Today:
Finish resolution
Learning objectives: you will be able to analyze the spatial and temporal resolution of your images. You will be able to manipulate dynamic range of color channels in an editor.

Time resolution

Other considerations of shutter speed:

Short enough to 'freeze' flow= TIME RESOLVED
VS long enough to get desired particle tracks
or long enough to be TIME AVERAGED.
Calculate motion blur. How many pixels long? If unacceptable, increase time resolution= shorter exposure time

Increase shutter speed
DSLR max = 1/4000 sec, = 250 µsec
Max on cell phone is 1/23000= 0.043msec, 43 µsec? At best.
High speed camera 30,000 fps ~ 3 x 10^{-5} sec = 30 µsec

Freeze the flow with short light source (won't work for light emitting fluids, i.e. flames)
Strobe, camera flash ~ 10-5 or -6 sec = 1-10 µsec
Best at low power
Pulsed laser 3x10^{-9} sec = 3 nsec or less
Good resource for high speed photography: http://www.hiviz.com/index.html

Time averaged images. Other end of the scale from time-resolved.

If long shutter is needed, might be too much light, even at low ISO and small aperture.
Try a
NDF = Neutral Density Filter. Neutral = all wavelengths equally. Gray.
NDF 1 = 1 /10 light transmission, 3 stops
NDF 2 = 1/100 etc. Log scale. 7 stops
http://en.wikipedia.org/wiki/File:Strickland_Falls_Shadows_Lifted.jpg
30 seconds. NDF 8x = 1/100,000,000 = 27 stops

Need a tripod for macros, or shutters > 1/30 sec
Full size start at $25. Highly recommended.

Estimate motion blur *in pixels* to guide choice of shutter speed.
Alternately, use length of motion blur streak and shutter speed to estimate flow speed

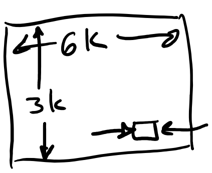
Motion Blur Example:
Field of view = 10 cm
Fluid moving at 0.5 m/s
18 Mpx sensor

Breakout rooms: will 1/1000 sec shutter speed 'freeze' this flow? Calculate on group whiteboard please. Save for discussion; available from annotate tools.

Flow = .5 m/s

$$.5 \text{ m/s} \times \frac{1}{1000} \text{ sec} = .0005 \text{ m}$$

.05 cm = streak length
=distance object moved



$$\text{object: } \frac{10 \text{ cm}}{6000 \text{ px}} = 1.67e^{-7} \text{ cm/px}$$

$$\frac{.05 \text{ cm}}{1.67\, e^{-7} \text{ px}} = 30 \text{ px} \qquad \frac{30 \text{ px}}{6000 \text{ px}} = \frac{1}{200} \text{ of image}$$

$18\ MPx \Rightarrow 5184 \times 3456\ px$

In flow, particle will move
$0{,}5\ m/s \times \frac{1}{1000}\ sec =$ .5/1000=0.0005 m = .05 cm
How many pixels will cover?

$\frac{5000\ px}{10\ cm} = \frac{?\ px}{.05\ cm}$ .05*5000/10=25.0 px = smear length.

5000px
10cm FOV
? 0,5 m/s for $\frac{1}{1000}$ sec = ? pixels

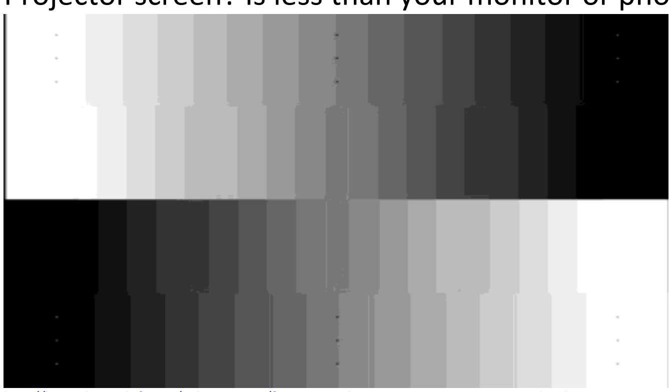
Do this analysis for each image; put in your report. Motion blur is surprisingly common and annoying.

Resolution in the Measurand: Light

Part 1: Dynamic range

Human eye sensitivity, dark adapted ~ 800 ISO
http://clarkvision.com/imagedetail/eye-resolution.html
Human contrast range detection: 14 to 24 EV, but is dynamic.

Sheet of paper: at most 7 EV (factors of 2 in brightness) from black to white.
Projector screen? Is less than your monitor or phone screen.



http://hometheaterhifi.com/volume_13_2/feature-article-contrast-ratio-5-2006-part-1.html

What can your camera detect?
Test: image a gray card. At low ISO, see how many stops of underexposure will make it black, and how many of overexposure will make it white. Probably a total range of 6-9. Best cameras can do 14.

Part 2: Resolution=Bit Depth

This total dynamic range then gets *quantized*/digitized into steps. The more steps, the finer the resolution. (http://www.peachpit.com/articles/article.aspx?p=1709190&seqNum=2. Nice discussion of dynamic range vs bit depth)

Part 2B: Counting steps
Bit = off or on, 0 or 1. Binary digit.

Binary= numbers in base 2, a series of bits. 0 1 1 0 = 6 in base 10

8 4 2 1

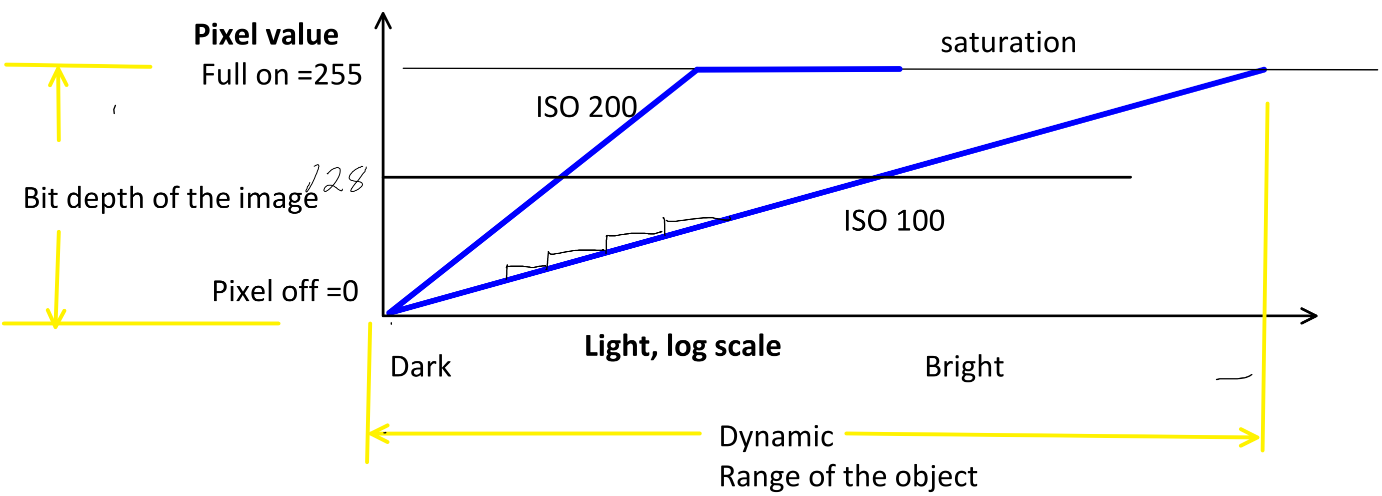
$2^3 2^2 2^1 2^0$

nibble

9F

With 4 bits, can count to 2^4=16
With 8, can count to 256 = one byte
Hexadecimal: single digit goes up to 16: 0-9, then A B C D E F
16^2=256 , so can express full range of a byte in two digits.

Camera A/D is likely 10-24 bits. That's the number of different levels possible but not the range of brightnesses



HDR = High Dynamic Range
Take multiple images with varied (bracketed) exposures of the same scene, some under exposed, some over exposed.
In-camera or post-processing algorithm assembles them together to provide additional measurand (light) resolution in highlight and shadow areas. Can make nighttime images look like daylight.

Here is an HDR image (made with 5 images from -3 to +3 EV) by Phil Nystrom 2018.

The word *pixel* is based on a contraction of *pix* ("pictures") and *el* (for "element");

Pasted from <http://en.wikipedia.org/wiki/Pixel>

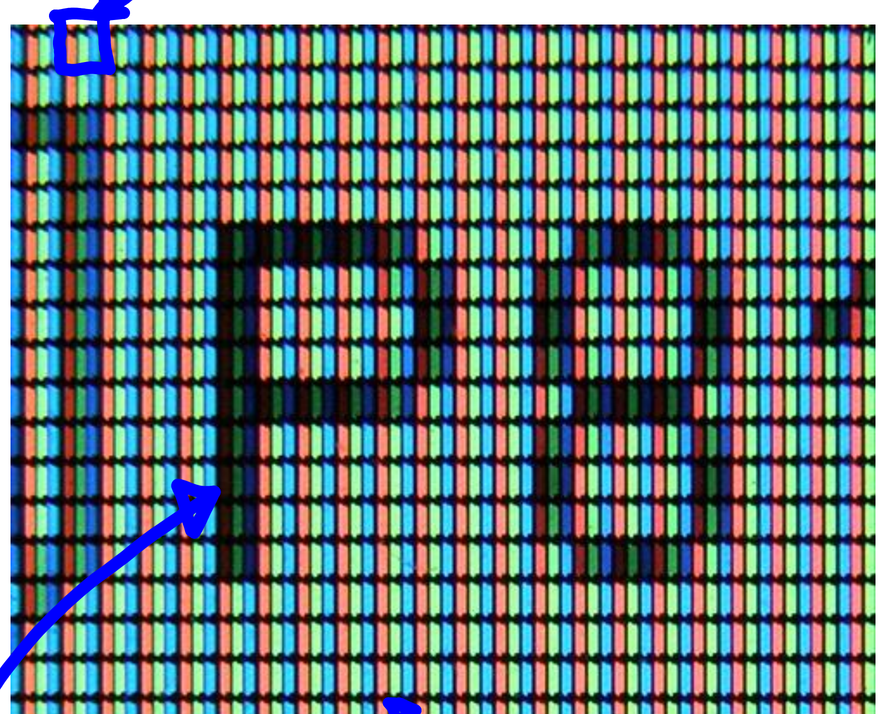
On a screen, = 1 red, 1 blue, & 1 green light emitter.
In editing software, access them separately in *color channels*
i.e. can control all blue pixels by themselves

CYMK

RGB is a common color space, good for screens. CMYK (Cyan, Magenta, Yellow and blacK is another color space, good for printing

0-256

1 PIXEL



http://en.wikipedia.org/wiki/File:Closeup_of_pixels.JPG

R,G,B = 0,0,0 = black, off.
R,G,B, = 255, 255, 255 = all full on = white   (8 bits = 2^8 = 256 possible levels)
R,G,B = 0,0, 256 = blue

FFFFFF = full white in hexadecimal, one digit can count to 16; 0-9, then a-f
0000FF= blue
808080=gray

Color channels

Red channel: Can address just the red elements in all the pixels. See histograms, adjust range and contrast

1. Test the dynamic range of your camera: take images of a gray card. At low ISO, see how many stops of underexposure will make it black, and how many of overexposure will make it white. Probably a total range of 6-9. What happens at high ISO?