

CSC 433/533

Computer Graphics

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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

What is an image?
How do we use them in our daily lives?

think-pair-share

im·age
a visual representation of something

im·age *noun \i-mij*

Definition of IMAGE Cite | [Cite](#) | [Share](#) | [Like](#)

1 : a reproduction or imitation of the form of a person or thing; especially : an imitation in solid form : **STATUE**

2 **a** : the optical counterpart of an object produced by an optical device (as a lens or mirror) or an electronic device

b : a visual representation of something: as (1) : a likeness of an object produced on a photographic material (2) : a picture produced on an electronic display (as a television or computer screen)

3 **a** (1) : exact likeness : **SEMILANCE** <God created man in his own image — Genesis 1:27(Revised Standard Version)>

b : a person strikingly like another person <she is the *image* of her mother>

4 **a** : a tangible or visible representation : **INCARNATION** <the *image* of filial devotion>

b : **archaic** : an illusory picture or impression of something <had a negative body *image* of herself> (2) : a mental conception held in common by members of a group and symbolic of a basic attitude and orientation <a disorderly courtroom can seriously tarnish a community's *image* of justice — Herbert Brownell>

5 **a** (1) : a mental picture or impression of something <had a negative body *image* of herself> (2) : a mental conception held in common by members of a group and symbolic of a basic attitude and orientation <a disorderly courtroom can seriously tarnish a community's *image* of justice — Herbert Brownell>

b : **IDEA, CONCEPT**

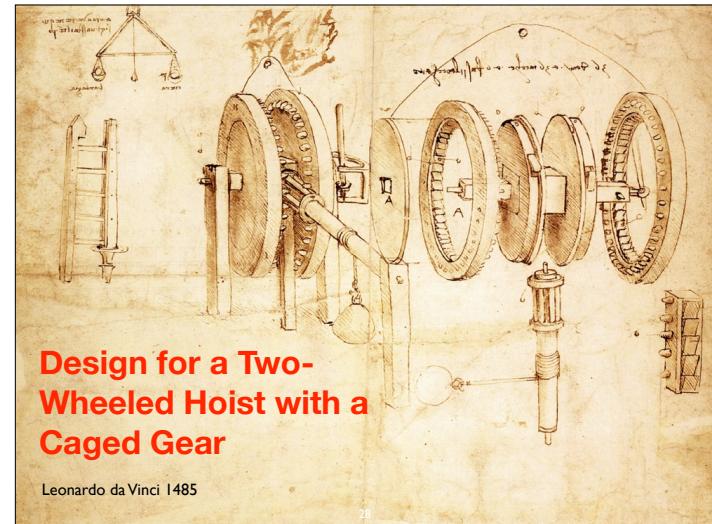
6 : a vivid or graphic representation or description

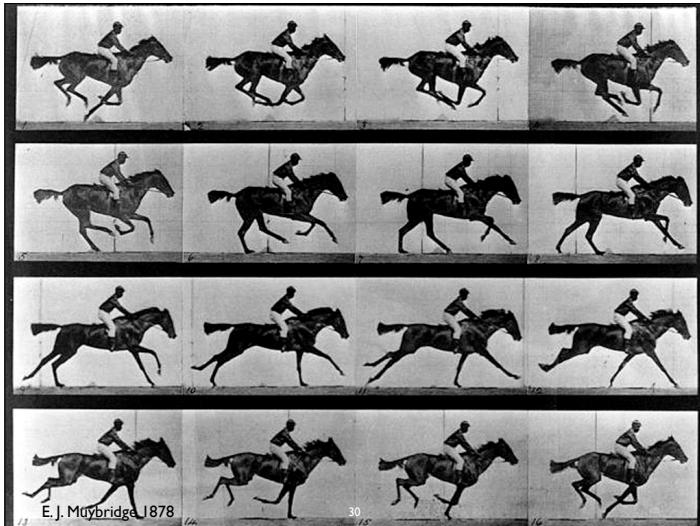
7 : **FIGURE OF SPEECH**

8 : a popular conception (as of a person, institution, or nation) projected especially through the mass media <promoting a corporate *image* of brotherly love and concern — R. C. Buck>

9 : a set of values given by a mathematical function (as a *loss function*) to a particular subset of the

<http://www.merriam-webster.com/dictionary/image>



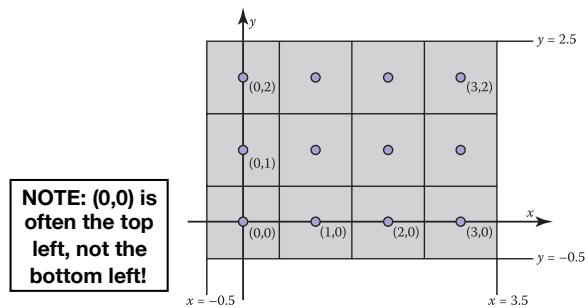


A Simple Mathematical Abstraction for Images

- We can abstract an image as a *function*, I
- $I: R \rightarrow V$
- The **domain**, R , is some 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 **picture elements**

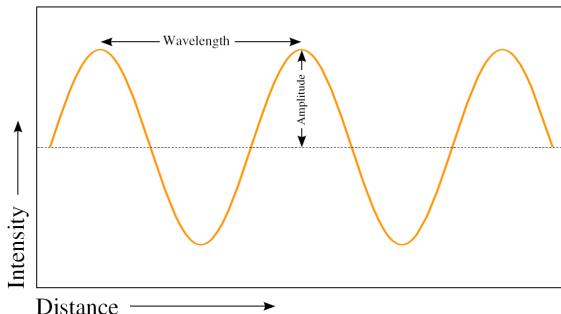


How Do We Acquire Raster Images?

Light

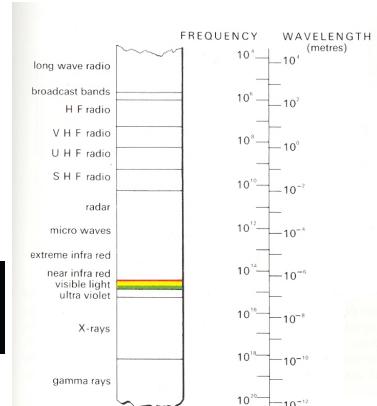
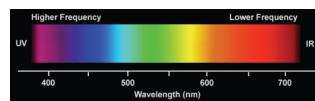
- Is both: (1) particles known as **photons** that (2) act as **waves**.
- **Amplitude** (height of wave)
- **Wavelength** (distance of which wave repeats)
 - Frequency is the inverse of wavelength
 - Relationship between wavelength (λ) and frequency (f):
 - $\lambda = c / f$
 - Where c = speed of light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

Light



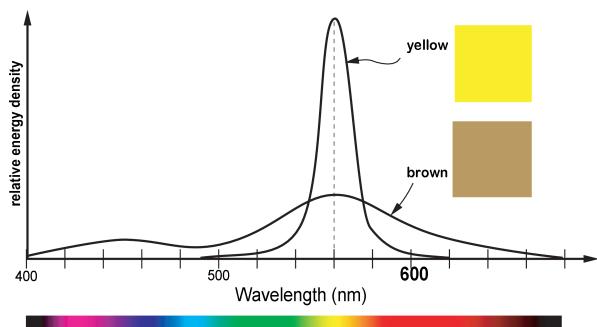
Light is Electromagnetic Radiation

- Visible spectrum is “tiny”
- Wavelength range: 380–740 nm

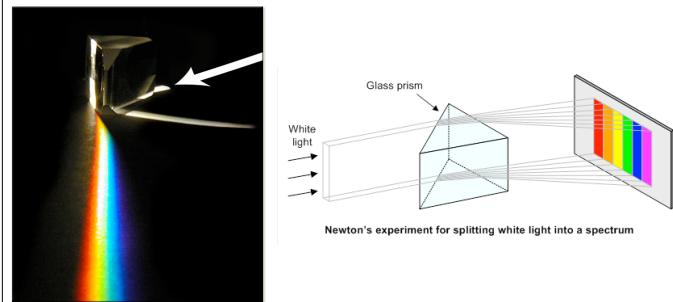


Color != Wavelength

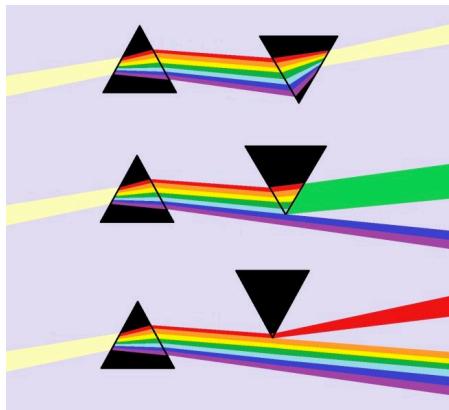
- But rather, a combination of wavelengths and energy



Isaac Newton, 1666



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

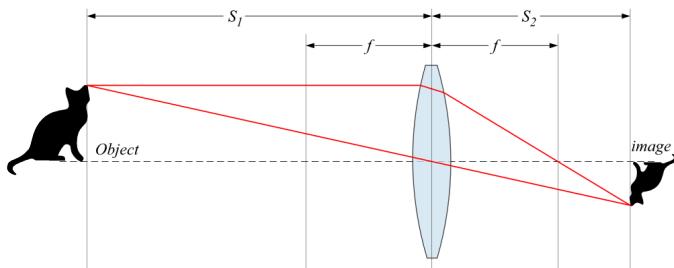


<http://www.thestargarden.co.uk/Newton's-theory-of-light.html>

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 S_1 and S_2 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**, $m = S_2/S_1$, relates the two distances.

Thin Lens Equation

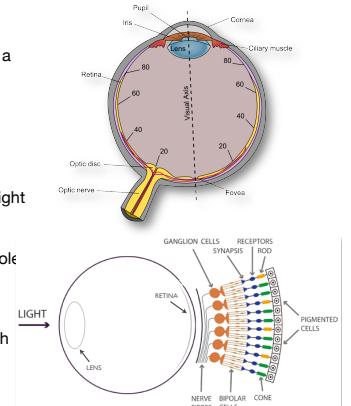


$$m = \frac{\text{image size}}{\text{object size}} = \frac{S_2}{S_1}$$

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

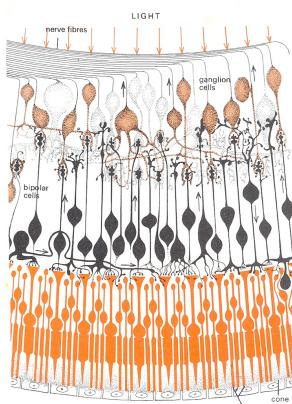
Human Optics

- 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 ultraviolet light which can damage the lens
- The **retina** is covered by **photoreceptors** (light sensors) which measure light



Photoreceptors

- Rods** (detect low-light / scotopic vision)
 - Approximately 100-150 million rods (Non-uniformly distributed across the retina)
 - Sensitive to low-light levels (scotopic vision)
- Cones** (detect day-light / photopic 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)



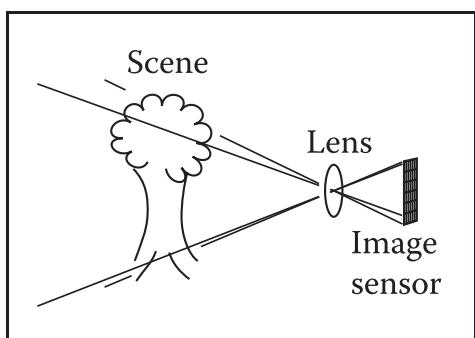
From Humans to Machines: Charge-Coupled Devices (CCDs)

- 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

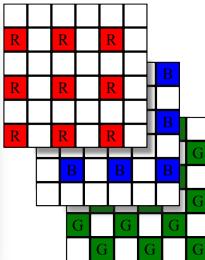
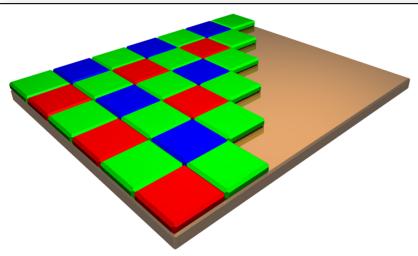
Color Image Acquisition



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.

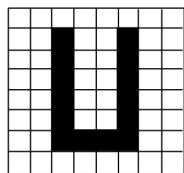
Bayer Filter



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

How Do We Encode Raster Images?

Bitmaps



```
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
```

- **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
```

11111111 | 11011011 | 11011011 | 11011011 | 11011011 | 11011011 | 11000011 | 11111111

FF DB DB DB DB DB C3 FF

- 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

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

```

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.from(Array(ROWS), () => 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];

```

Pixmap Declaration In Javascript

```

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]

```

Pixmap Declaration with TypedArrays

Image Allocation

```

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

```

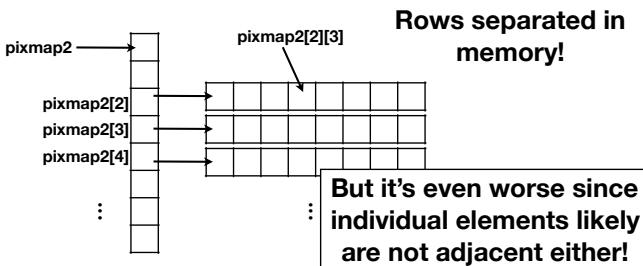


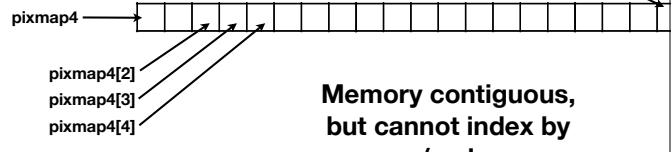
Image Allocation

```

let ROWS = 8;
let COLS = 8;
let pixmap4 = Uint8Array(ROWS*COLS); We don't have this

pixmap4[2][3]


```

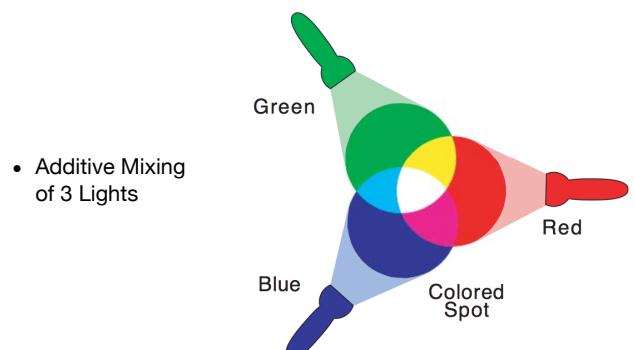


Encoding Color Images

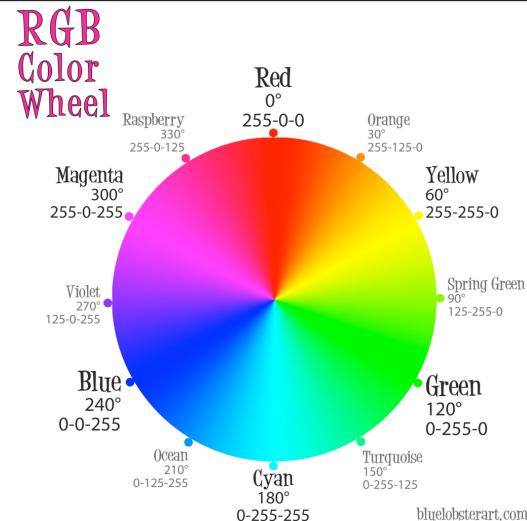
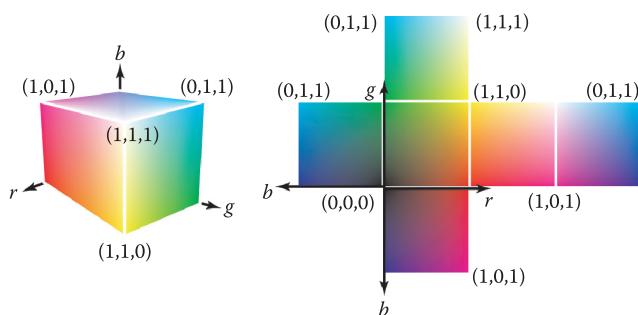
- Could encode 256 colors with an unsigned char. But what convention to use?
- One of the most common is to use 3 **channels** or bands
- Red-Green-Blue or RGB color is the most common -- based on how color is represented by lights.
- Coincidentally, this just happens to be related to how our eyes work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

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

RGB Colors



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
```

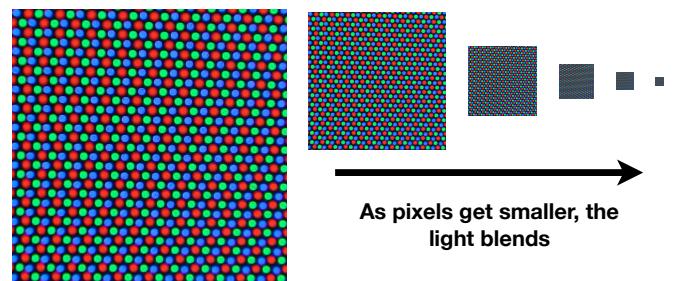
```
//can we do better??? What about OOP?
```

RGBPixmap Encoding Options

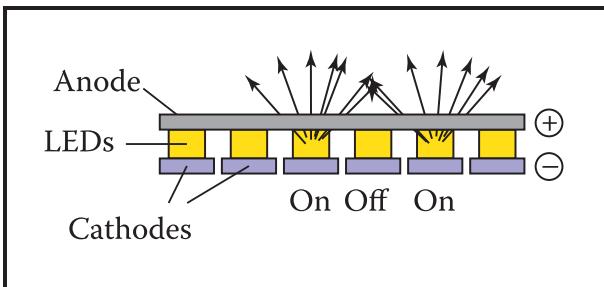
How Do We Display Raster Images?

Optical Mixing

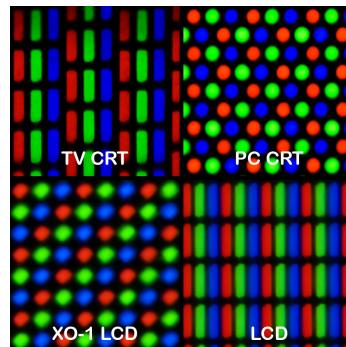
- To make (almost) any color, we combine light from three channels, Red, Green, Blue



LEDs (Light-Emitting Diodes)



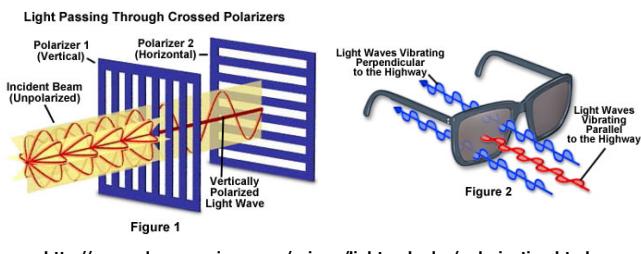
LCD Technology



- LCDs or Liquid Crystal Displays produce color by selectively blocking light through different filters
- Pixels are organized in various units of 3

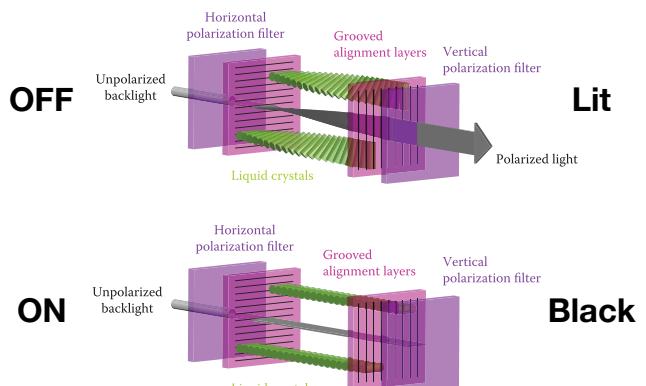
Polarized Light

- 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



For next lecture

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