CS559 – Lecture 2
Lights, Cameras, Eyes

These are course notes (not used as slides)

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Adjusted after class – stuff we didn't get to removed / mistakes fixed

Light

- Electromagnetic radiation
  - Wavelengths between 380nm – 800nm
  - Wavelength vs. frequency
- Particle model
  - Travels from source to receiver

Path of Light

- From source to viewer
- Not known until around 1000
  - Euclid and Ptolemy PROVED otherwise
- Ibn Al-Haythan (Al-hazen) around 985
  - Triumph of the scientific method
    - Proof by observation – not authority
  - Experiment – stare at sun, burns eyes, …
  - Also figure out light travels in straight lines

Looking at things

- Light leaves source
- Light bounces off object
- Light goes to receiver
  - Eye
  - Camera
- Receiver is 2D, process is 3D
- Mathematics later
- Camera first
  - Flat receiver

Getting light to "imager"

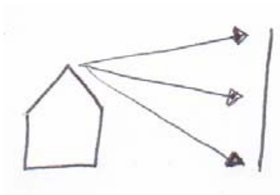
- Light generally bounces off things in all directions
  - See from any direction
  - Not the same! (mirror)
  - Deal with this in detail later
- Generally doesn't matter if emitter (source) or reflector
  - Same to receiver

Depth and Distance

- Light travels in straight lines
  - Except in weird cases that only occur in theoretical physics
- Doesn't matter how far away
  - Can't tell where photon comes from
  - Photons leaving source might not all make it to eye
  - Photons might bounce around on stuff
    - Longer distance, more chance of hitting something

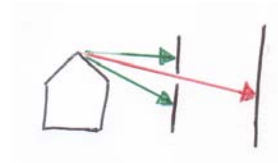
Capturing Images

- Measure light at all places on the “imaging plane”?
- Not quite…
- Potentially all paths between world and imager
  - Need to be picky about which rays we look at



“Ideal Imaging”

- Each point in world maps to a single point in image
  - Image appears sharp
  - Image is “in focus”
- Otherwise image is “blurry”
  - Image is out of focus
- How to do this?
- Pinhole Camera
  - Infinitessimal hole in blocking surface – just a point
  - Only 1 path from world point to image
  - Focal Point

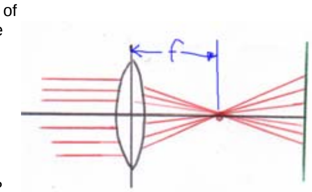


Why is pinhole imaging not so ideal in practice?

- Finite aperature
  - Always will be some blurryness
- Too selective about light
  - Lets very little light
- Smaller aperature
  - Less blurry
  - Less light
- Want bigger aperature, but keep sharpness

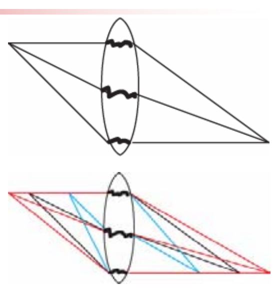
A “virtual pinhole” - Lenses

- Lens bends light
- convex lenses – take bundles of light and make them converge (pass through a point)
- Parallel rays converge
- A virtual pinhole!
- Light rays from “far away” are (effectively) parallel
- What about non-parallel rays?
- Infinitessimal aperature = infinite sharpness



“Thin” Lenses

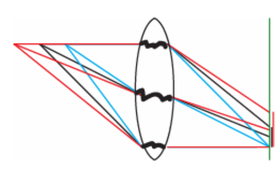
- All points at one distance get to another place
- Different distances map to different distances
- If we fix the distance to the image plane, then only objects at a single distance will be in focus
  - $1/D + 1/I = 1/F$
  - Farther objects image closer



Picture is wrong – inverse relationship between I and D

Focusing with a lens

- Objects at “focussed distance” – sharp (in focus)
- Objects at other distances are not sharp
- Some blurryness is OK
  - Circle of Confusion
- Depth of Field
  - Range of distances that things are “close enough” to being in focus



Controlling the image

- Smaller aperature = less blurry = larger depth of field
  - But less light
- Lens determines
  - What gets to the imaging surface
  - What is in focus

Measuring on the image plane

- Want to measure / record the light that hits the image plane
- At every position on the image plane (in the image) we can measure the amount of light
  - Continuous phenomenon (move a little bit, and it can be different)
  - Can think of an image as a function that given a position (x,y) tells us the "amount" of light at that position
    i = f(x,y)
  - For now, simplify "amount" as just a quantity, ignoring that light can be different colors

Measuring on the image plane

- i = f(x,y)
- Continuous quantities
  - Continuous in space
  - Continuous in value
- Computers (and measuring in general) is difficult with continuous things
- Major issue
  - Limits to how much we can gather
  - Reconstruct continuous thing based on discrete set of observations
  - Manipulate discrete representations

Measuring on the image

- Water/rain analogy
- Put a set of buckets to catch water
- Wait over a duration of time
  - Use a shutter to control the amount of time
- Measurement depends on
  - Amount of light
  - Size of aperature (how much of the light we let through)
  - Duration

Types of "buckets"

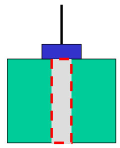
- Film
  - silver halide crystals change when exposed to light
- Electronic
  - Old analog ways – vidicon tubes
    - Store the charge on a plate, scan the plate to read
    - http://www.answers.com/topic/video-camera-tube
  - New ways: use an MOS transistor as a bucket
- Biological
  - Chemicals (photo-pigments) store the photon and release it as electricity
  - Isn't really a shutter

Similarities

- Low light levels are hard
  - Need to get enough photons to measure
  - Small counting errors (noise) – are big relative to small measurements
- Tradeoffs on bucket sizes
  - Big buckets are good (lower noise in low light)
  - Lots of buckets are good (sense more places)
  - For a fixed area, there is a tradeoff
    - Especially in digital cameras/videocameras

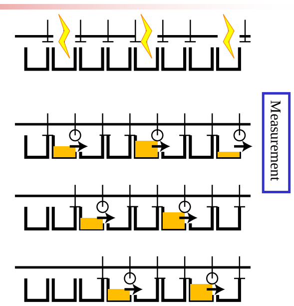
MOS Transistors

- Metal Oxide Semiconductors
- Semiconductor acts as a "bucket" for electrons
- Metal at top is a "gate" – creates electric field that can connect/disconnect the two sides



CCD sensors

- CCD = Charge Coupled Device
  - "Bucket Brigade" of MOS transistors
  - Use gates to move charge along
  - Read out "at edge"
  - Shift register to transfer out images
- Advantage:
  - Cheap / easy to make large numbers of buckets
  - Uniform
- Blooming



CMOS sensors

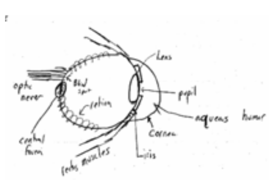
- Disadvantage of CCDs
  - Have to shift things out (slow, lose info)
  - Different than computer chips
- CMOS (complimentary Metal Oxide Semiconductor)
  - Just like computer chips
  - Put more circuitry around each sensor transistor
    - Amplify / switch signals as needed
  - Use normal "wires" to carry info to where it needs to go
- Downside: space for circuit means less space for sensors (smaller buckets = more noise), not uniform
- Upside: same "technology curve" as computers, so will get better, faster, cheaper, lower power, …

Digital Camera

- Megapixels = number of buckets
  - 7 or 8 million buckets in a consumer camera
- But…
  - How big are the sensors?
    - Same size / more megapixels = smaller buckets = more noise
    - (unless the sensor technology gets better)
  - How good is the lens?
    - Smaller buckets don't do you any good if the lens can't aim it into the right bucket

Eye

- Pupil – hole in the eye
- Lens
- Iris
  - round muscle – size of pupil
- Cornea
  - Clear protective coating
- Fluid filled spaces – acts as lens
  - Aqueous humor
  - Vitreous humor
- Rectus Muscles
  - Change shape of eyeball to focus
- Optic Nerve
  - Carries information away
- Blind Spot
  - Where the optic nerve is
- Central Fovea



Retina – the "image plane" of the eye

- Only place on body to see blood vessels directly
- Has photoreceptors
  - Cells sensitive to light
- Photopigments
  - chemicals that change when exposed to light
  - Different photoreceptors have different pigments
  - Different pigments behave differently
    - Sensitivity, color selectivity, regeneration speed
- Types of photoreceptors

Rods

- Photopigment: Rhodopsin
  - Breaks into retinene + protein
  - Must be reassembled before can work again
- Very sensitive
  - Bright light means that it breaks down faster than it is regenerated
  - Less useful in bright light
- Blinded by bright light at night