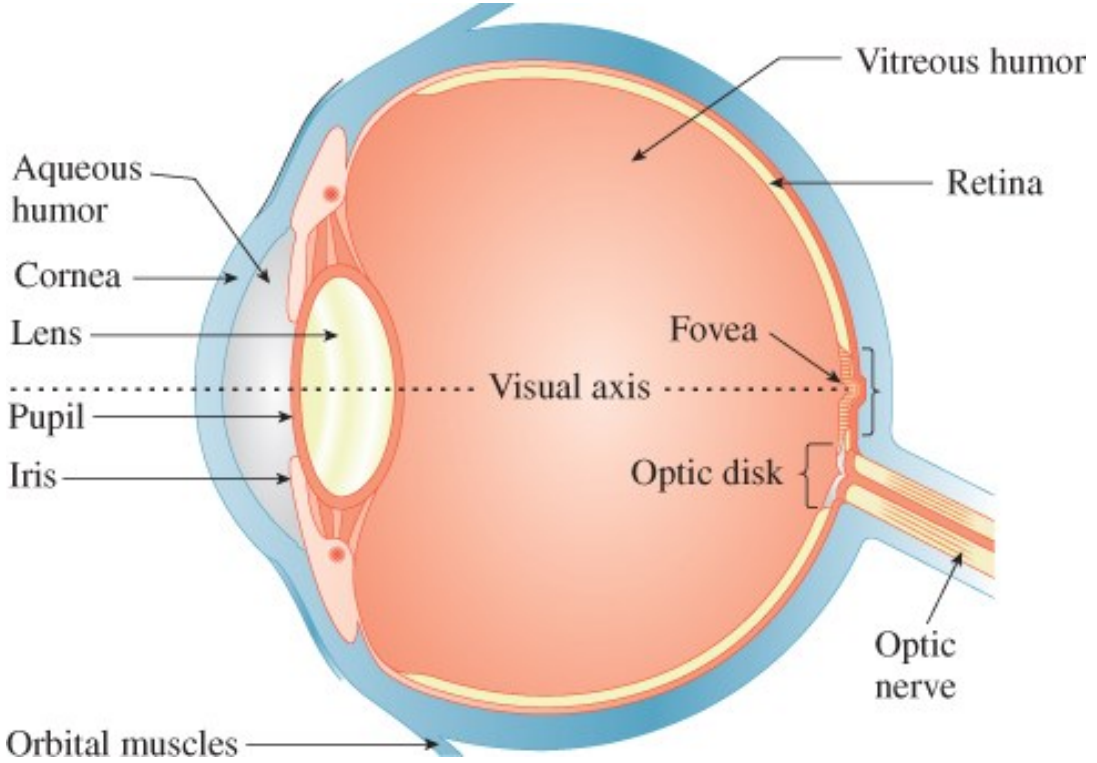
But that does not work well if they are upside-down

Modelling faces for a game is important and can pose issues if not done properly



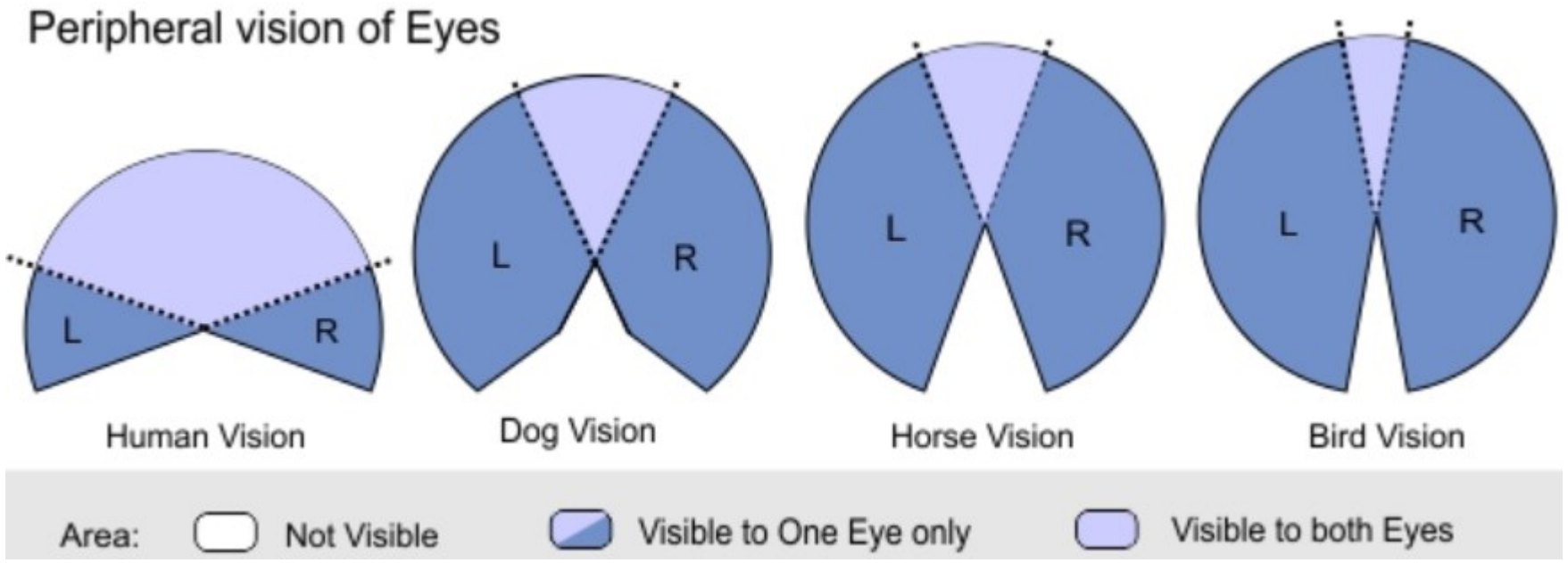

The end result of vision is a construction
created by the mind, and not objective reality

Eye Physiology

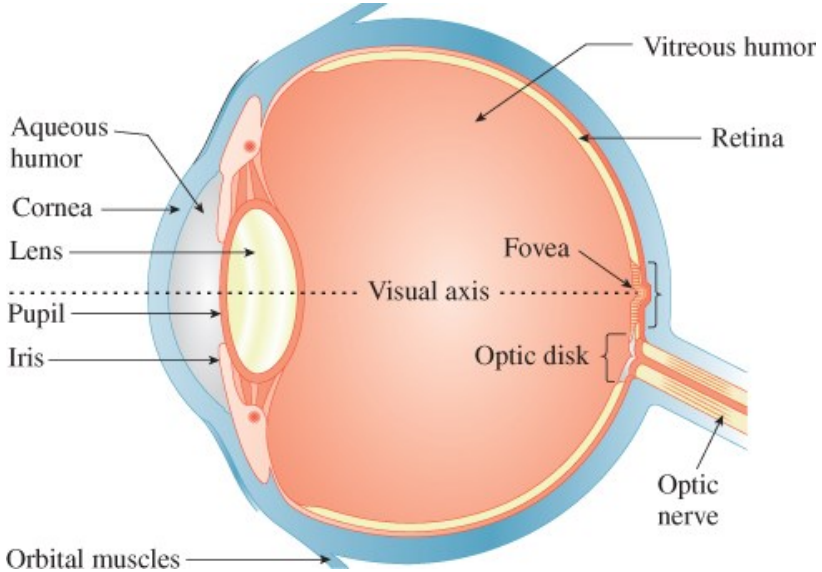


Field of view

Each eye: 160◦horizontal (H) by 135◦vertical (V).
With binocular viewing: approximately 200◦H by 135◦V
Overlap: approximately 120◦H by 135◦V.



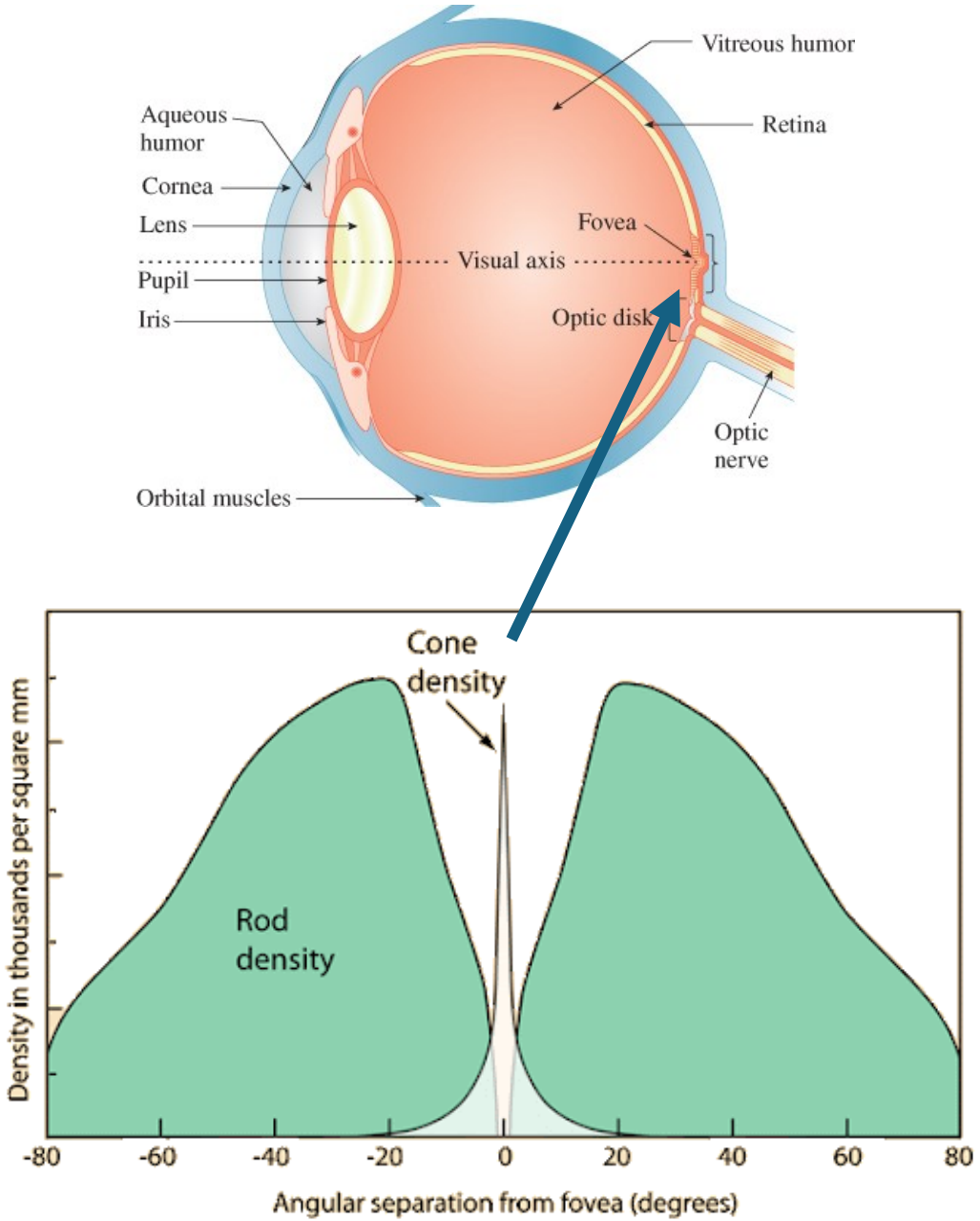
quora



The Retina

Filled with cells that respond to light

- Cones
- Rods



Rods and Cones

Cones are mostly concentrated at the fovea

Rods occupy the remaining areas

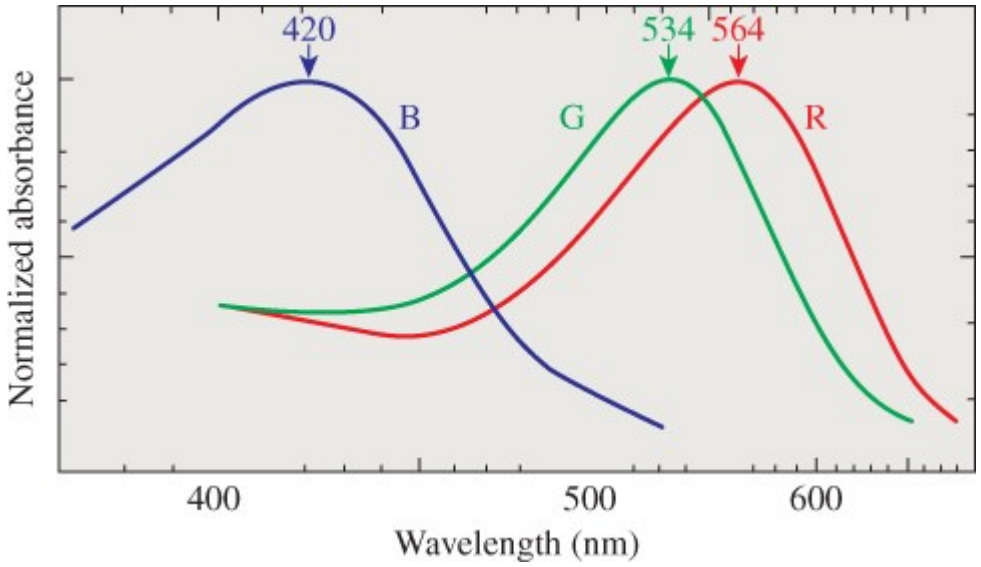
Cone response

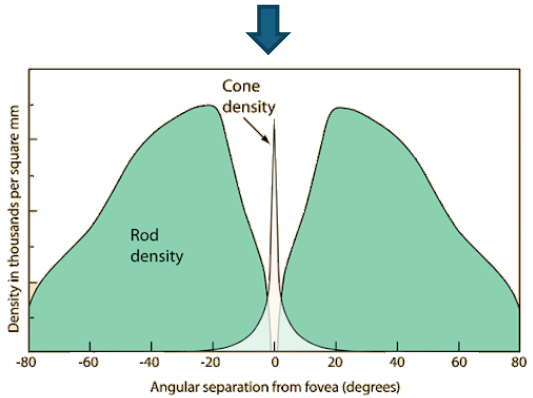
Three types of cones

- Short (B), Medium (G), and Long (R) wavelength detectors

Responsible for colour vision

Best at seeing details





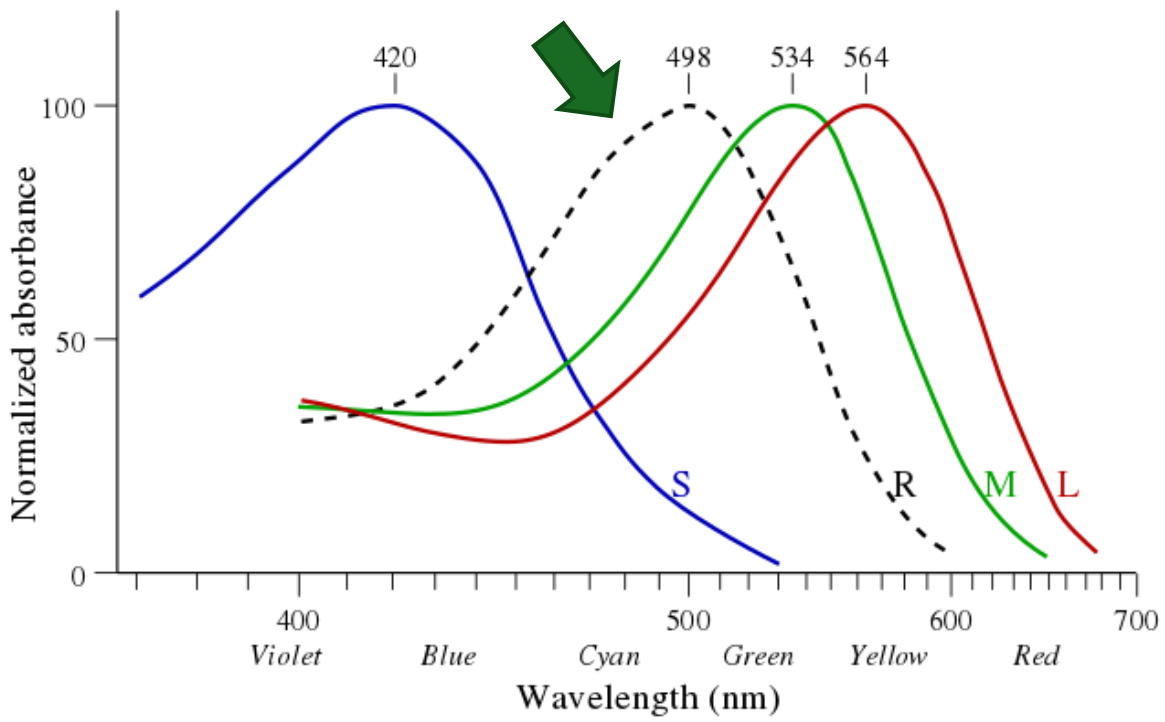
Rod response

Slower to respond to light

- More sensitive to small amounts of light
- Vision in low-light conditions

Most sensitive to light around 498 nm (green-blue)

But they **do not provide** colour information



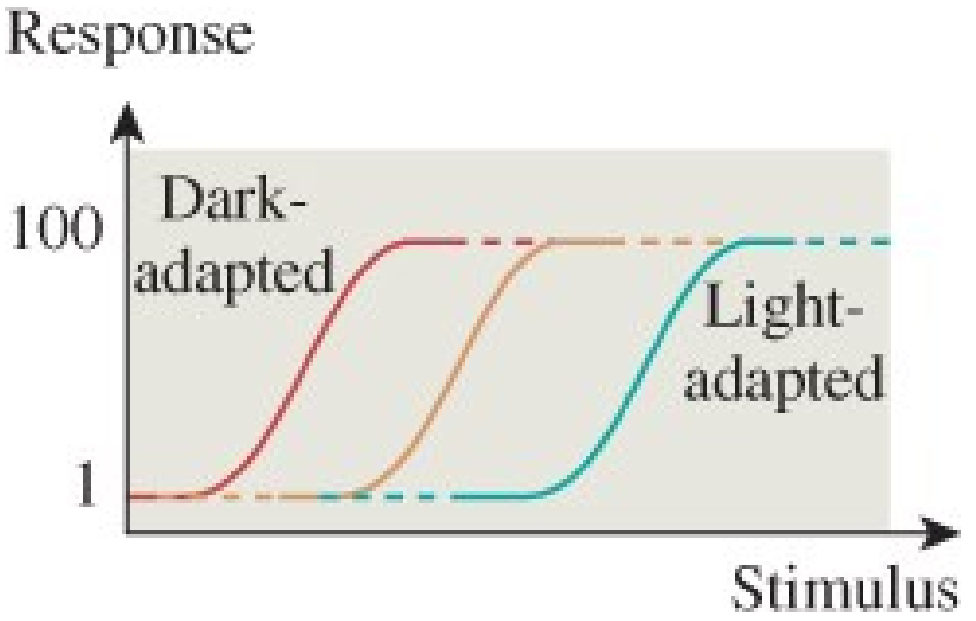
Brightness and Dynamic Range

The eye has a limited dynamic range in a particular context, but…

The eye adapts to the circumstances

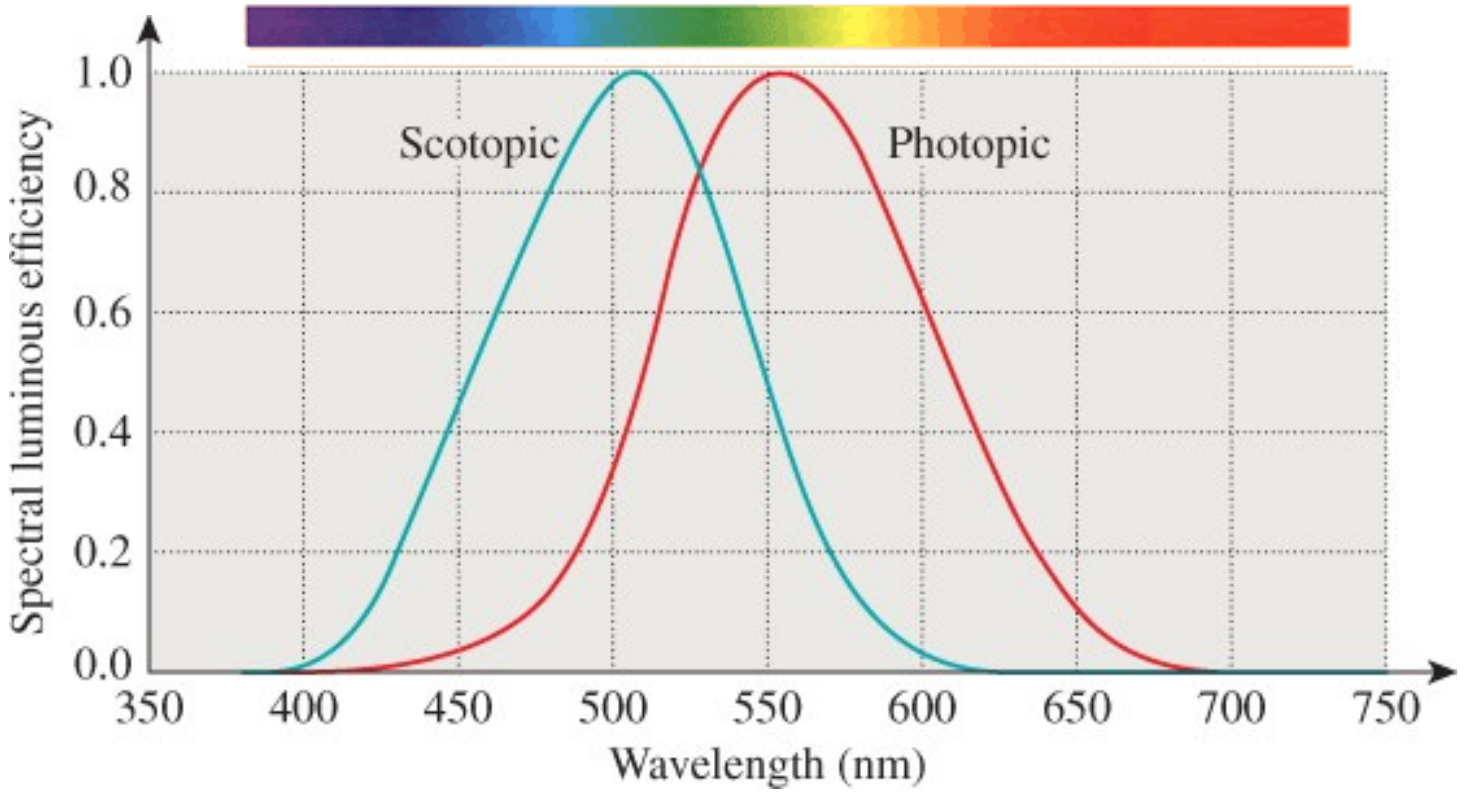
- It allows handling the wide range of illumination in everyday life

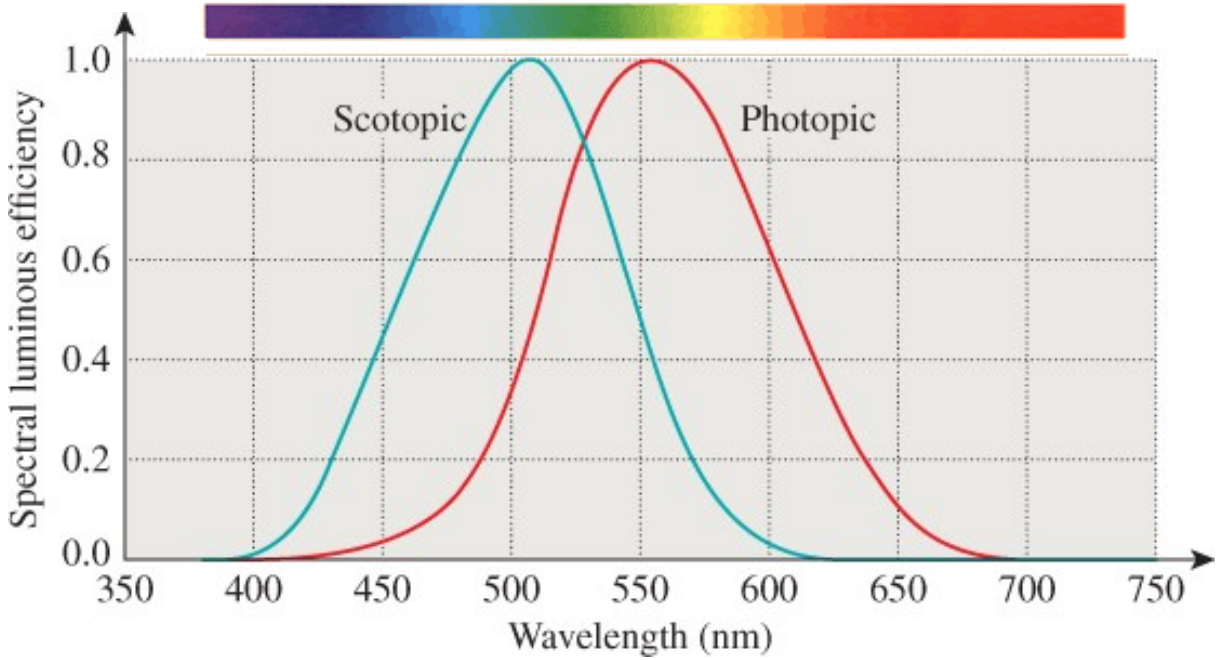
Cones and rods play complementary roles and adapt to the existing brightness levels



Hughes CG

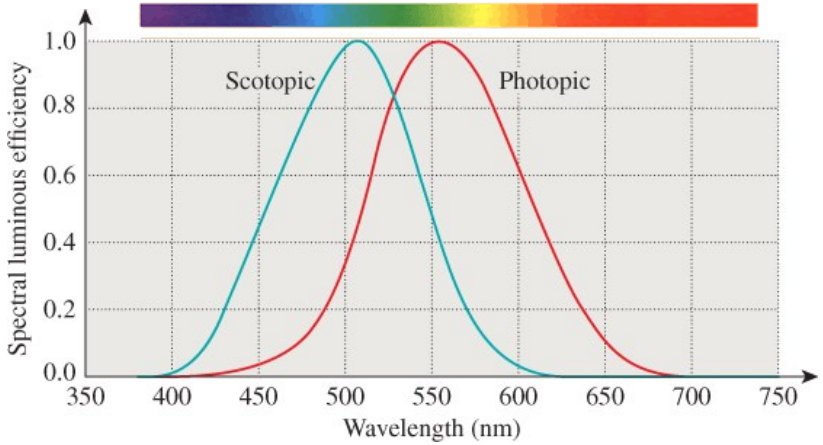
Rods (scotopic) and cones (photopic) vision complementarity





Explain...

- Police vehicle lights
- Ambulance vehicle colours
- Lighting for astronomy and submarines



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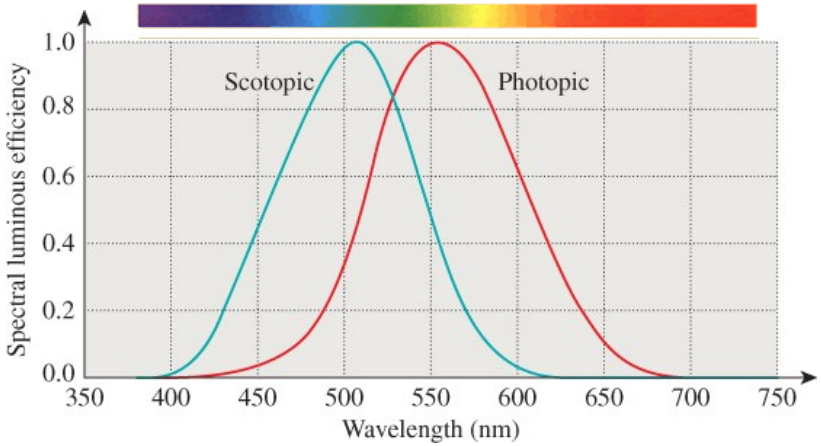
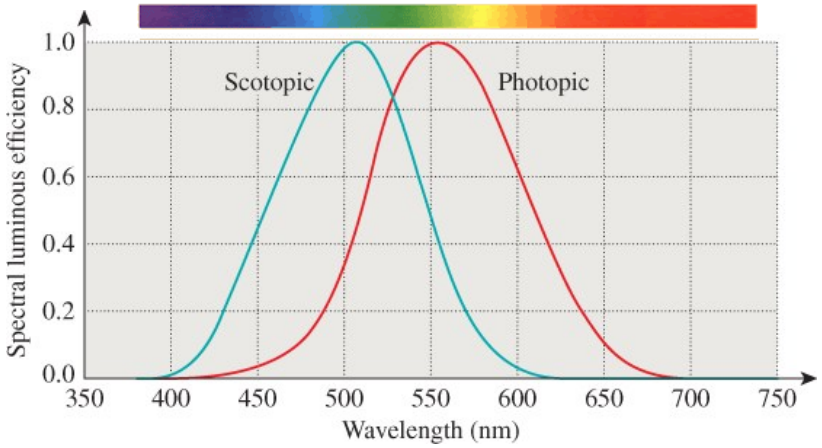
- Police vehicle lights



Explain...

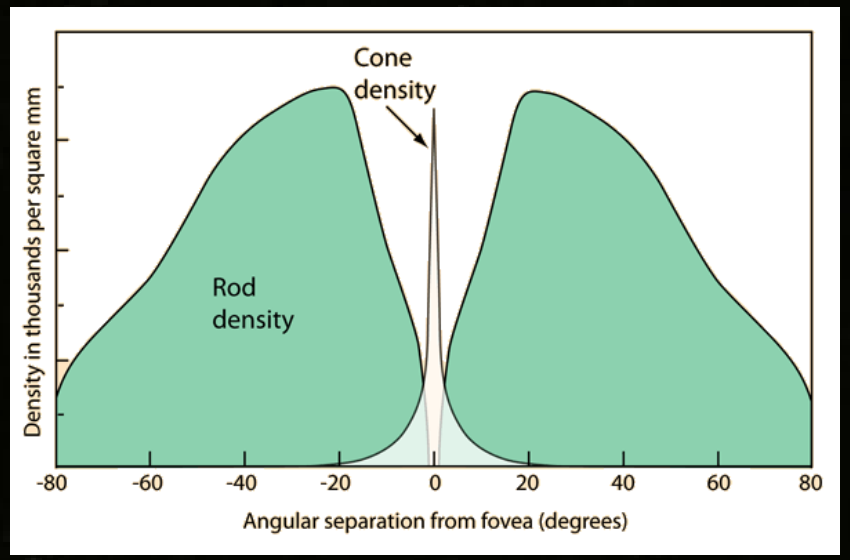
- Ambulance vehicle colours



Explain...

- Lighting for astronomy and submarines

With what you already know about visual perception, what is the best procedure to be able to see a very faint star in the night sky?

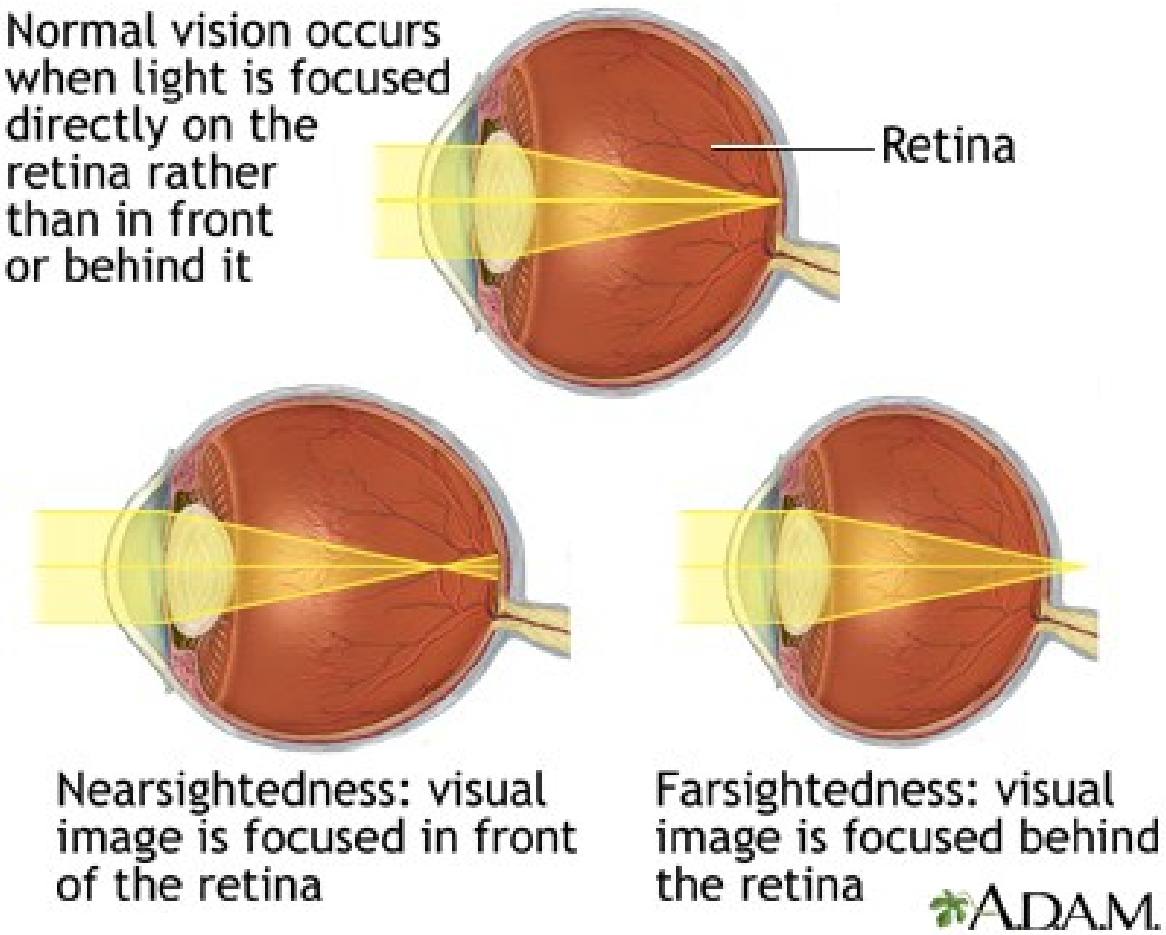


Visual Sensitivity

and some useful concepts

Acuity is better at the fovea

Sam is getting old, what is happening to his eyes?



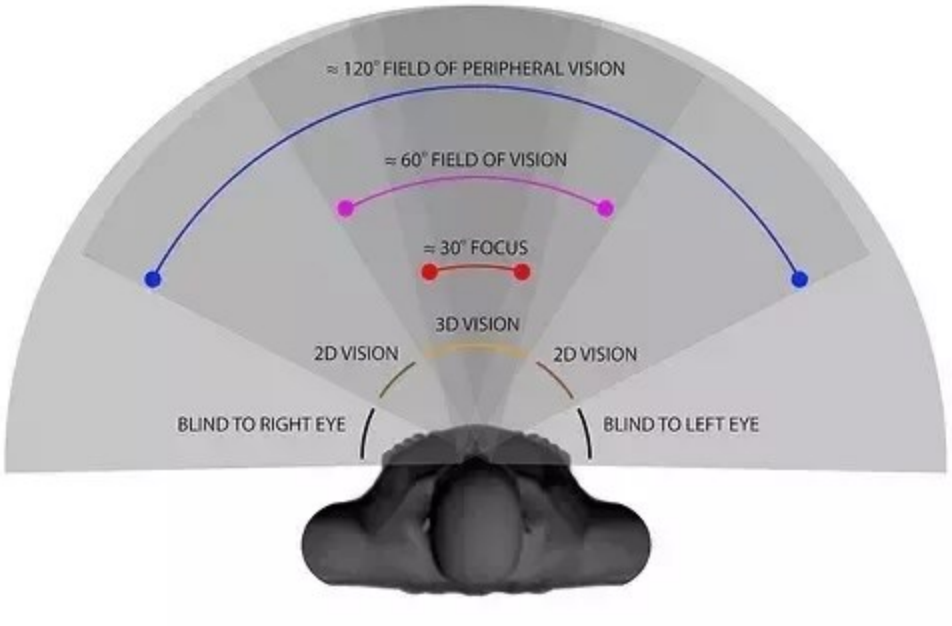
Visual Angle

Is how wide an angle an object occupies in the eye

It depends on the distance and size of the object

It can be a measure for calibration of size among various displays

Visual Angle

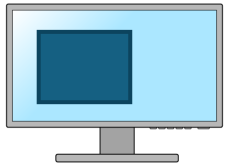


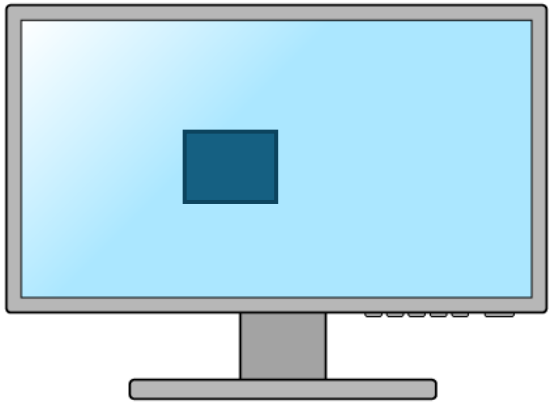
Important to control what the person sees and with what capabilities

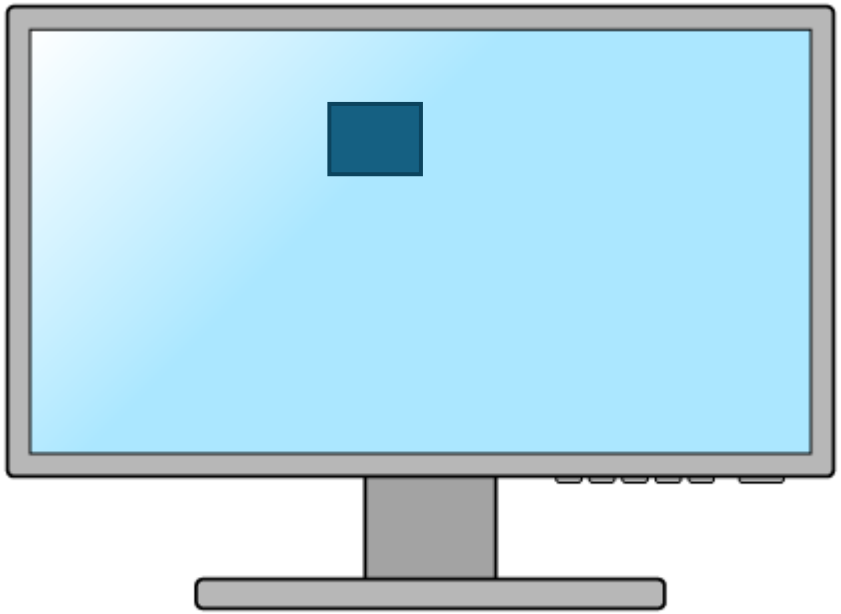
Depends on the distance to the target

Visual Angle

Ensure view size calibration



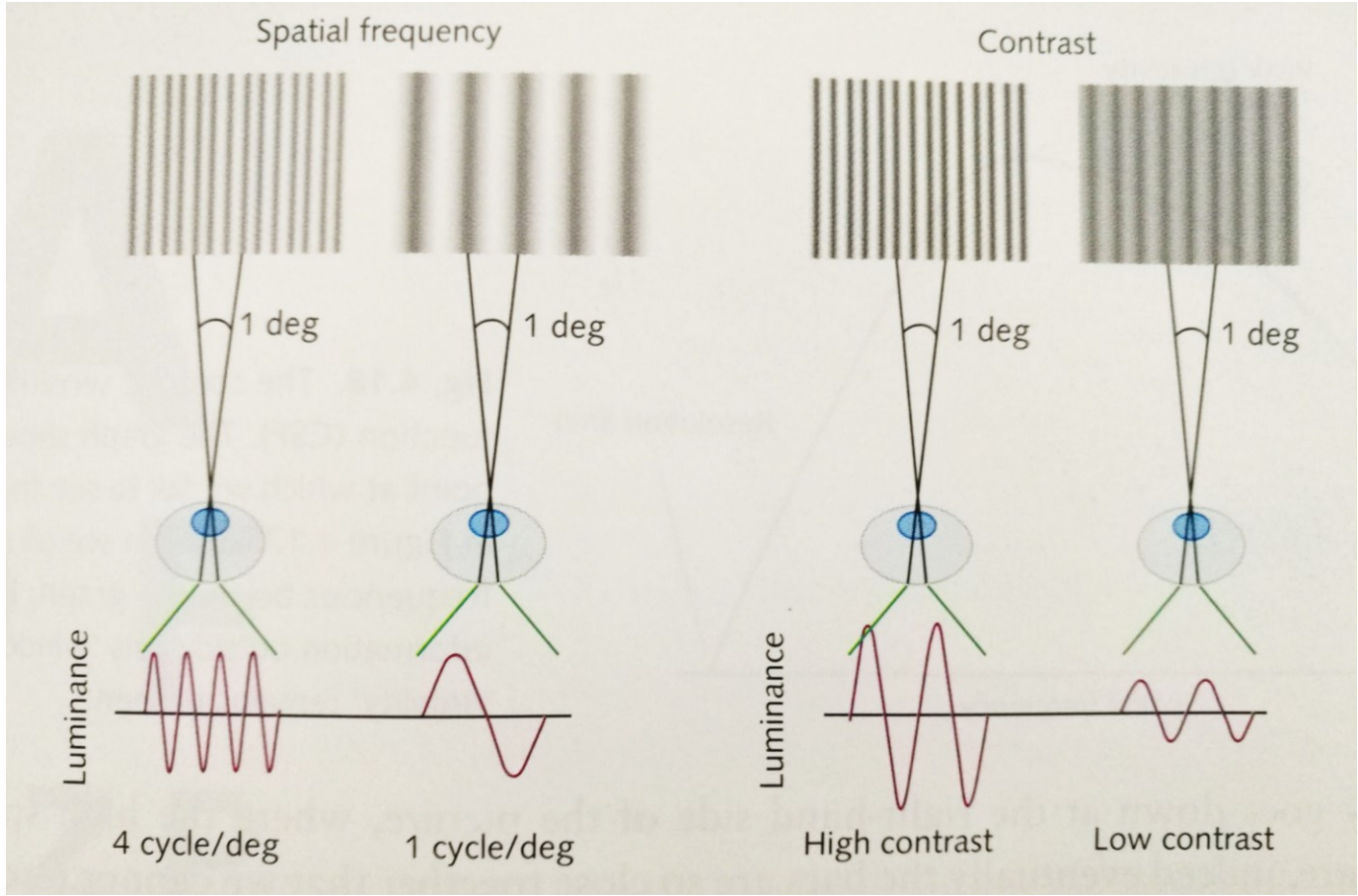




Spatial Frequency

Many changes in a particular region correspond to a higher spatial frequency

Low spatial frequencies are like having **a pen that cannot change direction rapidly** (which would be high frequencies)

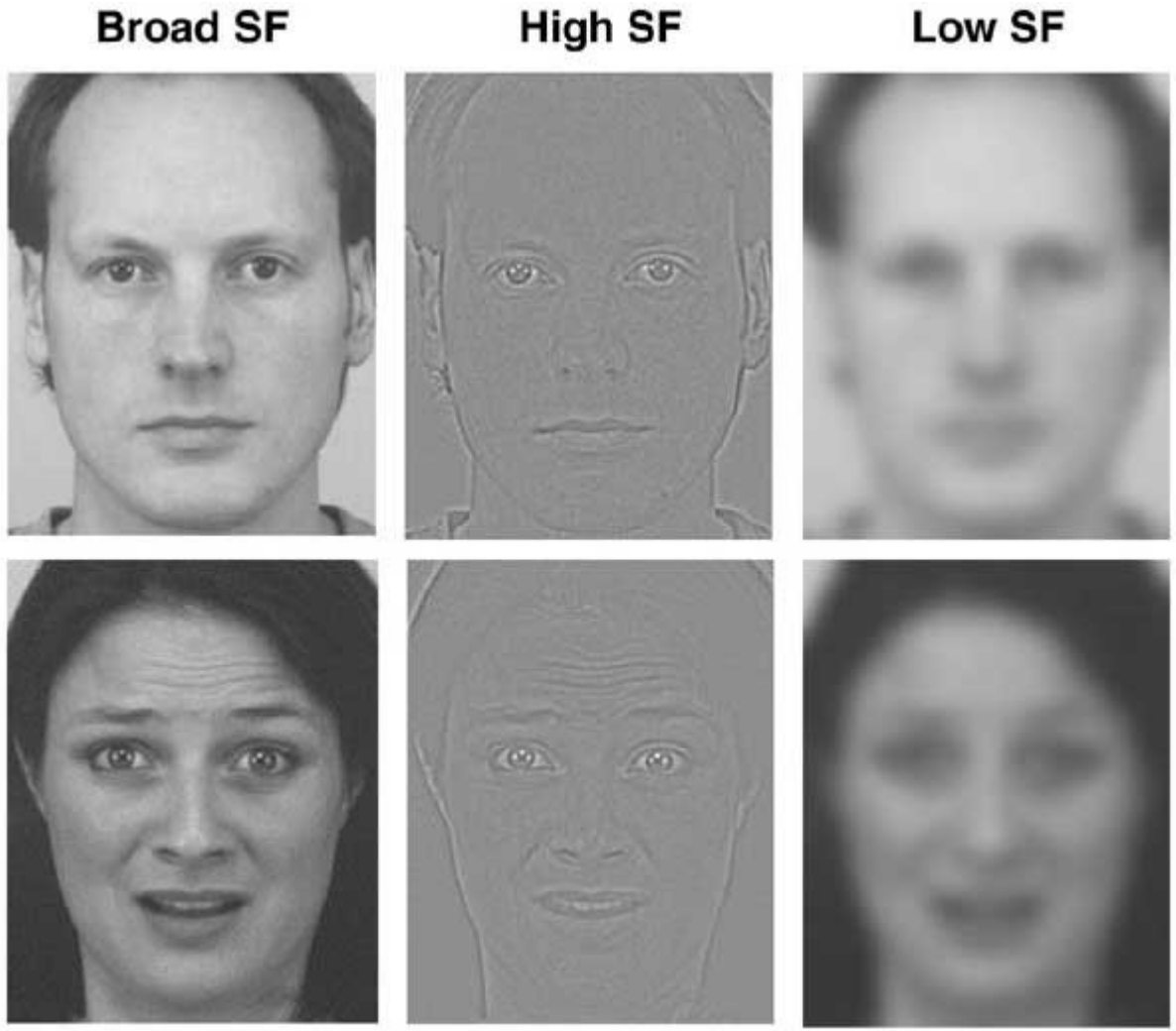


Spatial Frequency

Low spatial frequency concerns overall aspect

High spatial frequency concerns fine details

But WHY do I need to know this??
WHY?

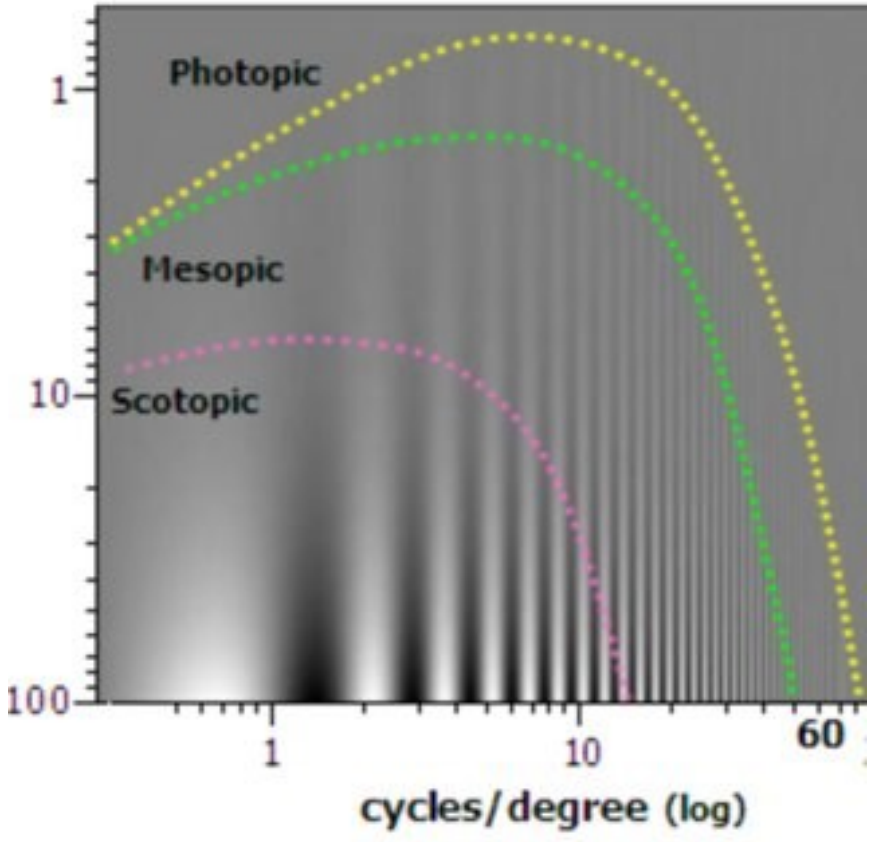


Contrast Sensitivity

High detail in low contrast is not perceived

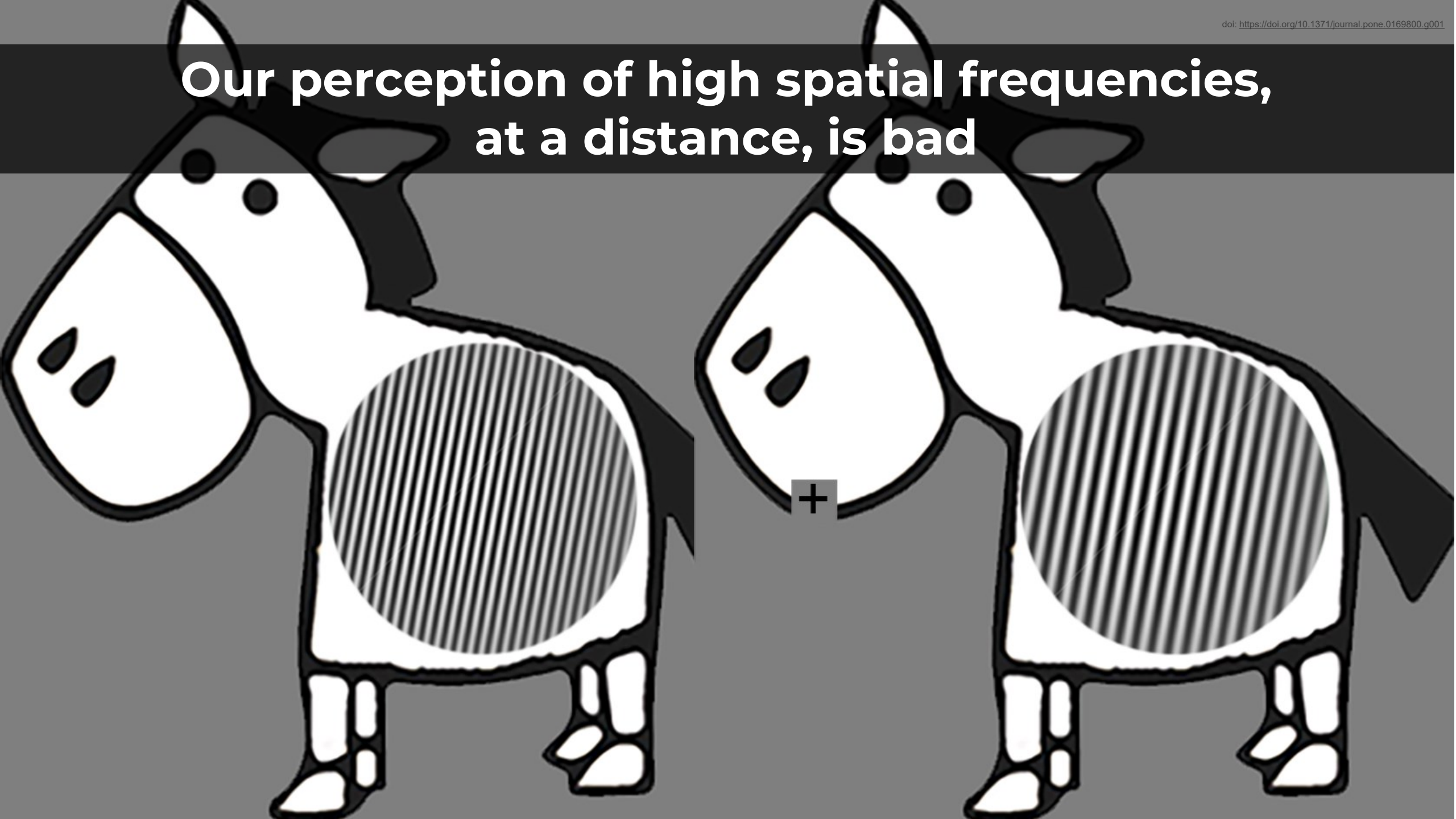
Scotopic (rods) vision has low resolution (remember best acuity is at the fovea)

No need to spend too much resources rendering objects at the periphery of our vision

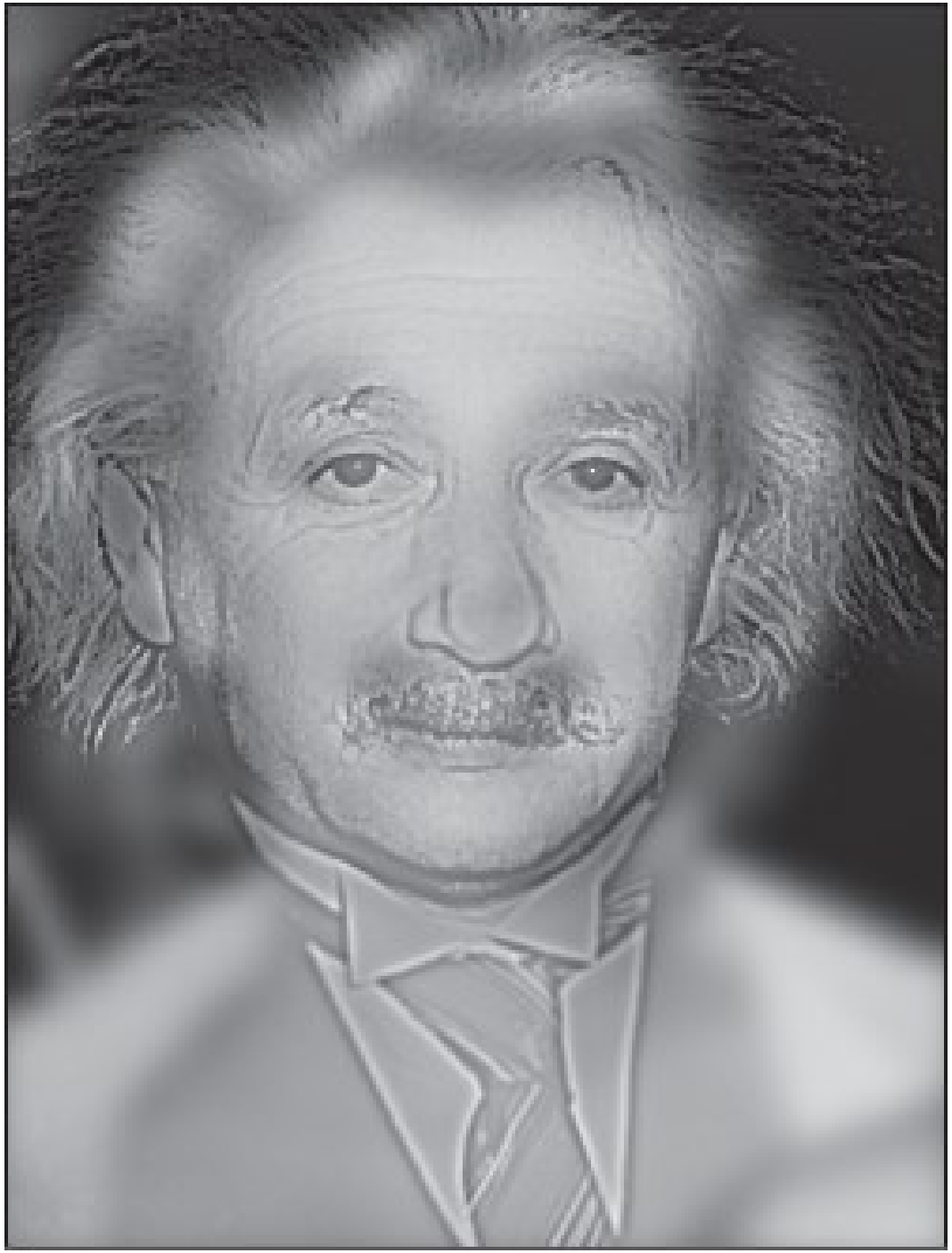


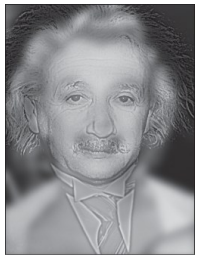
doi: https://doi.org/10.1371/journal.pone.0169800.g001

Our perception of high spatial frequencies, at a distance, is bad



- Different appearance when seen from close or afar
- **Can you explain why?**
- What does this tell us that is important for computer graphics?





No need to spend resources rendering far away elements in fine detail. We cannot perceive it!


Does not seem a good idea for camouflage...

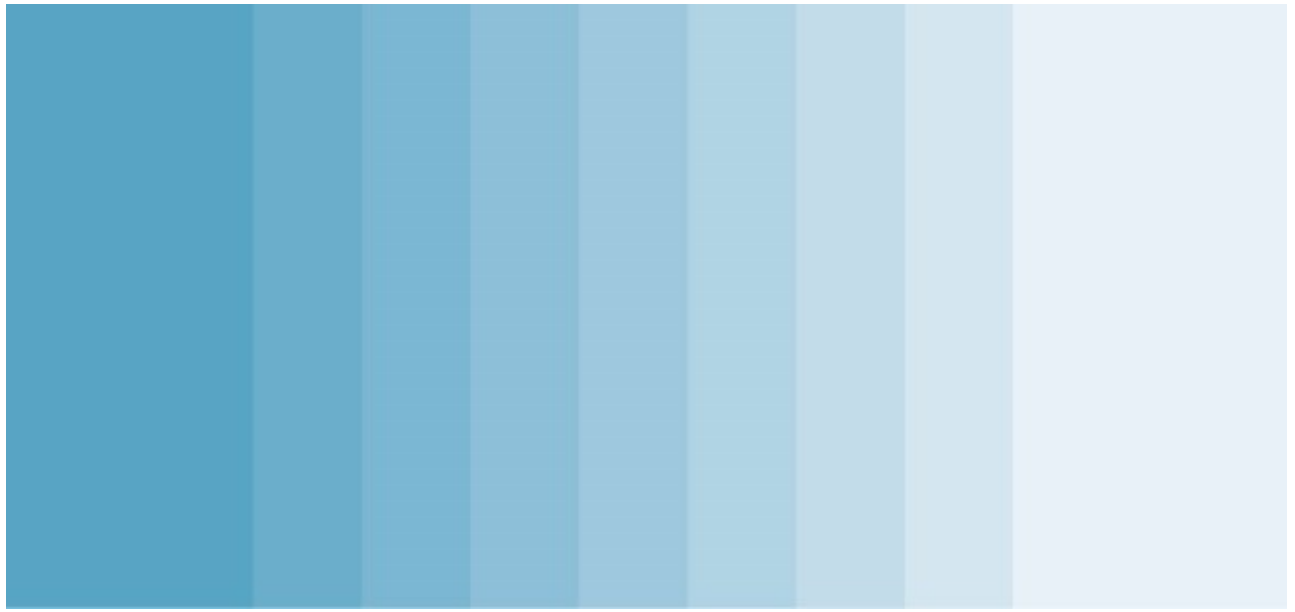

Now imagine you want to choose a zebra to attack while looking from behind the bush

Mach banding

Each strip is a single colour, but...

It looks brighter on the left and darker on the right

This strongly accentuates the perception of the transition between strips



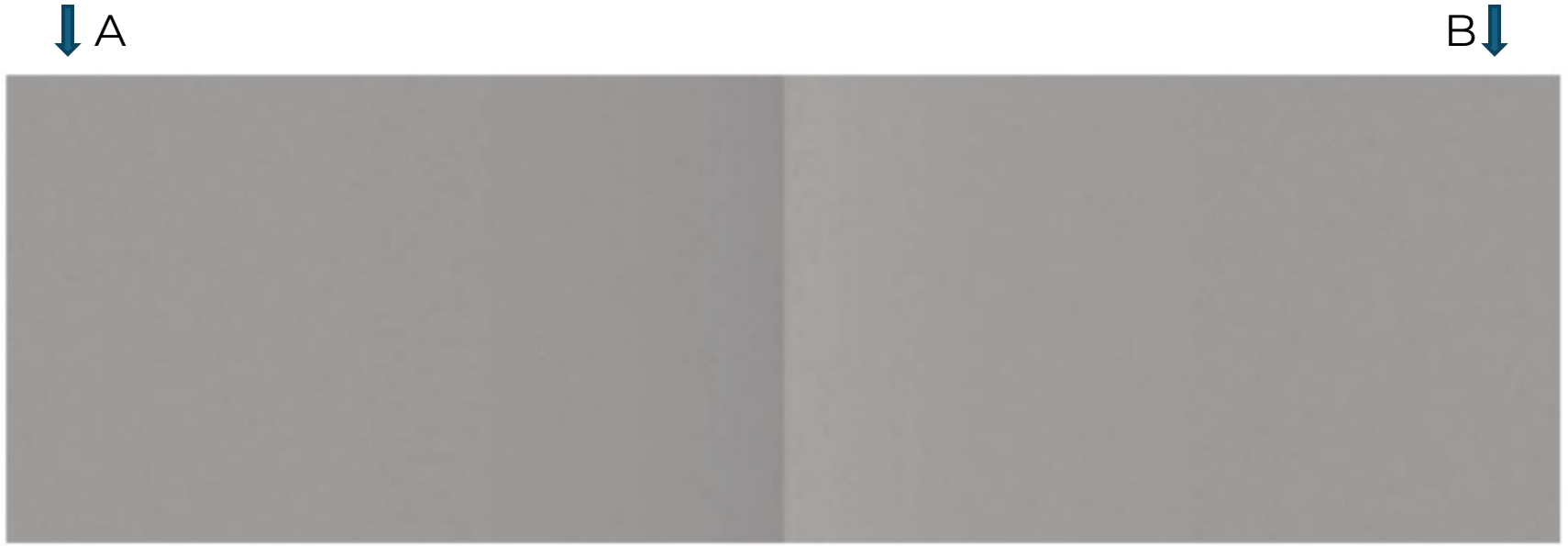
Hughes, Fig. 1.13

Mach banding

This explains why very simple illumination models provide such awkward results

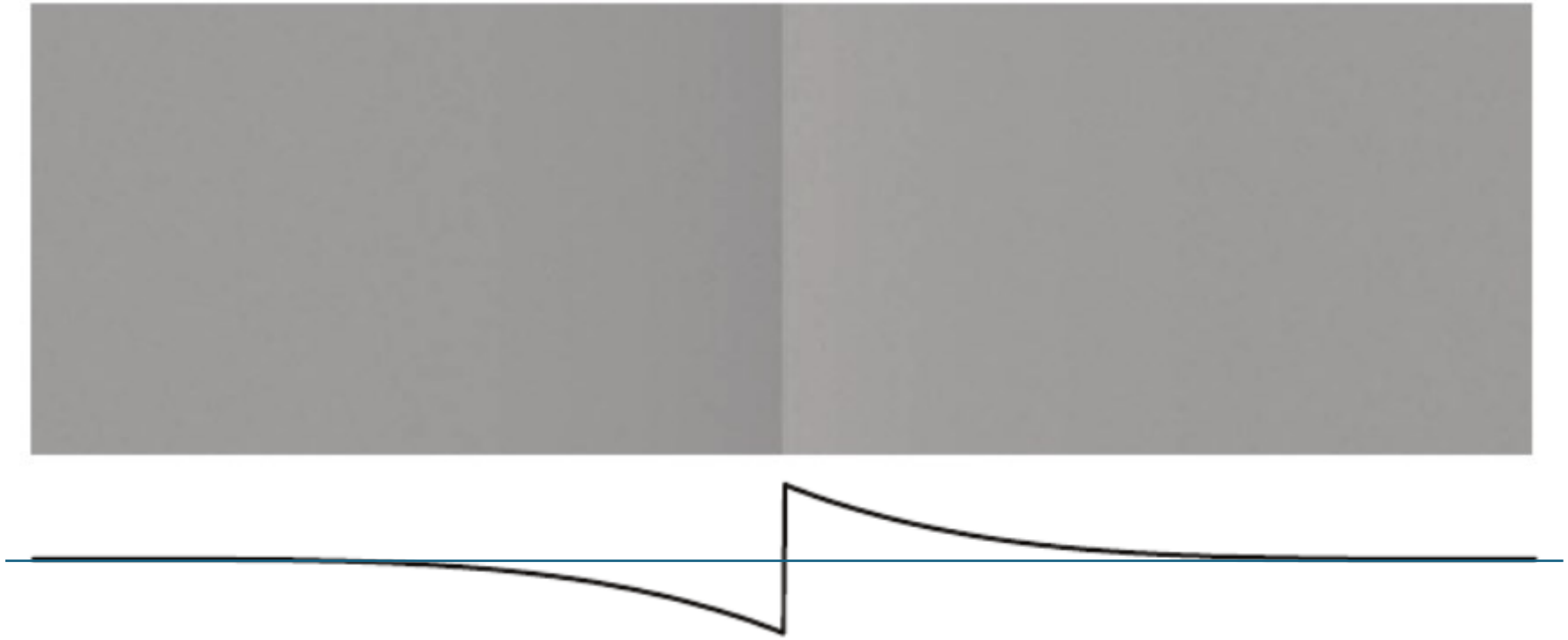
Craik-O’Brien-Cornsweet ilusion

It is rather easy to detect the brightest side



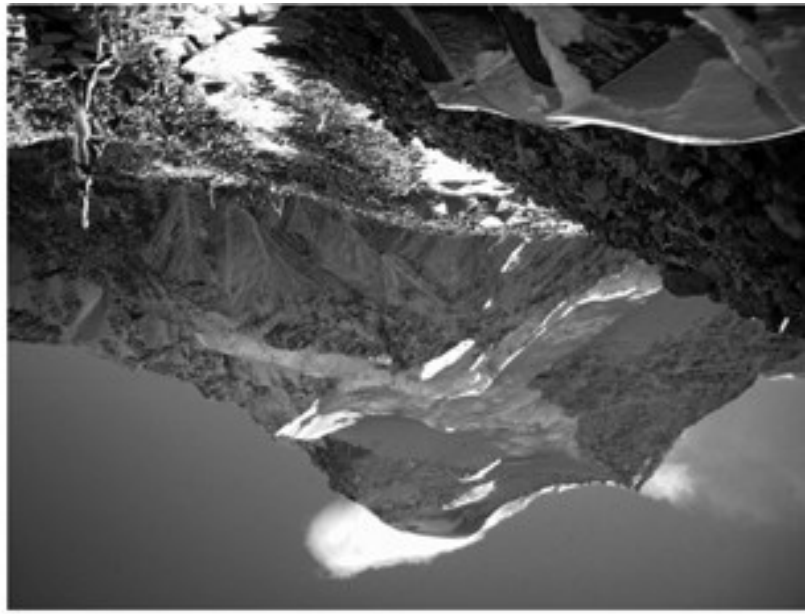
Craik-O’Brien-Cornsweet ilusion

The two halves are actually the same colour, with a glitch at the middle



Object Recognition and its Complexities

Some scenes are easier than others.
What's on the left? And on the right?



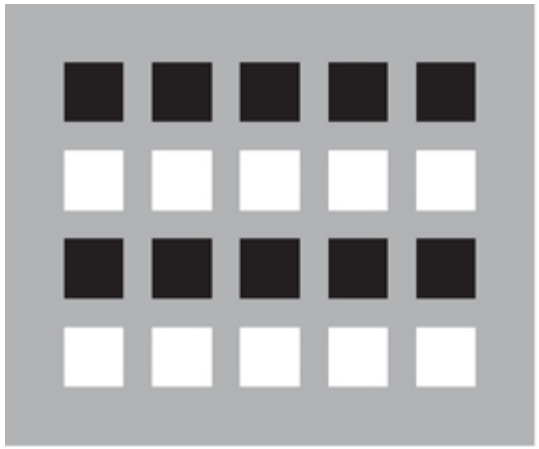
Object Recognition and its Complexities

Orientation matters: when we make sense of it, if gets easier to interpret

Gestalt Principles

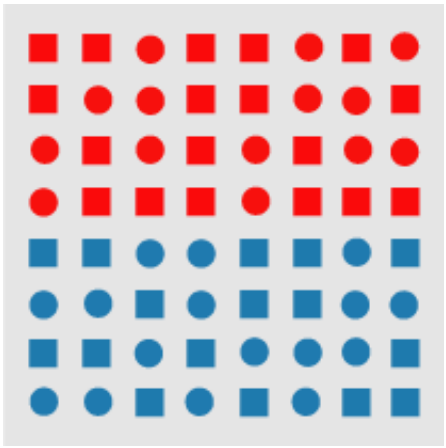
Object Recognition – Grouping

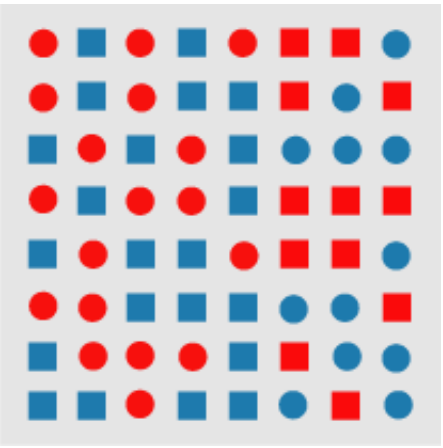
The first step is visual field organization into groupings



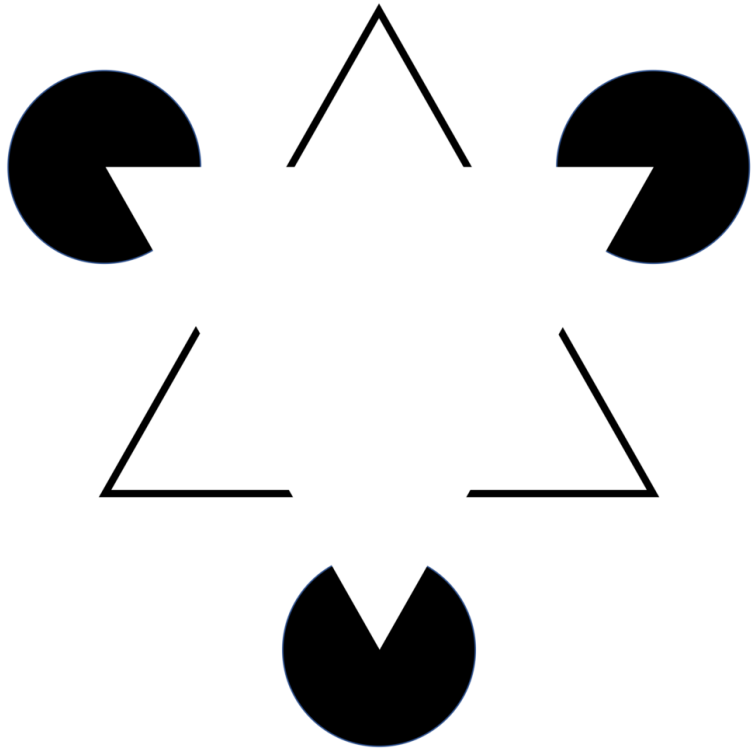
(a)

(b)

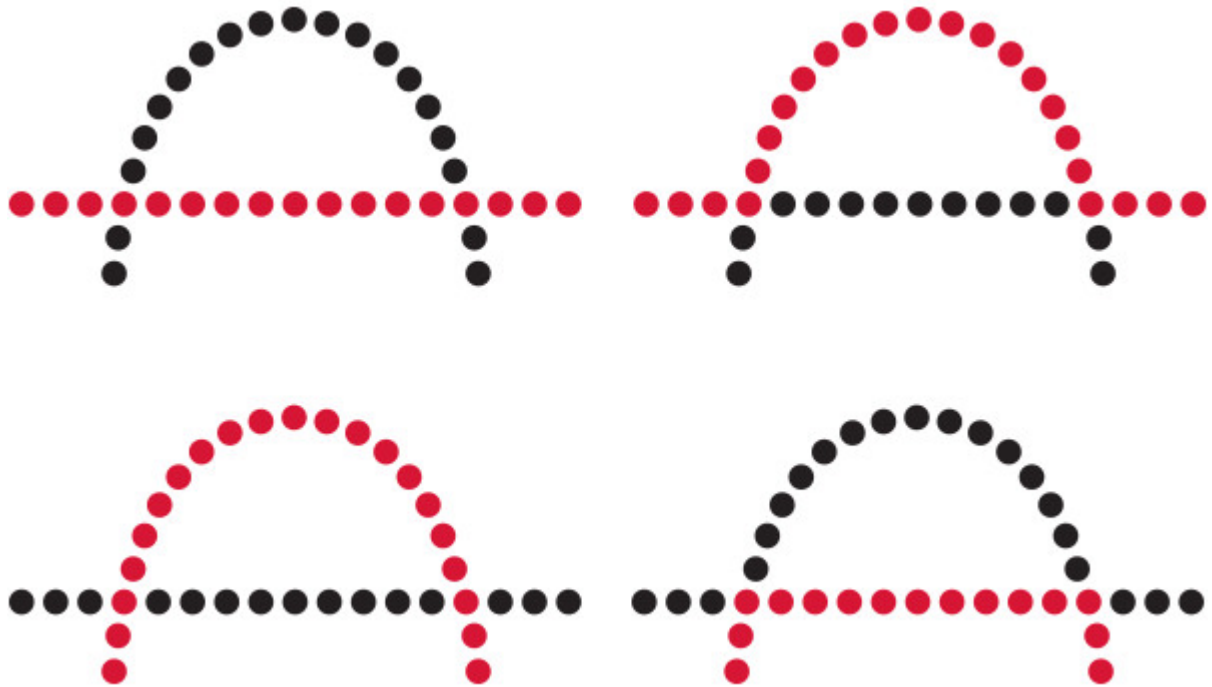




Closure



Continuity



Figure/Ground

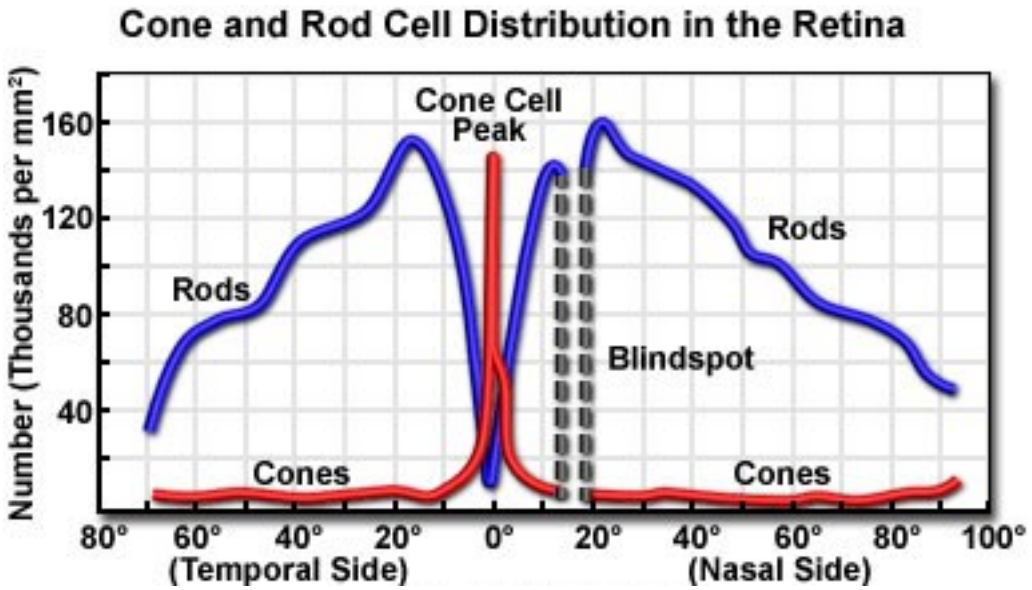
https://www.toptal.com/designers/ui/gestalt-principles-of-design#:~:text=Our%20brains%20are%20built%20to,order%20(also%20called%20pr%C3%A4gnanz).

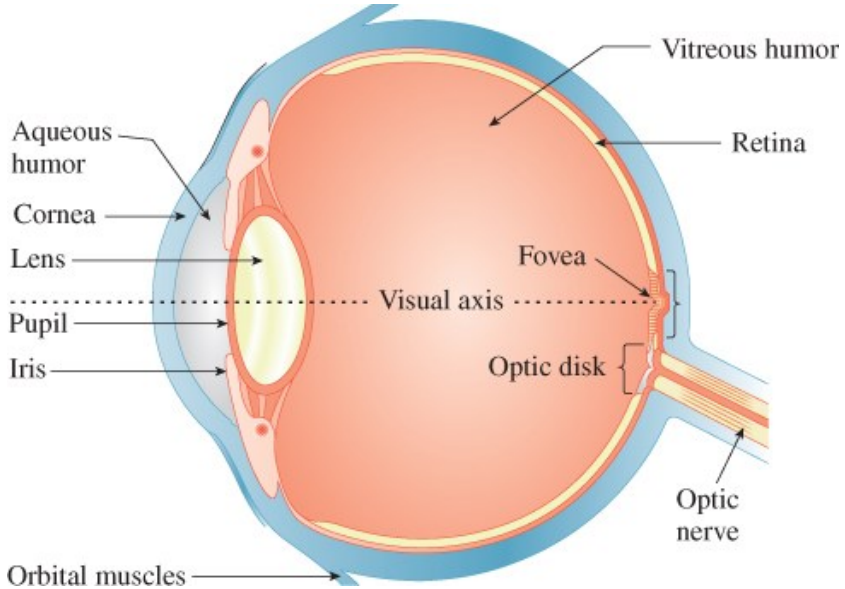
Thumbs up

The disappearing finger...

What is happening?

It is the eyes' blind spot!





Colour Perception

We already talked about how the cones capture light in different ranges of colour

The visual system adapts to what is seen also based on the characteristics of the environment

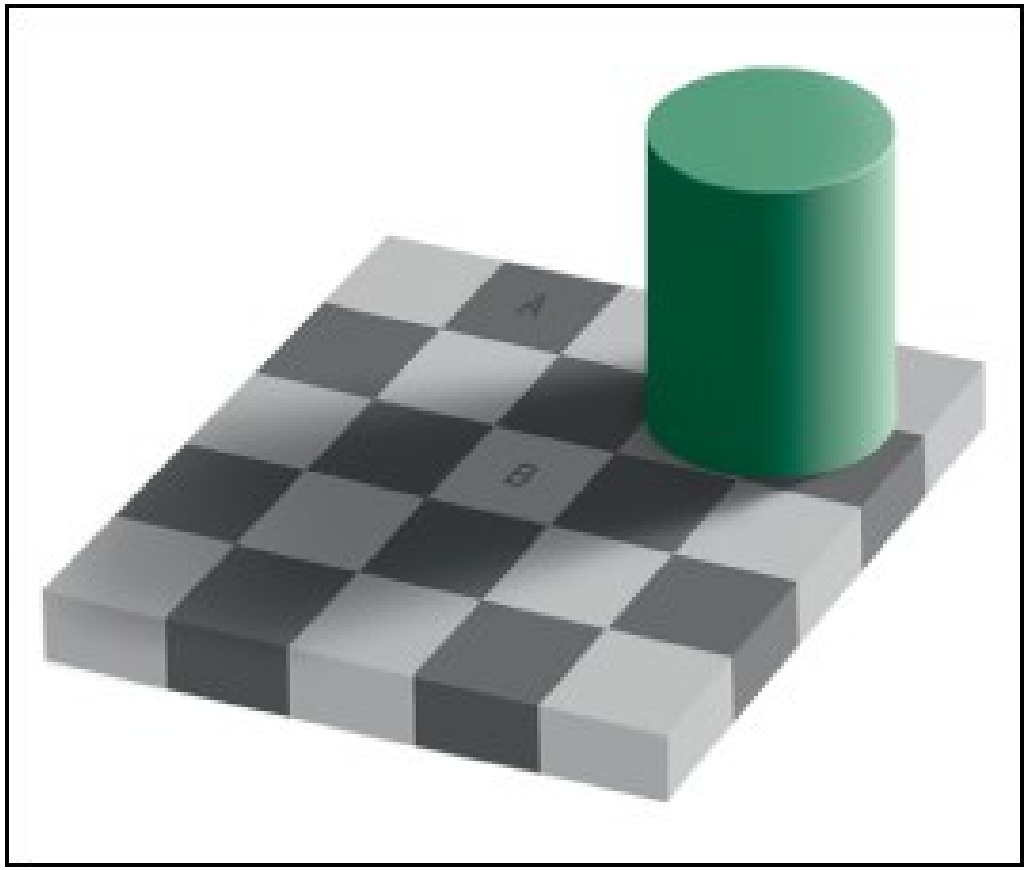
What we see in a photograph may not be what the person present at the scene actually saw

- We are in a different environment, hence, our visual system reacts differently

Maintaining the sense of colour in challenging illumination

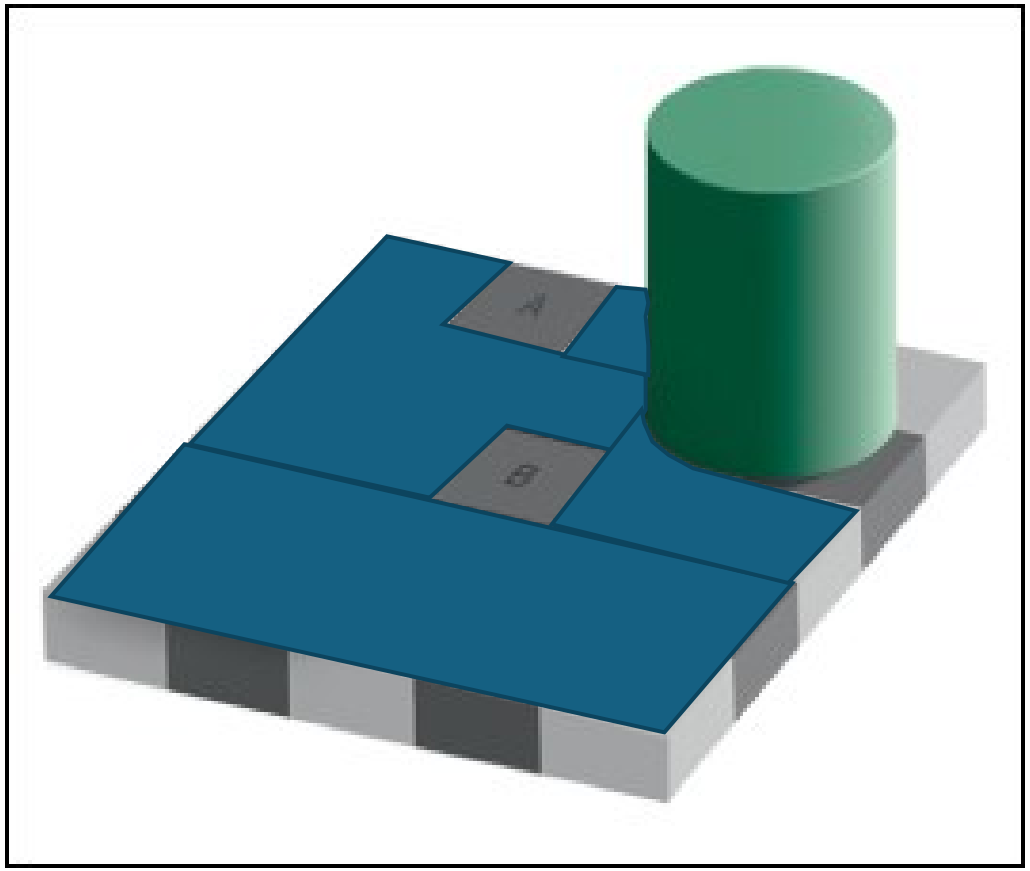
Despite the lighting differences over the board we can still distinguish which one is a lighter grey. A or B?

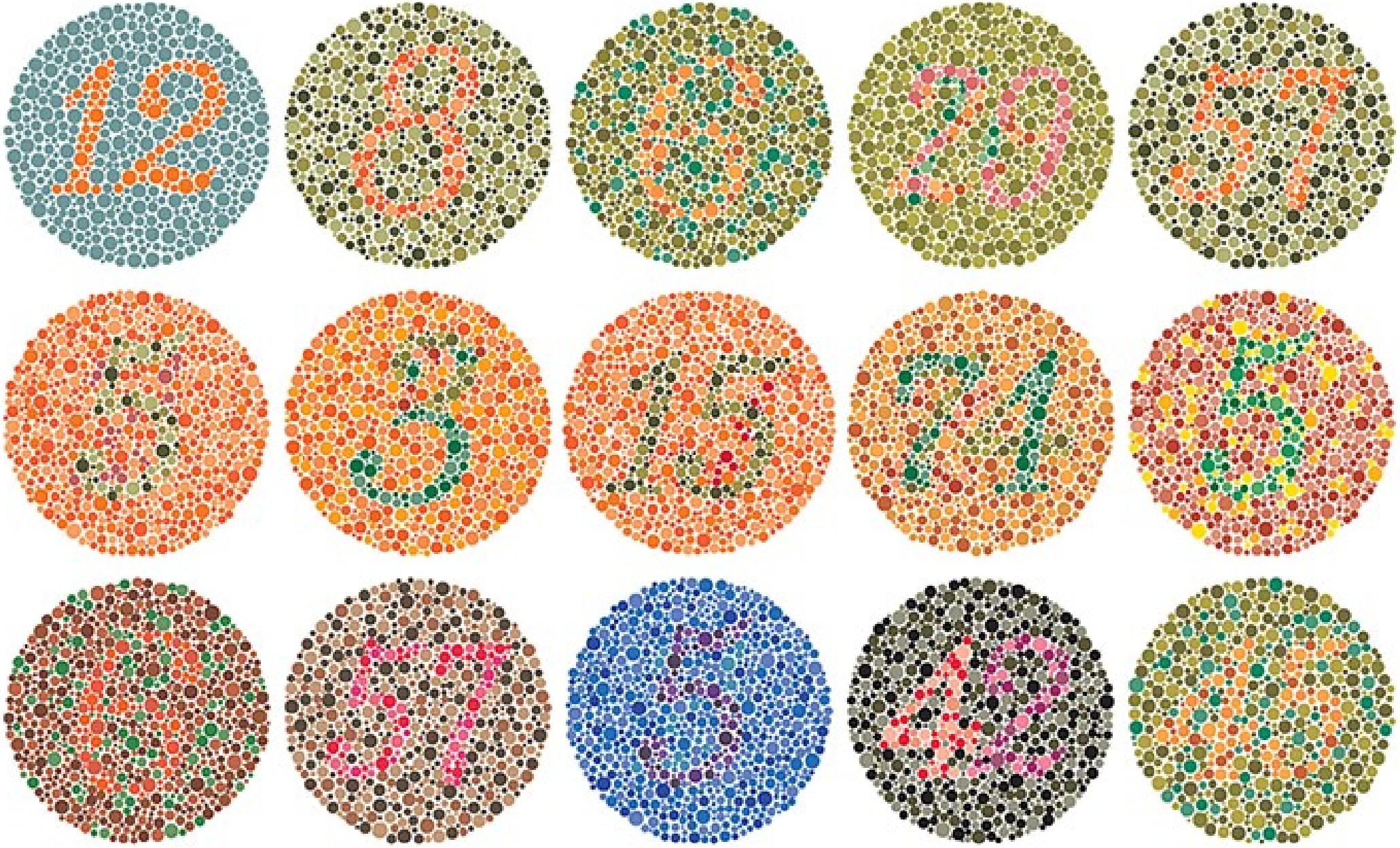
Colour constancy



Colour Constancy

They are actually the same colour

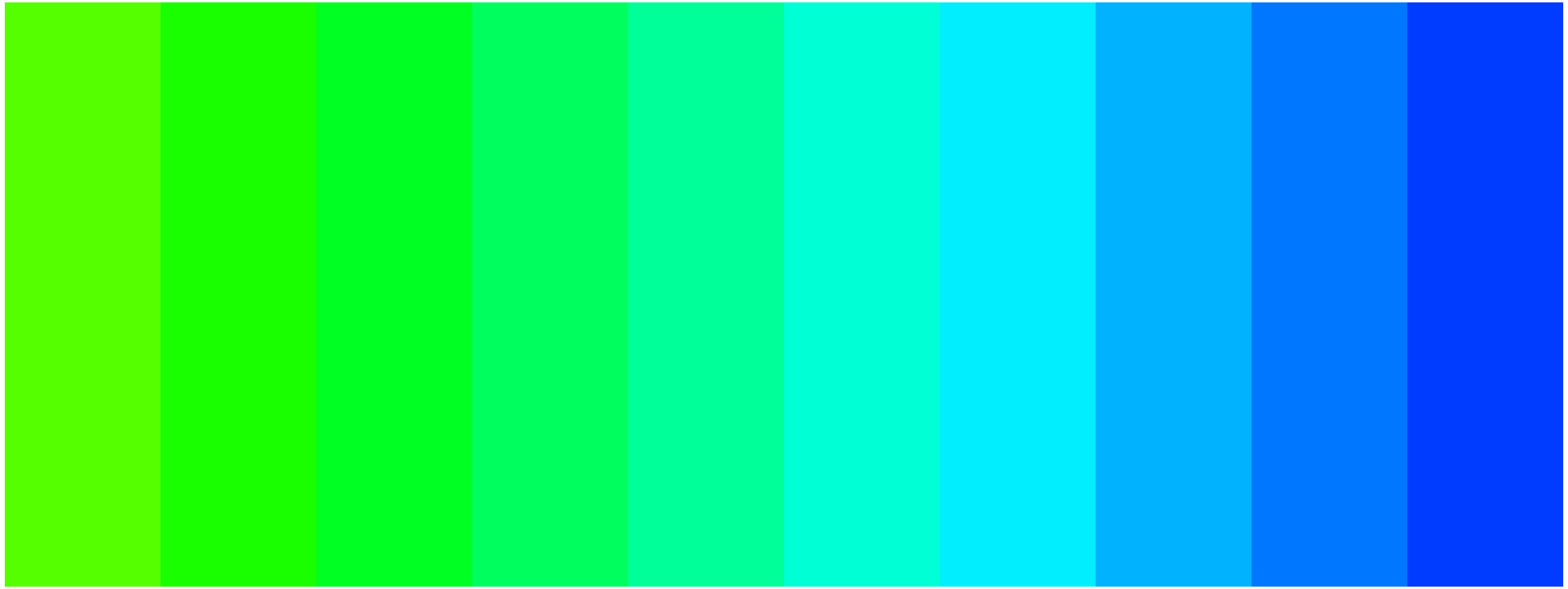




American Optometric Association

Color Spaces – VERY small note

If we consider the common RGB representation, we cannot ensure perceptual distances (what is that?)



Colour Spaces – VERY small note

Perceptual colour spaces

- The distance between colours has a correspondence to perceptual distance
- E.g., CIE L*u*v*

Depth Perception

Monocular Cues

Relative Size

More distant objects look smaller

https://the[illegible]nf[illegible]nt/uploads/2020/04/TakeoffQueue-scaled

Texture Gradient

Occlusion (interposition)

https://cappadociatourtickets.com/uploads/thumbnail_image_61c7194b06131.jpg

Linear Perspective

https://miro.medium.com/max/1125/1*JNnI_Xwg79jHYle7vdyzDQ.jpeg

Perspective

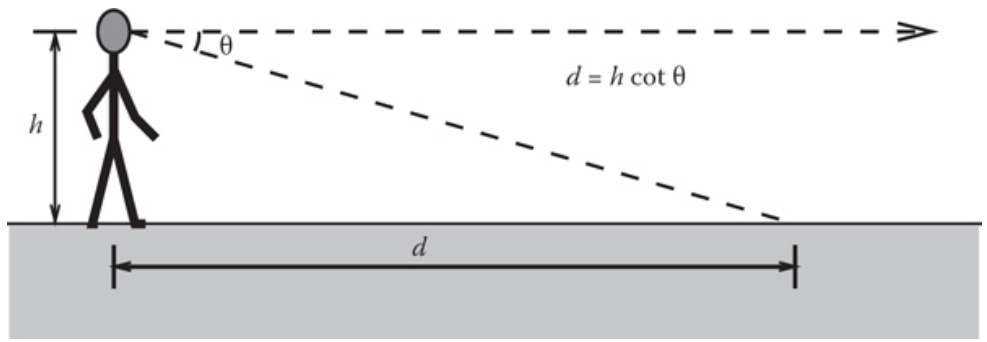
We immediately sense that something is inconsistent

Height in Plane

Distant objects tend to appear higher than closer objects

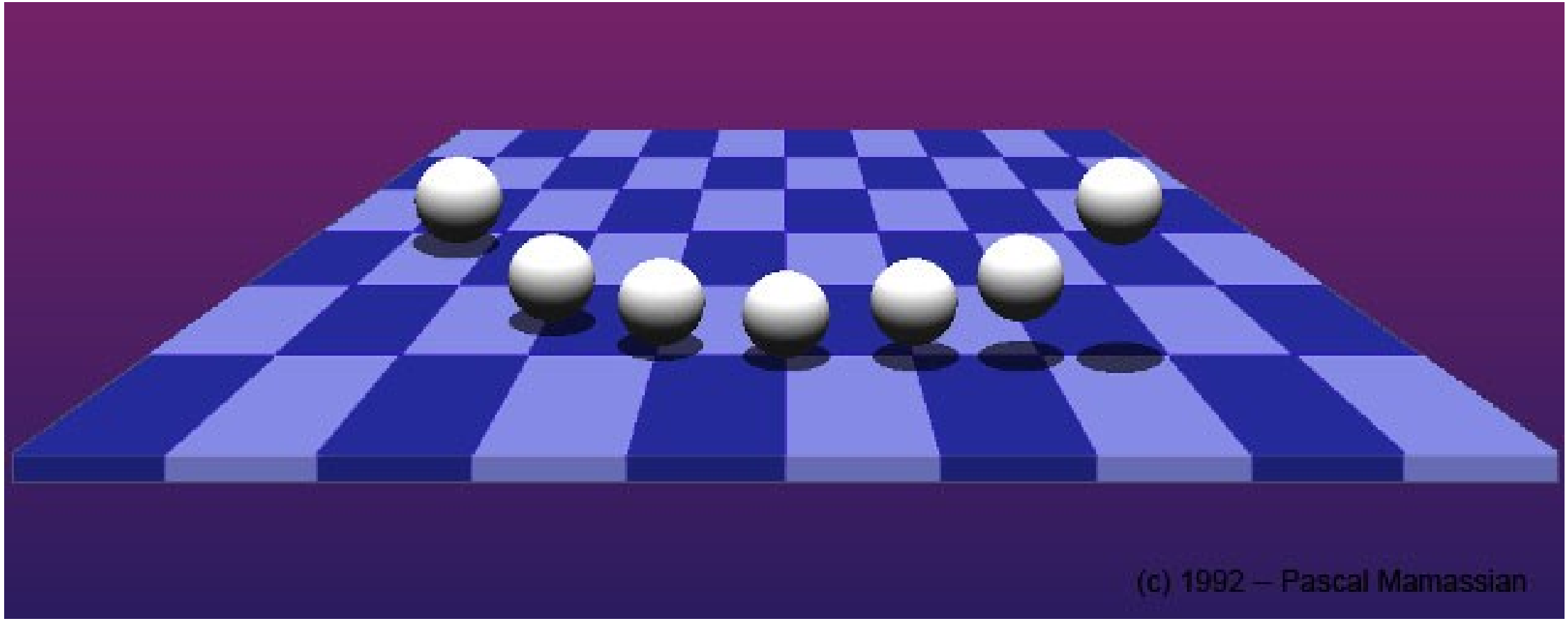
Angle Declination

The farthest something is, the closest it appears to the centre



https://docs.unrealengine.com/5.0/Images/building-virtual-worlds/lighting-and-shadows/environmental-lighting/exponential-height-

Light and Shadow



Light and Shadow

Just adding colour does not add much to the shape perception

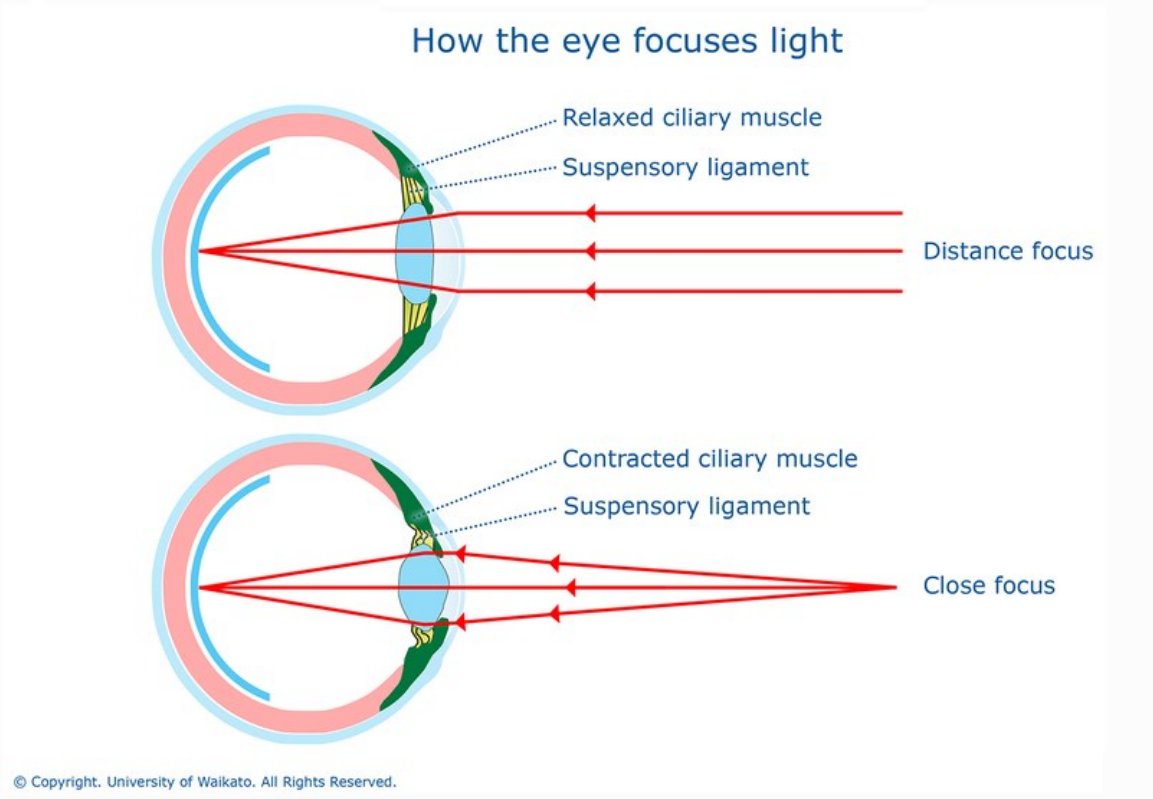
https://medium.com/my-games-company/using-light-and-color-in-game-development-a-beginners-guide-400edf4a7ae0

Motion-based Motion Parallax

Depth Perception – Accommodation

Relies on lens deformation information to focus on the target

Not a very strong depth cue and works up to around 2 m

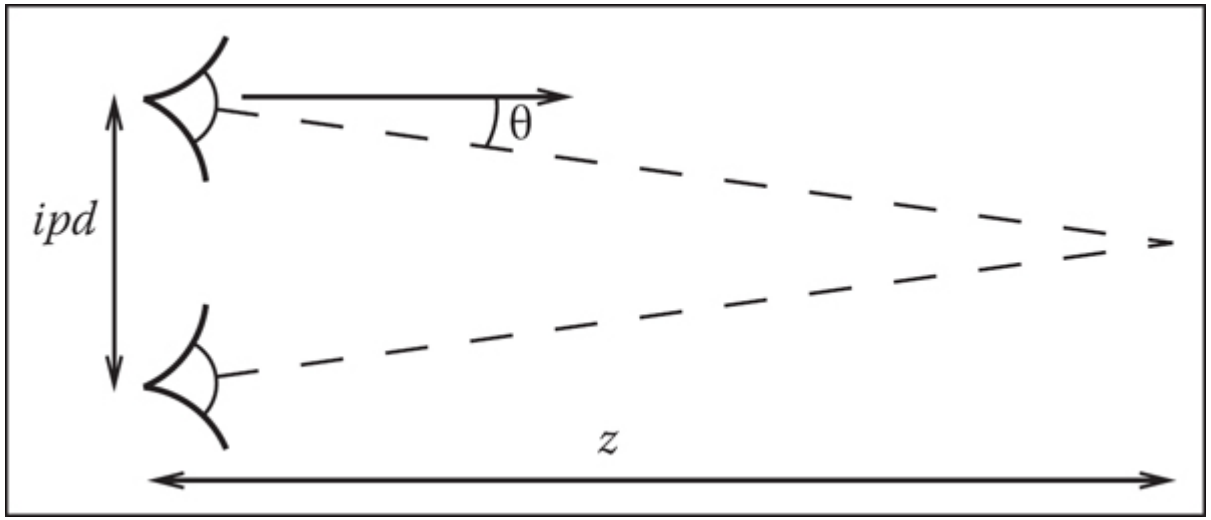


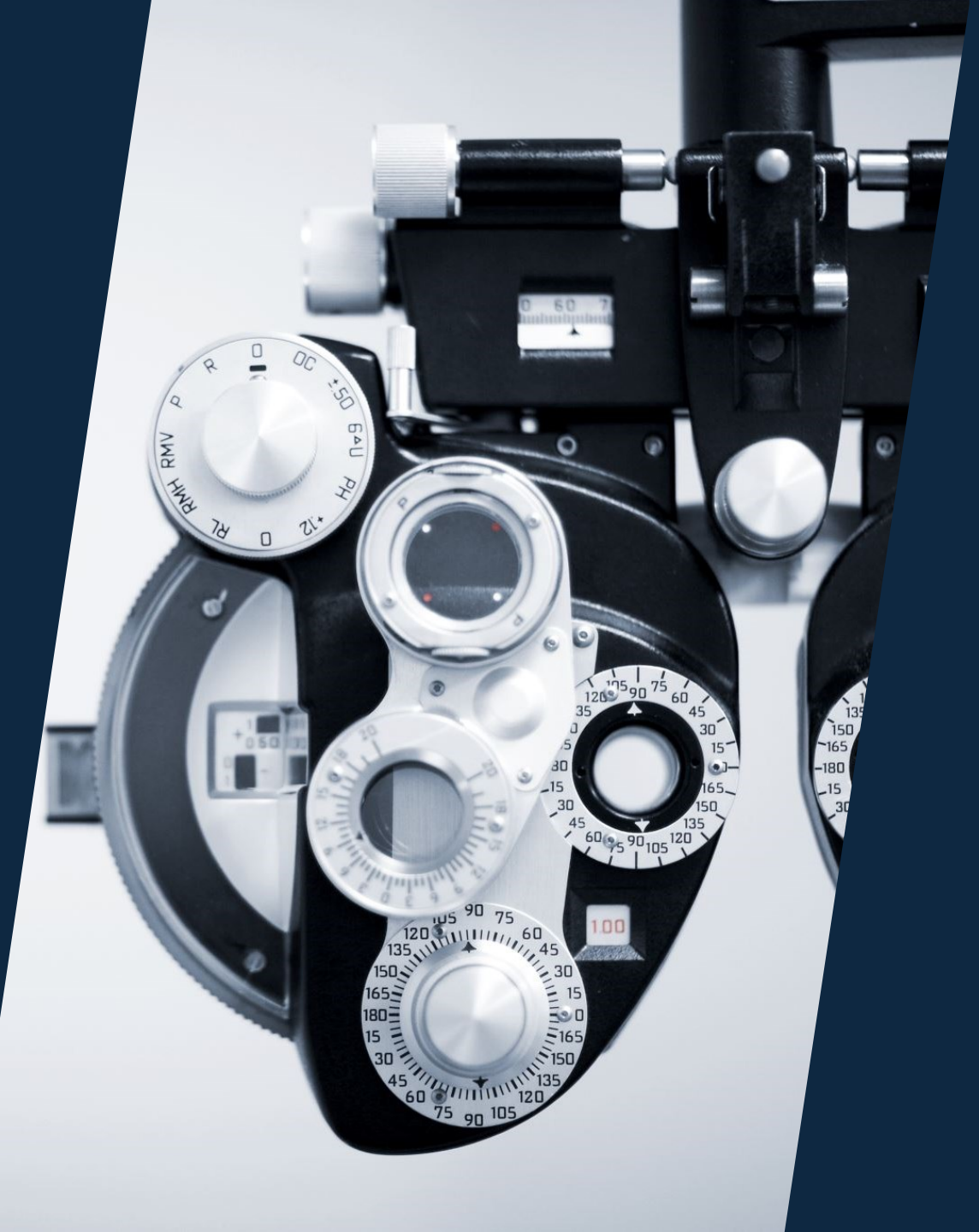
Depth Perception

Binocular Cues

Depth Perception - Convergence

Based on the angle of eye orientation to attain convergence at the object

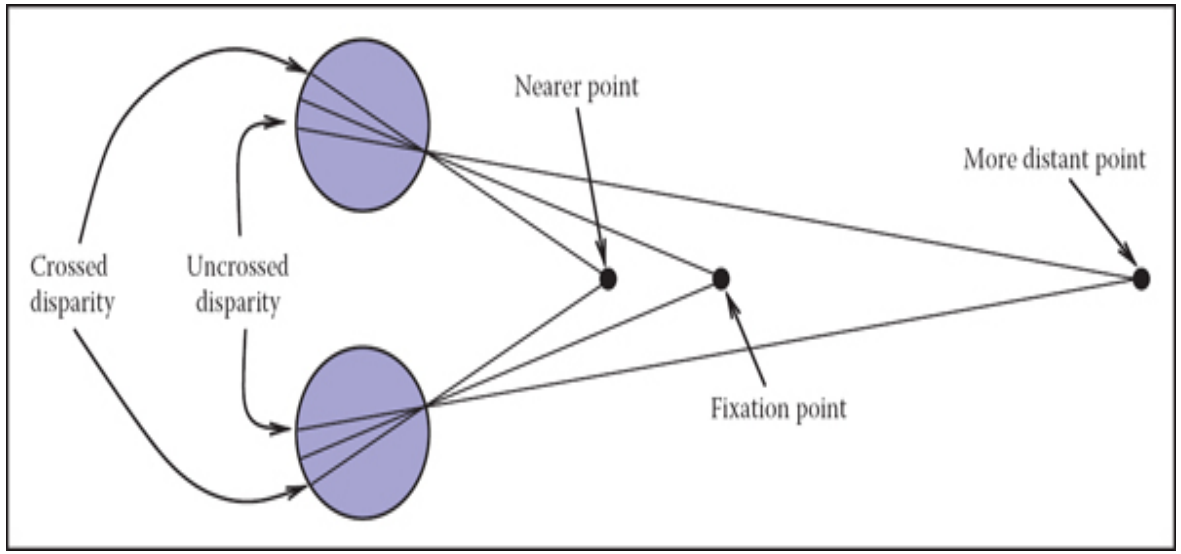




Thumbs Up Experiment. Again!

Binocular disparity

Depth Perception – Binocular Disparity



Binocular Disparity
Anaglyph 3D

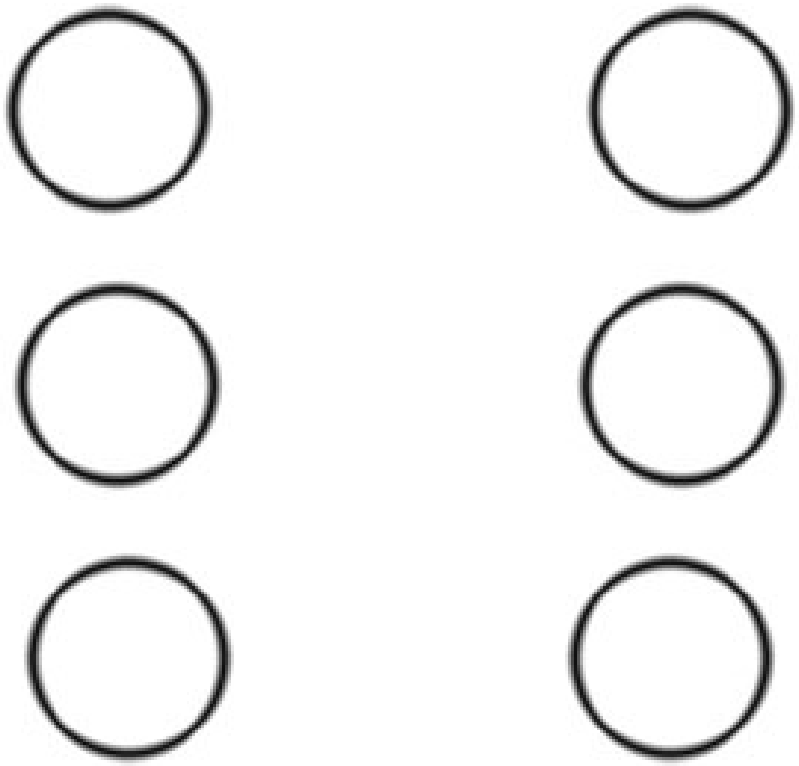
Anaglyph 3D, possible by using red-blue glasses enables watching movies in 3D by simulating the binocular disparity effect

https://www.youtube.com/watch?v=e00N024D7Lg&t=305s

Stereo Vision

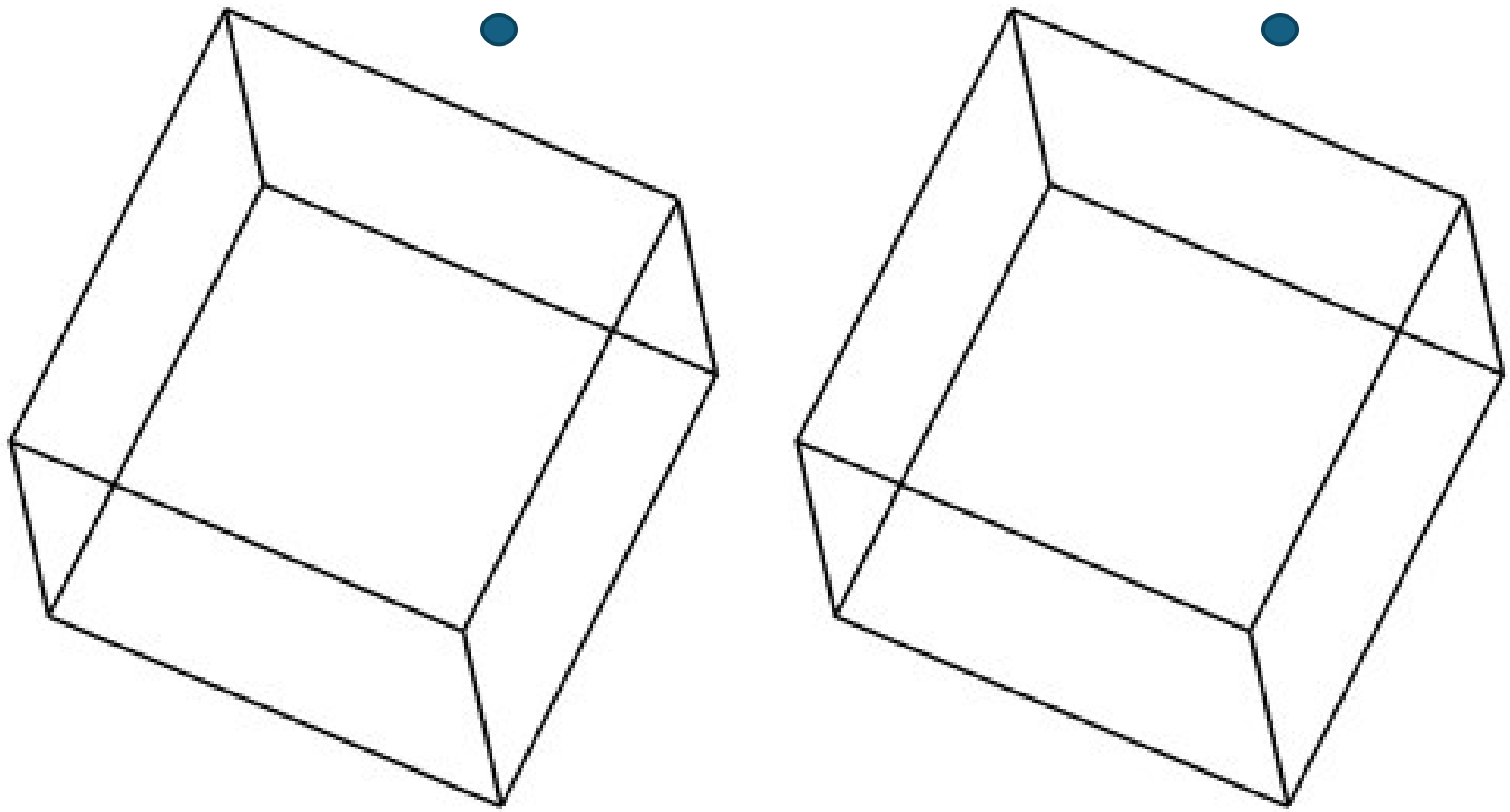
What makes us see in 3D?

Which circle is closer to you?



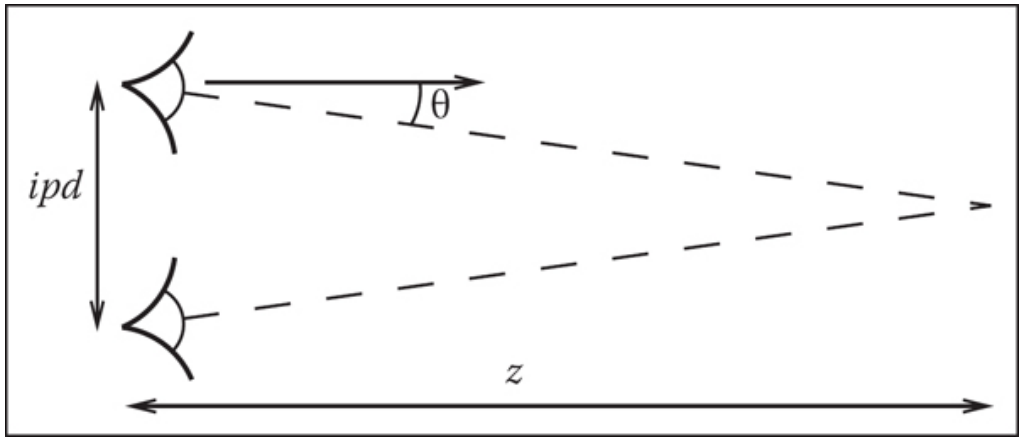
http://steipe.biochemistry.utoronto.ca/abc/index.php/Stereo_vision_practice

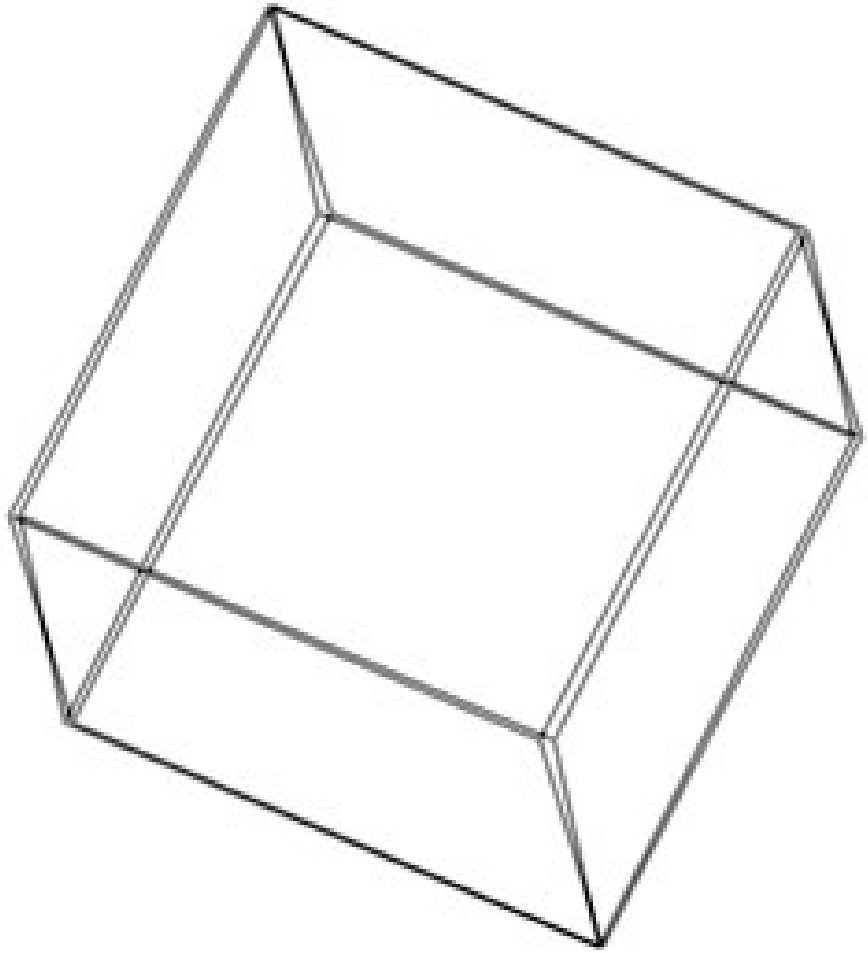
Stereo vision



Stereo Vision

The two cubes have subtle differences to appearance to each eye

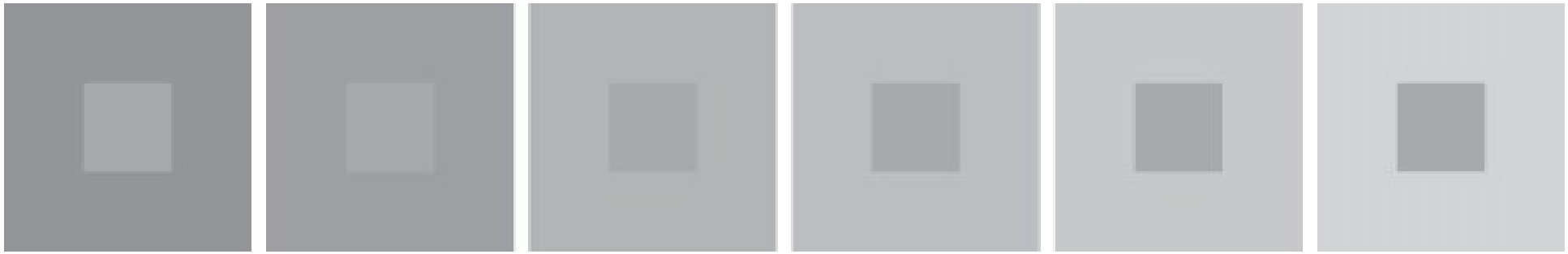




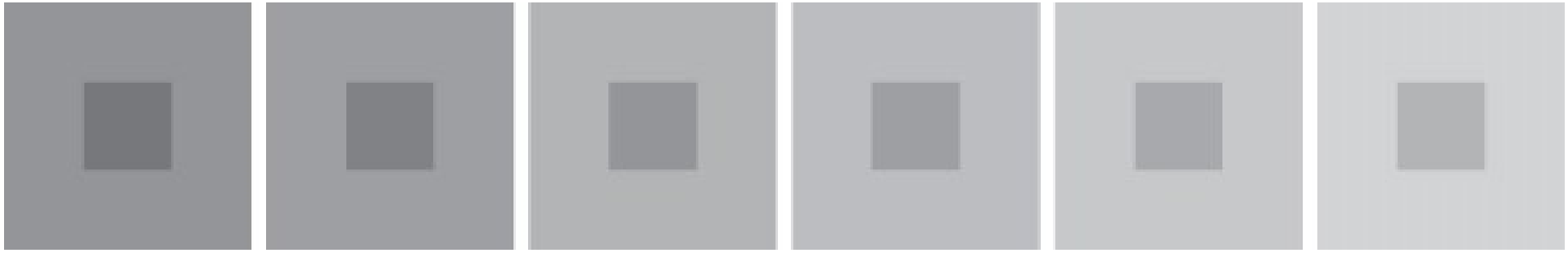
Constancy

Colour Constancy

Really bad at perceived brightness (affected by changing context)



Really good at keeping the lightness constancy under varying illumination



Color Constancy

Shape Constancy

- What is the shape of the table?

- Despite how it looks, we instantly know its true shape

Size Constancy

While we see small people, we instantly know that it is because they are at a distance

http://poshaylapsych15.blogspot.com/2014/11/perceptual-constancies-size-constancy.html

http://psychapprentice.weebly.com/psychology-lexicon/visual-constancy

Apparent interaction messes the effect

Motion Perception

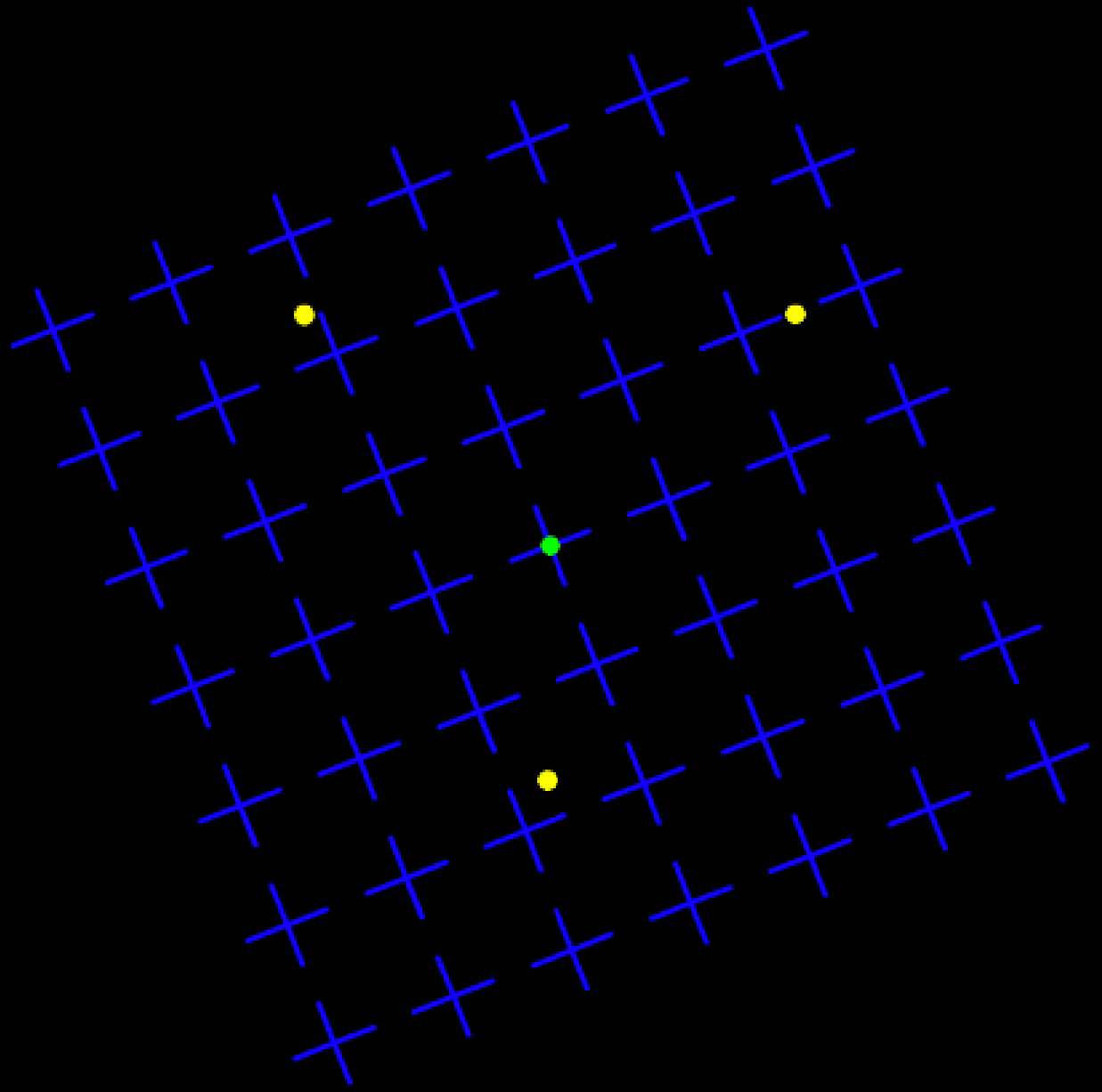
https://lightroom-photoshop-tutorials.com/wp-content/uploads/2024/03/Dance-in-Motion-Mastering-Motion-Blur-in-Nighttime-Photography.webp

Motion

Our visual system is particularly good at detecting motion or changes in optical flow

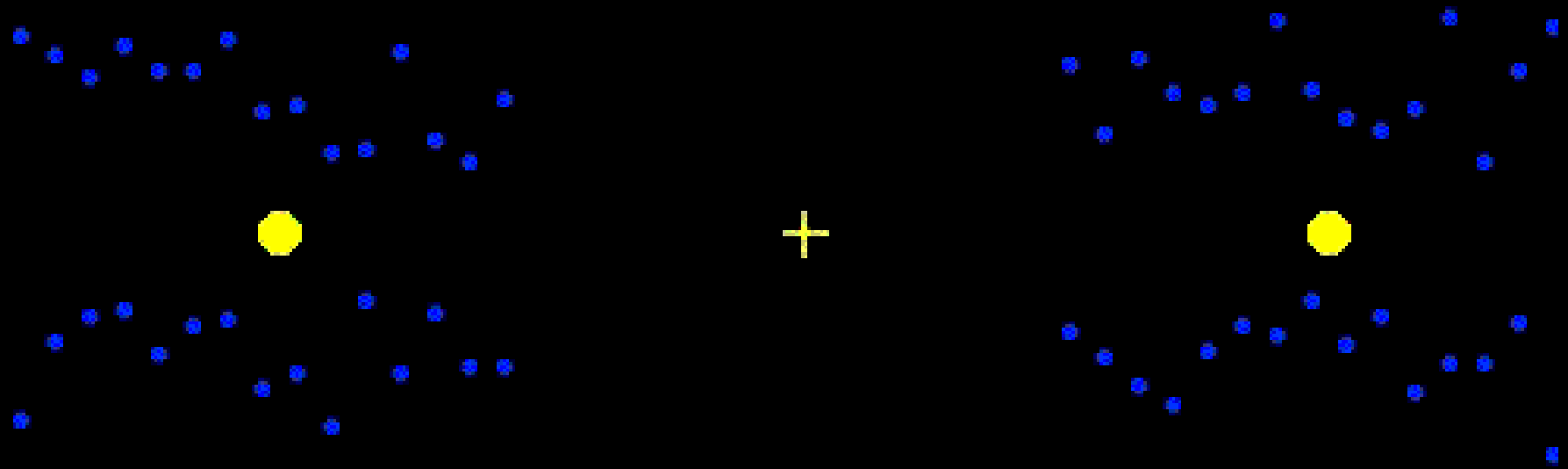
So, it can be an important clue to attract the eye… or to distract it

Blur as a cue for motion



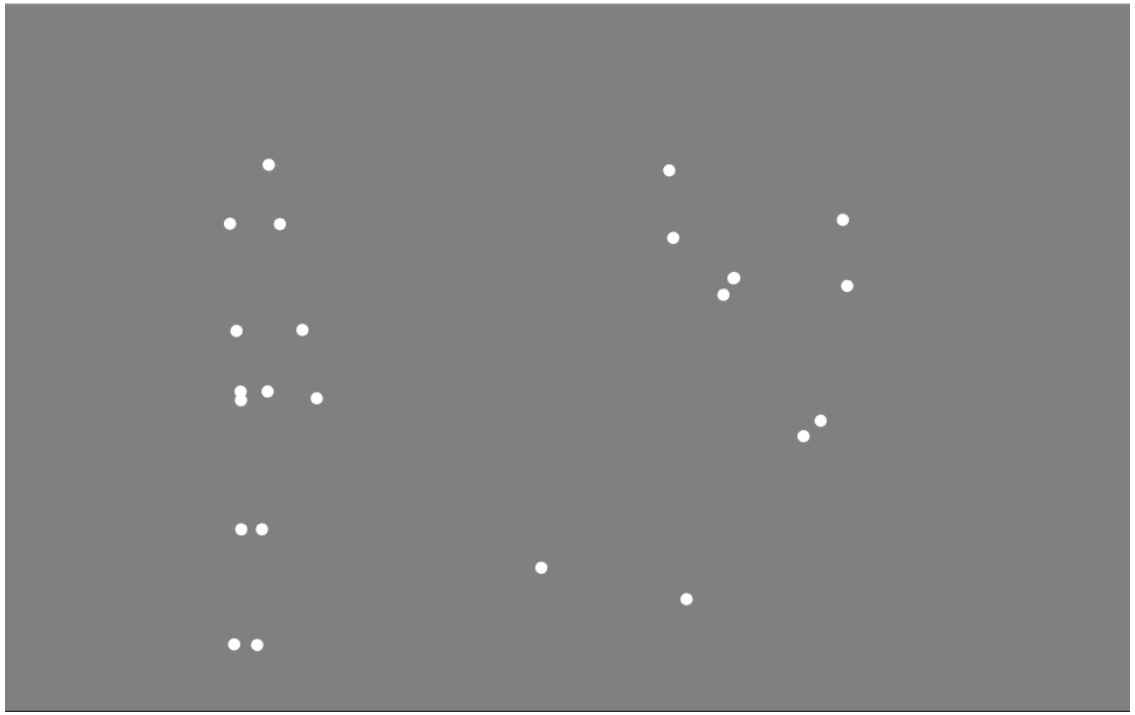
Motion induced blindness

Motion induced blindness



Perception of human movement

Our visual system is particularly sensitive to motion corresponding to human movement



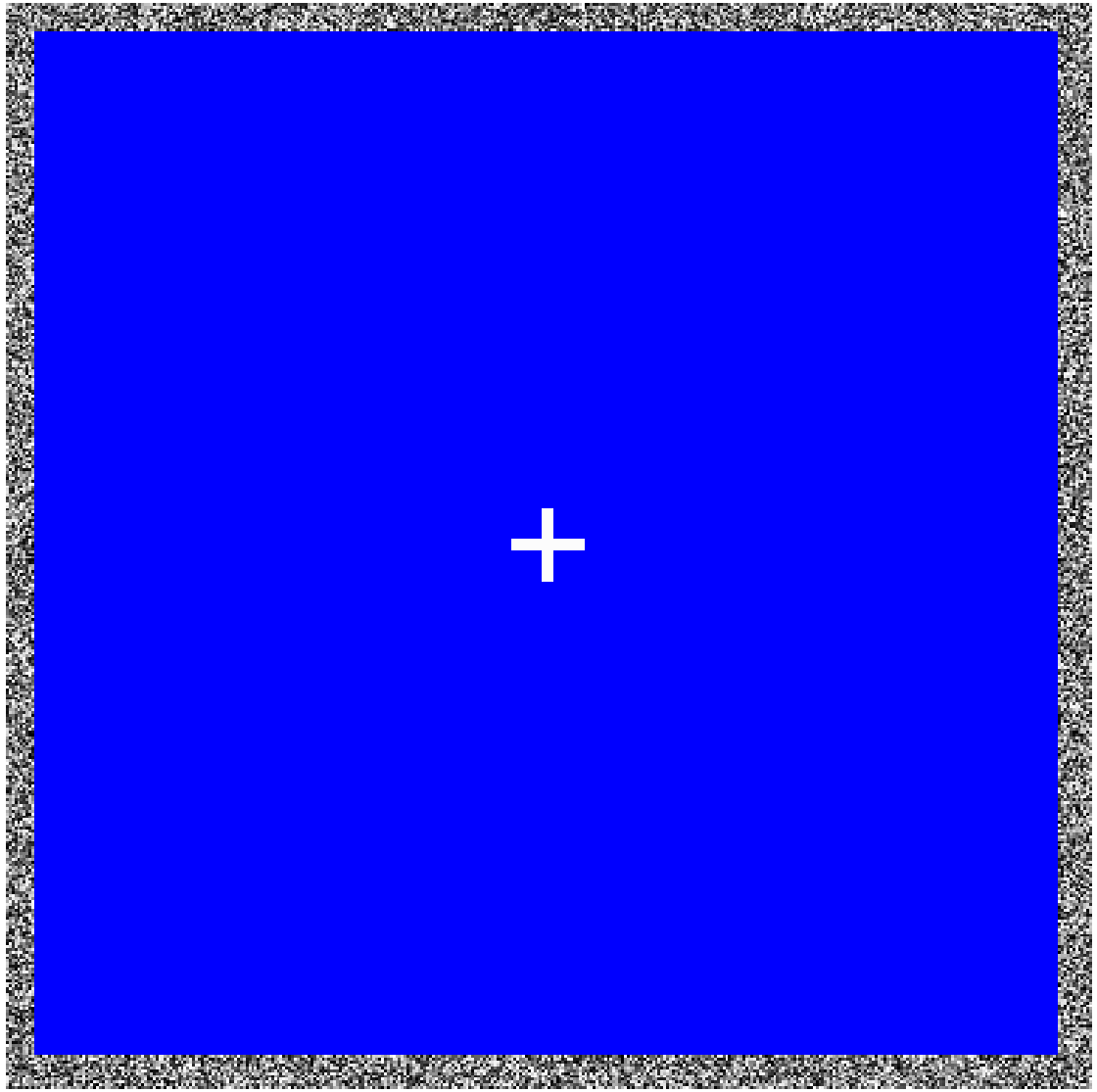
Rendering human motion is particularly challenging. Viewers will recognize even the smallest inaccuracy

Unconscious Perception

Continuous Flash Suppression

Enables showing something without the person being conscious of it

(see it with anaglyph glasses)

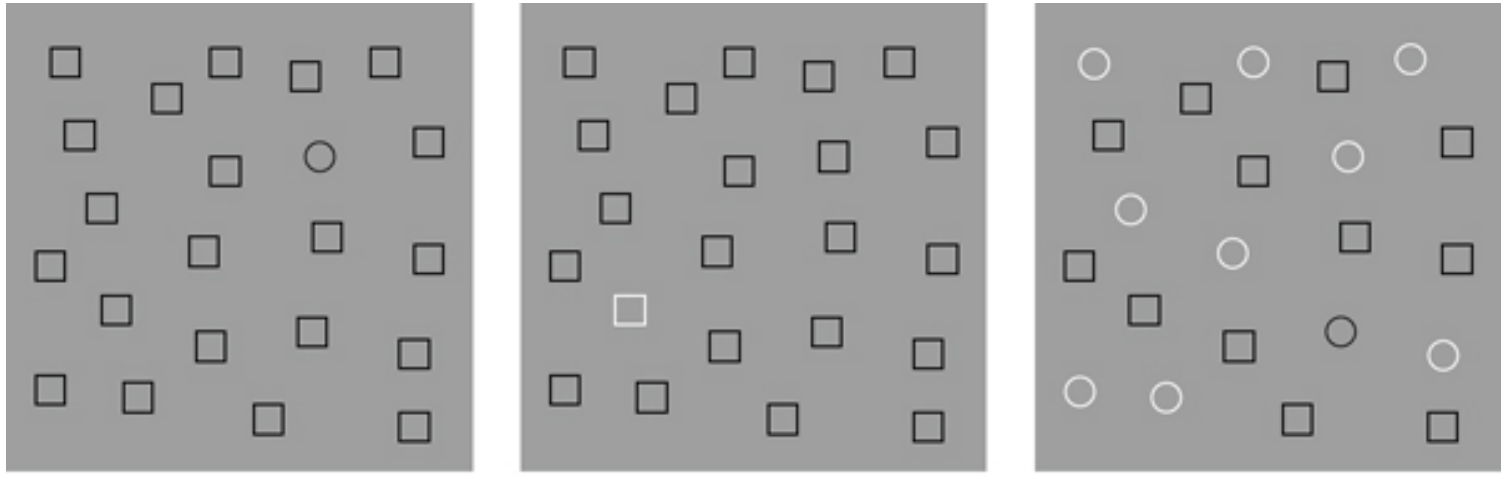


Visual Salience and Search

Visual Attention

Attention processes can affect vision

The “elephant in the room” pops out, in each of the images, but **not as fast in the rightmost image**. Why?



Attentional processes can be used to direct the user and communicate something quickly

But, they can also divert attention from what is important…

Complexity can slow down detection due to increased cognitive demand

Visual Salience

When we first look at a scene, there are certain regions that grab our attention. They are **visually salient.**

A

B

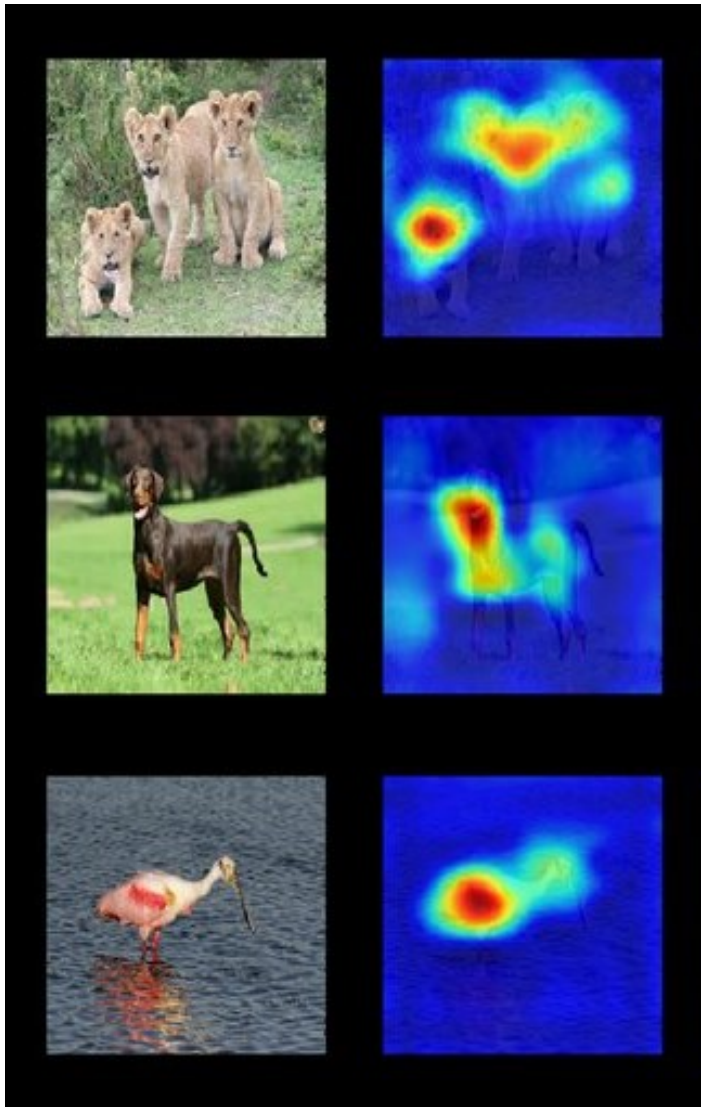
Gaspelin & Luck, 2008

Visual Salience

Knowing / predicting the most probable visually salient regions can help focus higher rendering quality on those spots

This may be done using models of visual salience or...

...any technology you think could help, here?



Visual Salience

Guiding the player

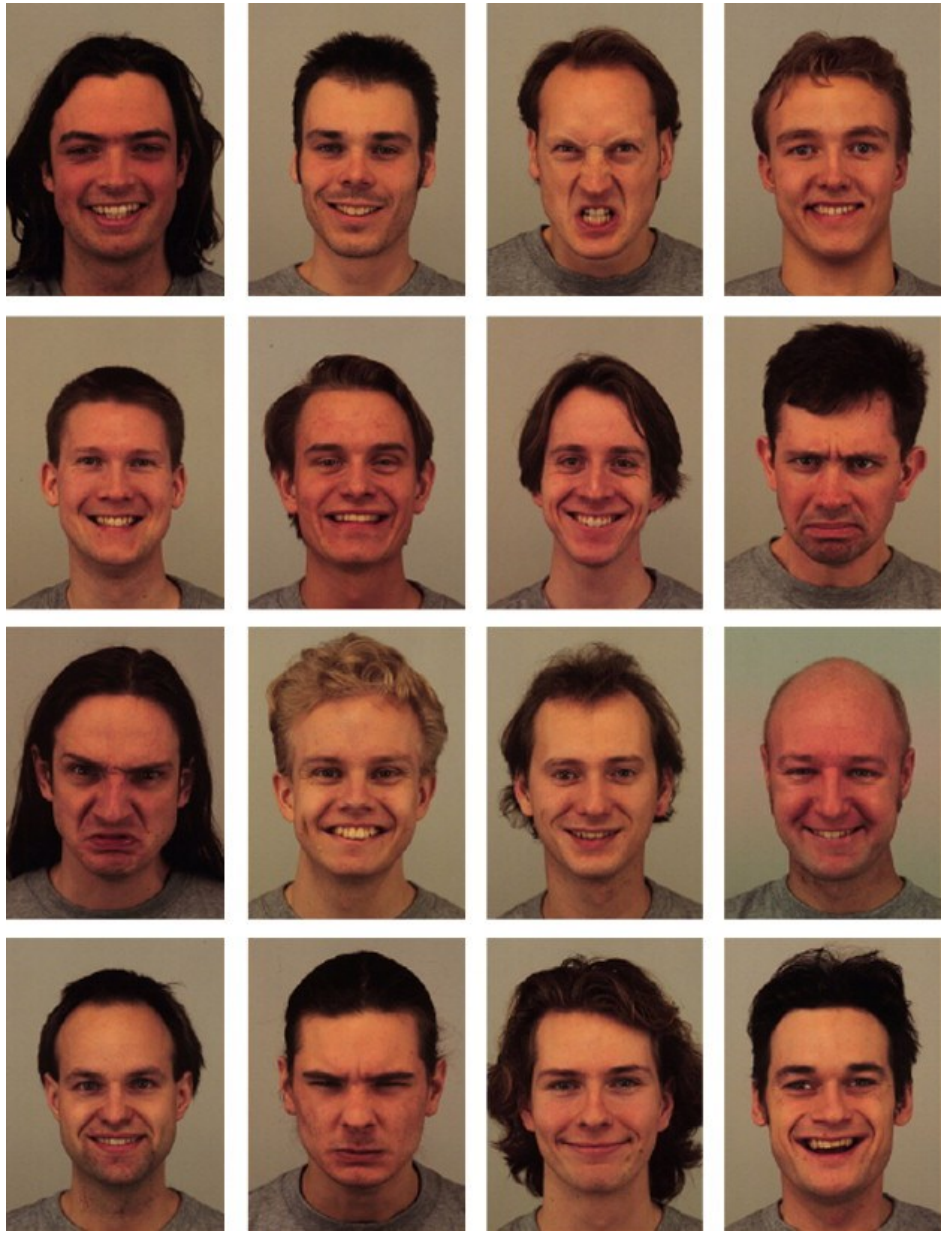
Emotional Salience

Given the importance of **emotion** in our daily lives, our visual system provides some advantages for processing it

A region inducing/representing a negative emotional state (e.g., angry face) can attract our eye, surpassing visual salience

Remember about snake detection early in this class!

An angry face on an NPC draws attention to it faster



KDEF database


That’s all, for today,
but there is more...

Bibliography

- W Thompson, R Fleming, et al., Visual Perception from a Computer Graphics Perspective, https://learning.oreilly.com/library/view/visual-perception-from/9781439865491/
- J F Hughes, A van Dam, et al., An Introduction to Human Visual Perception, chapter 5, in “Computer Graphics: Principles and Practice”, Addison-Wesley Professional, https://learning.oreilly.com/library/view/hughes-computer-graphics-3-e/9780133373721/ch05.html
- W Thompson, Visual Perception, chapter 20 in “Fundamentals of Computer Graphics”, 4th ed., A K Peters, https://learning.oreilly.com/library/view/fundamentals-of-computer/9781482229417/K22616_C020.xhtml#sec20-1

Additional Resources

- Visual illusions
  - https://michaelbach.de/ot/mot-mib/index.html
- Examples of visual perception properties
  - https://www.csc2.ncsu.edu/faculty/healey/PP/