Sound and Color

Clubes de Ciencia - Ensenada 2017

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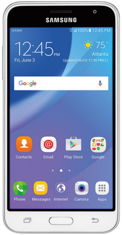
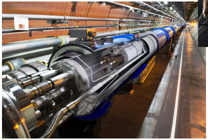
Synesthesia

- There is so much in the world that we can't see, smell, hear, taste or touch.
- We use technology to enhance our perceptions about the world around us. What are examples?

Synesthesia

- There is so much in the world that we can't see, smell, hear, taste or touch.
- We use technology to enhance our perceptions about the world around us. What are examples?
  - Microscopes, . . . , high energy accelerators
  - Spyglasses, . . . , telescopes
  - Gravitational wave detectors
  - Radios, . . . , smart phones



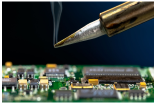


Synesthesia

- Modern technologies offer us some really exciting opportunities for creative sensory enhancement.
- In this course we are going to do this in 4 examples (each of you will participate in 3).
  1. Using sound to enhance color vision in software
  2. Using sound to enhance color vision in hardware
  3. Using temporal image processing (TIP) to enhance color vision in software
  4. Using temporal image processing (TIP) to enhance color vision in hardware

Synesthesia

- In working these out, you will acquire basic software and hardware skills that you might develop in many directions

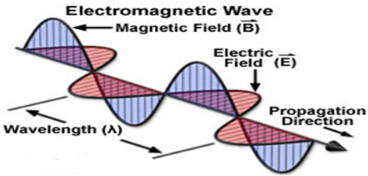


- We will also discuss general theoretical background, and possibilities for further development of these projects.
- We will also introduce you to an exciting new, cutting-edge hyperspectral camera. (We will talk about it, I wansn't able to bring it).

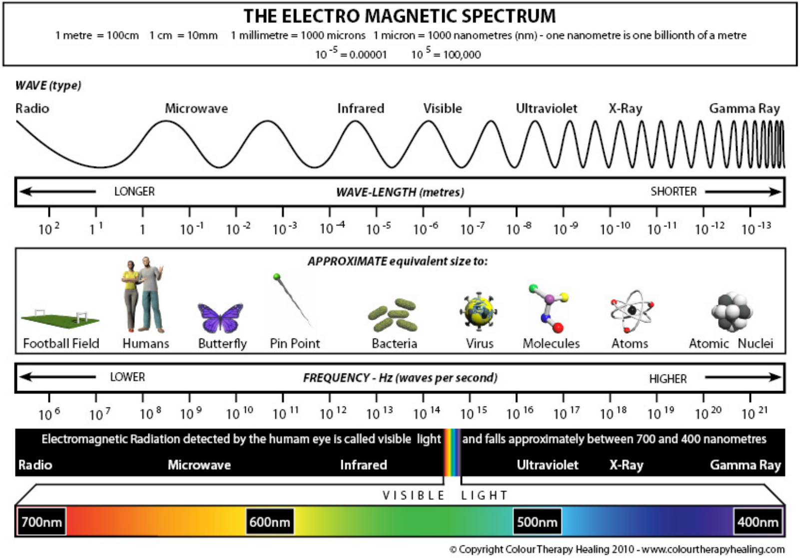
Physics of Light

Physics of Light

- Visible light is a special case of electromagnetic radiation, which are waves in electric and magnetic fields.



- Visible light is simply the part of the infinite spectrum of electromagnetic radiation that our eyes can detect.


THE ELECTRO MAGNETIC SPECTRUM
1 metre = 100cm 1 cm = 10mm 1 millimetre = 1000 microns 1 micron = 1000 nanometres (nm) - one nanometre is one billionth of a metre
$10^{-5} = 0.00001$ $10^{5} = 100{,}000$
WAVE (type)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-Ray
Gamma Ray
LONGER
WAVE-LENGTH (metres)
SHORTER
10^{2} 1^{1} 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12} 10^{-13}
APPROXIMATE equivalent size to:
Football Field
Humans
Butterfly
Pin Point
Bacteria
Virus
Molecules
Atoms
Atomic Nuclei
LOWER
FREQUENCY - Hz (waves per second)
HIGHER
10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20} 10^{21}
Electromagnetic Radiation detected by the humam eye is called visible light and falls approximately between 700 and 400 nanometres
Radio
Microwave
Infrared
Ultraviolet
X-Ray
Gamma Ray
VISIBLE LIGHT
700nm
600nm
500nm
400nm
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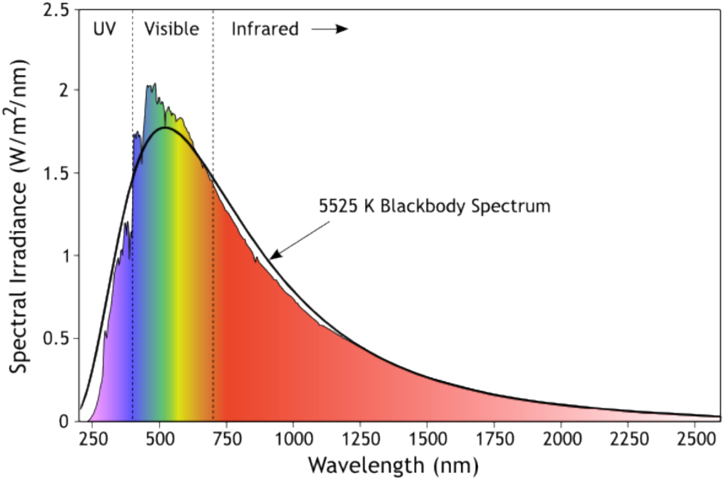
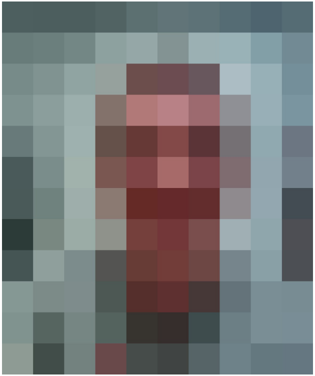
- Also, the light that we get from the sun mostly comes from the visible part of the spectrum. This is good because that's what we can see, otherwise the world would be a dark place.

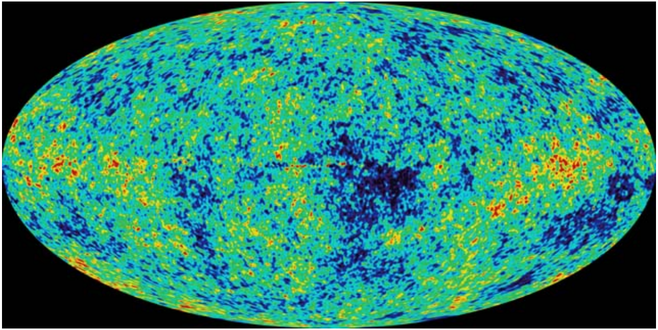


- Also, the wavelength of visible light is very small on everyday scales. This gives us the ability to resolve small objects with our eyes.



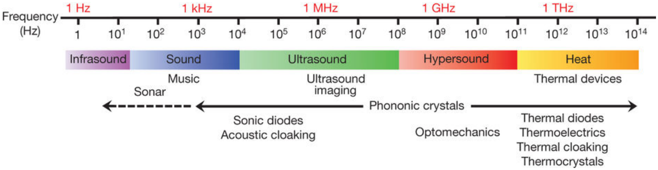
- With visible light we can form sharp images which carry enormously useful information about the sizes and shapes of objects.

- This is slightly off topic but sometimes longer wave lengths give us information that we can't see with shorter wave lengths.
- This is the cosmic microwave background. Images taken at 21cm to study to radiation left over from the big bang.



Physics of Sound

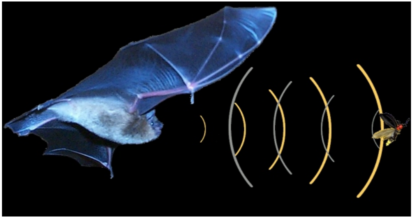
- Sound is also a wave, but it's a mechanical pressure/density wave, usually in air, but could be in other media as well.
- Unlike visible light which only coveres one octave (430-770 THz) audible sound coveres 10 octaves, or 3 decades.



Bumble Bee: 150 Hz
Middle C: 256 Hz
Mosquito: 1500 Hz
Grasshopper: 7 kHz
Bats: 20-200 kHz (Humans top out at $\sim$20 kHz)

- The frequencies of audible sounds are closely matched to the sounds of many mechanical objects.
  - Vocal cords
  - Musical instruments
  - Chair being pushed across the floor

- The wavelengths of audible sound are fairly large by the standards of everyday life, as you can infer from the size of musical instruments (and ears).
- This makes it difficult to get locate the source of sounds sharply, or to form images.
- Bats use *ultrasound* and timing of reflected signals to do spatial analysis, as do ultrasound cameras.



Physics of Sound

- Note that ultrasound cameras encode ultrasound information into visual information, so that humans can interpret it readily.

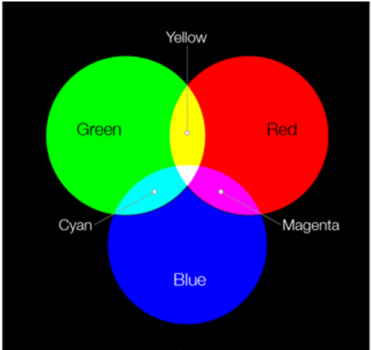
Light Perception

Light Perception

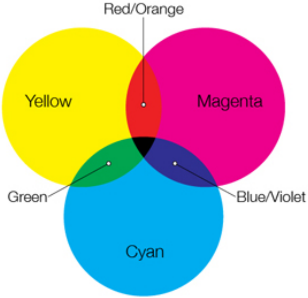
- Normal human color vision is three-dimensional, or "trichromatic".
- This basic discovery goes back to the nineteenth century. It was made quantitative and precise by James Clerk Maxwell, the same guy who proposed the electromagnetic theory of light.

Light Perception

- His color wheel showed that any color could be perceived by combining the colors red, green and blue in different proportions.



Additive Color Model
(light, RGB)



Subrtactive Color Model
(pigment, CMYK)

- Note that adding colored pigments is very different from adding colored beams.

Light Perception

- Human color vision is based on three (RGB) opsins, which are light-sensitive proteins in our retna.
- These opsins change shape when they absorb light. These shape changes in the molecules ultimately trigger electrical signals, that is neural impulses. These are the raw input for color vision.

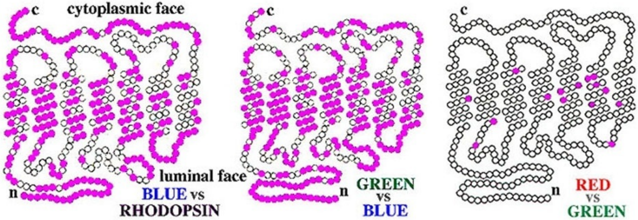
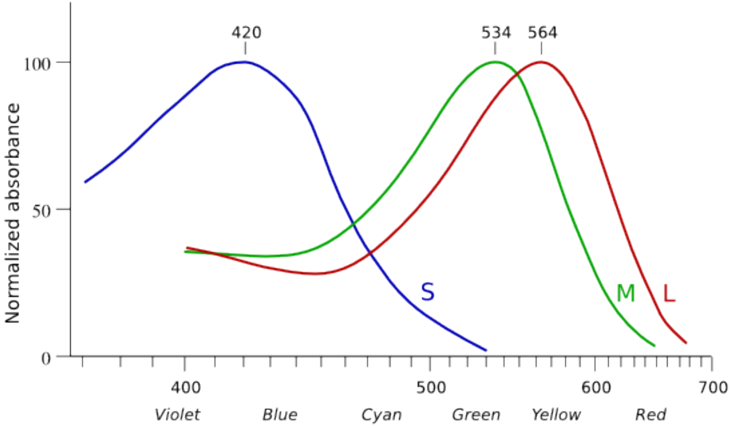


Figure 12. The closely related molecular structure of the cone opsins. The blue-cone opsin compared with rhodopsin. The blue-cone opsin compared with the green opsin and the minimal difference between the red- and green-cone opsins. The pink-filled circles represent amino acid substitutions between these molecules. The open circles indicate identical amino acids. Adapted from Nathans et al. (1986)

Light Perception

- These opsin molecules either change shape or they don't, there is no inbetween. Either they absorbed a photon or they didn't and that probability is given by a sensitivity curve - that is, different probabilities for changing shape in response to photons of different frequencies.

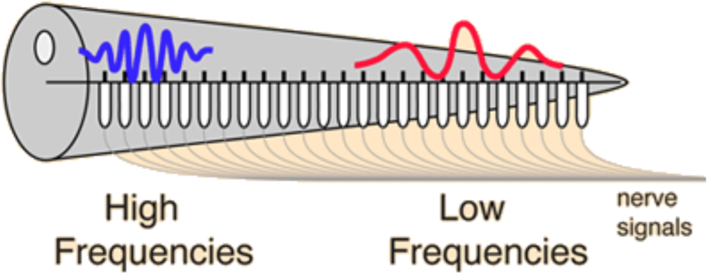


Light Perception

- Our brains do a lot of post-processing to turn that raw input - the differential response of three opsins - into color perception!
- Many electronic imaging devices do similar post-processing to create images out of combinations of these three colors.
- You are going to get some experience doing that yourselves!

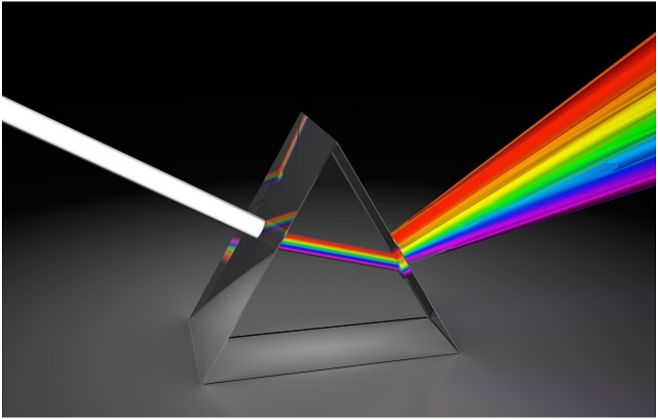
Sound Perception

- The central "idea" of auditory perception is sympathetic vibration of a sounding board - the basilar membrane - that has a range of resonant frequencies.



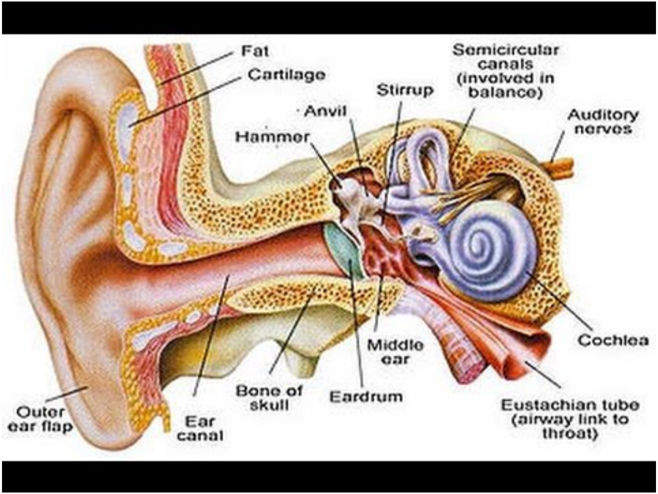
Sound Perception

- This is like an inverse piano, where the sounds drive the keys.
- It performs a spectral (Fourier, you'll see mor on this tomorrow) analysis of the incoming signal.
- It does what a prism does for light:



Sound Perception

- The complete auditory system has several clever adaptations to impedance match air to fluid, and to keep things reasonably small.



Comparing Light and Sound Perception

Comparing Light and Sound Perception

	Visible Light	Audible Sound
What is it	Electromagnetic waves	Pressure/density waves
Wavelength	$\sim$400 - 700 nm	$\sim$17 mm - 17 m
Frequency	$\sim$430 - 730 THz ($\mathrm{T} \rightarrow 10^{12}$)	$\sim$20 Hz - 20 kHz
Energy of Quanta	$\sim$1.5 - 3 eV	Ridiculously small

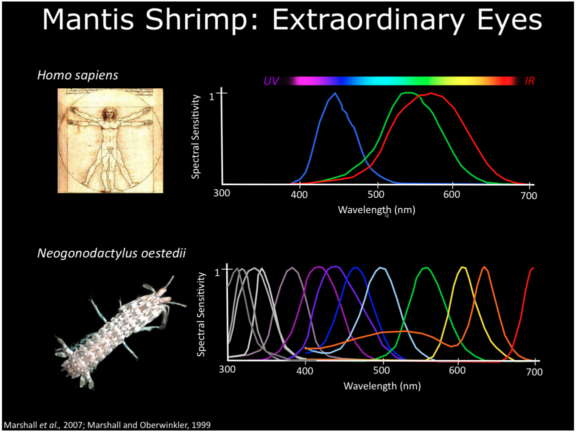
Comparing Light and Sound Perception

	Visible Light	Audible Sound
Transceiver strategy	Chemical - bending of molecules	Mechanical - sympathetic vibration
Quantum important?	Yes	No
Space analysis	Image formation	Timing and other tricks (crude)
Time analysis	Color vision (crude)	Harmonic analysis - sounding board

Hearing More Colors

Hearing More Colors

- Having three cones of colors that we can detect is great, but could be do better?
- In principle we could have a rich "chord" of intensities at each pixel. The mantis shrimp is an inspiration . . .



Hearing More Colors

- Why might this be useful?
- Hyperspectral cameras can give us more refined sampling inside and outside the visible spectrum.
- We can also have other kind of information associated with images or maps (e.g. temperature, pressure readings, densities of some neurotransmitter or antigen, median income . . .).

POPULATION DENSITY OF MEXICO

Hearing More Colors

- One way to combine the strengths of vision and audition is to encode multidimensional image files as chords.
- That is what we'll be doing, first in software, then in hardware.

Picture Citations

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Addative (Light) Primary Colors

The information for the next two slides comes from http://learn.leighcotnoir.com/artspeak/elements-color/primary-colors/

Red, green, and blue are the primary colors of lightâĂŤthey can be combined in different proportions to make all other colors. For example, red light and green light added together are seen as yellow light. **This additive color system is used by light sources**, such as televisions and computer monitors, to create a wide range of colors. When different proportions of red, green, and blue light enter your eye, your brain is able to interpret the different combinations as different colors.

Subtractive (Pigment) Primary Colors

However, there is another set of primary colors with which you may be more familiar. The primary colors of pigment (also known as subtractive primaries) are used when producing colors from reflected light; for example, when mixing paint or using a color printer. **The primary colors of pigment are magenta, yellow, and cyan (commonly simplified as red, yellow, and blue).**

Pigments are chemicals that absorb selective wavelengths-they prevent certain wavelengths of light from being transmitted or reflected. **Because paints contain pigments, when white light (which is composed of red, green, and blue light) shines on colored paint, only some of the wavelengths of light are reflected.** For example, cyan paint absorbs red light but reflects blue and green light; yellow paint absorbs blue light but reflects red and green light. If cyan paint is mixed with yellow paint, you see green paint because both red and blue light are absorbed and only green light is reflected.