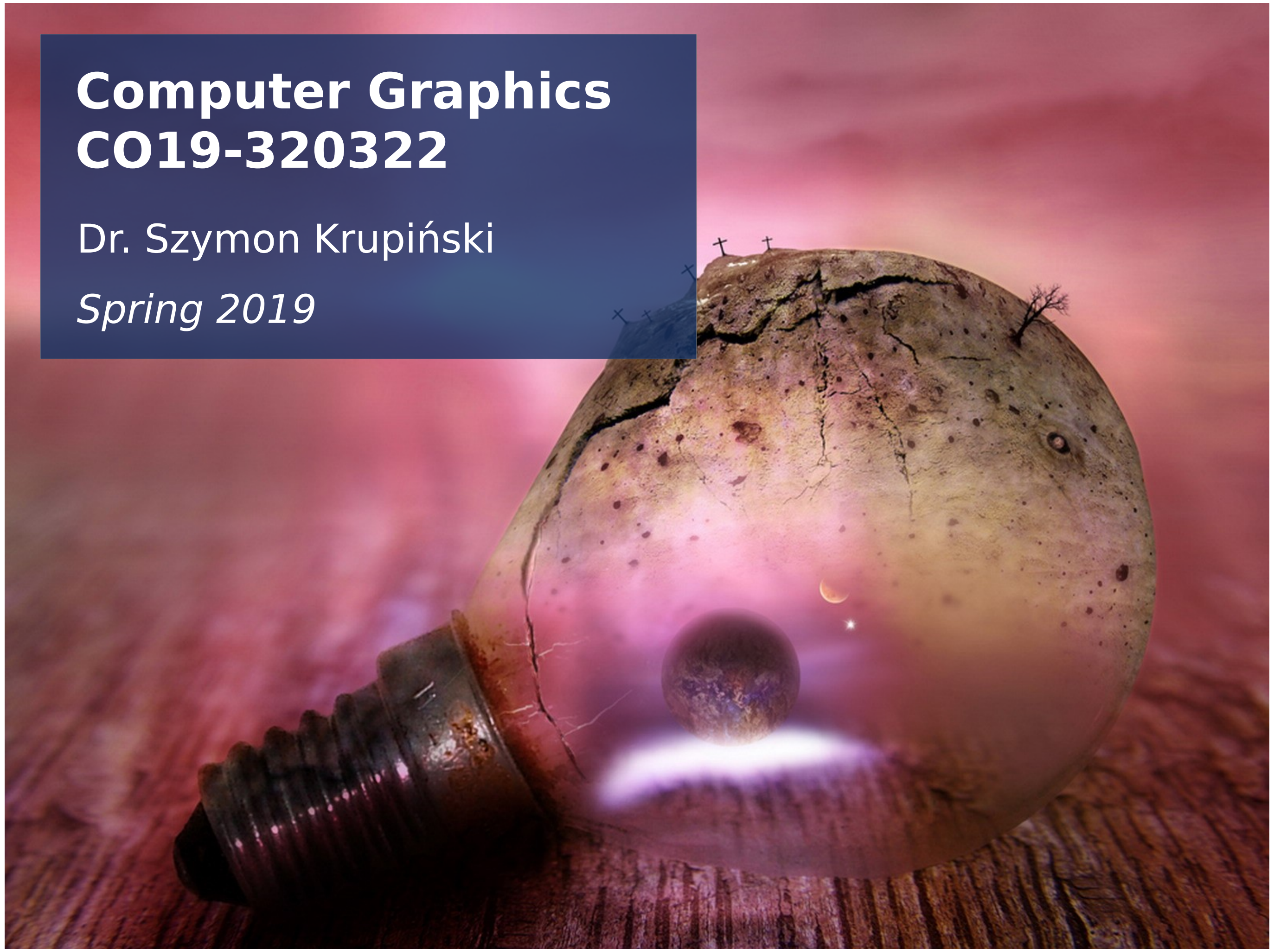
Lecture 13: Light and color

JACOBS UNIVERSITY



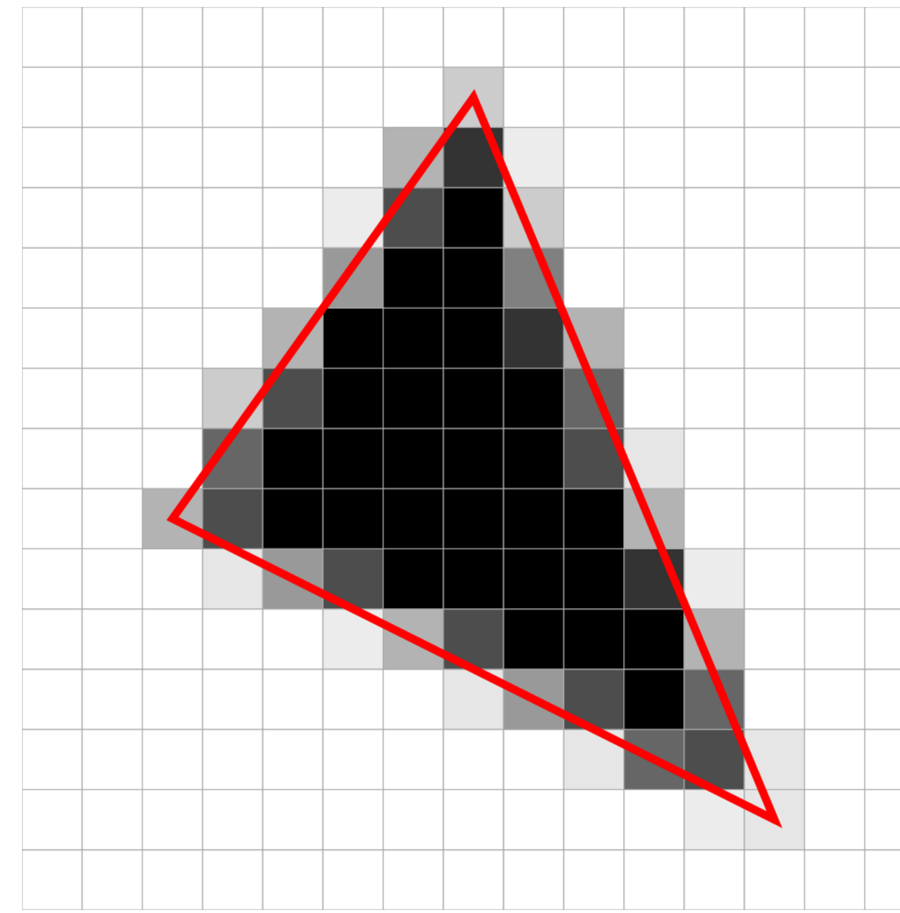
Computer Graphics
CO19-320322

Dr. Szymon Krupiński

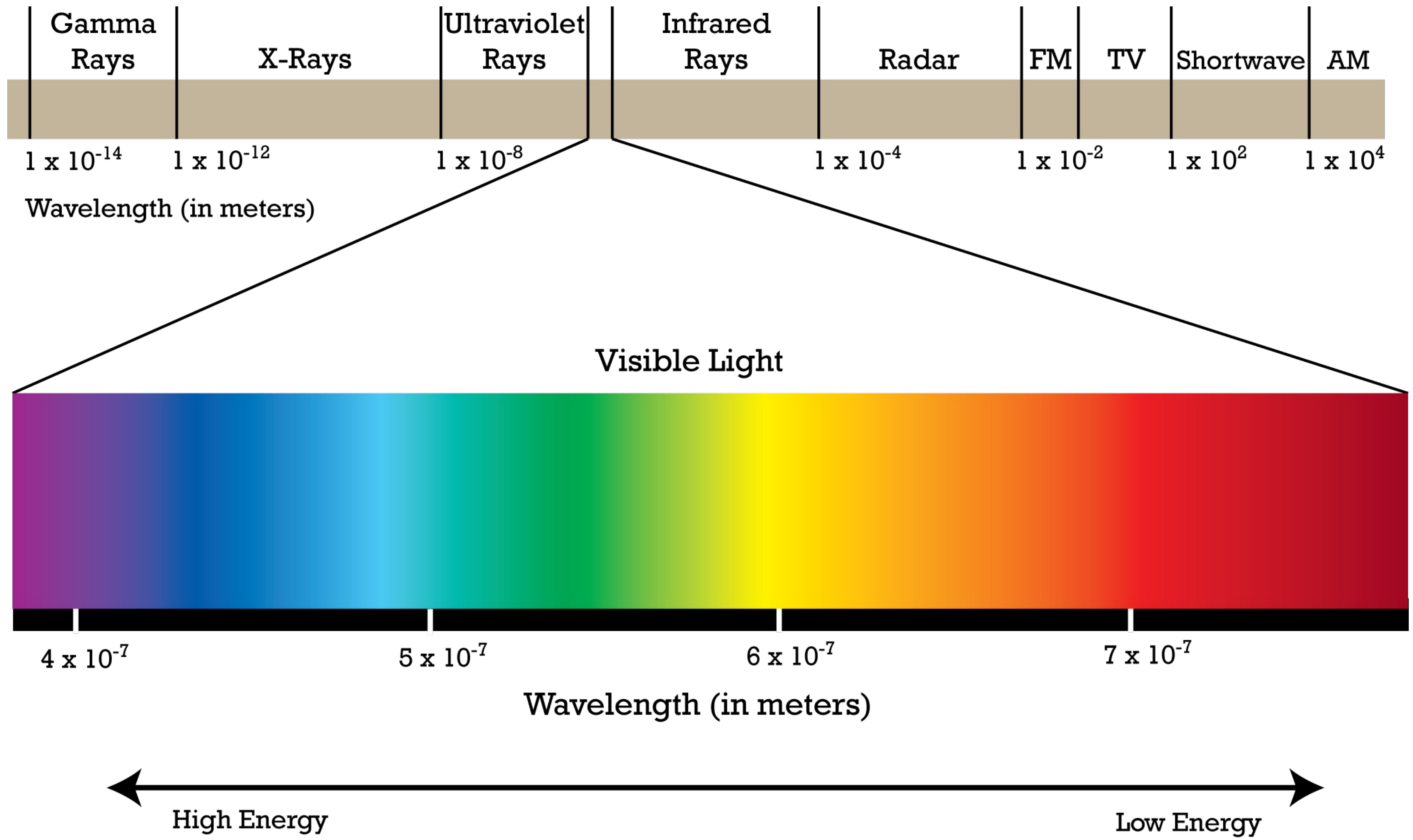
Spring 2019

We are missing something...

- We have worked a lot on how to generate the raster image
- Which shapes to which pixels?
- Which color to that pixel?
  - What if we have transparency?
  - What if we have texture?
- Ray tracing – metaphor of photons
- We never spoke about how it corresponds to the physics of light!

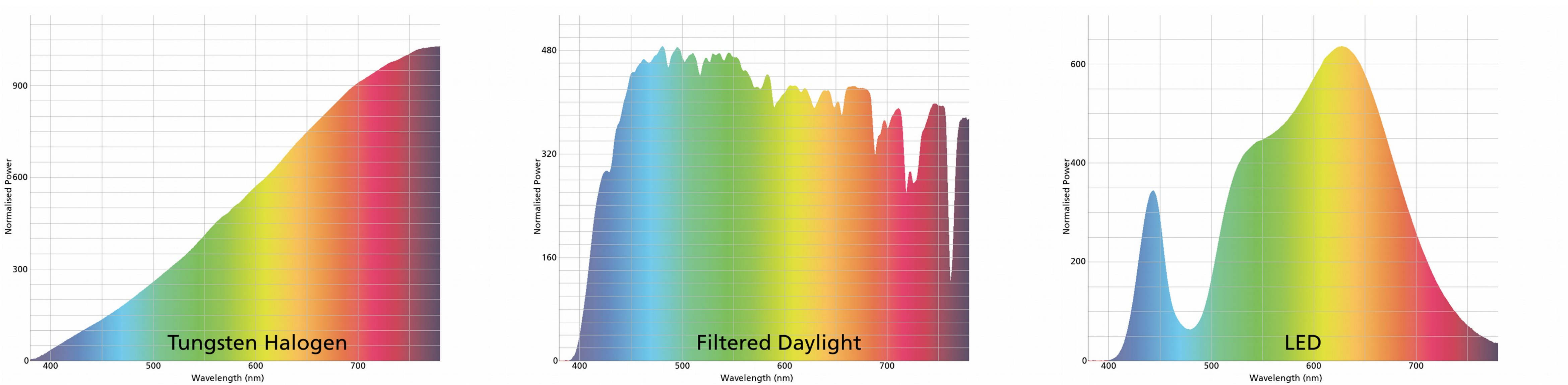


(Visible) Light



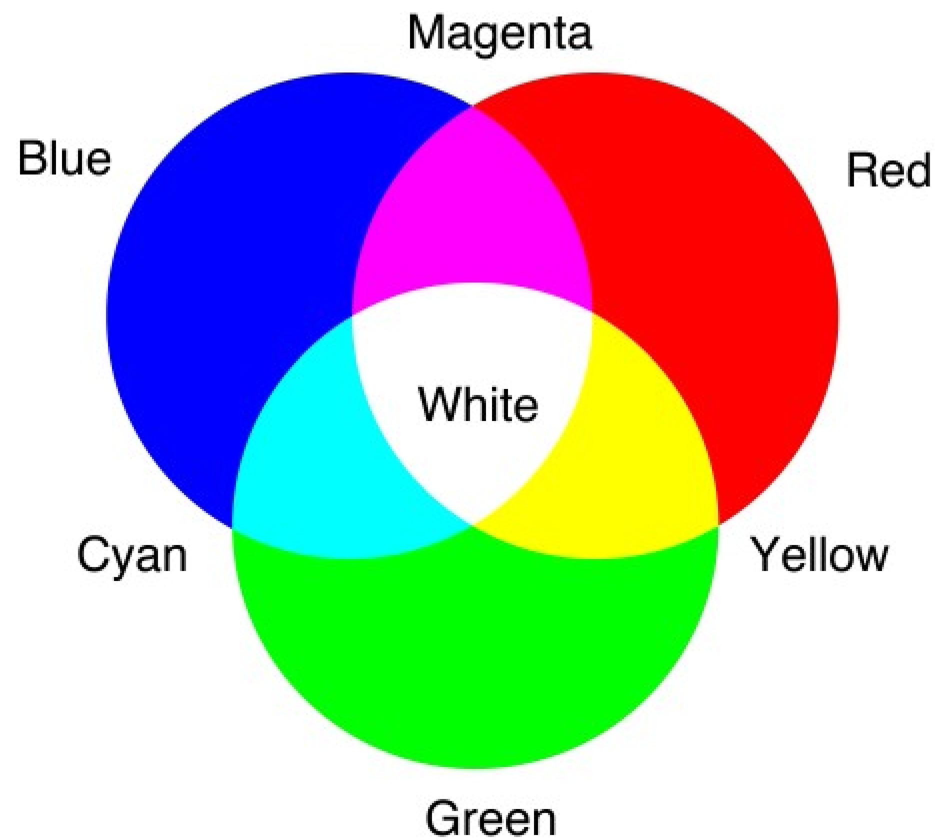
Light sources

- Each source of light can have a different composition of the frequencies
- Sun, the most “desirable” source in our perception, is a fairly uniform mixture of all frequencies



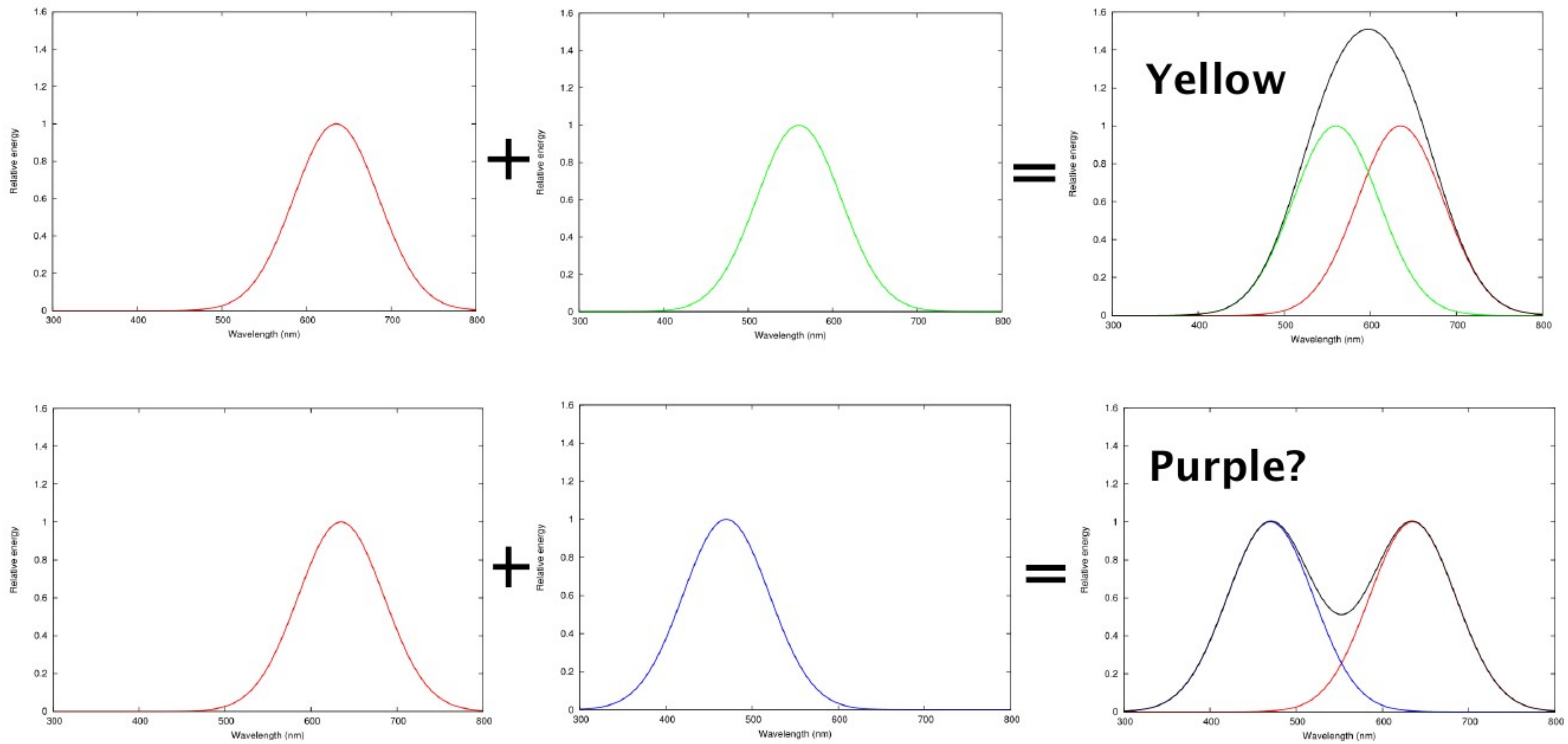
Light mixing

- The color of light coming from a particular source is constituted through an **additive color scheme**

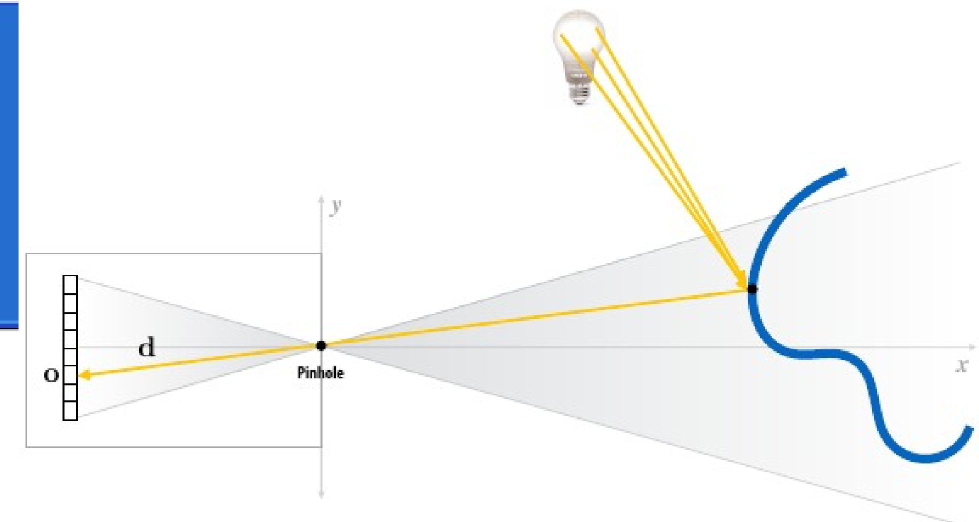


Light mixing – adding energy

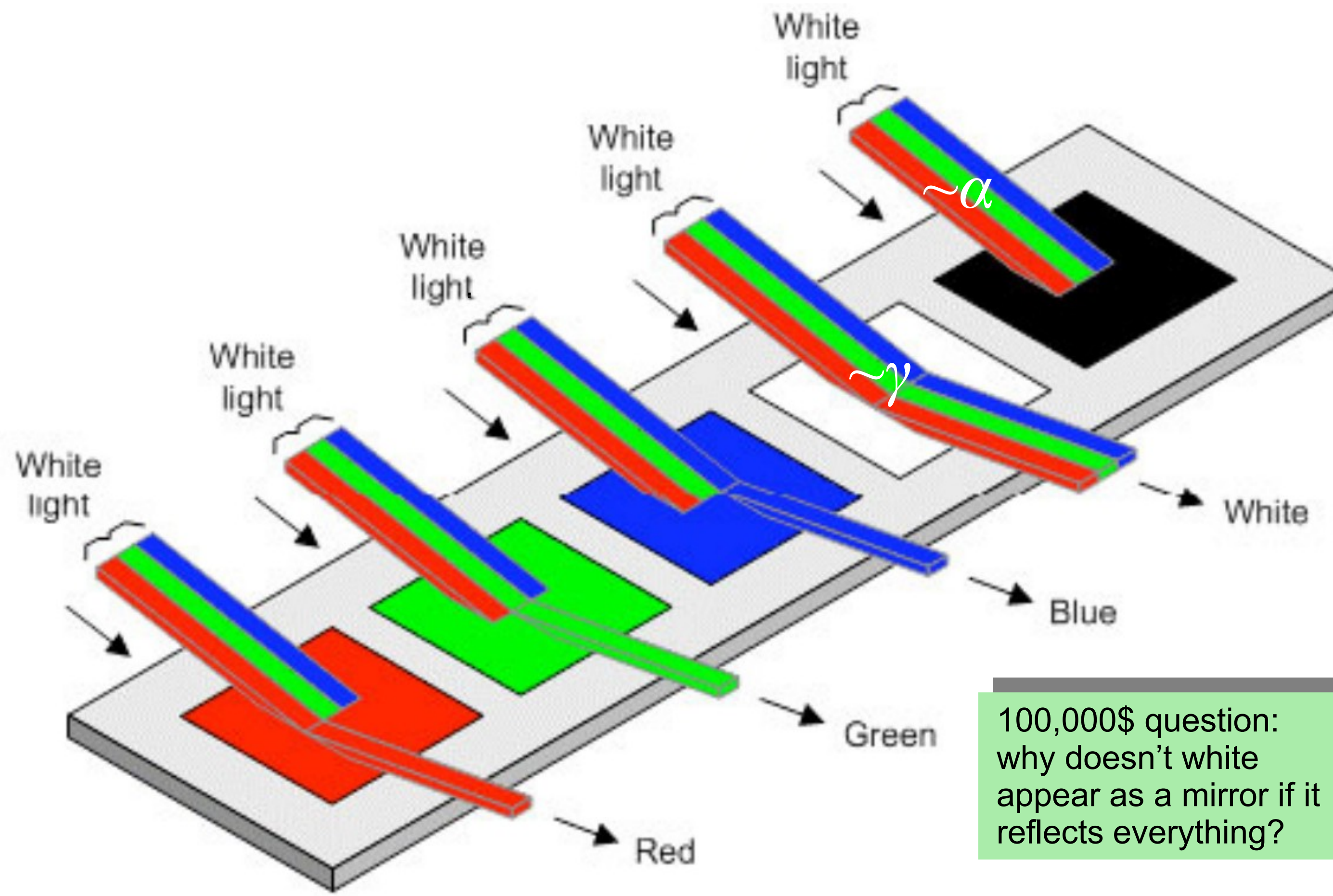
- The energy of light sources contributing particular frequency are simply combined into one spectrum



Why objects have colors?



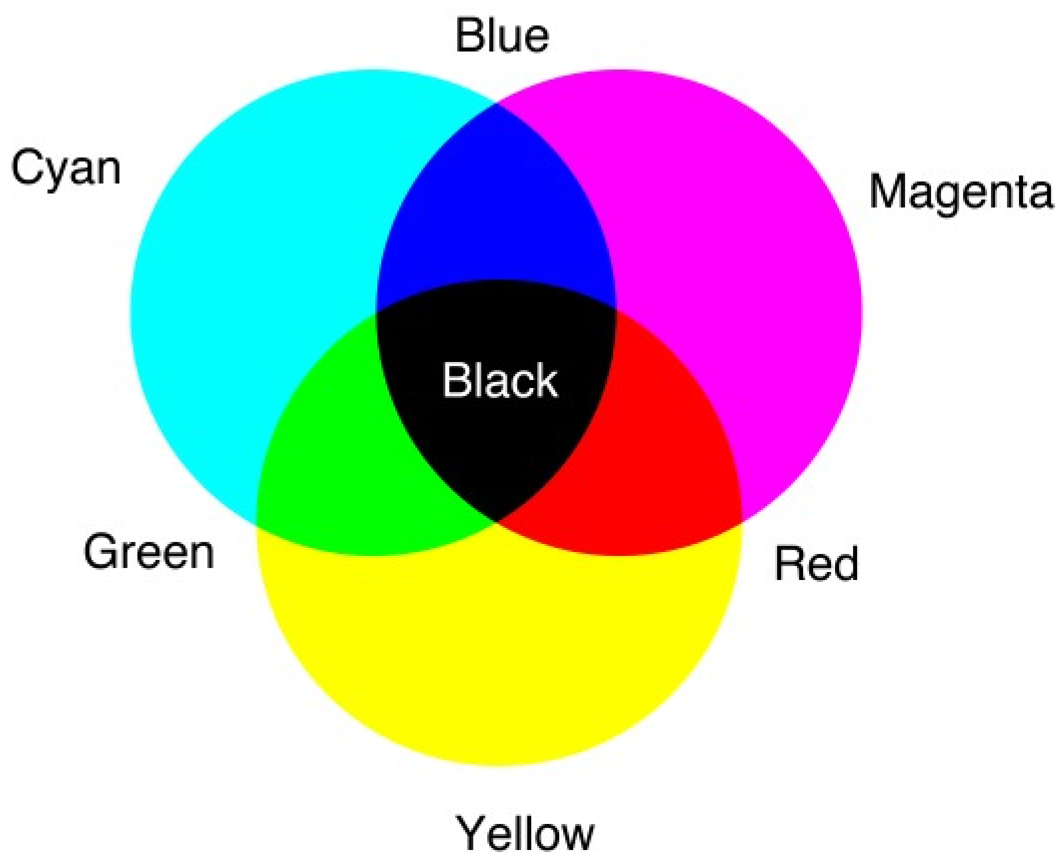
- When light of a particular make-up of frequencies strikes a surface
  - (a part of) some frequencies are eliminated (absorbed by the surface)
  - (a part of) some frequencies are reflected
- For now, this simple vision will allow us to grasp the creation of color, it will get more complicated later!



100,000$ question: why doesn't white appear as a mirror if it reflects everything?

Color creation

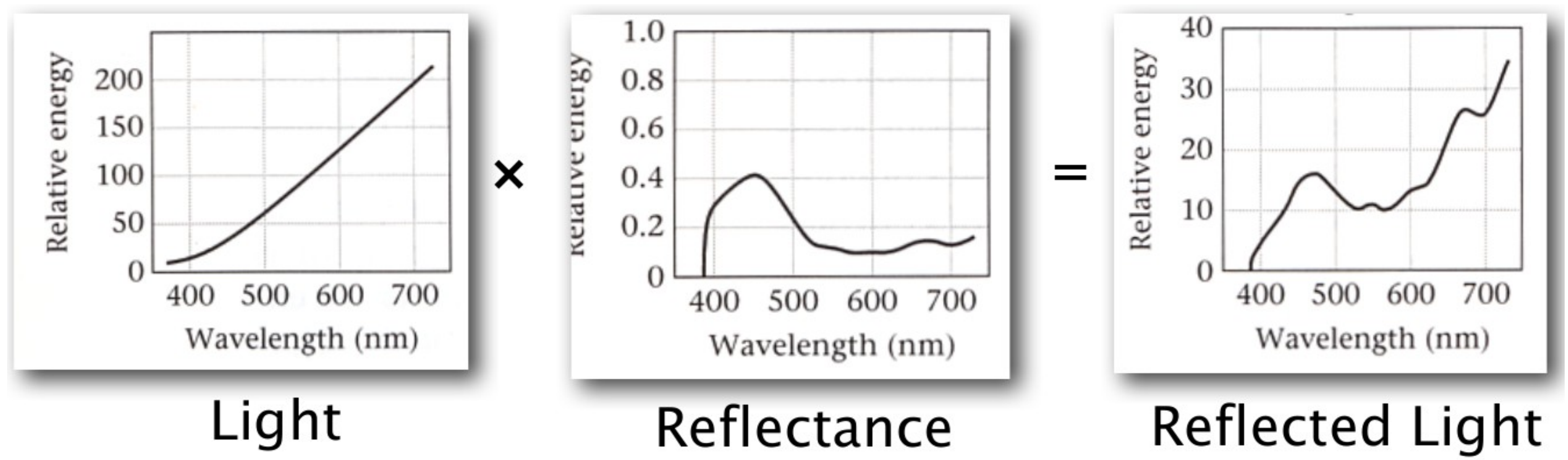
- The color that we perceive on the surface of an object or after light goes through a filter is described by the **subtractive color scheme**



Result

- The light coming off an object is a function of what light was shone on it and what the **reflectance** of the object is (the opposite of absorbance)

$$\mathbf{R(\lambda) = r(\lambda)\ E(\lambda) = (1\text{-}a(\lambda))\ E(\lambda)}$$



- **Radiometry** is the science of quantifying these and other phenomena concerning the behavior of light and its perception

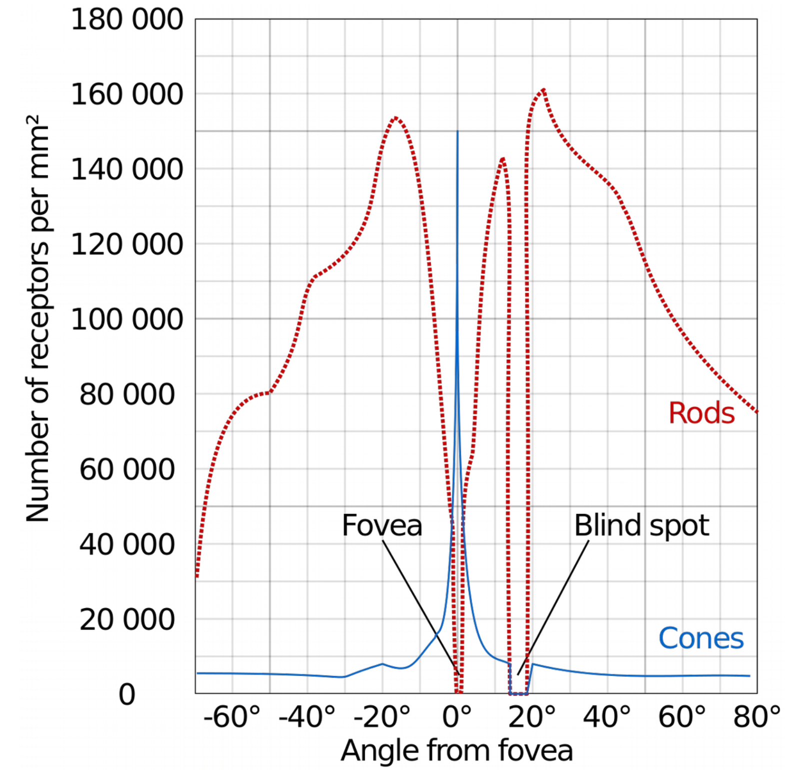
Human perception

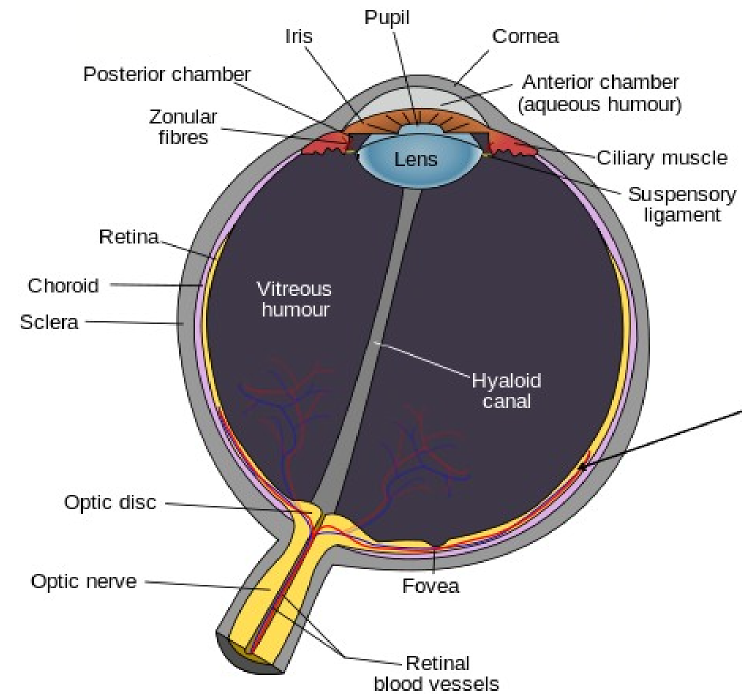
- We are equipped by nature in a very permanent optical instrument – the eye!
  - 120° of visual angle
  - > 500 Mpix of resolution
  - Dynamic range of 1,000,000 to 1, ISO sensitivity of 800 (dark adapted eye)
  - 22mm focal length
  - Can observe changes in frequencies above 1000 frames per second (FPS), but >15 FPS is already enough for smooth motion perception

versus

The eye

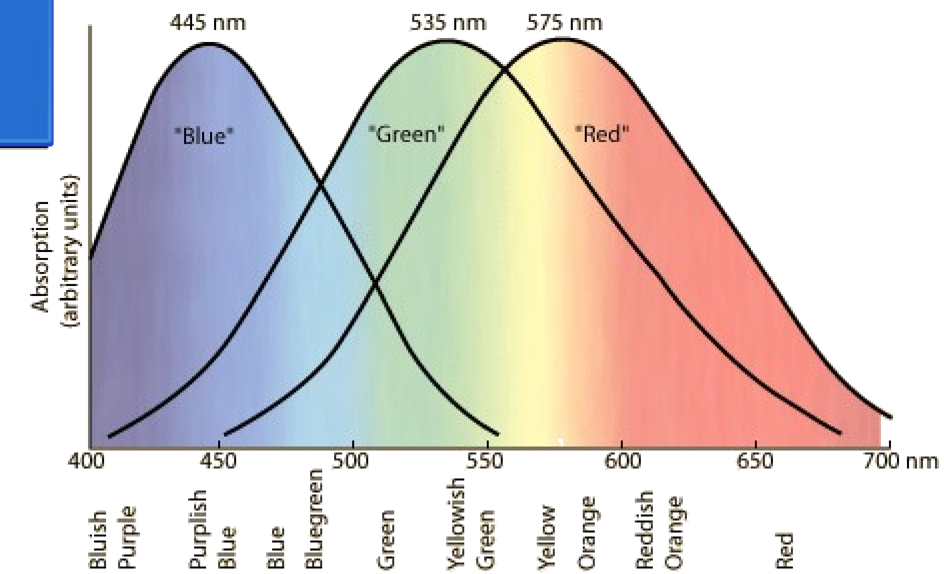
- We are equipped with two types of light sensitive cells in the retina
  - 3 different types of one-frequency sensitive cones
  - 1 type of rods – sensitive to the overall intensity of light
  - They are not uniformly distributed on the retina
    - A central region called fovea has an high concentration of cones – central sharp vision for complex tasks
    - Periferal regions have more rods
    - We have a spot with practically no receptors – the blind spot
    - … and we are not aware of any of it!

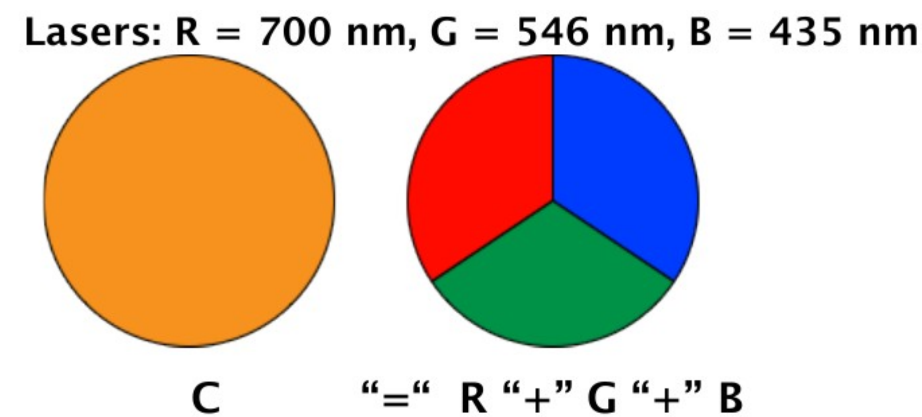




Human color perception

- Our eyes constantly gather four types of information:
  - Intensity of frequencies received by the individual cones: red, green, blue
  - Overall intensity measured by rods
- Therefore, we think all of the colors in the world can be matched by a mix of these frequencies at the right intensity!



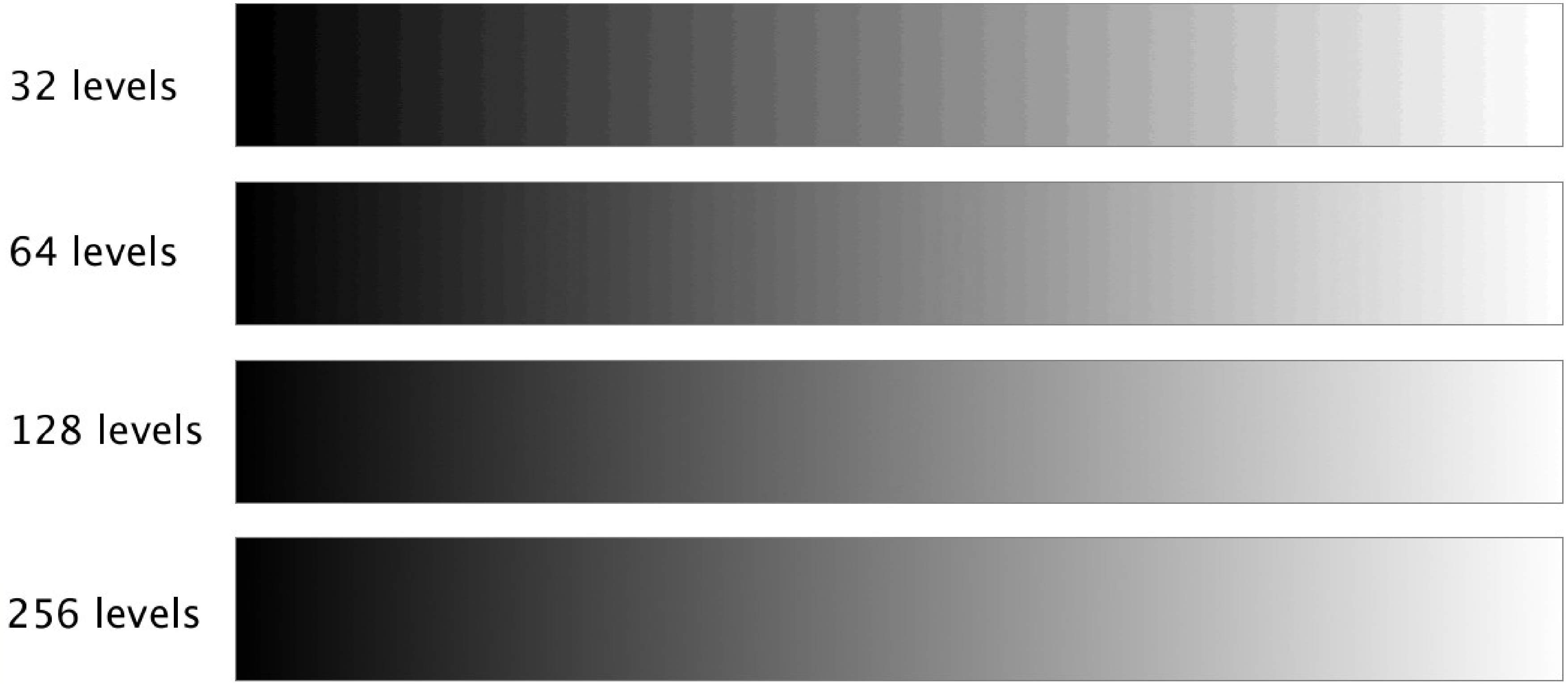


Human color perception

- The human eye is much more sensitive to spatial variations in brightness (gray scale) than to spatial variations in color
- The three images below add together to give the image on the top
- Which of those three images on the right has the most spatial details?

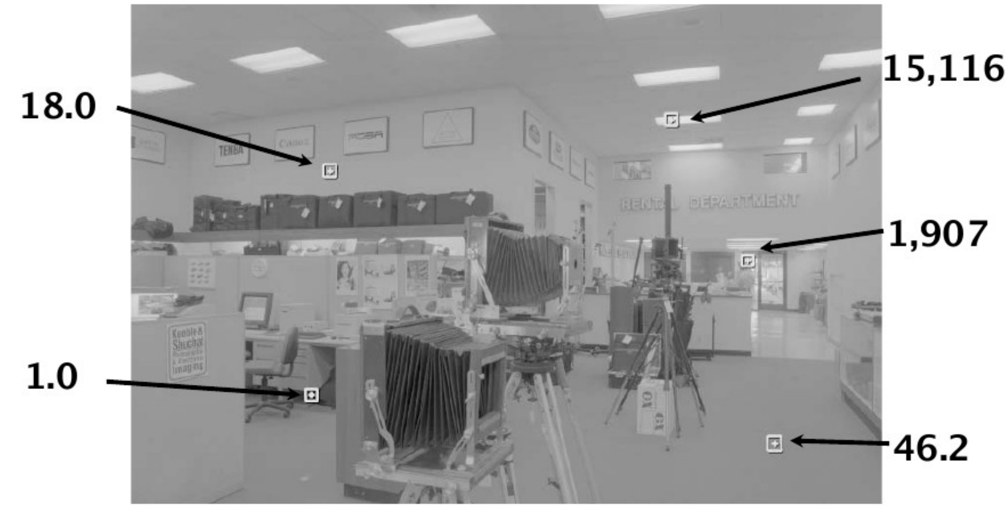
Human color perception

- Since the human eye can see small changes in brightness, we need many bits for brightness
- Otherwise changing the brightness by the smallest amount will be seen as a visual discontinuity
- Proof:



Dynamic range

- We can talk about the **dynamic range**:
  - What is the ratio of the biggest to the smallest intensity we can express?
  - Possible: 100,000,000,000:1 (from the sun to pitch black)
  - Typical Real World Scenes: 100,000:1
- Other examples
  - Newsprint: 10:1
  - Glossy print: 60:1
  - Samsung F2370H LCD monitor: static 3,000:1, dynamic 150,000:1



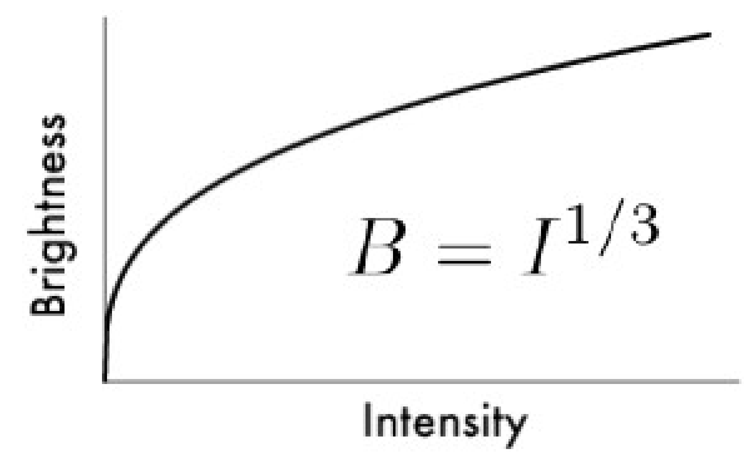
- Static **contrast ratio** is the **luminance** (luminous intensity per unit area of light travelling in a given direction) ratio between the brightest white and darkest black within a single image
- Dynamic contrast ratio is the luminance ratio between an image with the brightest white level and an image with the darkest black level
- The contrast ratio in a TV monitor specification is measured in a dark room. In normal office lighting conditions, the effective contrast ratio drops from 3,000:1 to less than 200:1

Dynamic range

- Our perception of many quantities is not linear but exponential!
  - How exponential it is, changes for the quantity. Light intensity: 1/3
- Brightness intensity differences are better perceived by humans at lower light intensities
- A logarithmic compression uses more of the display's brightness resolution for the lower intensities in the image
  - Thus less of the display's resolution is used on the higher intensities
  - This causes more quantization in the higher intensities of the image than in the lower intensities of the image (and is more optimal for human consumption)

$$S = I^p$$

Sense	Exponent
Brightness	0.33
Loudness	0.60
Length	1.00
Heaviness	1.45

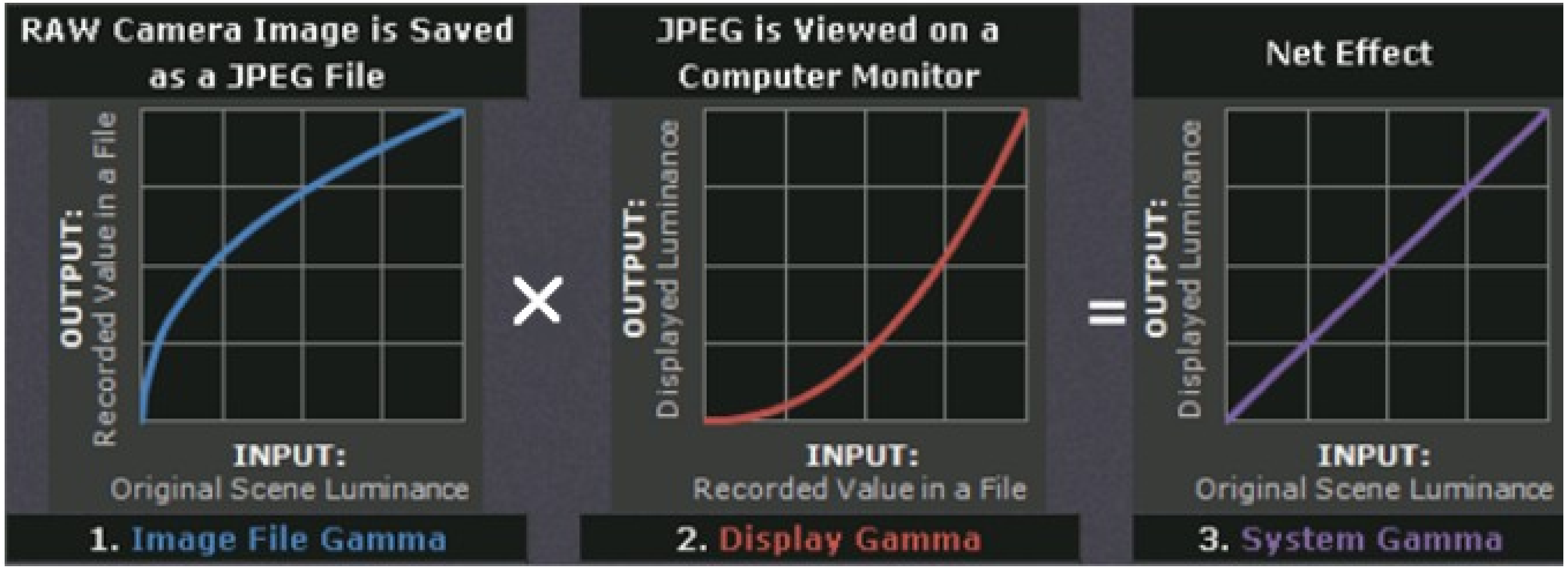


Color model

- Since the human eye works with only 3 signals (ignoring rods), we work with 3 signals for
  - Images
  - Displays
  - Printers
  - ...
- Image formats store values in the R, G, and B channels
- The values stored are typically between 0 and 255 (unless its HDR)
  - How many colors can we represent?
- The relative values give the color, and the overall values give the intensity
- The computer monitor/display can be used to further increase or decrease the overall global image intensity (brightness/darkness)

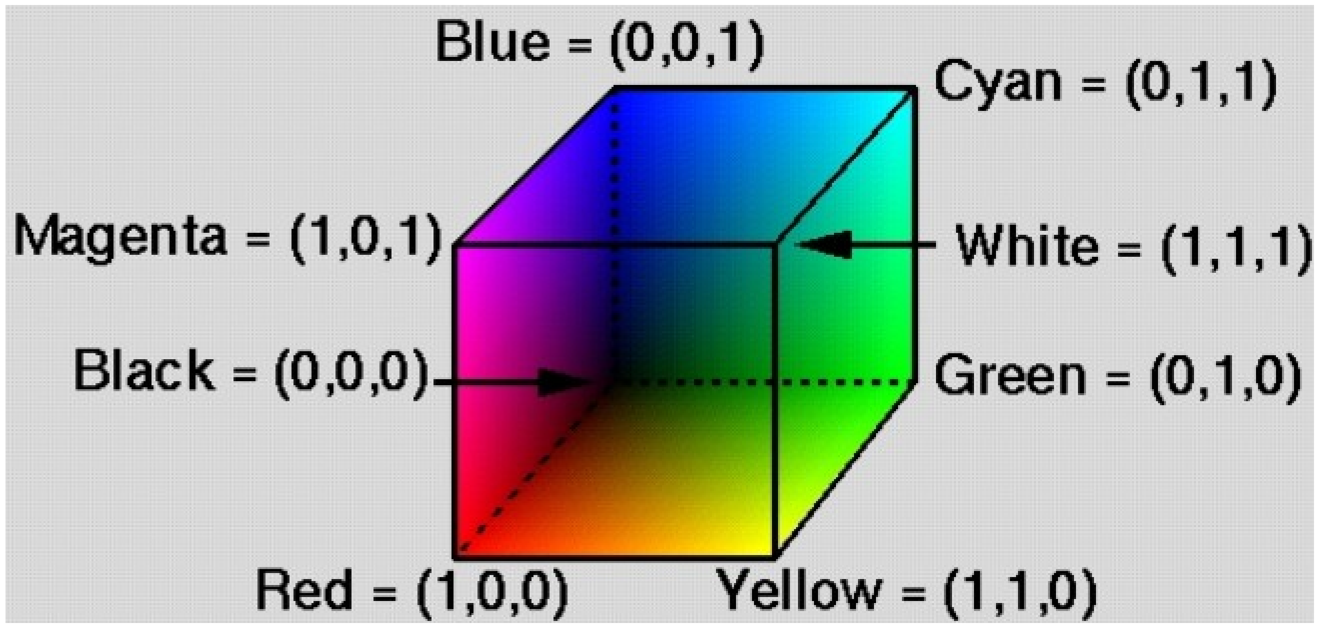
Gamma Encoding and Correction

- Color model optimisation: maximize the use of the bits relative to human perception
- More bits are allocated to the darker regions of the image than to the lighter regions
- Gamma correction is applied to the gamma encoded (compressed) images to convert them back to the original scene luminance



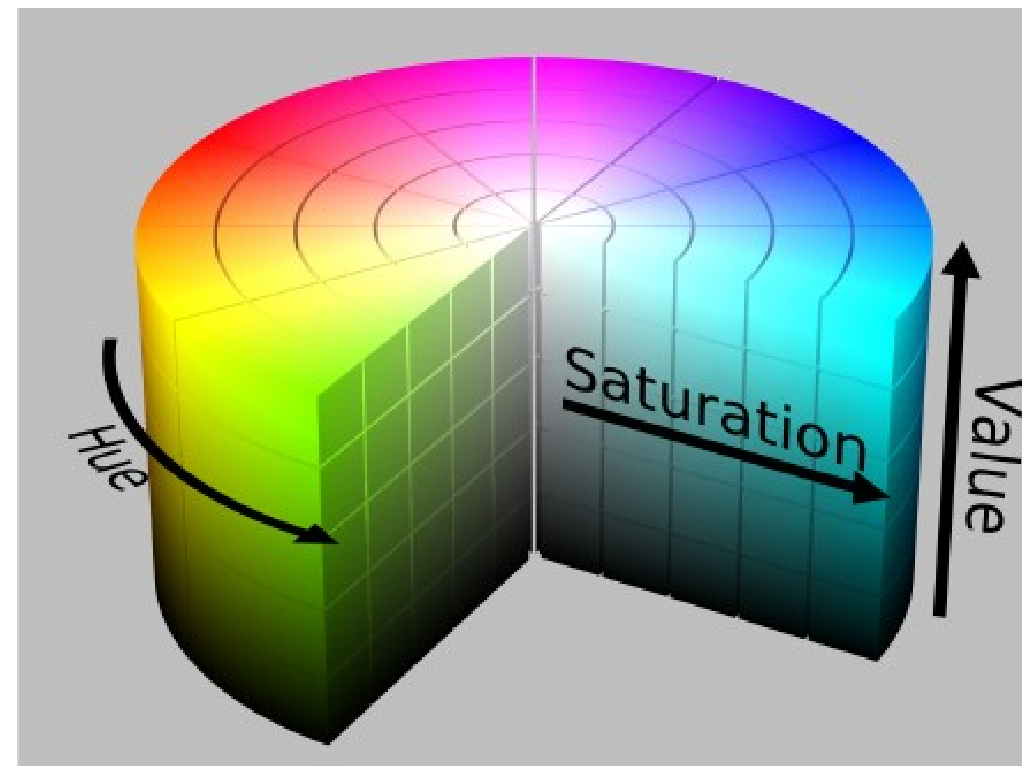
RGB color cube

- A symbolic representation of our color spectrum (**gamut**)
- Map each primary color in the RGB color space to the unit distance along the x, y, z axes
  - Black at (0,0,0), white at (1,1,1)
  - The color cube represents all possible colors
  - ...in our very limited perception of them!!



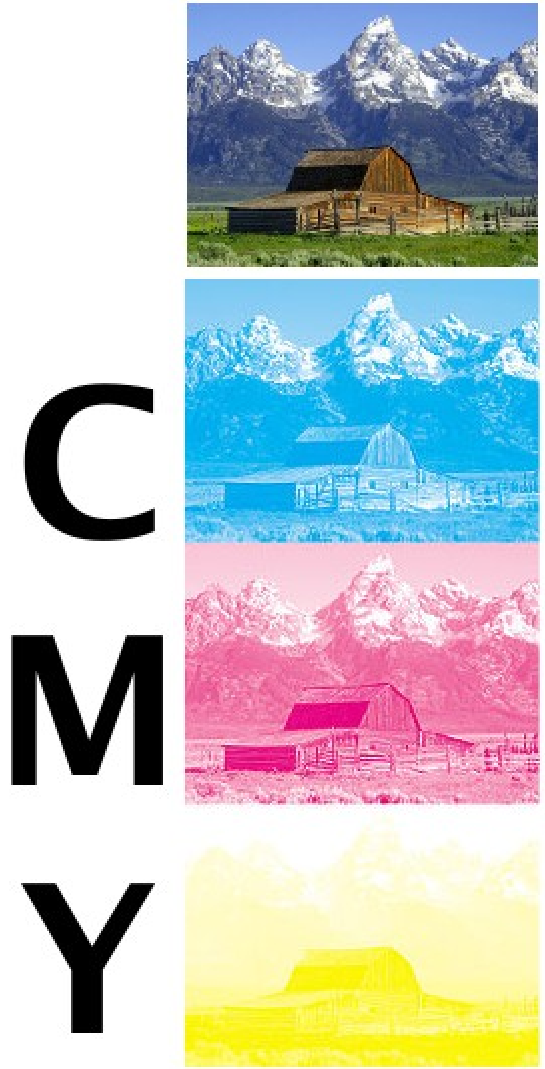
HSV color model

- RGB is not the only possible representation!
- HSV: Hue, Saturation and Value
  - **Hue**: rainbow of colors ("wavelength")
  - **Saturation**: distribution of intensity for a particular color
  - **Value**: relative lightness or darkness of a particular color
- great for user interfaces, "color picker"



CMY(K) color model

- Cyan, Magenta, Yellow – the three primary colors of the subtractive color model
- Partially or entirely masking/filtering (=absorbing colors) a white background
- The ink reduces the light that would otherwise be reflected
- Equal mixtures of C,M,Y should (ideally) produce all shades of gray



CMY(K) color model

- Advantages of using black ink:
  - Most fine details are in printed with the Key color (K=black in most cases)
  - Less dependency on (perfectly) accurate color alignment
  - Mixtures of 100% C, 100% M and 100% Y do not give perfect black in practice
- Reduce bleeding and time to dry
- Save colored ink

Thank you!

- Questions?