Prog3D: Light, Colour, Colour Spaces and Images

interact LAB

UNIVERSITY OF SUSSEX

Light and Colour

Pink Floyd, 'Dark Side of the Moon'

Brainstorm (5 min) + Share

- **What is light?**
- **What is Colour?**

interact LAB

UNIVERSITY OF SUSSEX

Brainstorming

– What is light? → Physics

– What is Colour? → Human perception

What is light?

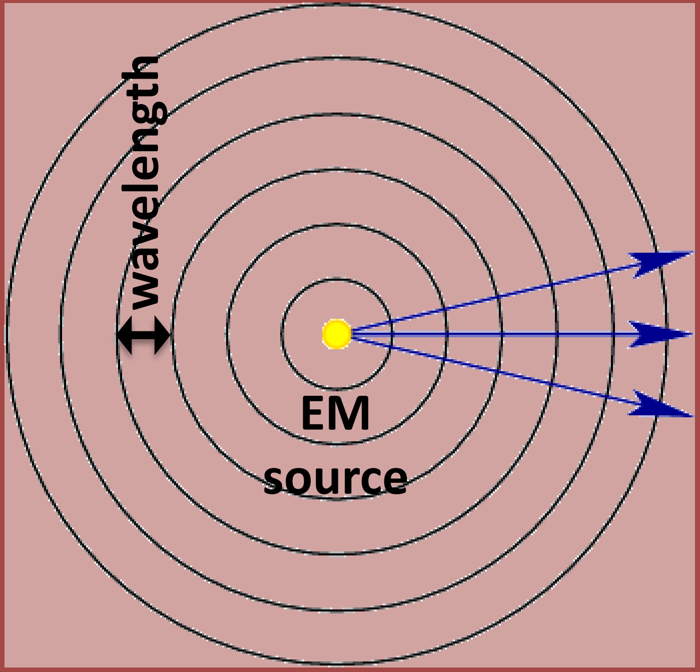
– Several ways of describing it:

1. **Waves**: EM waves travelling through space
2. **Photons**: tiny energy particles in motion
3. **Rays**: linear trajectories followed by photons

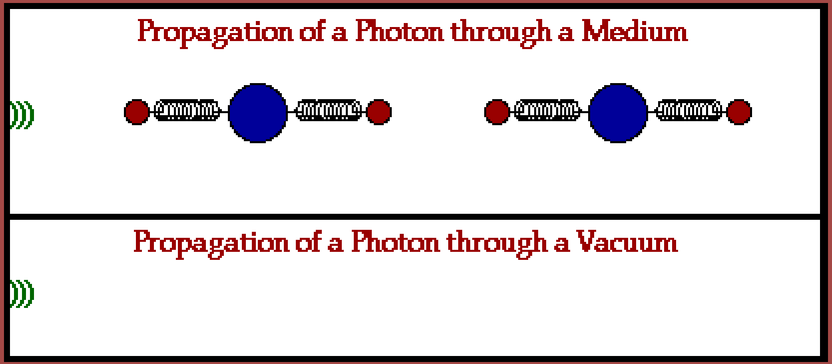
- They are all correct, and convenient in some cases

Light: Waves, photons and rays

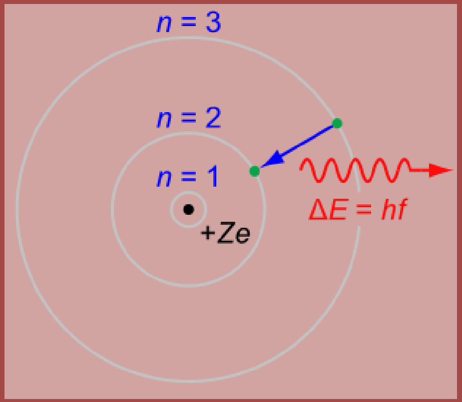
An EM source, creating a wave



Wave: EM energy in motion



Electron Energy levels and photons



interact LAB

http://www.physicsclassroom.com/mmedia/waves/em.cfm

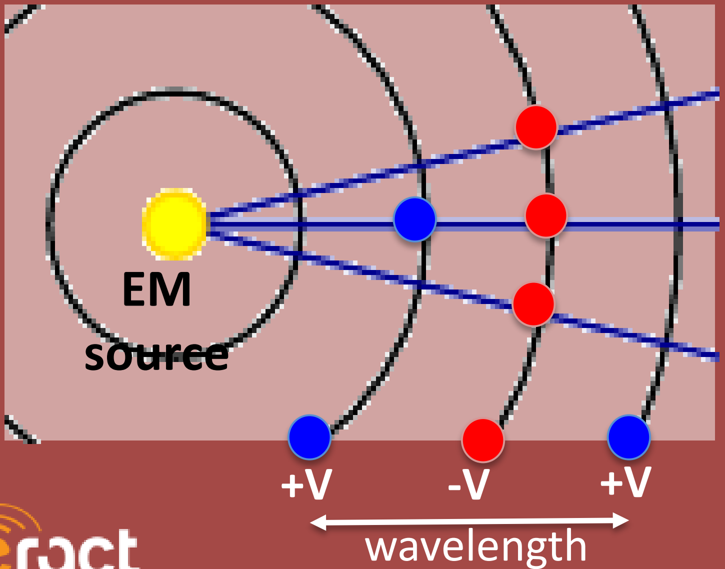
US UNIVERSITY OF SUSSEX

Light: Seen as waves

- An EM source creates a variable E field
- This E field excites nearby atoms, moving electrons to higher layers
- This atom now is at an unstable state, and creates an E field itself
- Electrons in nearby atoms feel attracted
- The first electron returns to its stable state, releases its energy (photon) and excites next atom

Light: what about photons and rays?

- **Photons:** Are the minimum amount of energy that causes electron interactions (propagation)
  - We “measure” light propagation, using **photons**.
- **Light rays:** Photons propagate perpendicular to the wavefront



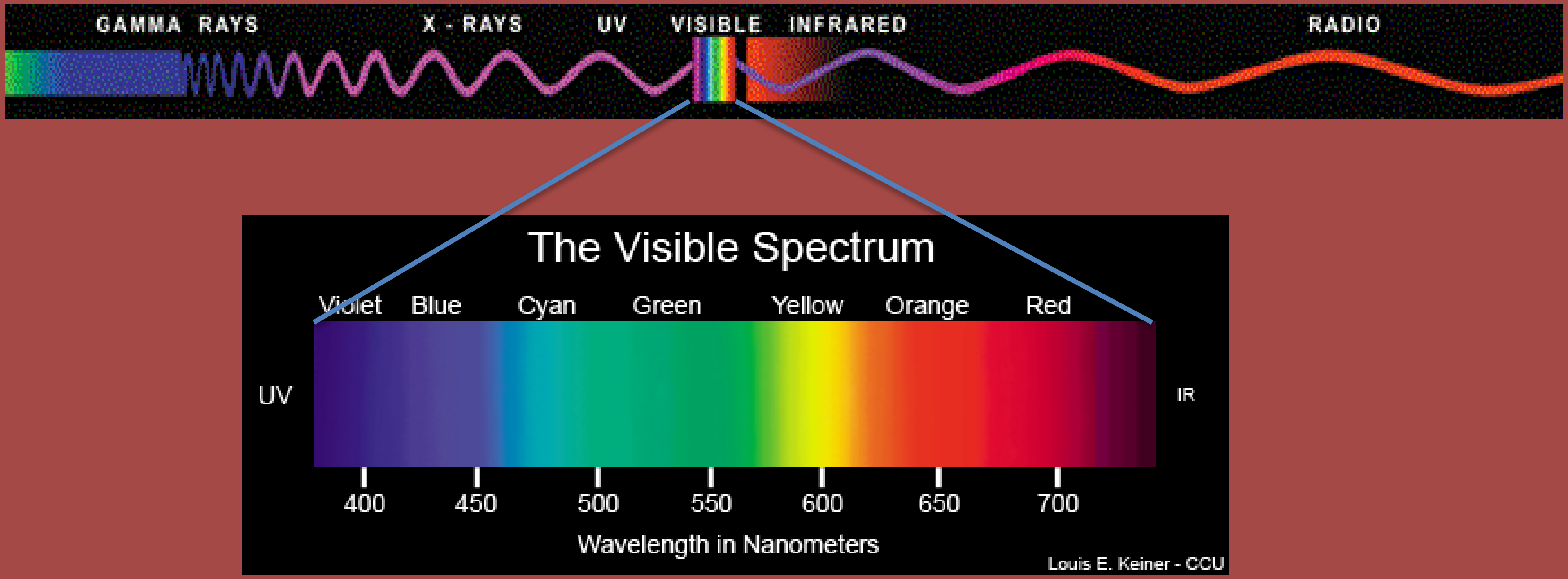
- Wavefront creates a gradient

- Gradient is strongest perpendicular to wavefront

- Photons follow a linear path

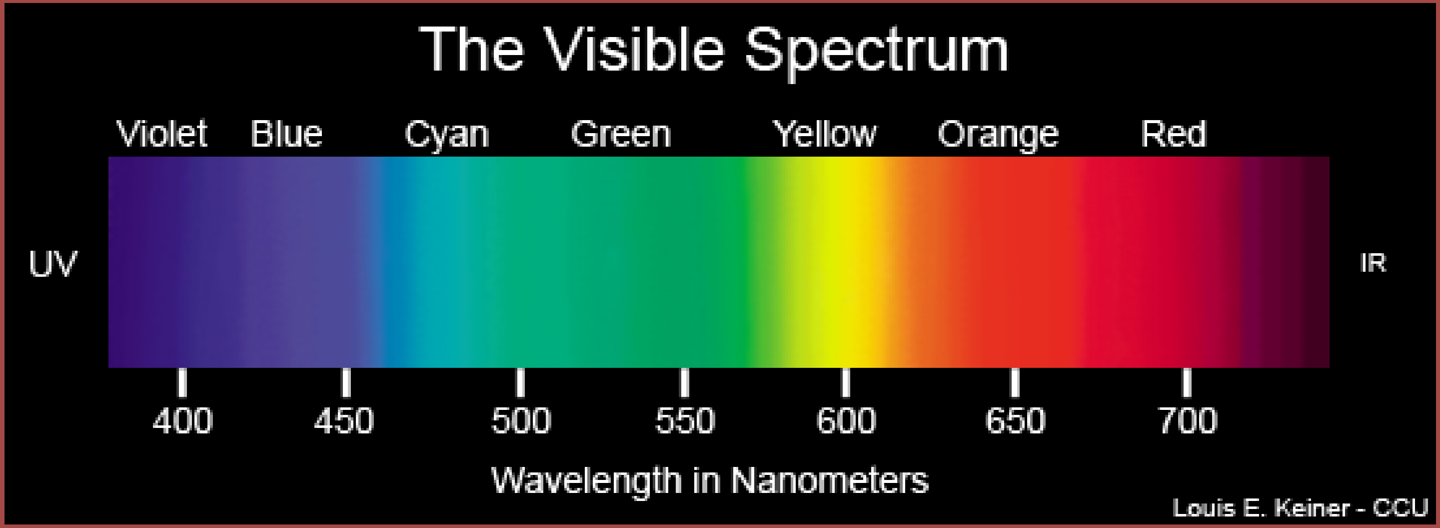
So… any EM radiation is light? (2 min)

– There are many types of EM waves: radio waves, X-rays, Gamma-rays … and **visible light**



So… that's it!! This is what **colours** are!!!

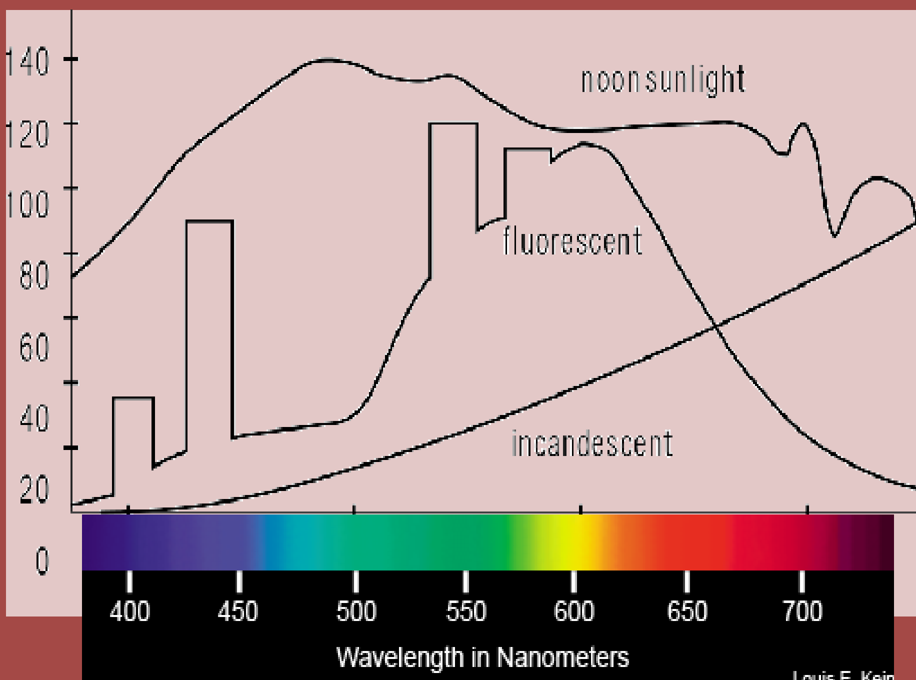
So… that's it!! This is what colours are!!!

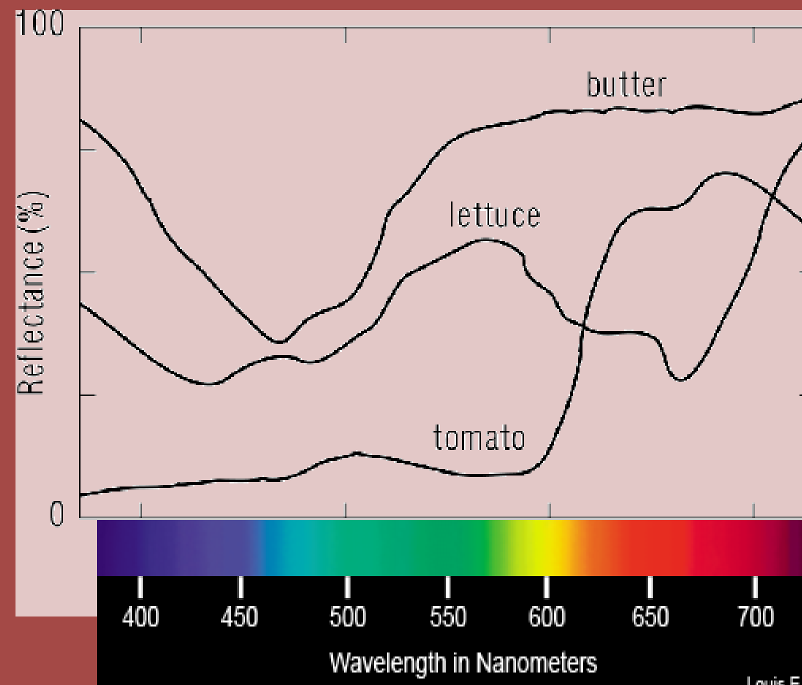


- **Is this true?** Are these all the colours? (2 min)
  - Where is white? Where is grey?
- These are the physical stimuli present in the world … our brain **perceives** many more colours

Colour ≠ wavelength hitting our eye

- Actually, lights can have many wavelengths…
- Object’s appearance also.





http://vr.cs.uiuc.edu/node103.html

Let’s leave the Physics of light here…

– **A few things to keep in mind:**
  - Light refers to the **physical stimuli**
  - Colour refers to our **human perception** of that stimuli
  - Light frequency (wavelength) correlates to perceived colour
    – … but we can perceive many more “Colours”

… we will focus on **perception** of light now

interact LAB

UNIVERSITY OF SUSSEX

Colour

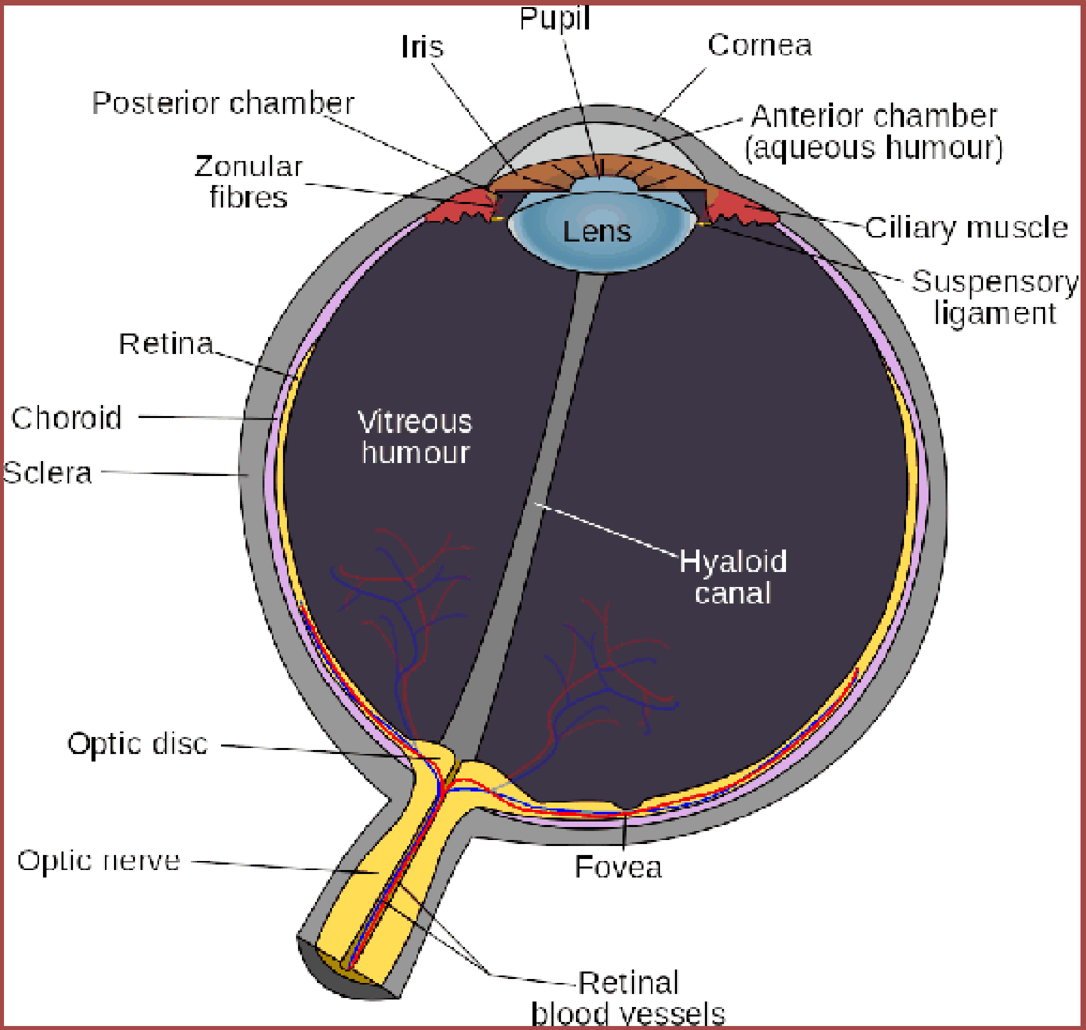
=

perceived light

What do we know of the eye?

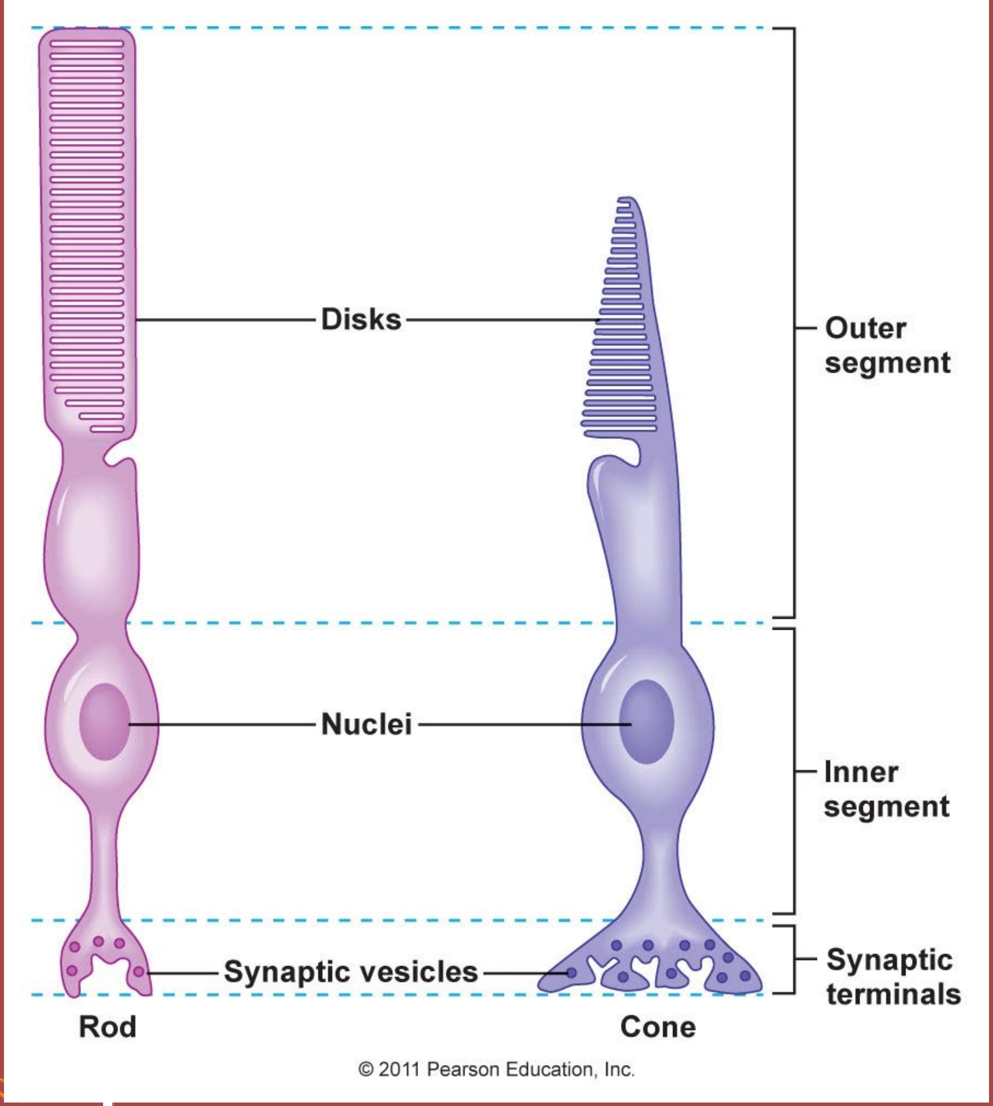
- How does the human eye work? Why do we see what we see? (Discuss (3min) + Share)

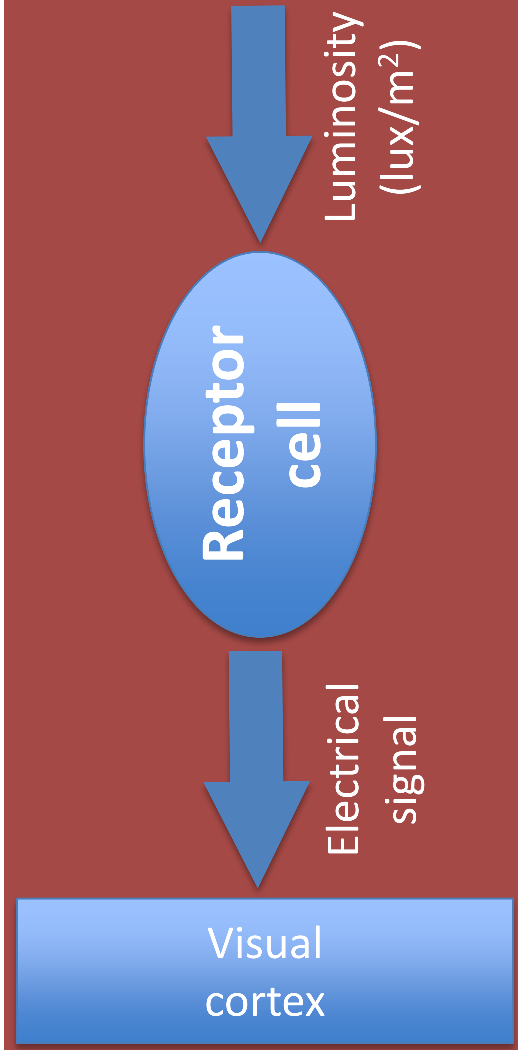
Physiology of human eye



http://vr.cs.uiuc.edu/node129.html

Retina & Receptors



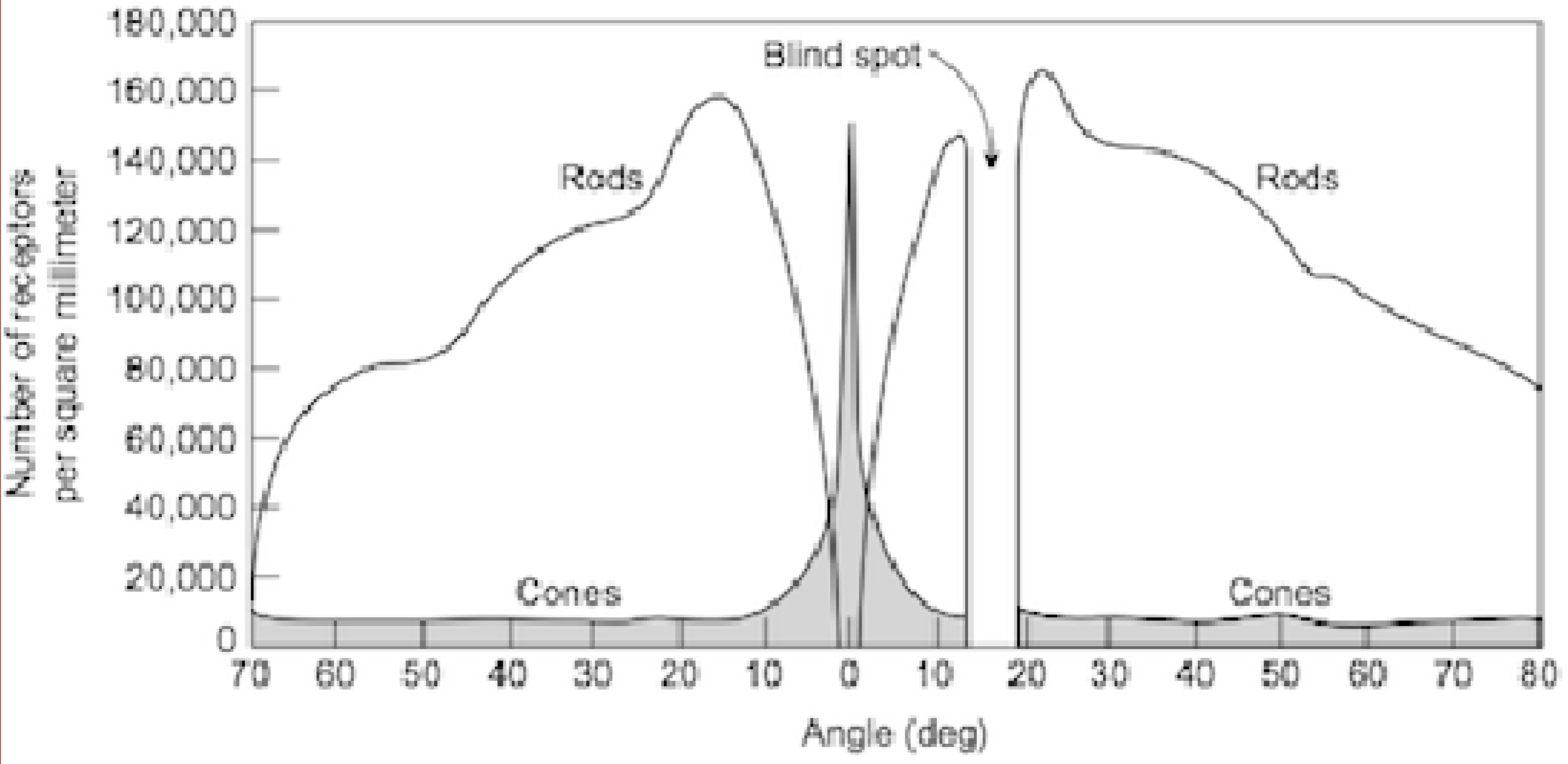


http://droualb.faculty.mjc.edu/Course%20Materials/

interact LAB

US UNIVERSITY OF SUSSEX

Fovea & Receptors distribution



http://droualb.faculty.mjc.edu/Course%20Materials/

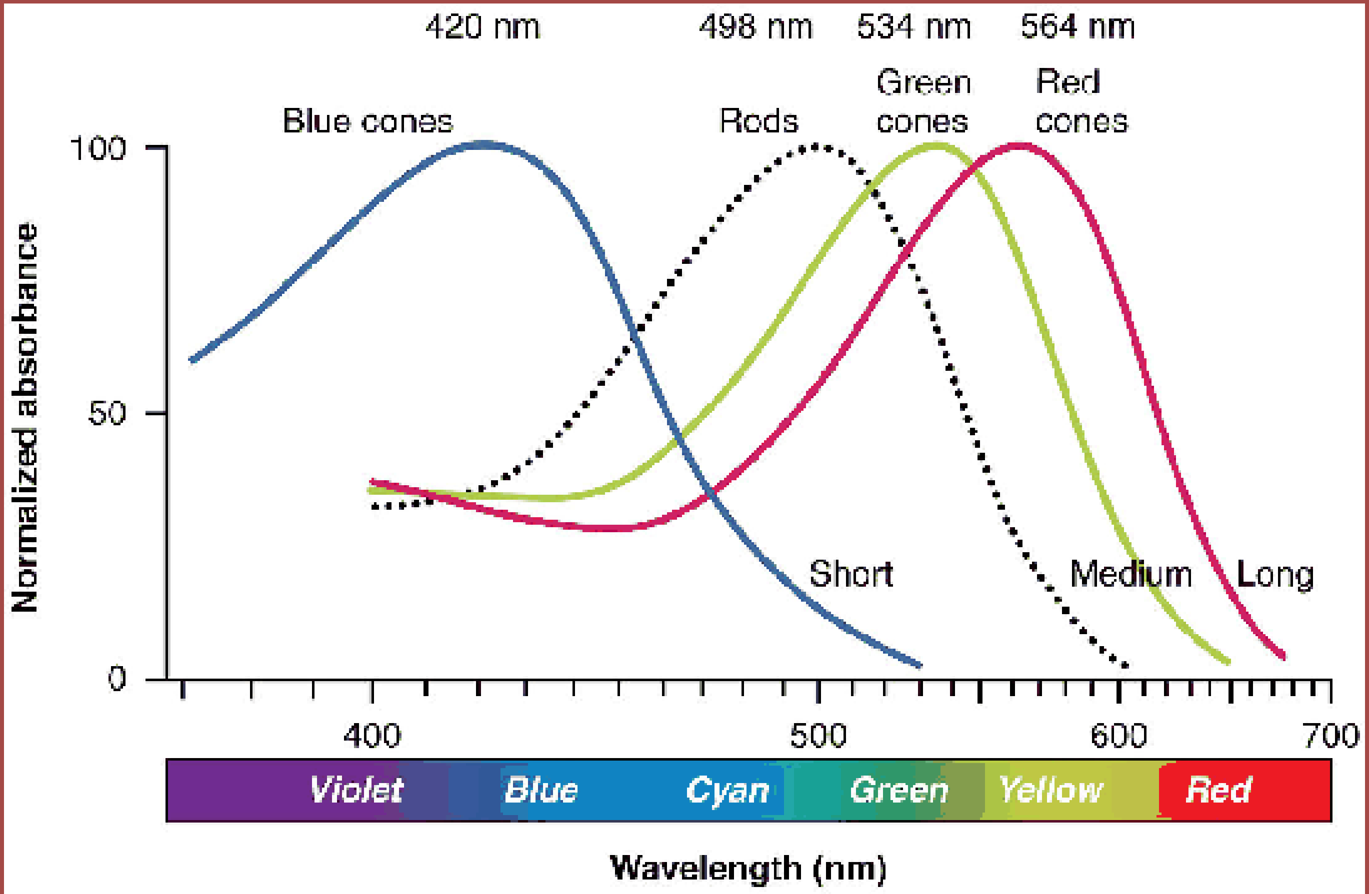
Receptors' response

– Receptors' response is not fixed
  • … it changes with brightness

– Rods become dominant in low lighting conditions
  • SCOTOPIC VISION

– Cones become dominant in bright conditions
  • PHOTOPIC VISION
  • Applies to visual displays, printed media, etc…

Photopic Colour matching function



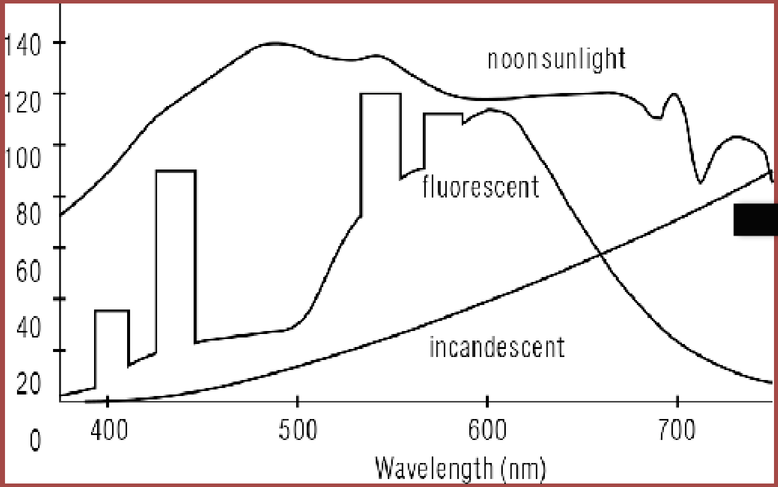
Receptor's response to each wavelength

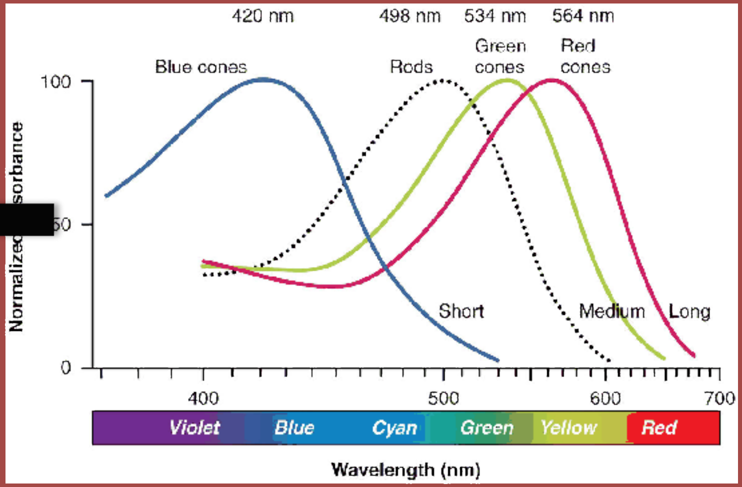
interact LAB **Highly recommended:** http://feynmanlectures.caltech.edu/I_35.html

UNIVERSITY OF SUSSEX

From receptors to colour vision:

- OK, we know how receptors behave
  - How did they work it out? Check [Feynman's lectures](), it's great!
- … and we know how light sources behave
- **How does this add up**?





Well it doesn't add up, **it multiplies!!**

interact LAB

UNIVERSITY OF SUSSEX

Light does not add up, it multiplies

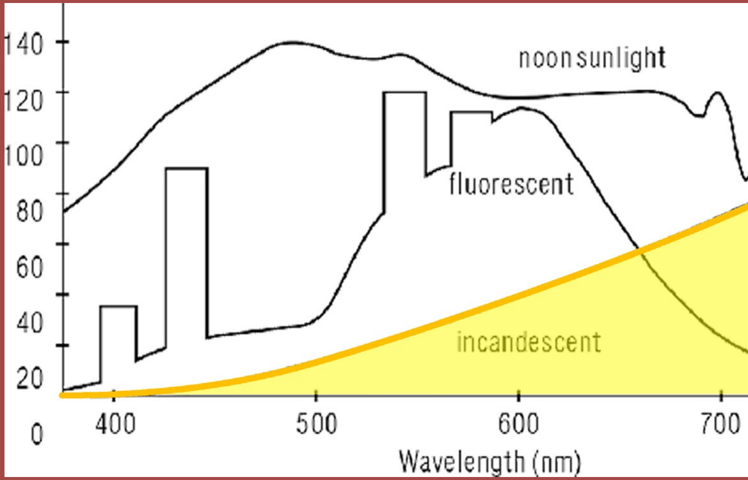
- Incandescent source L:
  - Many individual lights (λ).
  - …each with different intensity.

    L: λ → intensity

    L(700nm) = 80 lux/m^2

    L(400nm) = 0 lux/m^2

L (λ)

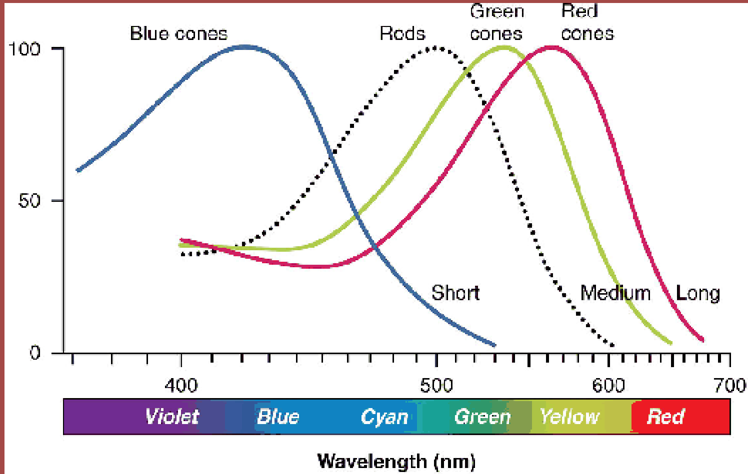


- Compute perceived intensity: multiply individual component (L) and receptor response (R):

$$P\_I_i(L) \propto \int_{\lambda=400}^{780} L(\lambda) * Ri(\lambda)$$

$$(i \in \{R, G, B\})$$

$R_B(\lambda)$ $R_G(\lambda)$ $R_R(\lambda)$

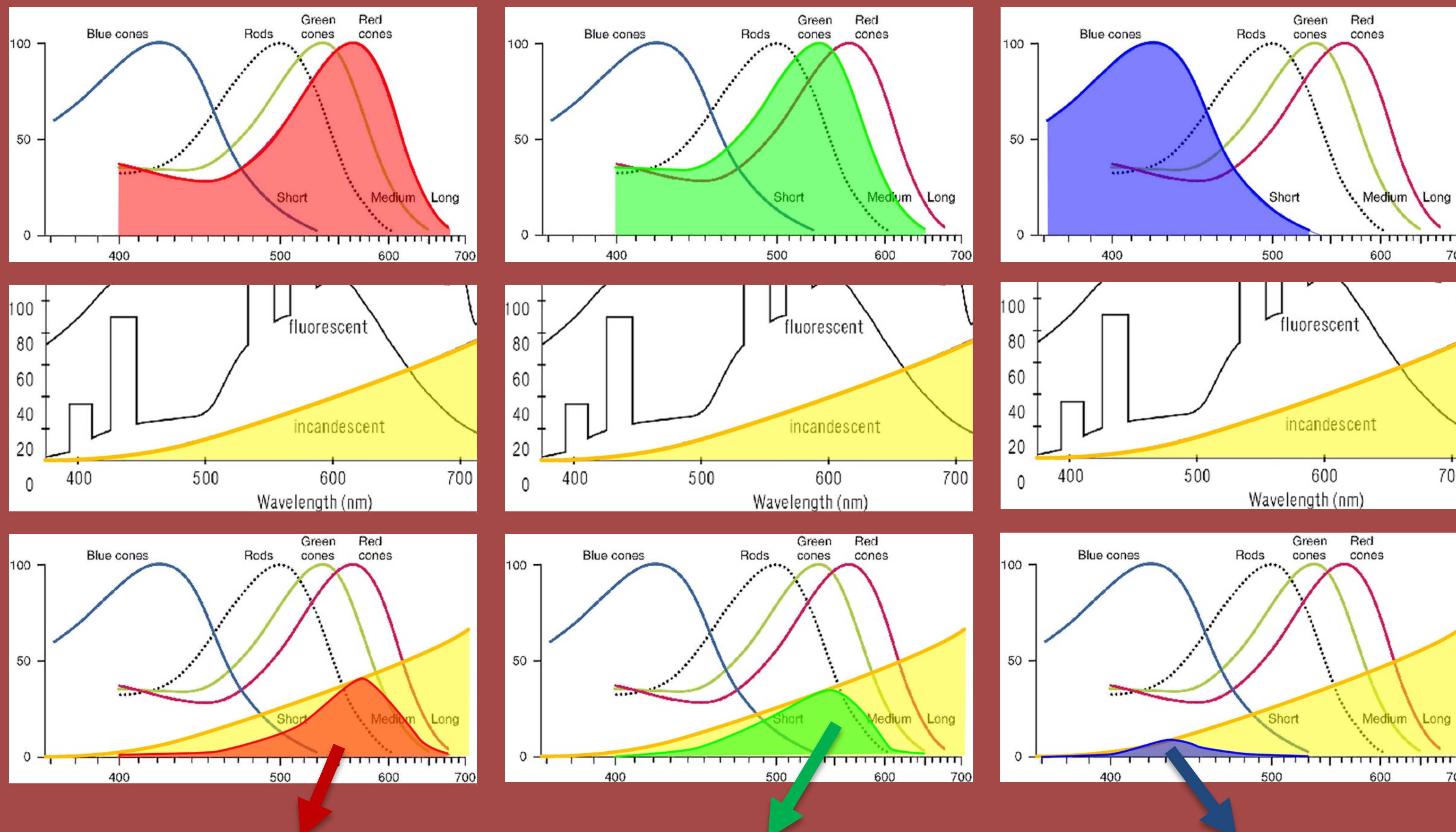


Perceived Intensity: P_I(L) $\propto \int_{\lambda=400}^{780} L(\lambda)\cdot R(\lambda)\cdot \mathbf{d}\lambda$

$R\_(\lambda)$

$L(\lambda)$

$L(\lambda)\cdot R\_(\lambda)$

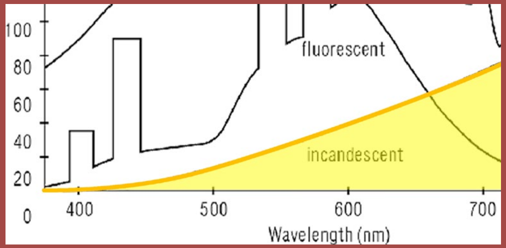


$\int L(\lambda)\cdot R(\lambda)\cdot \mathbf{d}\lambda$

P_I$_R$=0.4 **P_I$_G$=0.35** **P_I$_B$=0.05**

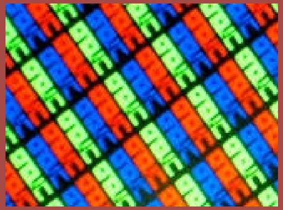
Perceived colour

– Understand **Receptors**: We know which **Colour** we will perceive.

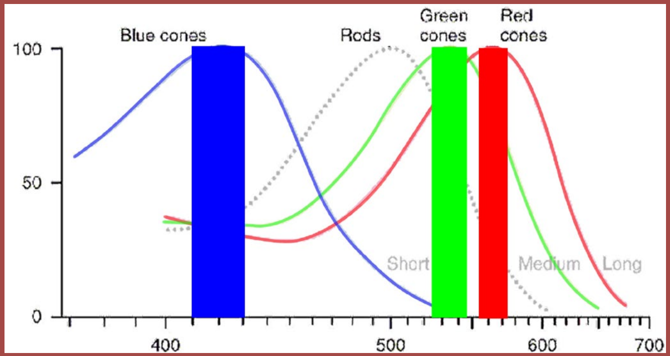


0.4 0.35 0.05

– More important, we can **create Colours**



Monitor= Lots of RGB transducers



We know response to each of our RGB sources (transducers)

Given a "perceptual colour":

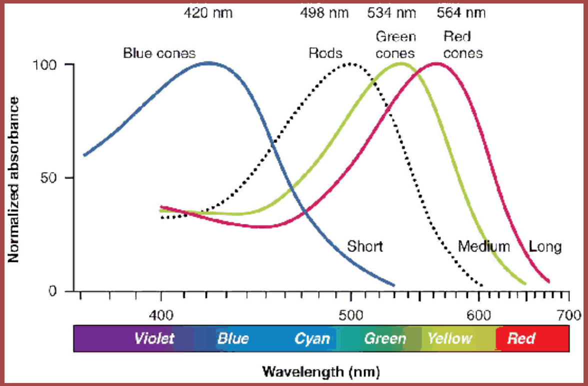
(0.4, 0.35, 0.05)

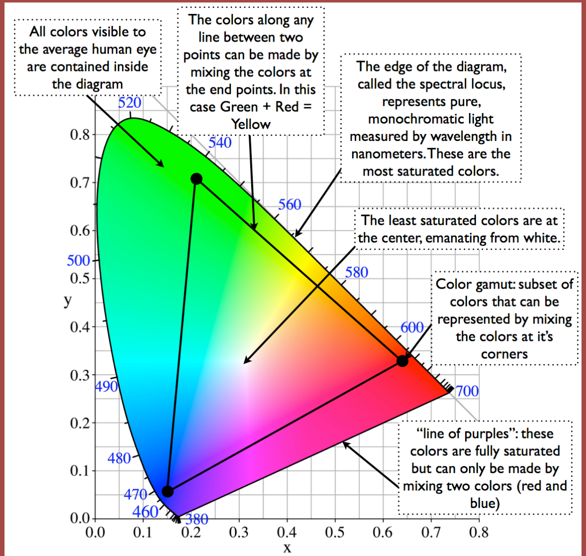
We can know **exact** input (V) for each light source

(3.3V, 3.7V, 1.02V)

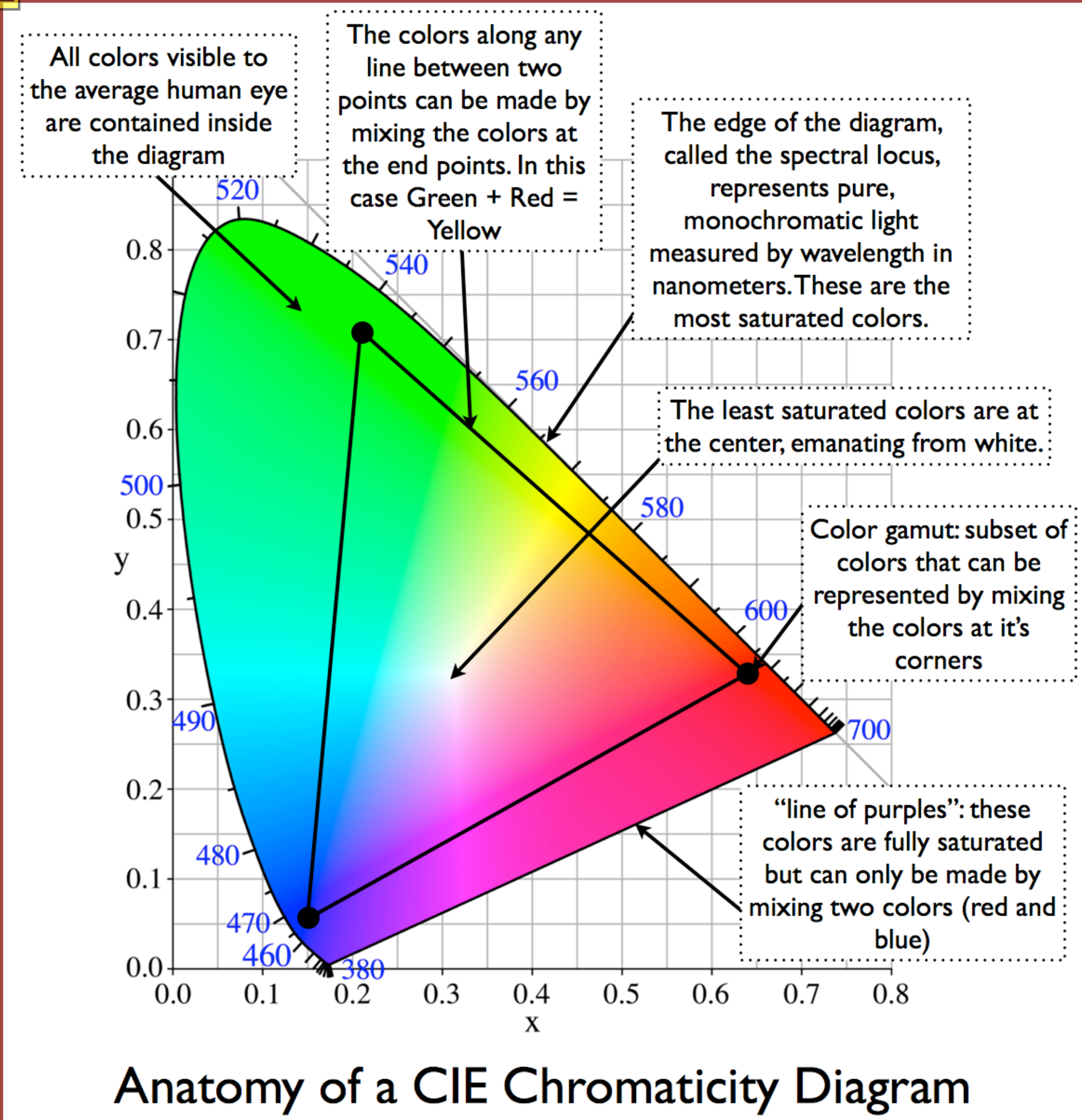
The CIE colour space

- The **Photopic Colour Maching function** was the key for CIE colour spaces.
  - It describes colour in terms of **what a human will perceive**
  - ...but connects colour to the **physical properties** of light sources
- Given three light sources, we know the perceptual colours they can create.
  - Content creators work in CIE space
  - Display standardization (TV, monitors)
  - **Revolutionary:** display, broadcast, printed media, Comp. Graphics





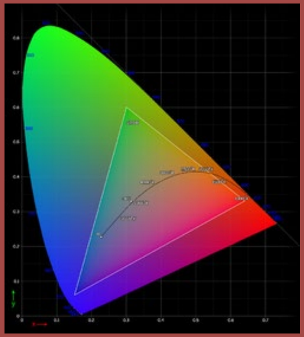
Anatomy of a CIE Chromaticity Diagram



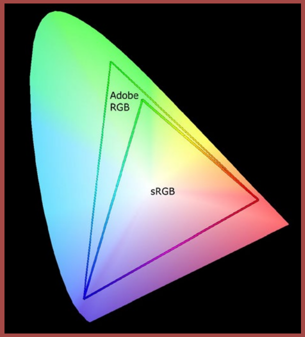
- Spectral colours
- Non-spectral colours
- Colour Gamuts
- XYZ vs RGB
- Tuned for the human eye
- [A nice story]

Other Colour Spaces

– **Many other "utility" colour spaces:**

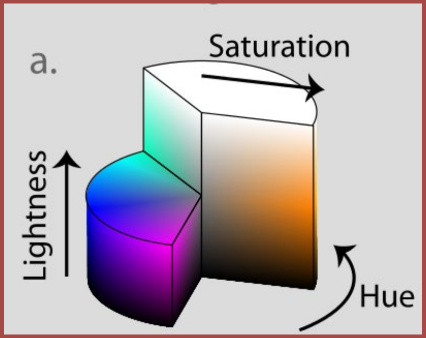


sRGB
Web
@ gamma 2.2



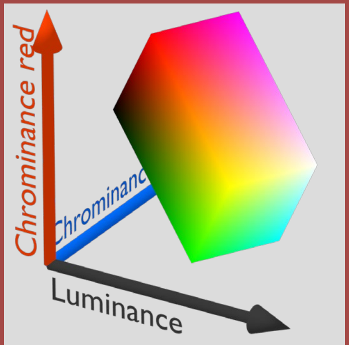
Adobe RGB

Printed media



HSL

Broadcast &
Colour picker



YCbCr

Compression

– They ease development for different tasks.

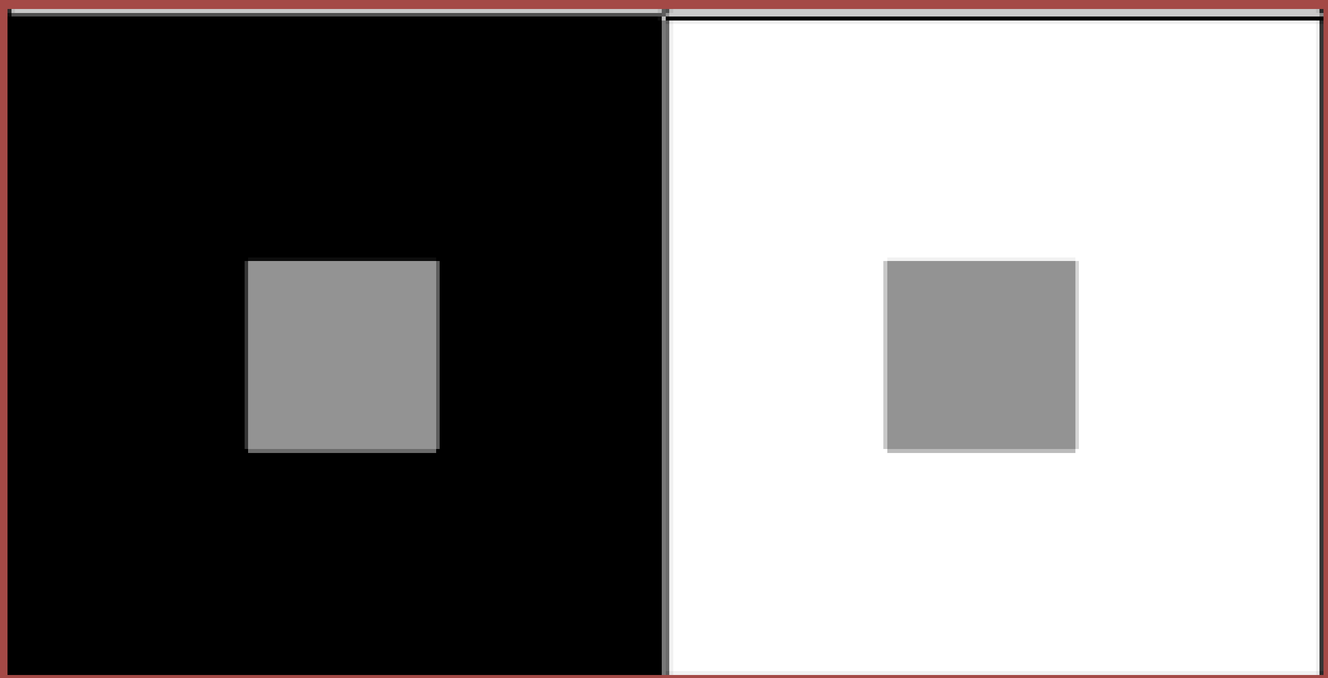
– They can all be tied back to **perceptual Colour Spaces**…

- … and **physical properties**

Light, Colour, CIE Colour Space

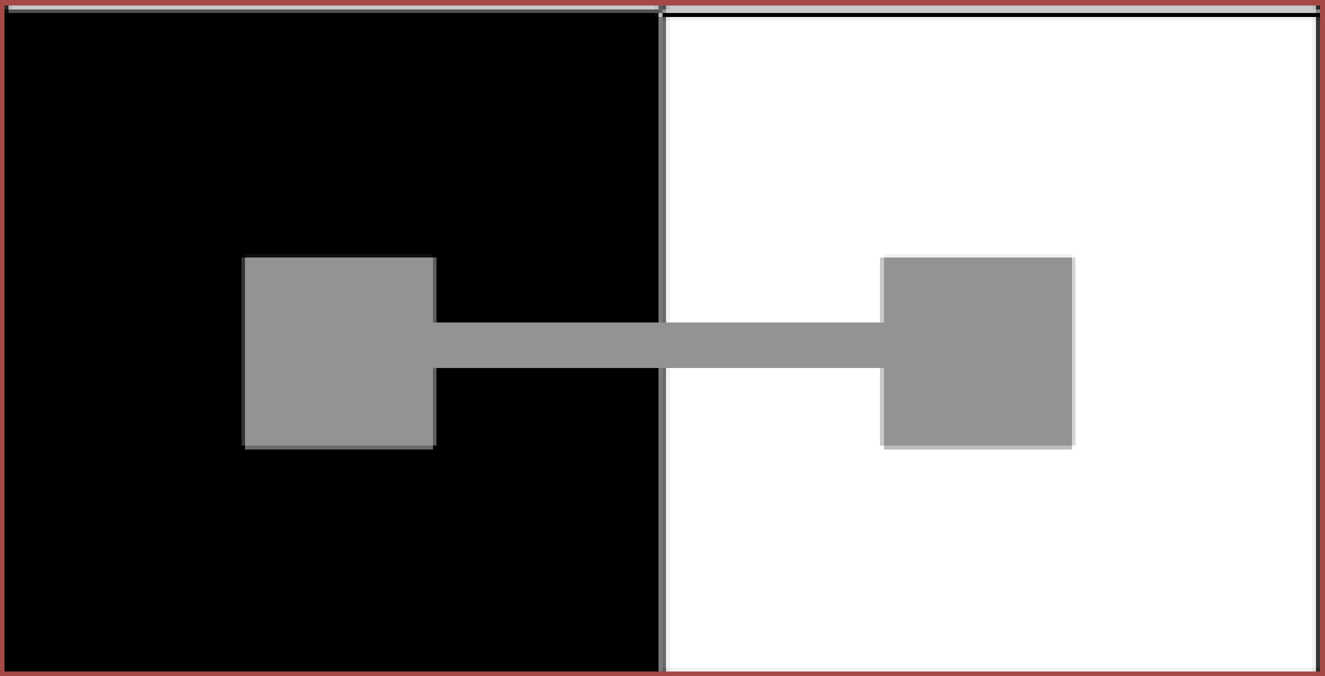
- **Summary:**
  - **Lights** in the real world can be **complex** (mix many wavelengths)
  - Light reflected by **objects** (lettuce, tomato) is also **complex**
  - Our eye has **three receptors** (photopic view)
  - For any stimuli our eye could detect, we can create **the exact same effect** by combining three monochromic sources.
    - Receptors, Colour matching function
  - When working with images, we use "Perceptual Colour Spaces"
    - We describe what we want the **observer to perceive**
    - The underlying technology will **work out the mapping** (physical stimuli)

More complex colour processing



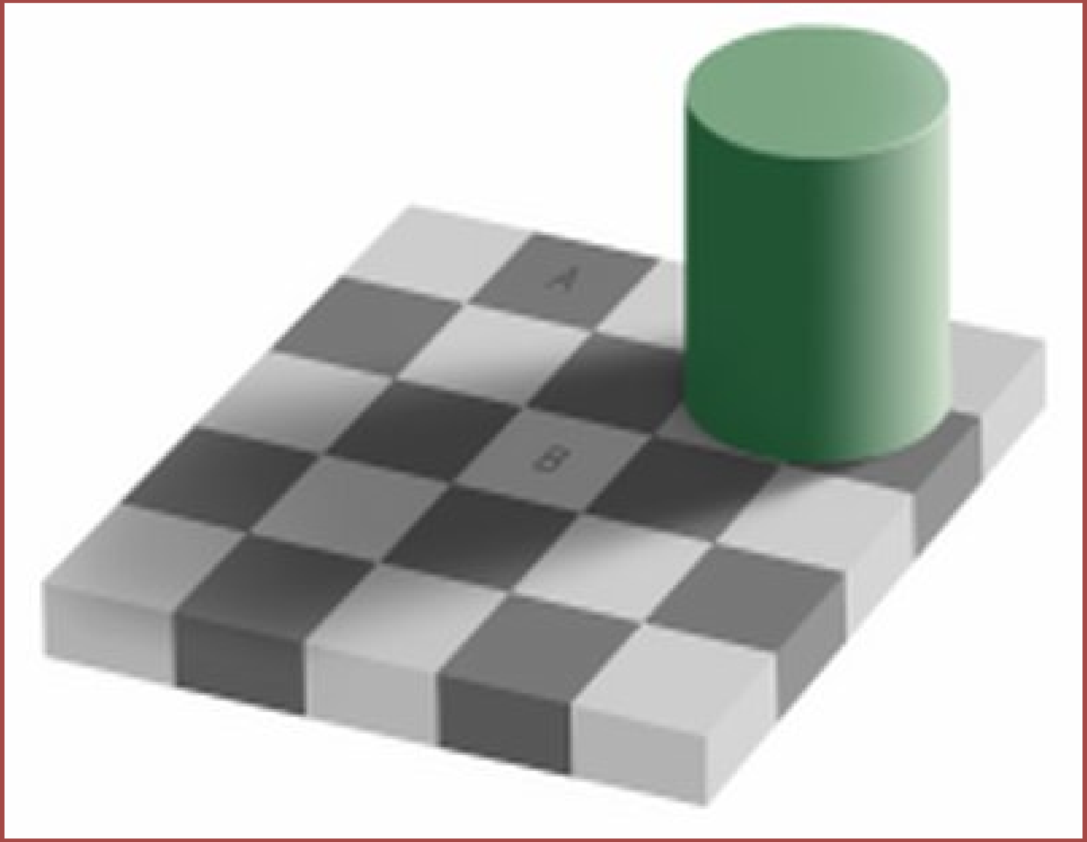
Chromatic adaptation

More complex colour processing



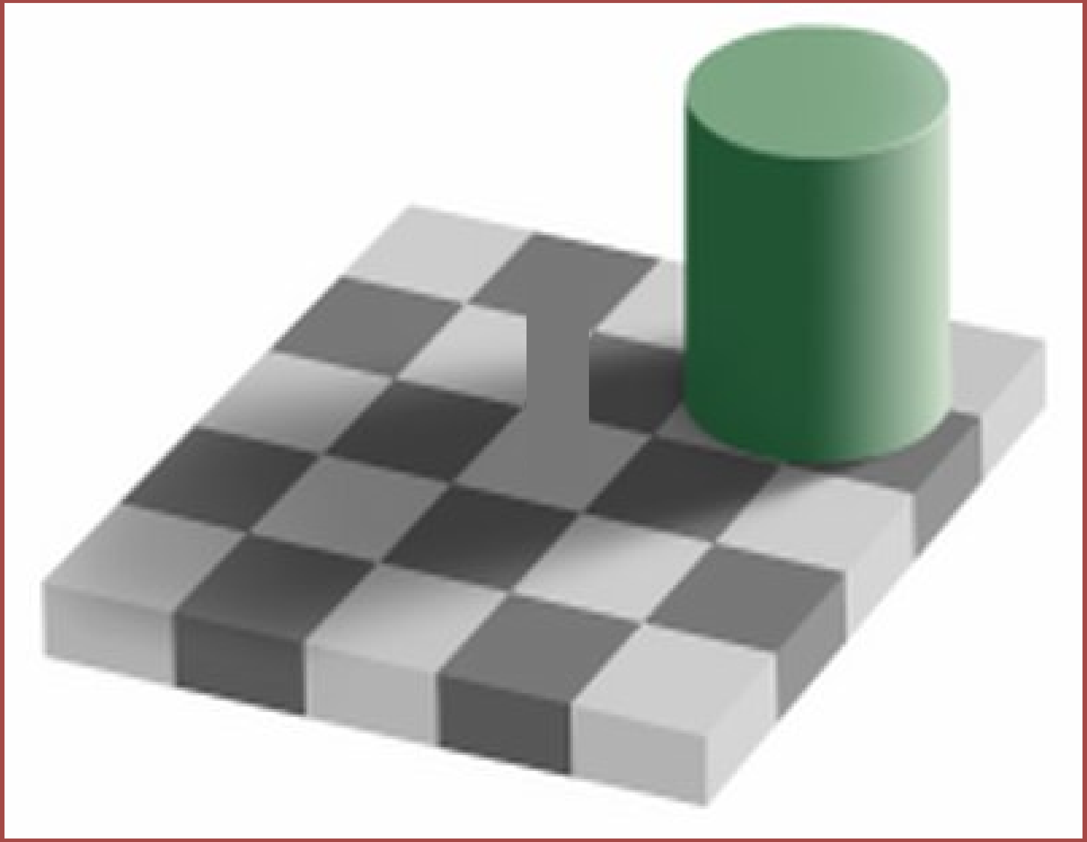
Chromatic adaptation

More complex colour processing



Chromatic adaptation

More complex colour processing

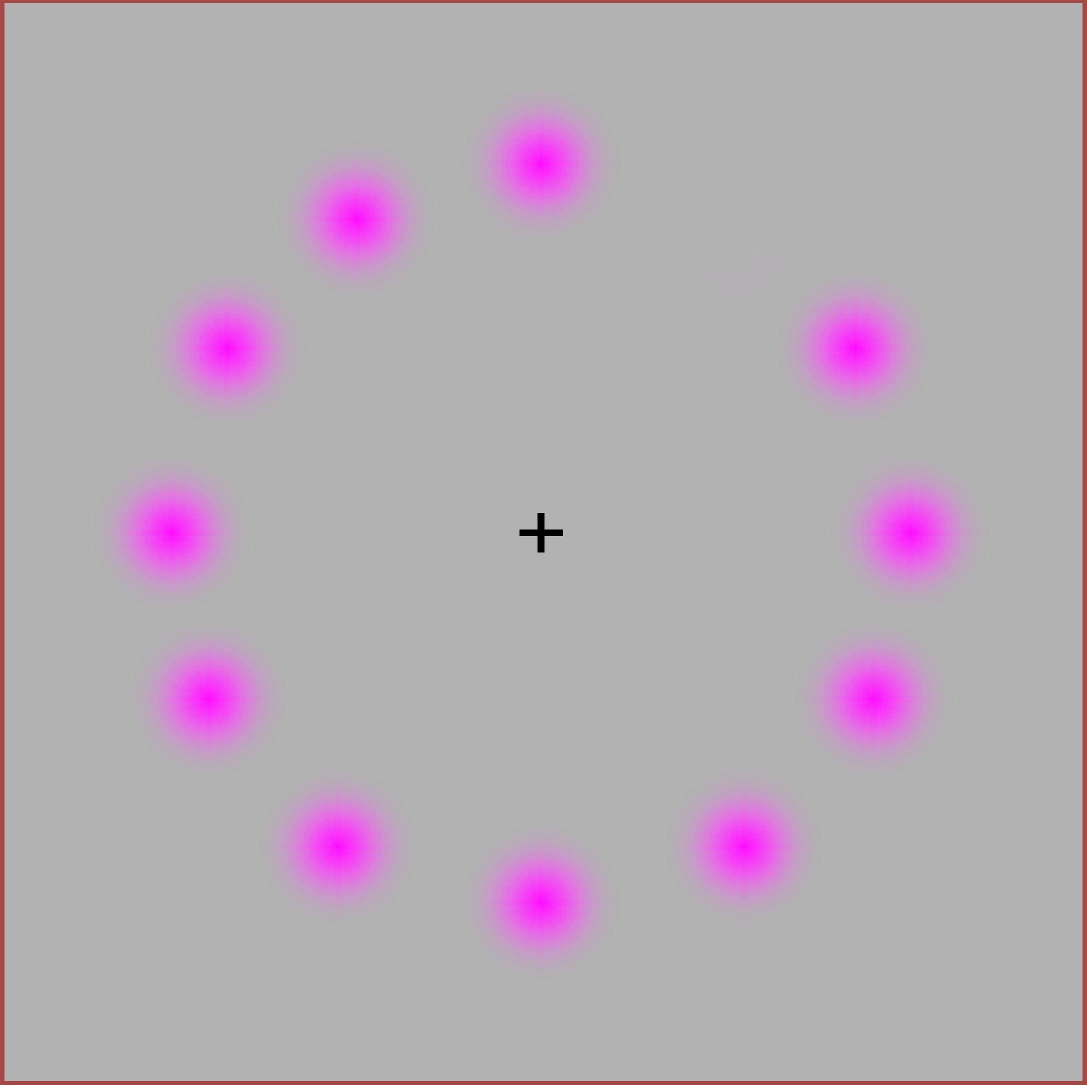


Chromatic adaptation

More complex colour processing

Chromatic adaptation

More complex colour processing

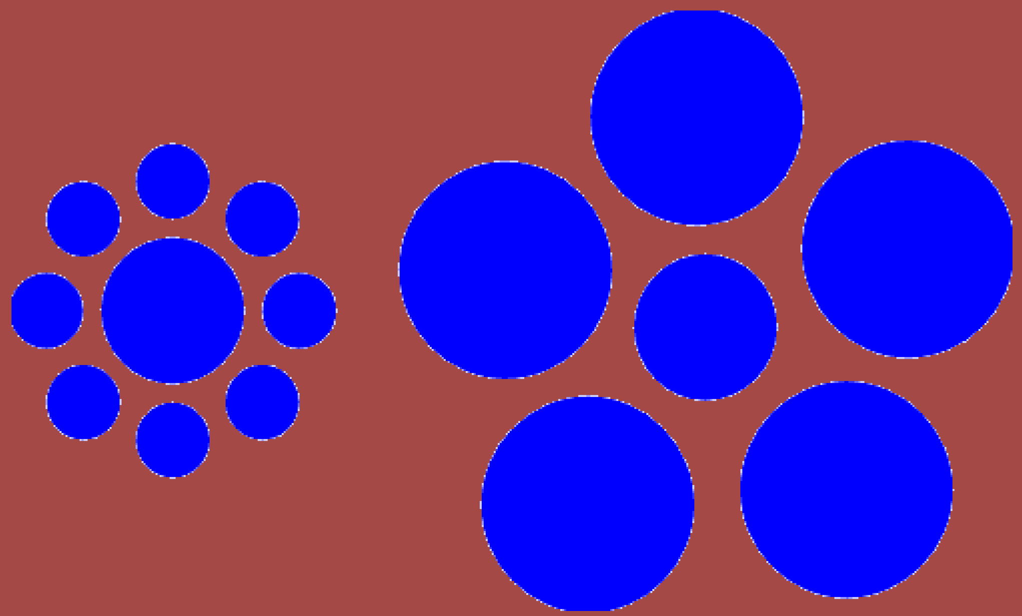


Opponent after-images

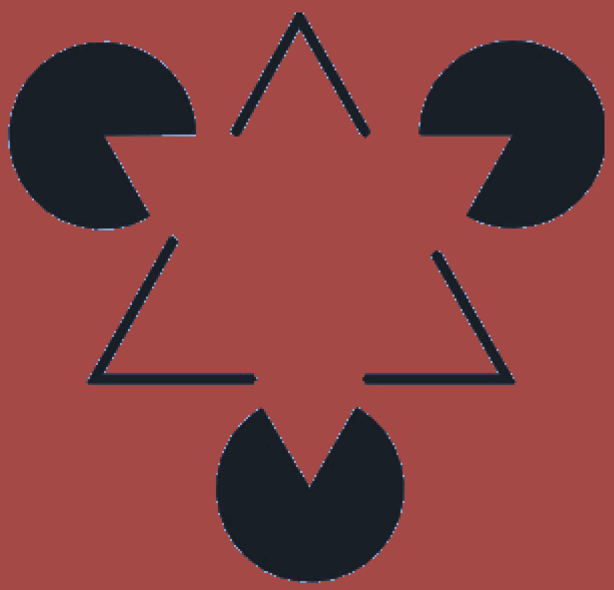
interact LAB

UNIVERSITY OF SUSSEX

More complex colour processing



Contrast in Shape



Pattern recognition

Next Week: Introduction to Ray tracing

- **Preparing for next week?**
  - Transformation matrices
  - Parametric, implicit & explicit functions;
  - Vectors, lines, planes, line-line intersection
    - Grab your notes from Secondary School
    - … or browse the web!
  - Keep reading about good Software Design:
    - O-O principles (Encapsulation, Abstraction, Inheritance, Polymorphism)
    - Design Principles (e.g. S.O.L.I.D)
    - Design Patterns.

interact LAB

UNIVERSITY OF SUSSEX

Light and Colour

Pink Floyd, 'Dark Side of the Moon'