CSC 433/533 Computer Graphics

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Credit: Joshua Levine

Today's Agenda

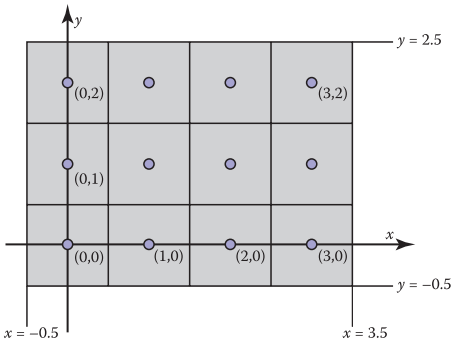
- Hw1 discussion
- **PLEASE START EARLY** so that we can debug any issues wrt git, Javascript, etc.
- Goals For Today:
- Finish discussing Javascript odds-and-ends (e.g. Accessing the DOM)
- Introduce images, displays

A Simple Mathematical Abstraction for Images

- We can abstract an image as a *function*, I
- $I: R \rightarrow V$
  - The **domain**, R, is a some **continuous** rectangular area ($R \subseteq \mathbb{R}^2$) and the **range**,
- V, is a set of possible values.
- Since R is two dimensional, we can use $I(x,y)$ to represent the value of the image at a position $(x,y) \in R$

Raster Images

- We digitize $I(x,y)$ as an array of values, $I[y][x]$, called **pixels**, for **pic**ture **el**ements



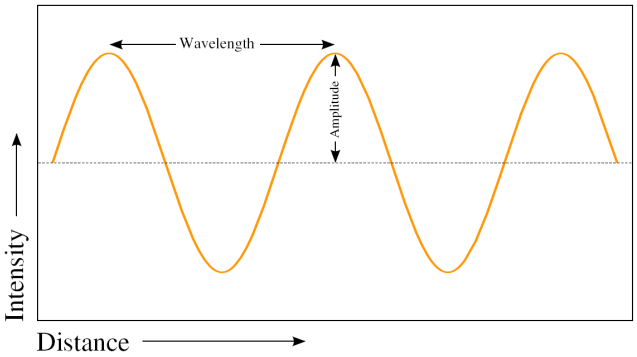
NOTE: (0,0) is often the top left, not the bottom left!

How Do We **Acquire** Raster Images?

Light

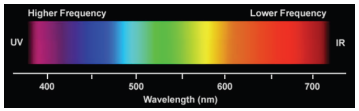
- Is both: (1) particles known as **photons** that (2) act as **waves**.
  - **Amplitude** (height of wave)
  - **Wavelength** (distance of which wave repeats)
    - Frequency is the inverse of wavelength
    - Relationship between wavelength (λ) and frequency (f):
      - $\lambda = c / f$
    - Where c = speed of light = 299,792,458 m / s

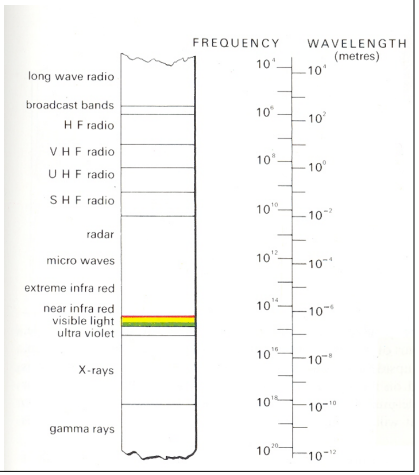
Light



Light is Electromagnetic Radiation

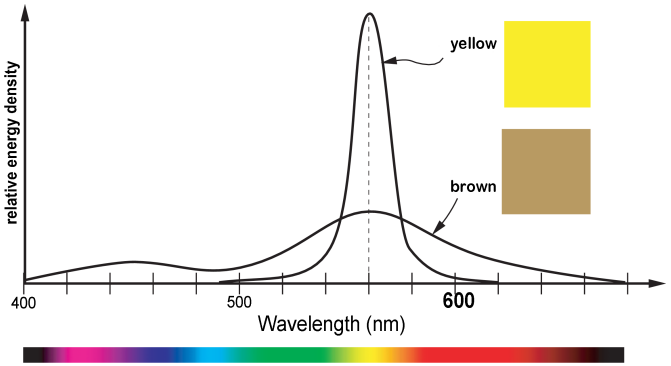
- Visible spectrum is "tiny"
- Wavelength range: 380-740 nm



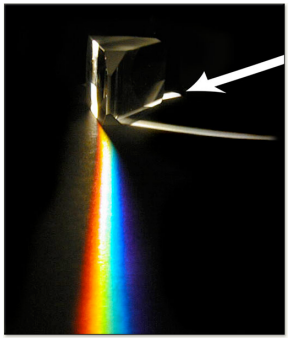


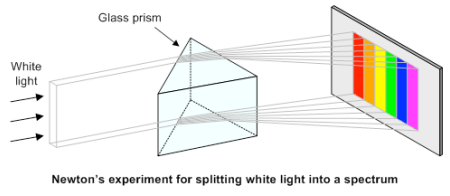
Color != Wavelength

- But rather, a combination of wavelengths and energy



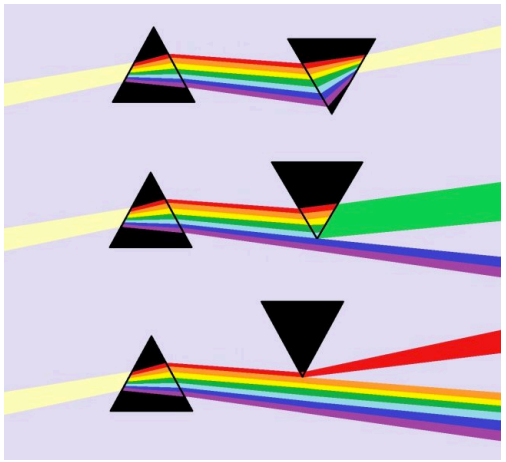
Isaac Newton, 1666





Newton's experiment for splitting white light into a spectrum

http://www.webexhibits.org/colorart/bh.html
https://www.clivemaxfield.com/diycalculator/popup-m-cvision.shtml

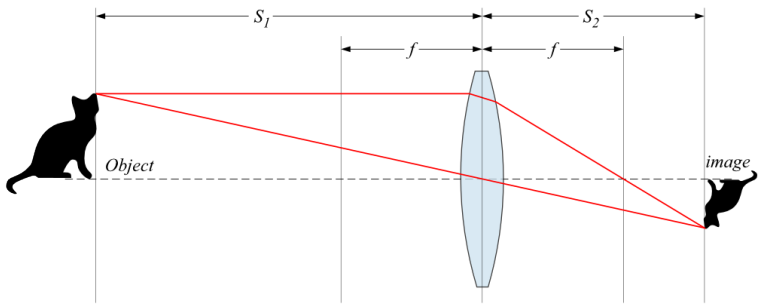


http://www.thestargarden.co.uk/Newtons-theory-of-light.html

Optics: Thin Lenses

- A **lens** is a transparent device that allows light to pass through while causing it to either converge or diverge.
- Given a camera, a target object, and a single converging lens:
  - Let S1 and S2 be the distance from the lens to the target and film
  - The **focal length**, f, is a measure of how strongly a lens converges light
  - The **magnification factor**, m = S2/S1, relates the two distances.

Thin Lens Equation

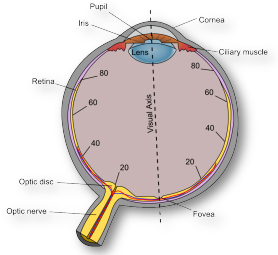


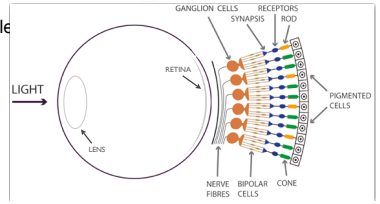
$$m = \frac{\text{image size}}{\text{object size}} = \frac{S_2}{S_1}$$

$$\frac{1}{S_1} + \frac{1}{S_2} = \frac{1}{f}$$

Human Optics

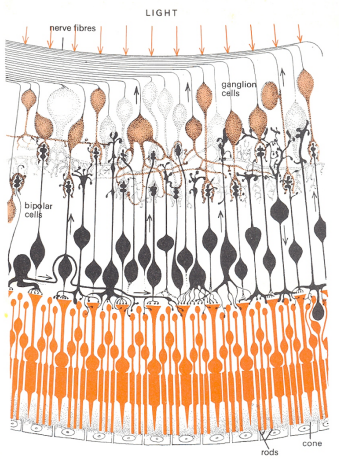
- In human vision, the **cornea** acts as a protective lens that roughly focuses incoming light
- Iris controls the amount of light that enters the eye
- The **lens** sharply focuses incoming light onto the retina
  - Absorbs both infrared and ultraviole light which can damage the lens
- The **retina** is covered by **photoreceptors** (light sensors) which measure light





Photoreceptors

- **Rods** (detect low-light / scoptopic vision)
  - Approximately 100-150 million rods (Non-uniformly distributed across the retina)
  - Sensitive to low-light levels (scotopic vision)
- **Cones** (detect day-light / phototopic vision)
  - Approximately 6-7 million cones.
  - Detect color with 3 different kinds:
    - Red (L cone) : 564-580nm wavelengths (65% of all cones)
    - Green (M cone) : 534-545nm (30% of all cones)
    - Blue (S cone) : 420-440nm (5% of all cones)

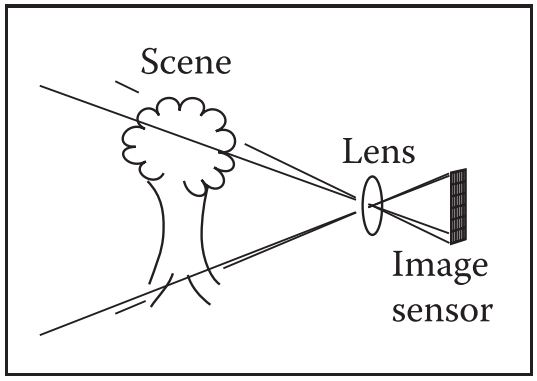


From Humans to Machines: Charge-Coupled Devices (CCDs)

- A CCD is an electronic circuit with a grid of small rectangular photocells.
- The optical lens focuses a scene onto the sensors.
- Each photocell measures the amount of light that hits it.
- The collective data of the sensors represents an image when viewed from a distance.

http://en.wikipedia.org/wiki/Charge-coupled_device

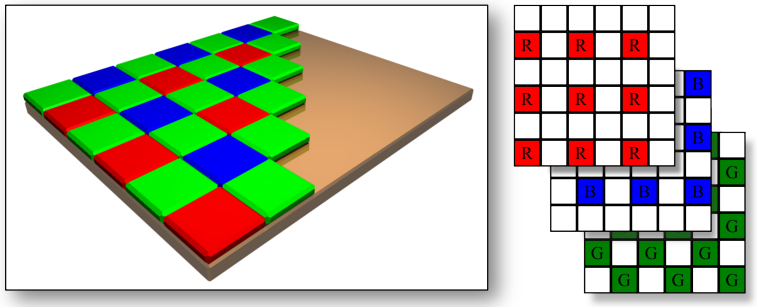
Color Image Acquisition



Color Image Acquisition

- In a single CCD color digital camera each individual photosite of the CCD is filtered to detect either red, green, OR blue light
- Most filters mimic the cone density of the human eye
- The Bayer filter uses 50% green and 25% red and blue sites.
- The 'RAW' data must be **demosaiced** (fill in the gaps) to produce a true-color image.

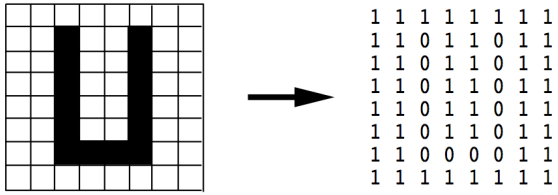
Bayer Filter



- Newer technology allows each photosite is able to discriminate and measure red, green and blue light simultaneously.

How Do We **Encode** Raster Images?

Bitmaps



- **Bitmap**: digital image that is a 2d array of pixels which store one bit.
  - Simplest digital image, a representation of a black and white image.
- Bit: ones/zeros, convention is 0 = black & 1 = white.

Digital Images Linearized

1 1 1 1 1 1 1 1
1 1 0 1 1 0 1 1
1 1 0 1 1 0 1 1
1 1 0 1 1 0 1 1
1 1 0 1 1 0 1 1
1 1 0 1 1 0 1 1
1 1 0 0 0 0 1 1
1 1 1 1 1 1 1 1

- While we think of images as 2-dimensional, in memory we usually prefer to pack storage so that they are 1-dimensional.
- The same image can be represented in both binary and hexadecimal

11111111	11011011	11011011	11011011	11011011	11011011	11000011	11111111

FF	DB	DB	DB	DB	DB	C3	FF

Greyscale Images - Pixmaps

- We use 0 for black and 1 for white -- what value should we use for grey?
- Could use floating point numbers
- Instead, one convention is to use 8 bits for pixel -- how many different “shades of grey”?
- Can convert to [0.0,1.0] by dividing by 255

Javascript and Arrays

- Standard `Array` type in Javascript is *sparse*:
  - No guarantee of contiguous block of memory, memory is allocated on demand.
  - Can store mixed types
- Javascript `TypedArray` does use a contiguous block of memory
  - But, requires a fixed type

Pixmap Declaration In Javascript

```
let ROWS = 8; let COLS = 8;

//pixmap is an array of arrays
let pixmap = [];
for (let r=0; r<ROWS; r++) {
  pixmap[r] = [];
}

//pixmap2 is an array of arrays, but with lengths specified
let pixmap2 = Array(ROWS), () => Array.from(Array(COLS));

//pixmap3 is utilizes a 1-d array for the whole thing
let pixmap3 = Array(ROWS*COLS);

//top left pixel (x,y) = (0,0)
pixmap[0][0]; pixmap2[0][0]; pixmap3[0];

//top right pixel (x,y) = (7,0)
pixmap[0][7]; pixmap2[0][7]; pixmap3[7];

//bottom left pixel, in general [index] = [y*COLS+x]
pixmap[7][0]; pixmap2[7][0]; pixmap3[56];
```

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//bottom left pixel, in general [index] = [y*COLS+x]
pixmap[7][0]; pixmap2[7][0]; pixmap3[56];
```

Pixmap Declaration with TypedArrays

```
let ROWS = 8; let COLS = 8;

//pixmap4 is utilizes a 1-d array for the whole thing
let pixmap4 = new Uint8Array(ROWS*COLS);

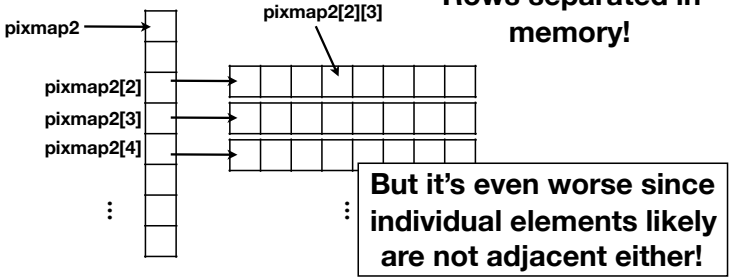
//Instead of storing as 0..255, can use other types
//e.g. Uint8ClampedArray, Float32Array, etc.

//Can we do multidimensional TypedArray
//using Arrays of arrays?
let pixmap4 = new Uint8Array(ROWS);
pixmap4[0] = new Uint8Array(COLS);    //incorrect!


//for TypedArrays, we must use 1-d indexing
//e.g. [index] = [y*COLS+x]
```

Image Allocation

```
let ROWS = 8;
let COLS = 8;
let pixmap2 = Array.from(Array(ROWS), () => Array(COLS));
```



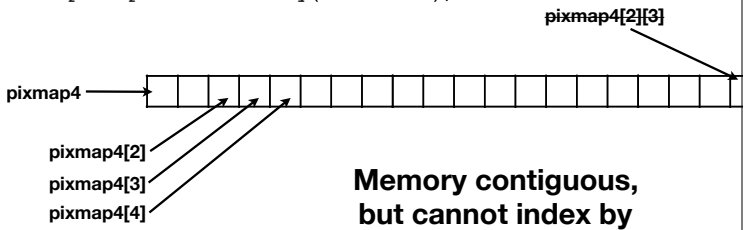
Rows separated in memory!

But it's even worse since individual elements likely are not adjacent either!

Image Allocation

```
let ROWS = 8;
let COLS = 8;
let pixmap4 = Uint8Array(ROWS*COLS);
```

We don't have this



Memory contiguous, but cannot index by row / column

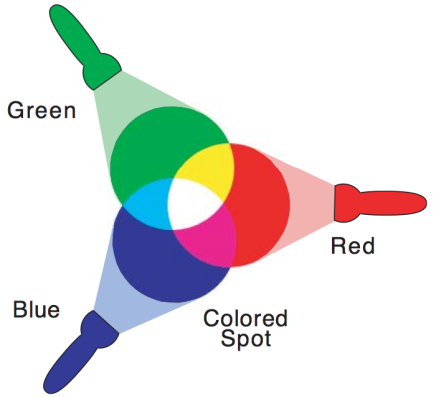
Encoding Color Images

- Could encode 256 colors with an unsigned char. But what convention to use?
- One of the most common is to use 3 **channels** or bands
- Red-Green-Blue or RGB color is the most common -- based on how color is represented by lights.
- Coincidentally, this just happens to be related to how our eyes work too.

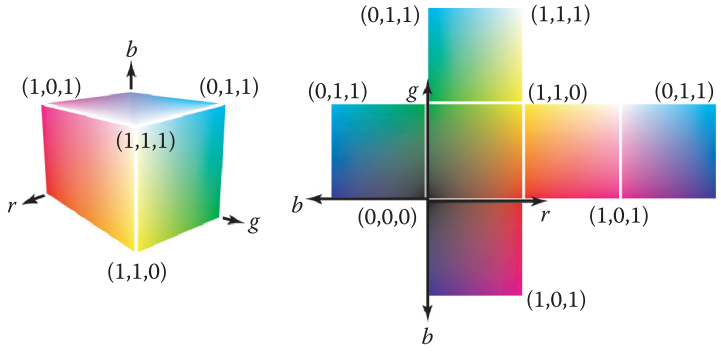
NOTE: There are many schemes to represent color, most use 3 channels. We'll come back to this next lecture

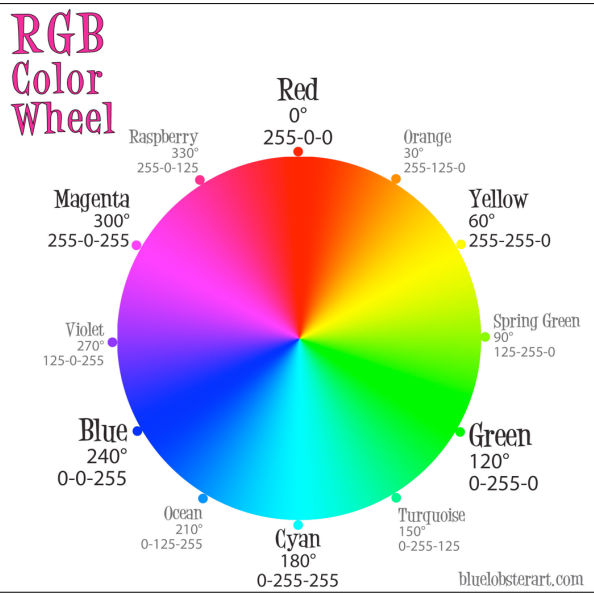
RGB Colors

- Additive Mixing of 3 Lights



RGB Color Cube





Encoding Color Channels

- Could use 8-bits, spread across all 3 channels (a bit ugly…)

$$59_{16} = \begin{array}{|c|c|c|}\hline 010 & 110 & 01 \\ \hline \text{R} & \text{G} & \text{B} \\ \hline \end{array} = (2/7, 6/7, 1/3) = (0.286, 0.757, 0.333)$$

- The textbook outlines a collection of other methods. The most common? 8-bit RGB images (24-bits per pixel)

```
//separate channel encoding
let red_pixmap = new Uint8Array(ROWS*COLS);
let green_pixmap = new Uint8Array(ROWS*COLS);
let blue_pixmap = new Uint8Array(ROWS*COLS);

//all together, could use an 32-bit uint,
//by standard convention we have 4 channels
let rgb_pixmap = new Uint8Array(4*ROWS*COLS);

//access colors
let index = COLS*r + c;
rgb_pixmap[4*index + 0];  //red
rgb_pixmap[4*index + 1];  //green
rgb_pixmap[4*index + 2];  //blue

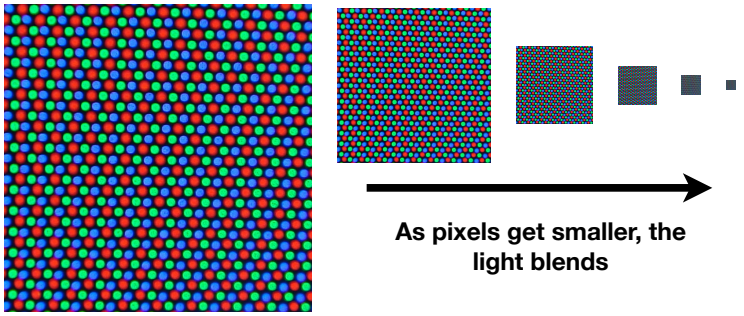
//can we do better???  What about OOP?
```

RGB Pixmap Encoding Options

How Do We **Display** Raster Images?

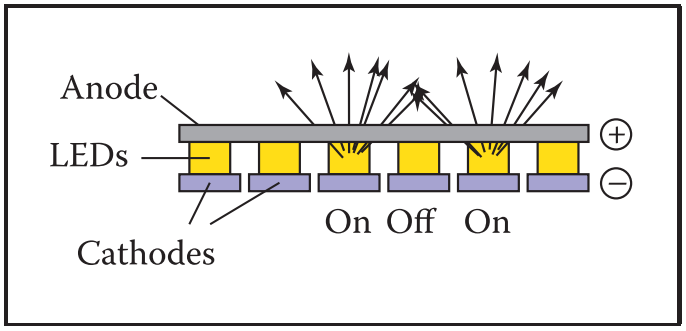
Optical Mixing

- To make (almost) any color, we combine light from three channels, Red, Green, Blue

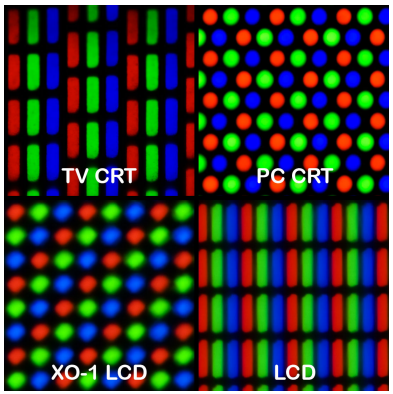


As pixels get smaller, the light blends

LEDs (Light-Emitting Diodes)



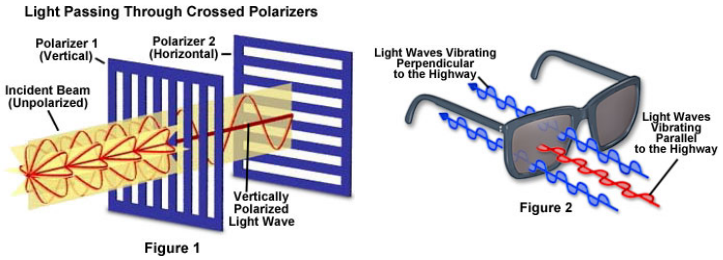
LCD Technology



- LCDs or **L**iquid **C**rystal **D**isplays produce color by selectively blocking light through different filters
- Pixels are organized in various units of 3

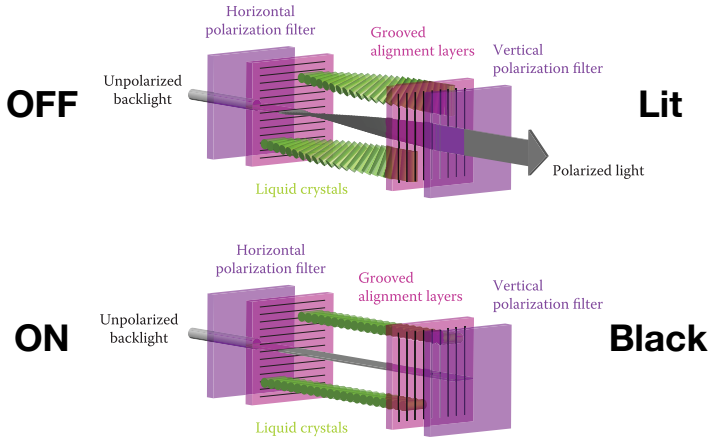
Polarized Light

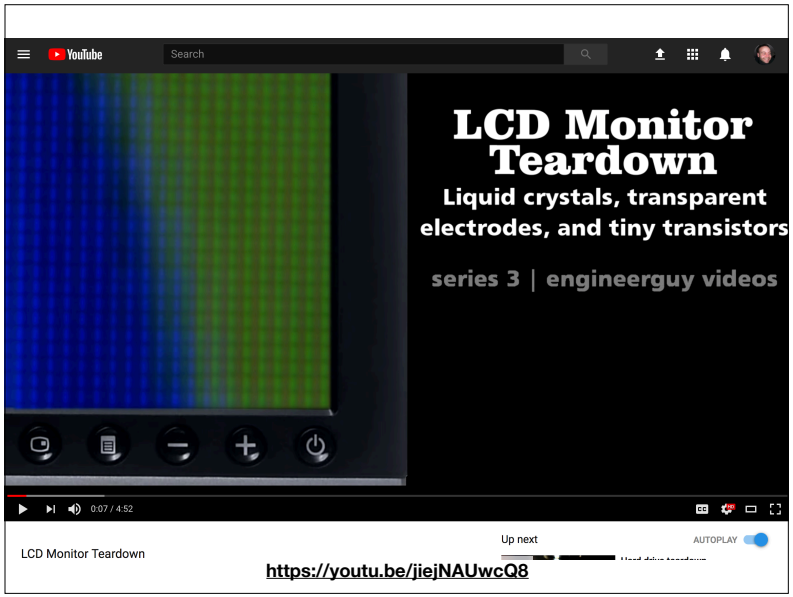
- Light oscillates as a wave in all directions perpendicular to its path. Polarizers selectively block certain oscillations



http://www.olympusmicro.com/primer/lightandcolor/polarization.html

Twisted Nematics





https://youtu.be/jiejNAUwcQ8

For next lecture

- FOCG, Ch. 3.3, 19
- See also optional readings!