Photography for Science

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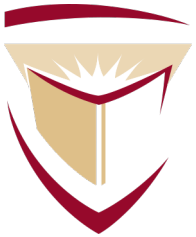
June 14, 2023

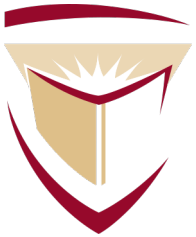
Basics of Photography

- **Exposure** is key: the art of capturing the correct amount of light so the picture you take is pleasant to look at and, potentially, useful.
- There are 3 basic parameters to taking a picture
  - **Exposure duration**, a.k.a. “shutter” time (even if there’s no shutter in the camera)
  - Lens **Aperture** (even if you’re not really dealing with a lens)
  - Film **Sensitivity** (even if pretty much nobody uses film anymore)
- **Those basics are ALWAYS the same**, regardless if the image is captured on film, on a CCD or CMOS (a.k.a. on a digital sensor), if it’s a single picture or a movie, etc.



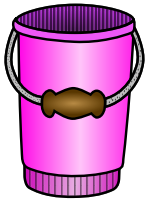
Basics of Photography

- **Exposure Duration (Shutter Time)**: how long you take a picture for, i.e. *the integration period*
  - Typically measured in (fractions of) seconds (for high speed movies though, it will be in ms, microsec, ns)
- Lens **Aperture**: how “open” the lens is, i.e. *the rate at which light enters the camera*
  - Measured in f-stop, a.k.a. f# (or f/#)
- **Sensitivity**: how much light is needed to generate a picture, i.e. the “scale”
  - Measured using an old film standard from the mid 1970s, iso 100, 200, 400, etc.



Basics of Photography

- Think of exposure like filling a bucket with water
  - When the bucket is full, the picture is correctly exposed to show something useful



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- Think of exposure like filling a bucket with water
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A large bucket requires a lot of water

A small bucket requires only a little bit of water

Basics of Photography

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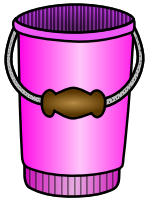
Large bucket = insensitive film = low iso, e.g. iso 100



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Large bucket = insensitive film = low iso, e.g. iso 100

Small bucket = sensitive film = high iso, e.g. iso 8000

Basics of Photography

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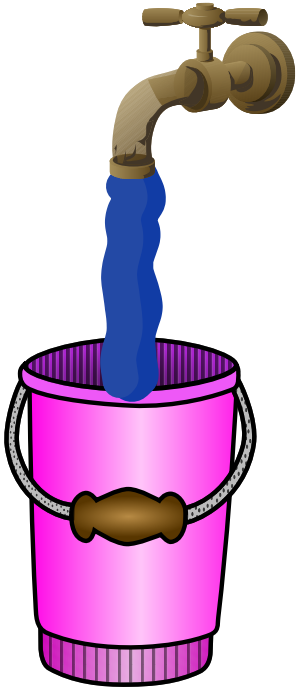
Bucket size = sensitivity

Large bucket = insensitive film = low iso, e.g. iso 100

Small bucket = sensitive film = high iso, e.g. iso 8000

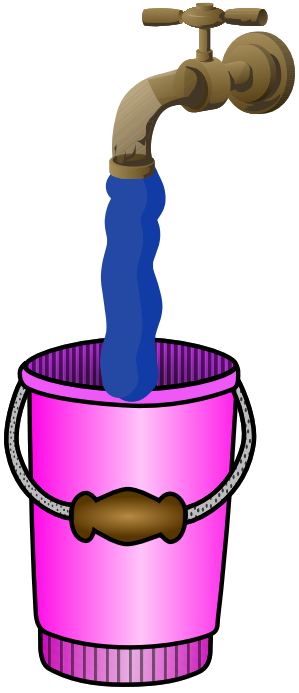
Basics of Photography

- How much I open the faucet is the aperture, the rate at which I'm filling the bucket
  - 


Basics of Photography

- How much I open the faucet is the aperture, the rate at which I'm filling the bucket
  -

Fully open faucet
large aperture
faster fill

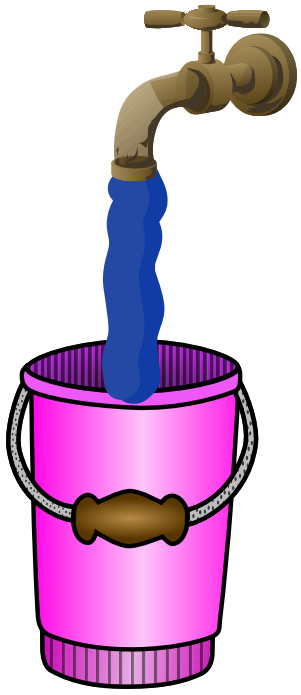


Dripping faucet
small aperture
slower fill

Basics of Photography

- Finally, the amount of time the faucet is opened for is the exposure time or the “shutter” time
  -

Fully open faucet
large aperture
faster fill



Dripping faucet
small aperture
slower fill

Practical Example 1

- Take a picture on manual with a camera
  - Try different apertures
  - Try different exposure times
  - Try different sensitivity

From Bucket to Reality

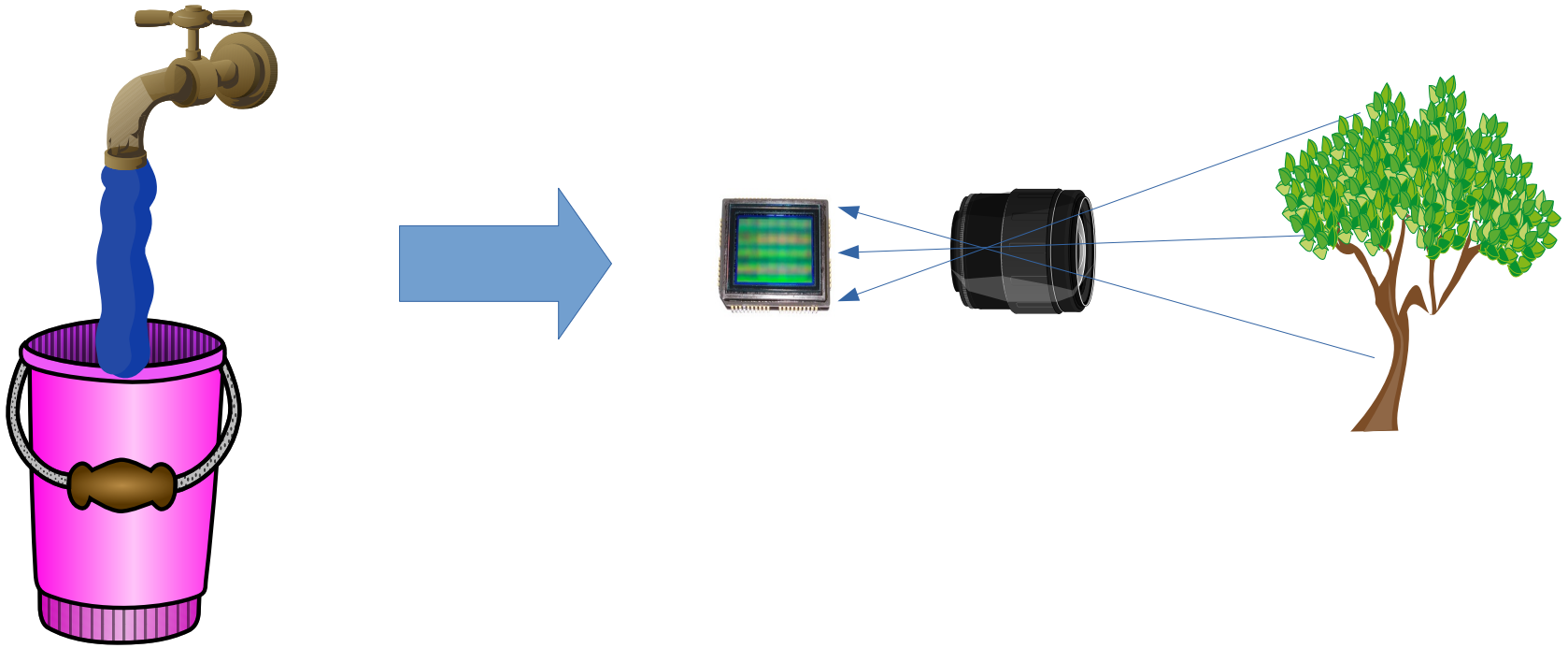
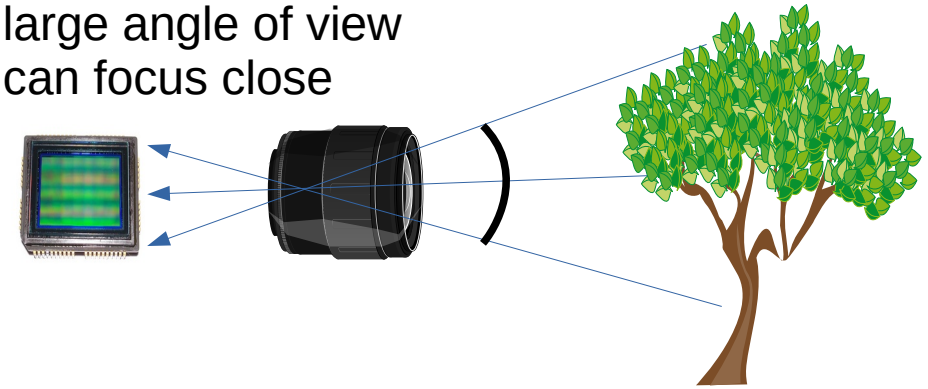
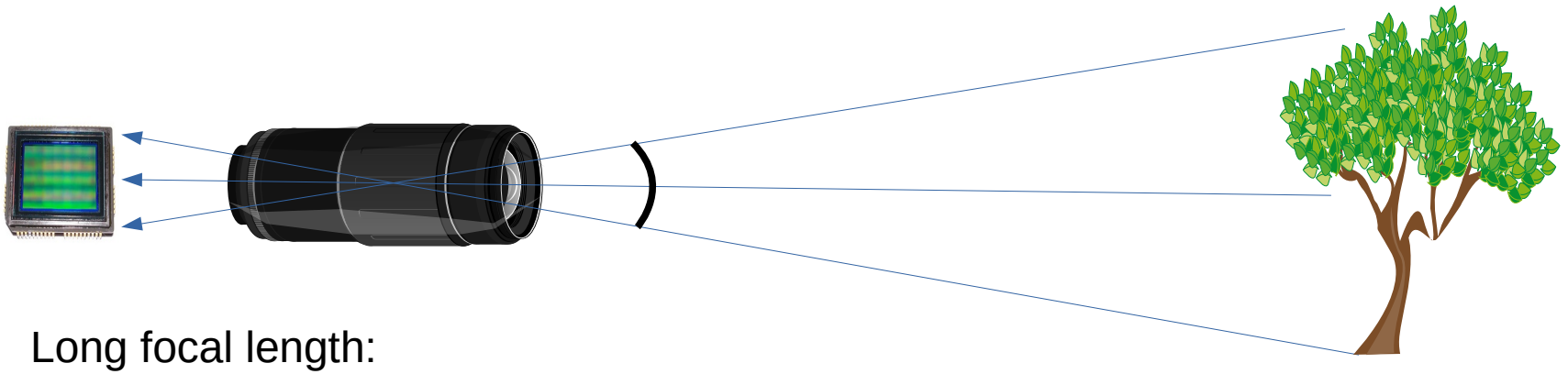


Photo Basics: Focal Length

Short focal length:
- “for closer objects”
- large angle of view
- can focus close

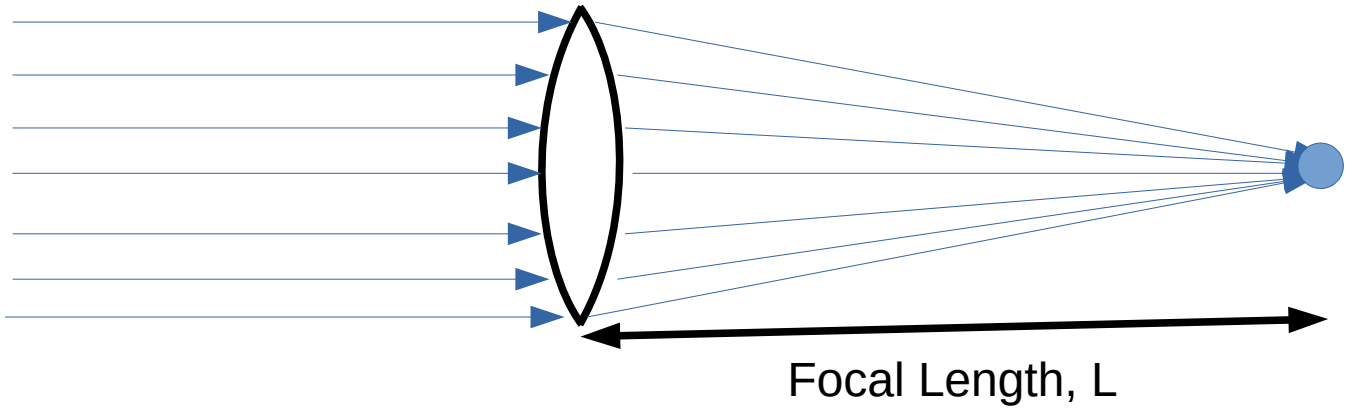


- Focal length is measured in mm
- The angle of view depends on focal length **and** sensor size (camera)
- “Normal”, human-like, angle of view, f = sensor diag



Long focal length:
- “for farther objects”
- smaller angle of view
- cannot focus close

Photo Basics: Aperture



f-stop = L/D

The f-stop is the number of times the lens opening fits in the focal length

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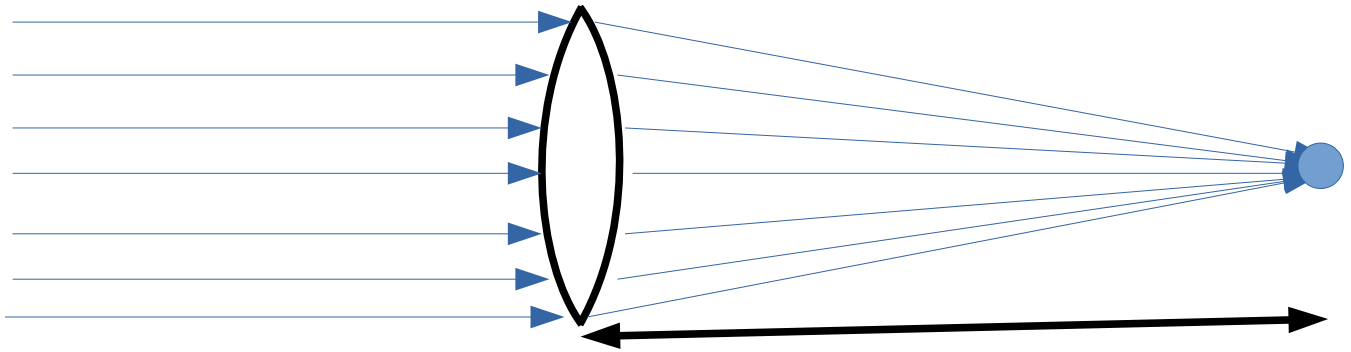

Diameter, D

Focal Length, L

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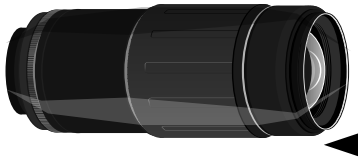
The f-stop is the number of times the lens opening fits in the focal length



Focal Length, L

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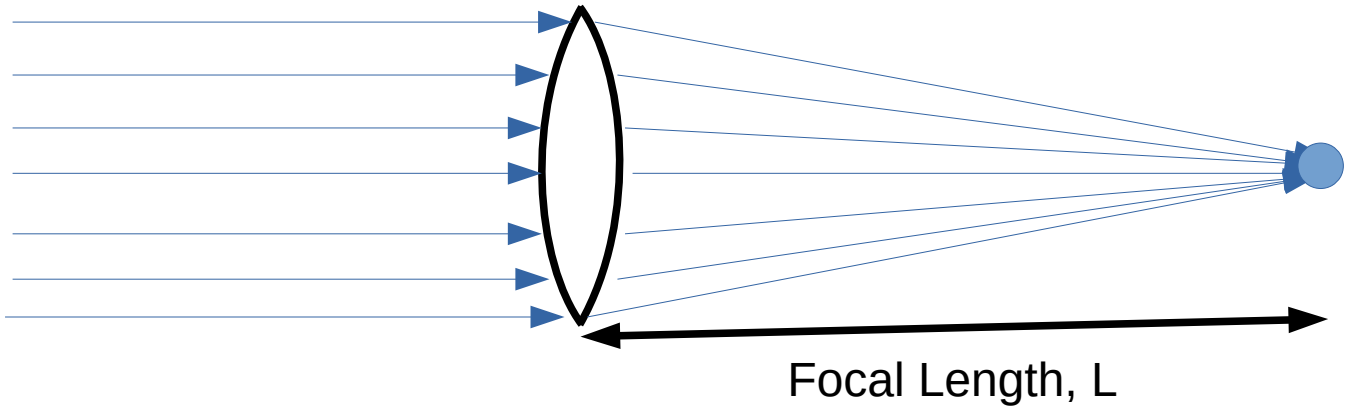

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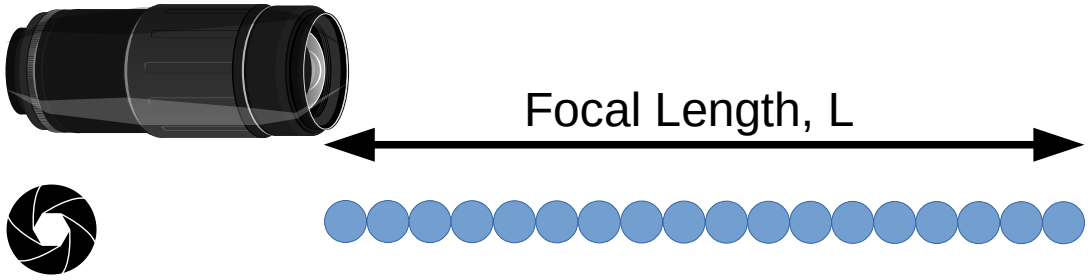
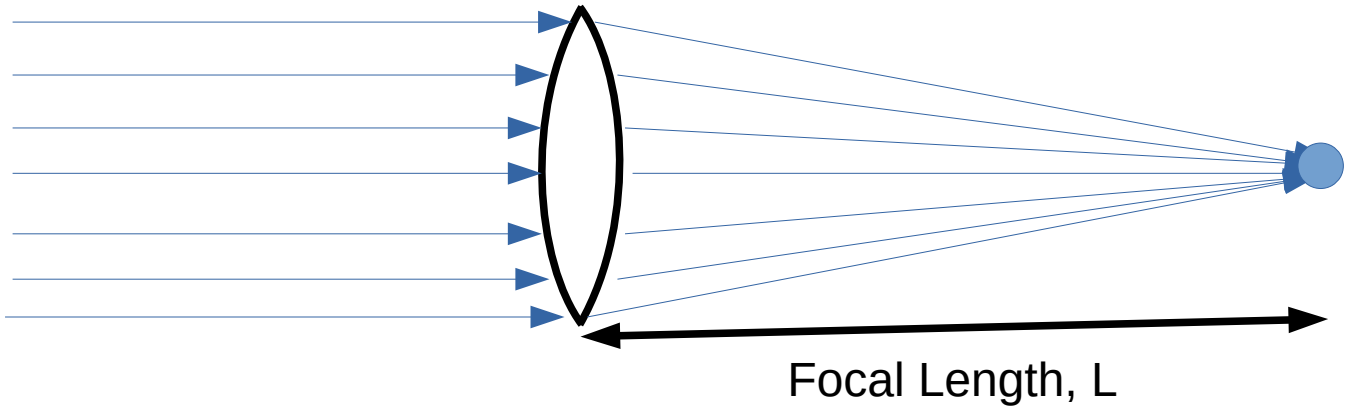


- 18 diameters in the focal length
- L/D = 18
- Write f/18

Photo Basics: Aperture



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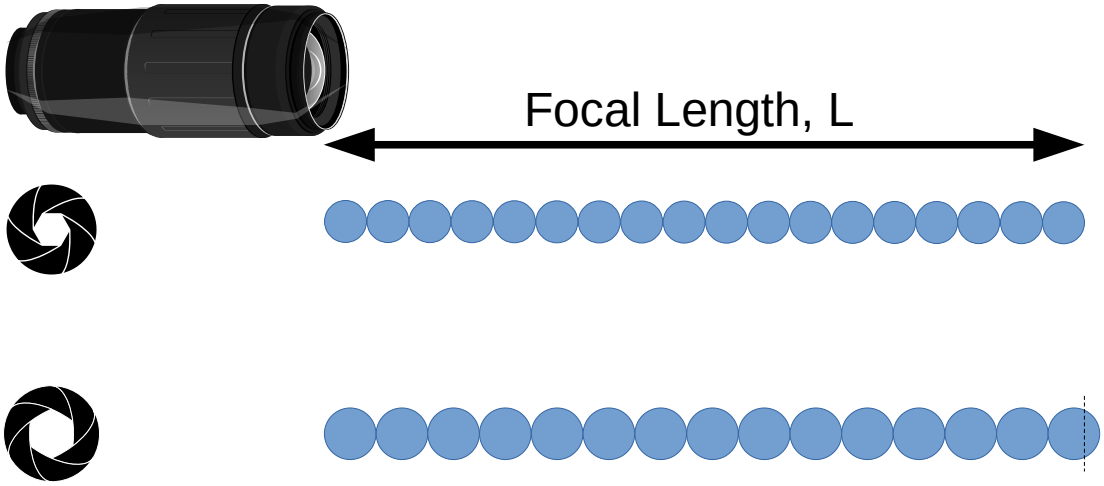


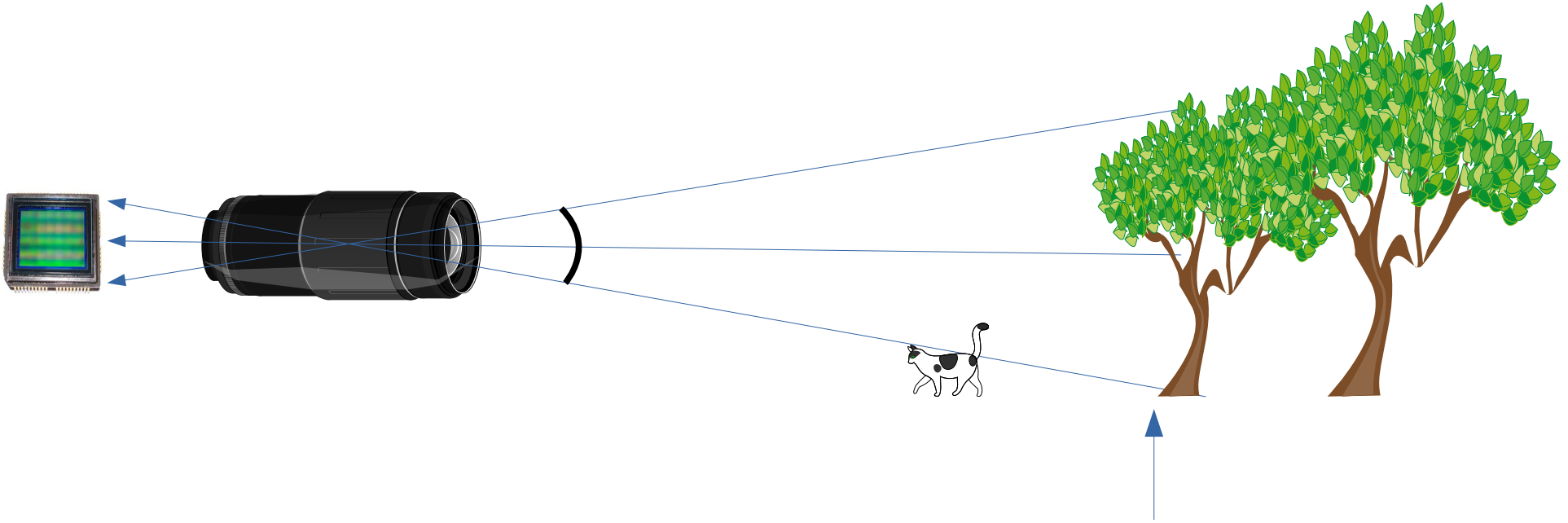
Photo Basics: Exposure Equivalence

- **Exposure time:** 1/50 s is twice as long as 1/100 s => 2x the light
- **Sensitivity:** iso 200 is twice as sensitive as iso 100 => need half the light
- **Aperture?**
  - There's a sequence 1, 1.4, 2, 2.8, 4, 5.6, 8, 11, 16, ...
  - Each number in the sequence is 2x the opening area, thus 2x the light!

Photo Basics: Exposure Equivalence

- The following exposures are all equivalent (same brightness):
  - iso 400, 1/100 s, f/8
  - iso 200, 1/50 s, f/8
  - iso 400, 1/50 s, f/11
- Why pick a particular exposure?

Photo Basics: Focusing



Turning the focus ring sets the *focal plane* closer or farther. Objects at the arrow appear sharp. Objects in front and back appear fuzzy.

Photo Basics: Focusing

- Each lens has a minimum focus distance, but no maximum (can focus at infinity)
- Long focal length cannot focus very close (typically not less than 1.5m)
- Short focal length can focus much closer
- However, objects **not** on the focal plane **can** appear sharp too! How?!?!

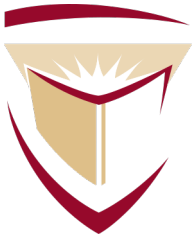
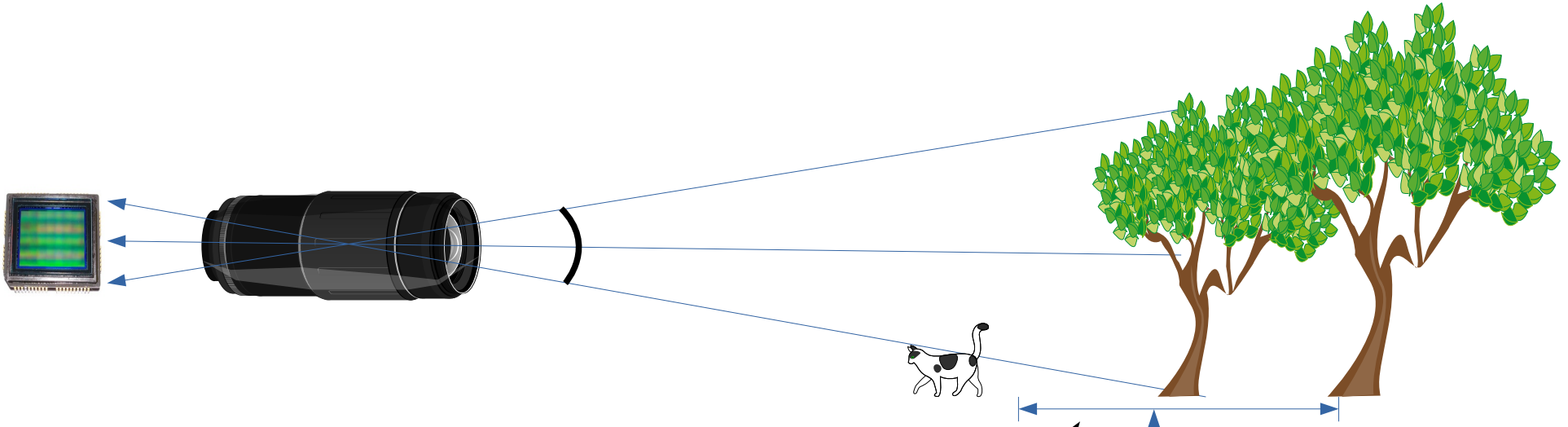


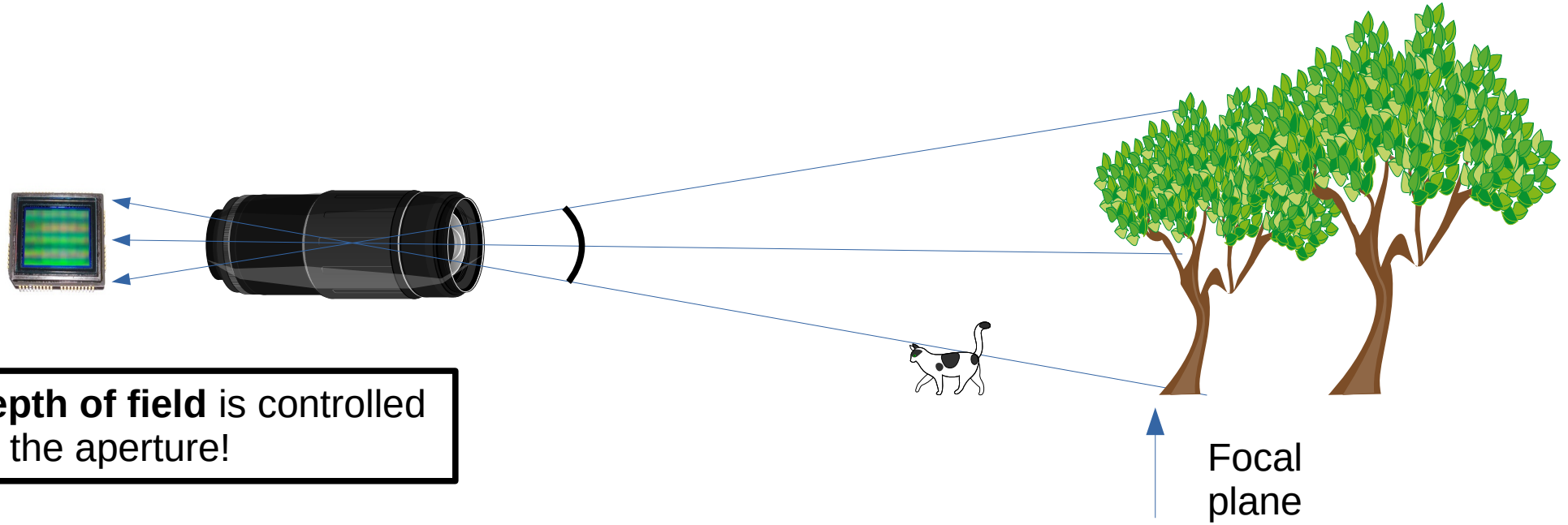
Photo Basics: Depth of Field



Depth of field: in this region **around** the focal plane, objects will appear **sharp.**

Focal plane

Photo Basics: Depth of Field



Depth of field is controlled by the aperture!

Small aperture (**large** f/#): less light in, bigger DoF

Large aperture (**small** f/#): more light in, smaller DoF

Photo Basics: Shutter Time

- There are 3 reasons why a picture may be blurry:
  - Wrong focus (see before)
  - Unsteady camera, a.k.a. camera shake
  - Object moving too fast, a.k.a. motion blur

Photo Basics: Camera Shake

- Defn: The object is steady, but while the picture is being acquired, the camera moved
  - How to spot: everything in the frame is blurry, the object of interest, the background and surrounding objects, etc.
  - How to fix (1): use a sturdy tripod to eliminate camera vibrations, i.e. eliminate camera movement (in certain situations, you can also brace the tripod with weight, e.g. sandbags, bolting to the floor, etc).
  - How to fix (2): use a shorter exposure time, i.e. less overall camera movement during the exposure. However, this limits your exposure options.

Photo Basics: Motion Blur

- Defn: The camera is steady, but while the picture is being acquired, the object being imaged moves
  - How to spot: everything in the frame is sharp (the background, the foreground, etc) except the object being imaged which is blurry.
  - How to fix: use a shorter exposure time, i.e. less overall object movement during the exposure. You can quantify the motion blur:

$$L_{blur} = V_{object}\, t_{shutter}$$

Photo Basics: Resolution and Noise

- For film, sensitivity was changed by varying the size of the light-sensitive crystals. This means at high iso (high sensitivity i.e. low light film) you would see “blotches” or “dots”. **It was very beautiful.**
- For digital sensors, the image is amplified electronically. The sensor has a “base iso” (i.e. the actual sensitivity of the sensor) and for higher iso, you multiply the signal by a factor. This also amplifies noise and you end up with bands, colored dots, etc everywhere. **It is very ugly.**

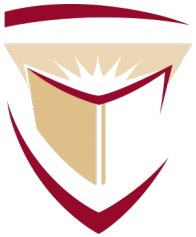
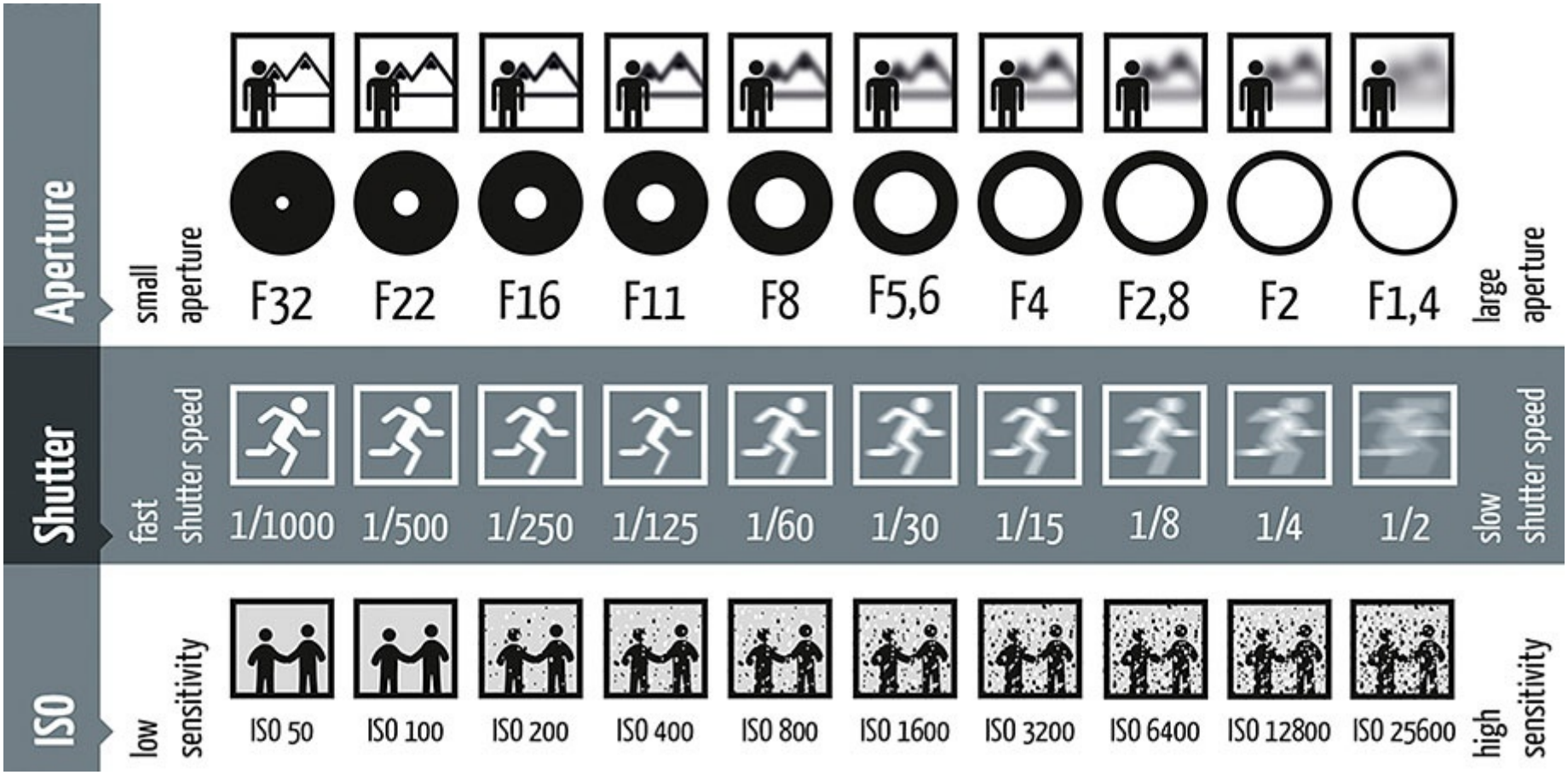


Photo Basics: Resolution and Noise

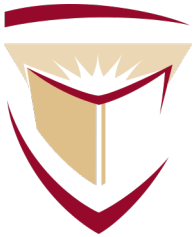
- Pixels have a size called pixel pitch. It's the physical size of the side of each pixel. **Bigger size equals less noise equals more sensitive equals more expensive.**
- Resolution is counted in # of pixels (e.g. 10MP) or by its extent (328x16 pixels). **Higher resolution (more pixels) means more details.** For the same sensor size, **more MP means more noise**.
- Higher iso means more amplification, means more noise. This is bad. **For scientific equipment, often only runs at base iso and you can do amplification and treatment in software later.**
- Colour sensors have each pixel capture only 1 colour. That means a **B&W sensor captures a lot more detail (eqv to 1.5-2 times the MP count) than a colour sensor. That's why you often see the fastest, most expensive scientific cameras only capture B&W.**

Photo Basics: Summary



Video Basics

- A movie is a sequence of still images shown in succession
- The photo basics from before still apply to video
  - Exposure
  - Focal Length
  - Focusing
  - Depth of Field
  - Resolution
- “One” new consideration:
  - Frame Rate

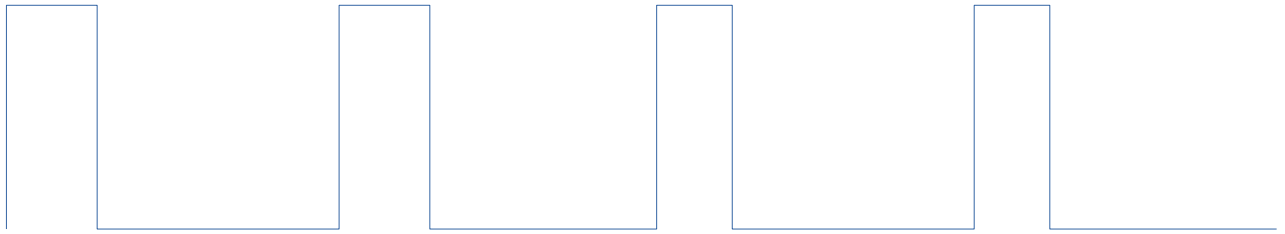


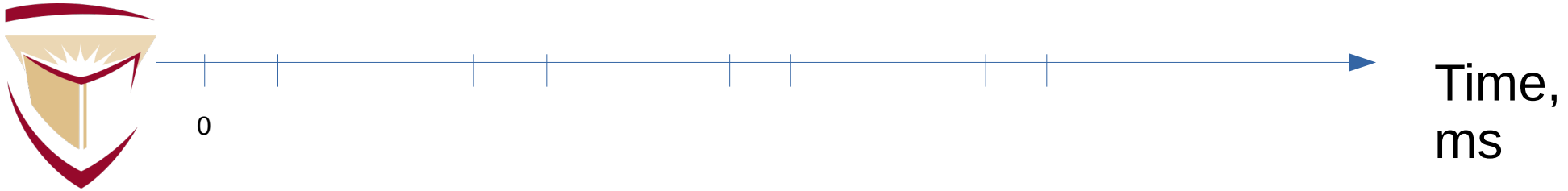
Video Basics: Frame Rate

- Frame rate: the number of images captured per second
  - Usually reported in FPS = Frames Per Second (“normal” speed is 24 fps for movies and 30 fps for TV (in the US)
  - One BIG consequence is that we are now limited in the exposure time

Video Basics: Frame Rate

- Each frame (i.e. image) must be acquired before the next one starts
- Example: shooting at 50 fps with a shutter time of 1/250 s.





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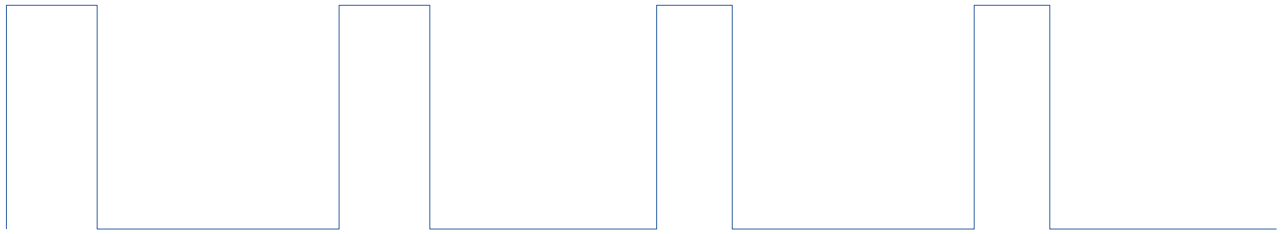

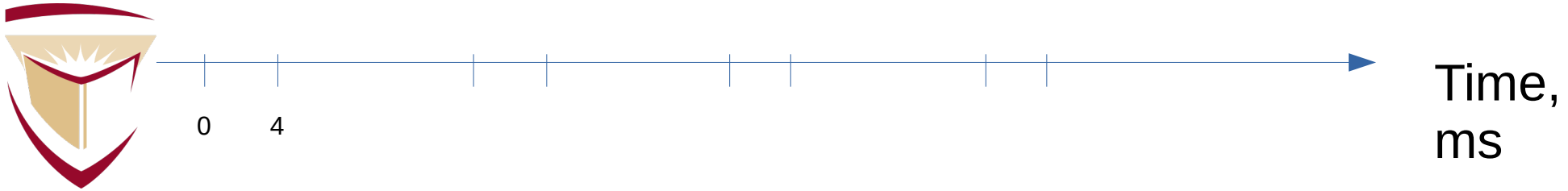

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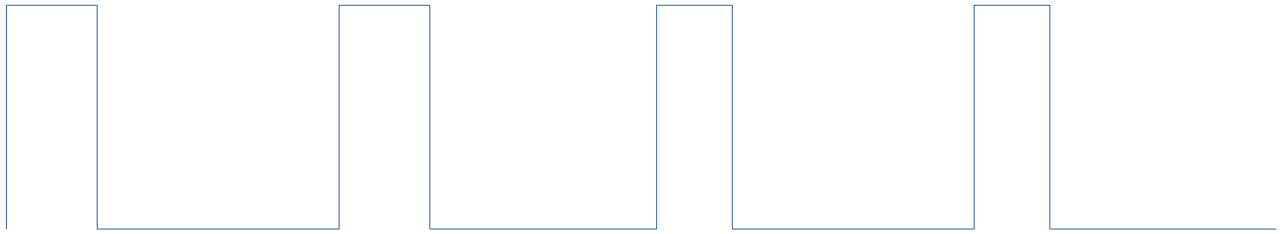

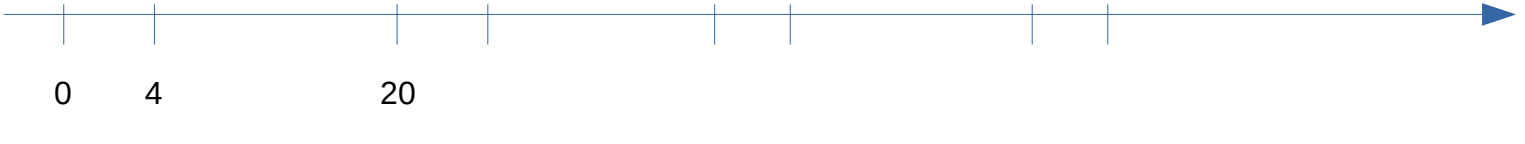

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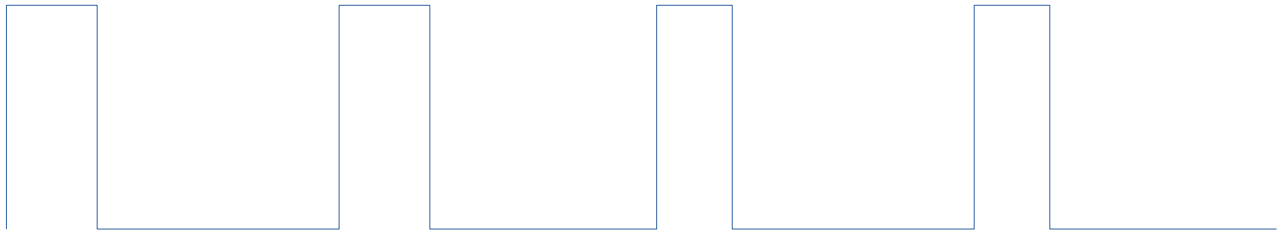
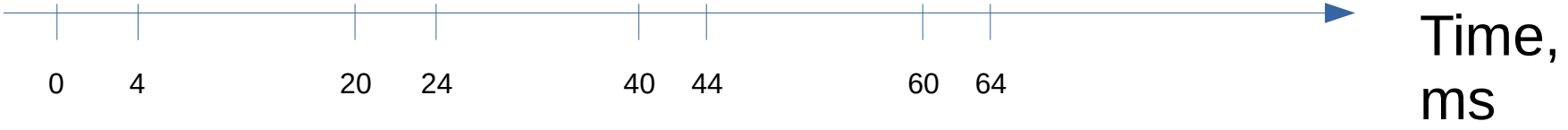
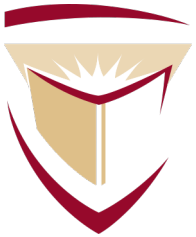




Video Basics: Frame Rate

- Each frame (i.e. image) must be acquired before the next one starts
- Example: Capturing a movie at 1 000 000 fps, what's the maximum exposure time?



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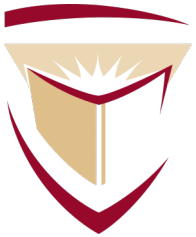
  - Inter-frame time is 1 microsec, so maximum exposure is 1 microsec



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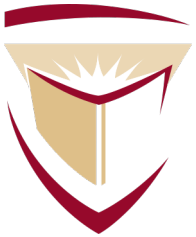
  - Inter-frame time is 1 microsec, so maximum exposure is 1 microsec
  - This means that for the same object, you will need to: open the aperture, or add light (projectors), or increase sensitivity, or all of those together.



Cool Technique: Macrophotography

- Problem: Must take a picture/movie of an object, but the camera is too close to focus or the object is very small
  - Solution: give the camera myopia a.k.a. macrophotography
- Macrophotography: focusing well below what is “normal”
  - Optimize resolution (don’t waste sensor area)
  - Depth of field can be VERY SMALL
  - Can be done with any lens using extension tubes

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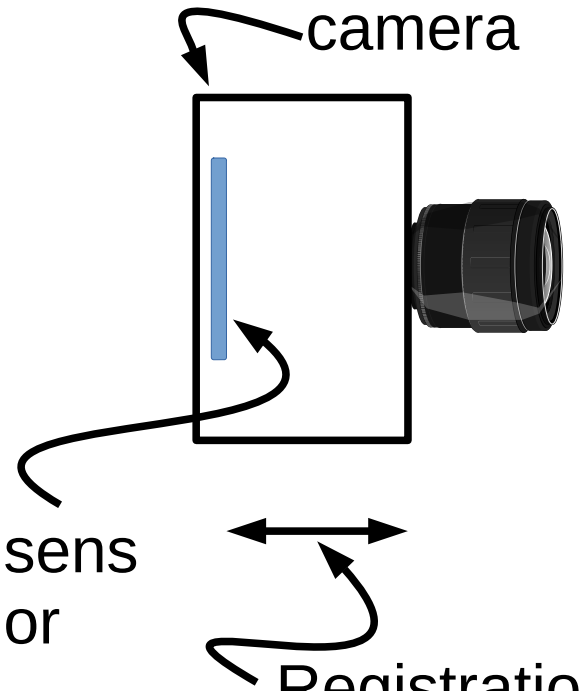

Registration distance: normal distance between sensor and lens (specified by the make of camera/lens mount, e.g. nikon, canon, pentax, etc)

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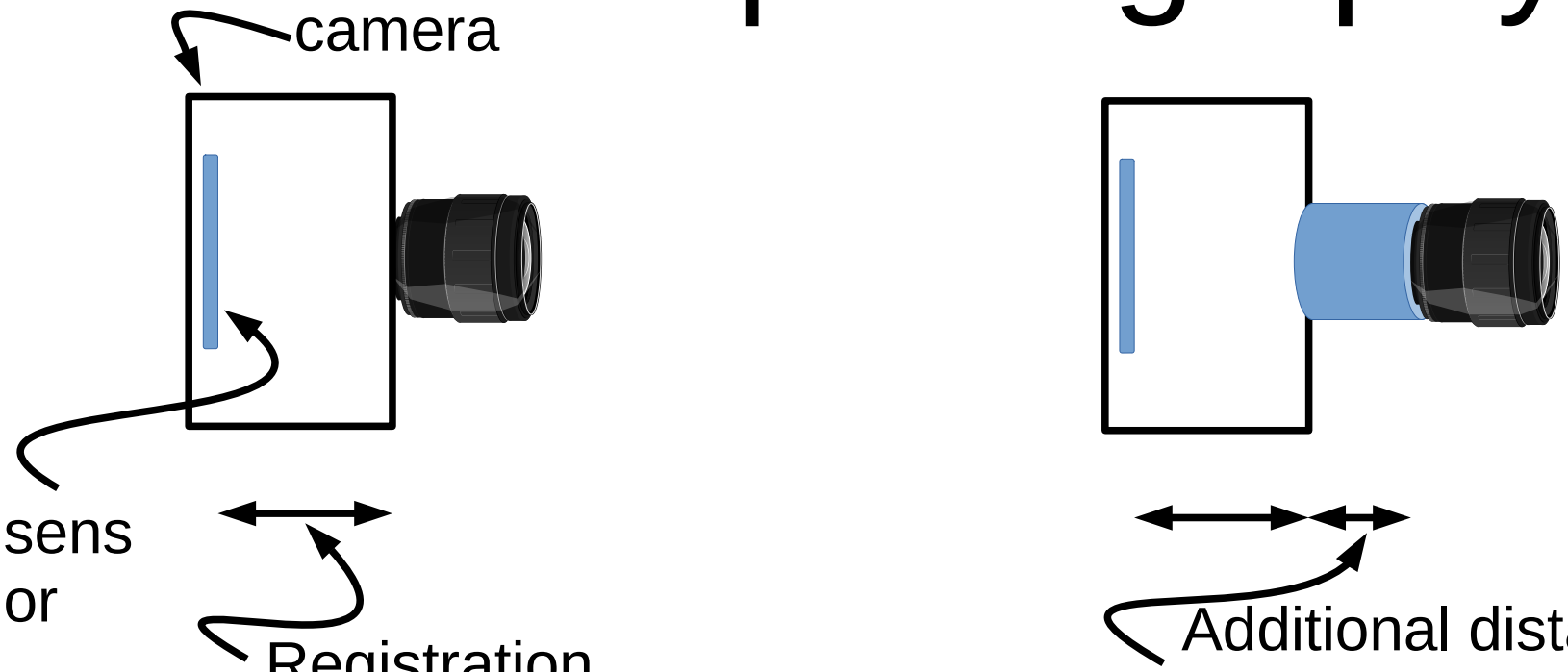

Registration distance: normal distance between sensor and lens (specified by the make of camera/lens mount, e.g. nikon, canon, pentax, etc)

Additional distance allows the lens to focus closer.
Practical tip: use a zoom lens, set the lens focus to infinity and adjust the “focus” by changing the focal length

Cool Technique: Open Shutter

- Exposure time is “infinite”, i.e.
  - Start acquiring before light is emitted
  - Stop acquiring after light is emitted
  - Exposure is only controlled by aperture and sensitivity

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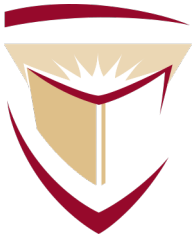
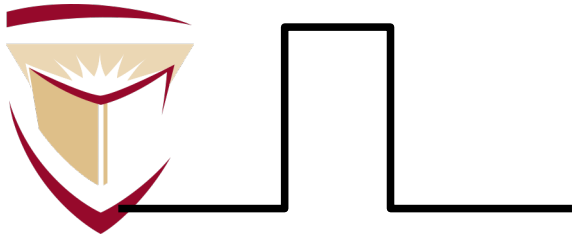
Scientific Equipment

- Scientific cameras have a few peculiarities and typically give you more control over acquiring images



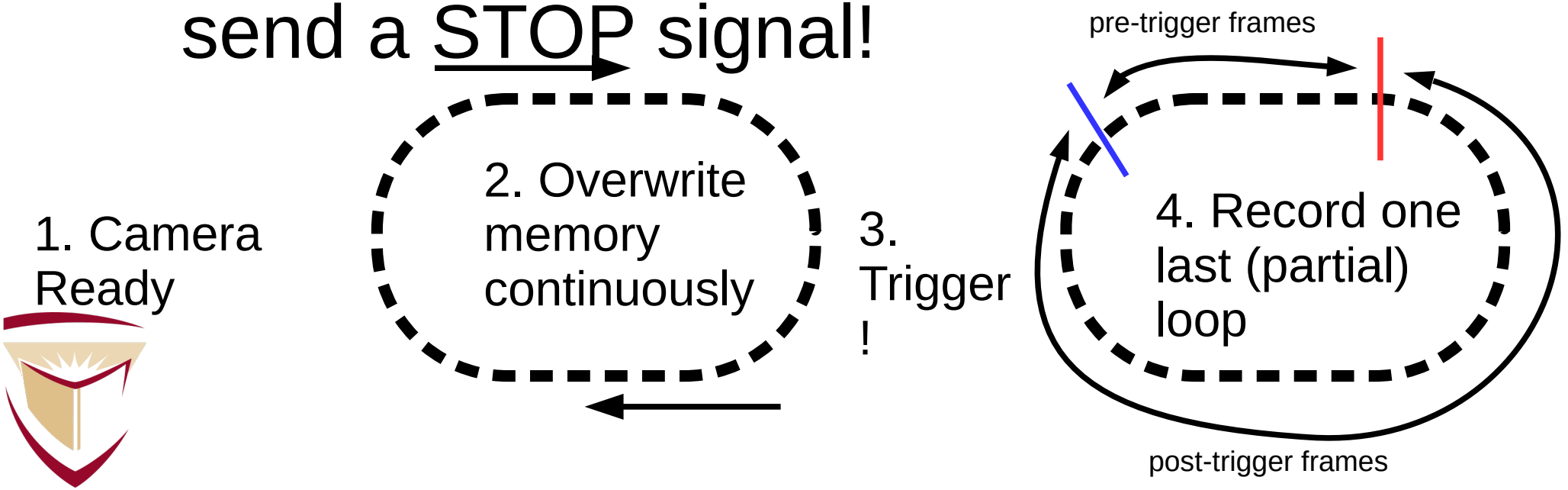
Triggering

- To time picture acquisition with experiment, use a trigger signal
  - Similar to oscilloscope triggering
  - Connect with BNC input
  - Often TTL, i.e. 5V square wave (if you generate it on your own, make sure you can supply ~5-20 mA at 5V)
  - You can often trigger from a more general signal



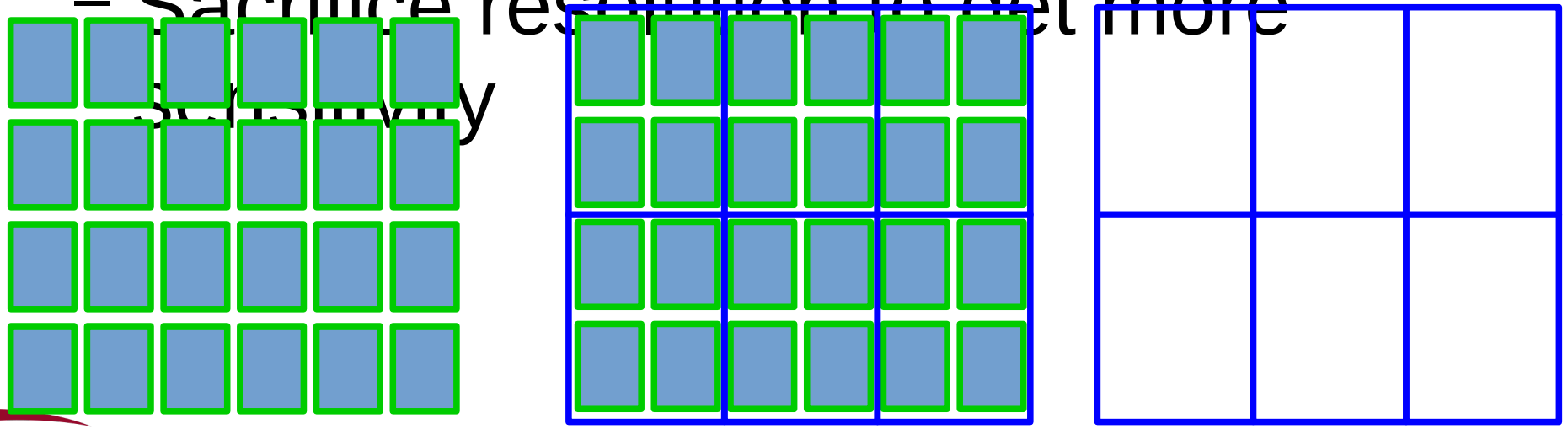
Continuous Recording

- Problem: Electronics can't react fast enough to trigger a 1000 fps movie
  - Solution: don't send a start signal, send a STOP signal!



Binning

- Definition: Combine the signal from several pixels into a single “virtual”, bigger, pixel.
  - Sacrifice resolution to get more sensitivity



CCD (actual pixels)

2x2 binning

Equivalent