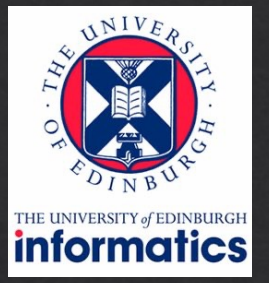
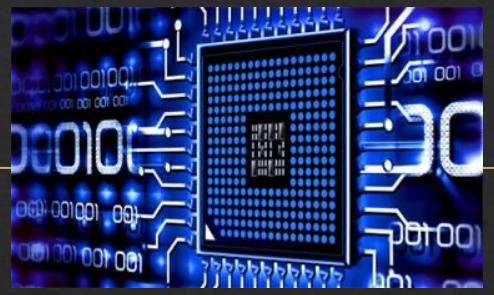


Computer Graphics

Lecture 4: Cameras

Kartic Subr

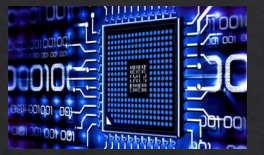
photography



rendering

Virtual

Cameras

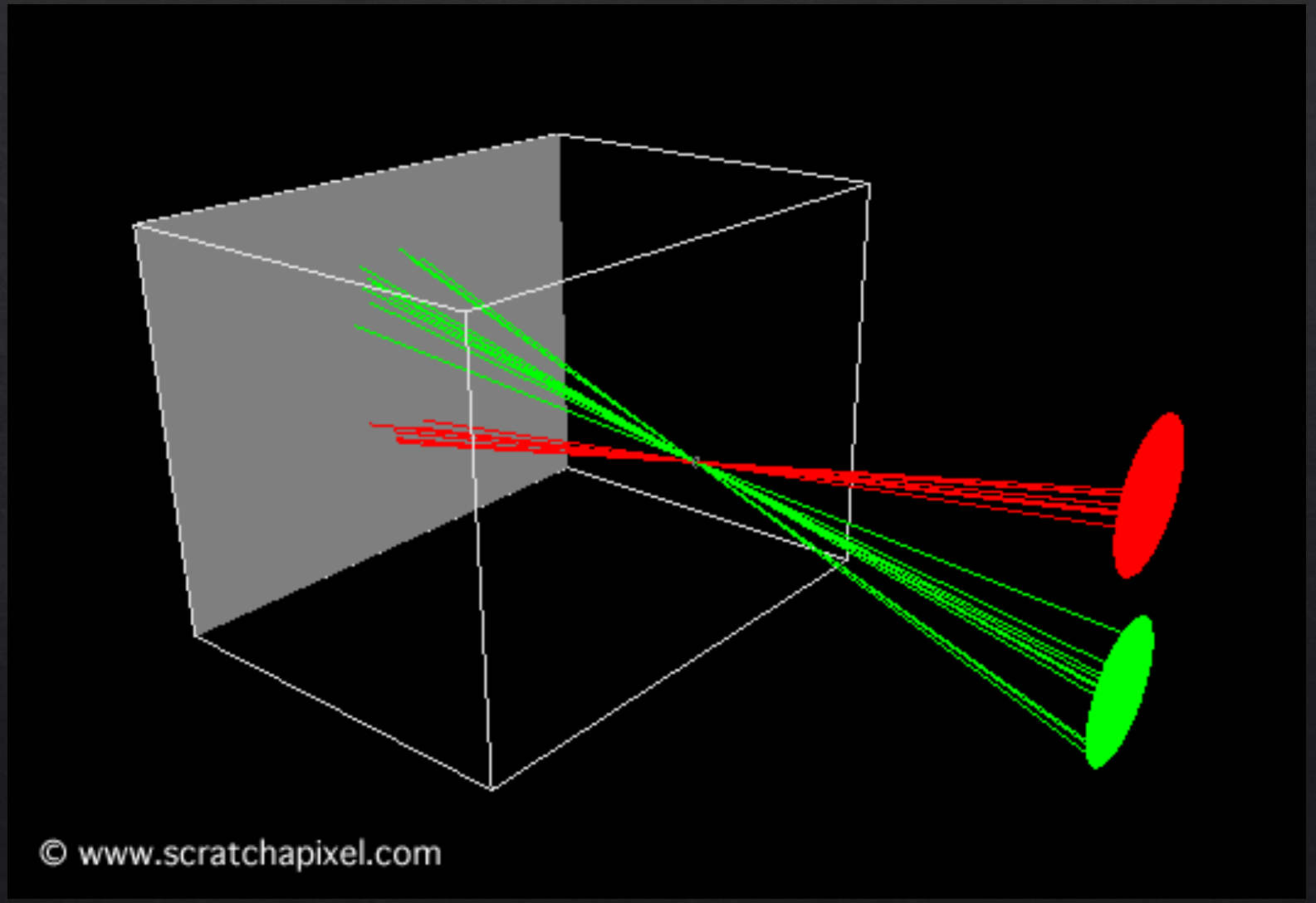


THE UNIVERSITY of EDINBURGH
informatics

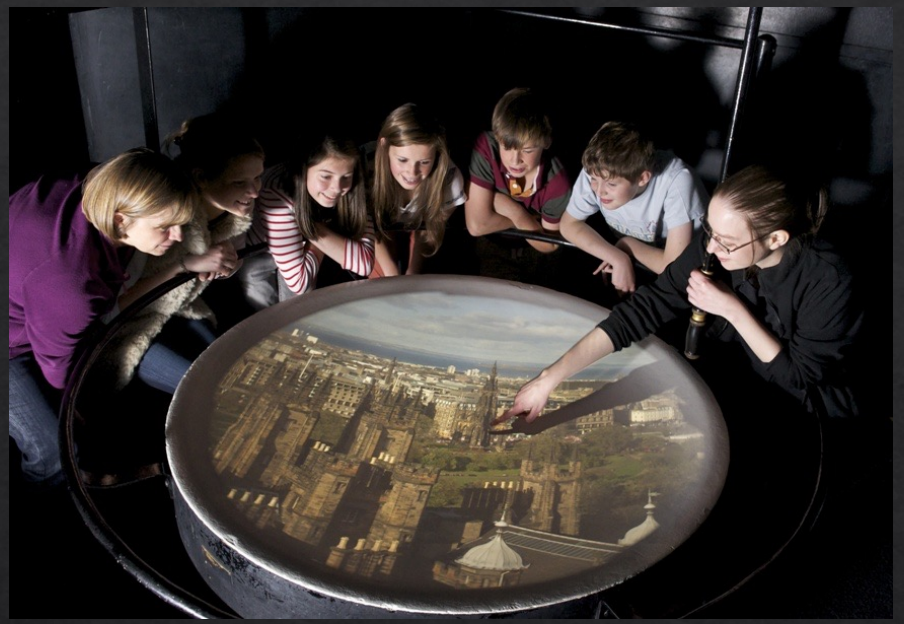
The pinhole camera

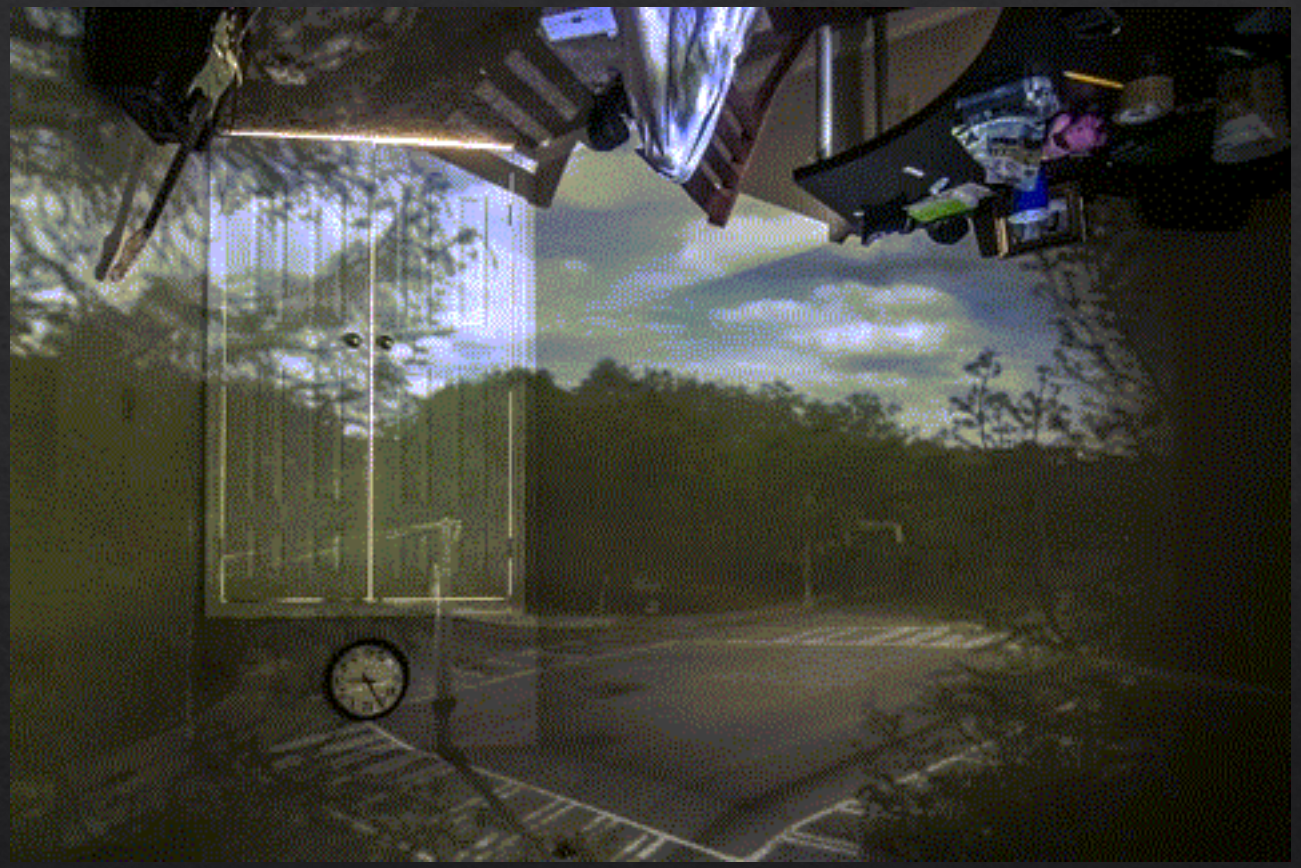
Pinhole camera

Ibn al-Haytham (965-1040 AD)



Camera Obscura



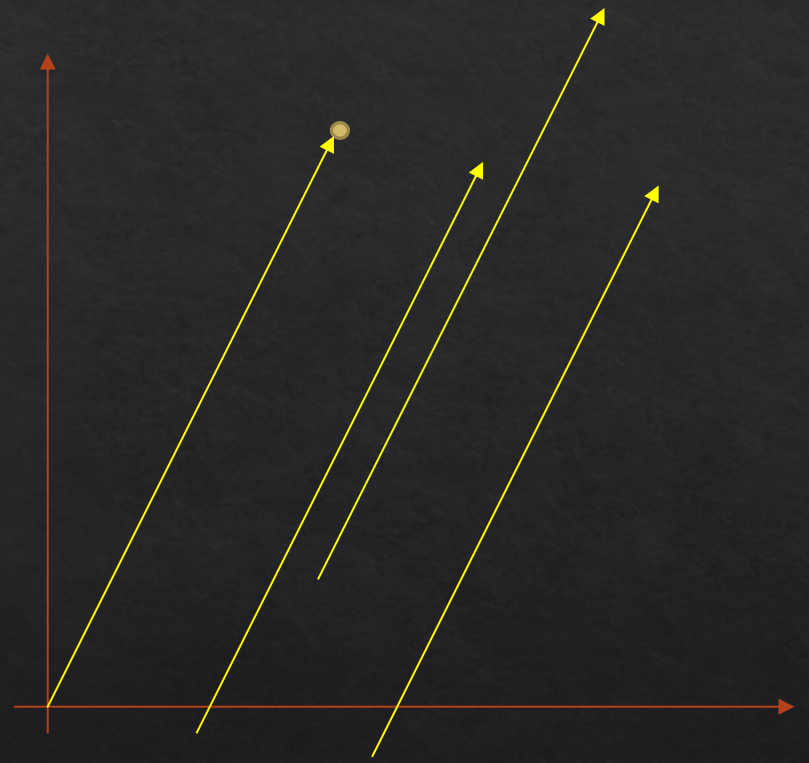


The making of …

Projection

What is a vector? e.g. 2D

$$\begin{bmatrix} u \\ v \end{bmatrix}$$



What is a matrix? e.g. 2x2

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix}$$

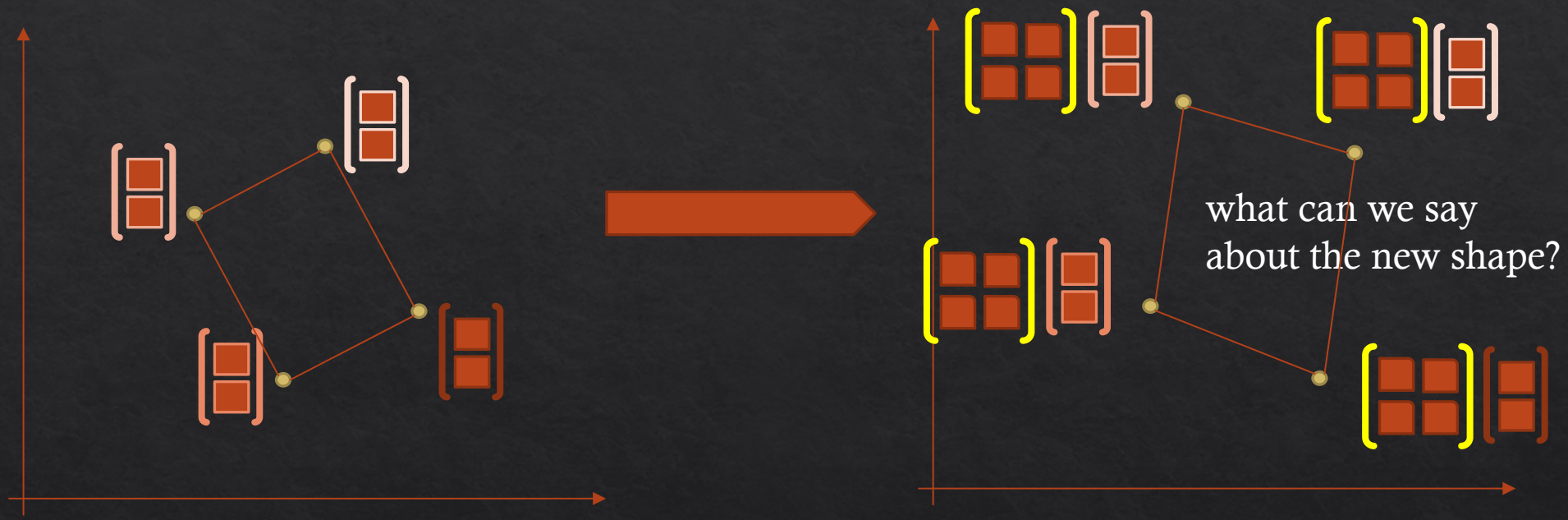
Can we ‘operate on’ a vector?

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} au + bv \\ cu + dv \end{pmatrix}$$

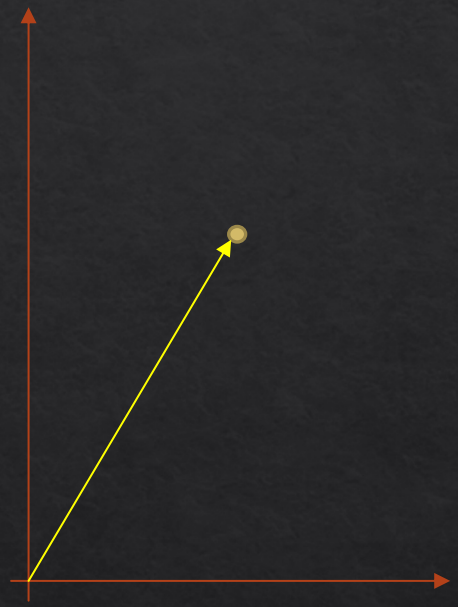
Can we ‘operate on’ a vector?

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} au + bv \\ cu + dv \end{pmatrix}$$

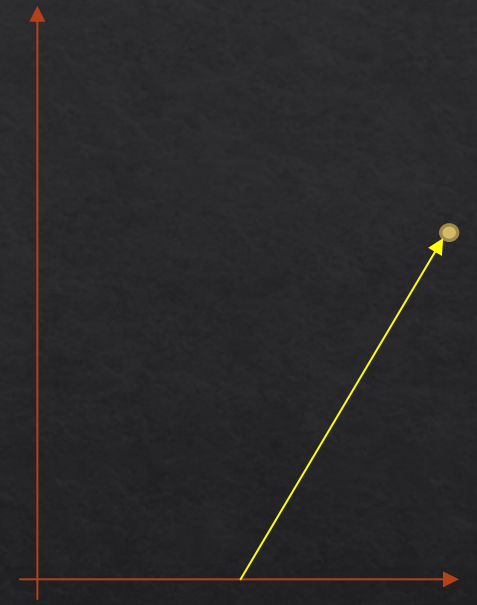
What operations can it achieve?



What operation achieves translation?

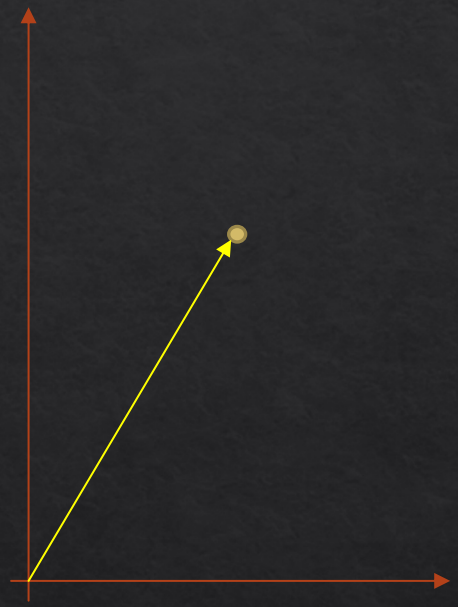


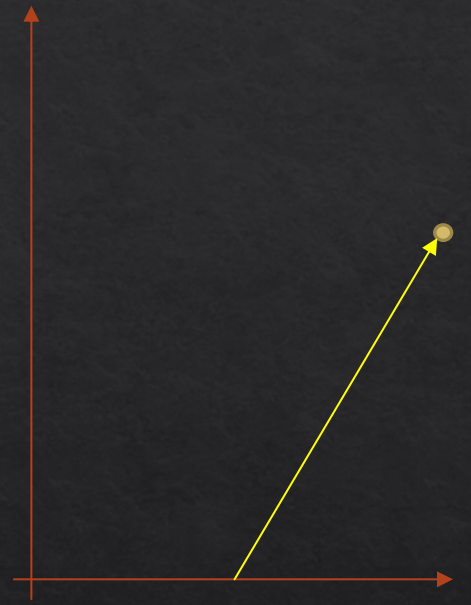
?



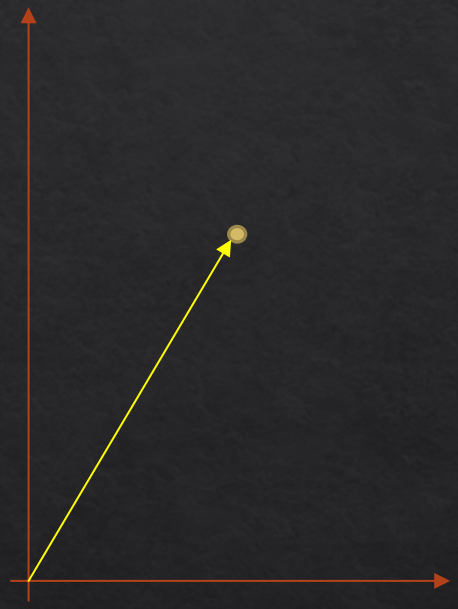
$$\begin{bmatrix} u \\ v \end{bmatrix} + \begin{bmatrix} c_x \\ 0 \end{bmatrix}$$

Can we achieve this with a matrix?

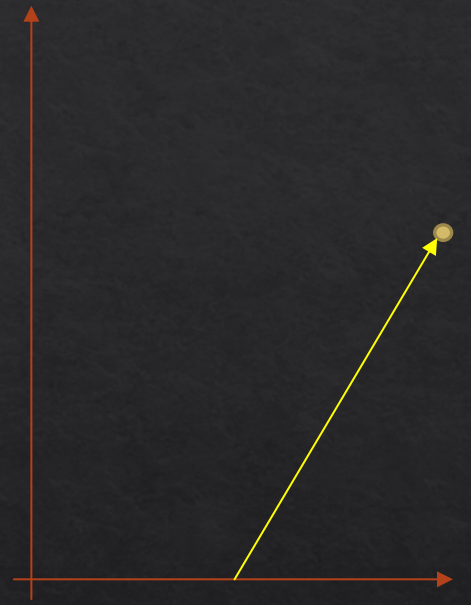




Can we achieve this with a matrix?



Ans: Not with a 2x2 matrix



What if we add a dimension?

$$\begin{pmatrix} a & b & c \\ d & e & f \\ g & h & i \end{pmatrix} \begin{pmatrix} u \\ v \\ 1 \end{pmatrix}$$

matrix is 3x3

still 2D vectors

Now, translation is possible as an operation

$$\begin{pmatrix} 1 & 0 & c_x \\ 0 & 1 & c_y \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} u \\ v \\ 1 \end{pmatrix} = \begin{pmatrix} u + c_x \\ v + c_y \\ 1 \end{pmatrix}$$

Homogeneous coordinates are useful!

$$\begin{pmatrix} u' \\ v' \\ s \end{pmatrix}$$

equivalent to

$$\begin{pmatrix} u'/s \\ v'/s \\ 1 \end{pmatrix}$$

point in 3D homogenous space

point in 2D space

Homogeneous coordinates are useful!

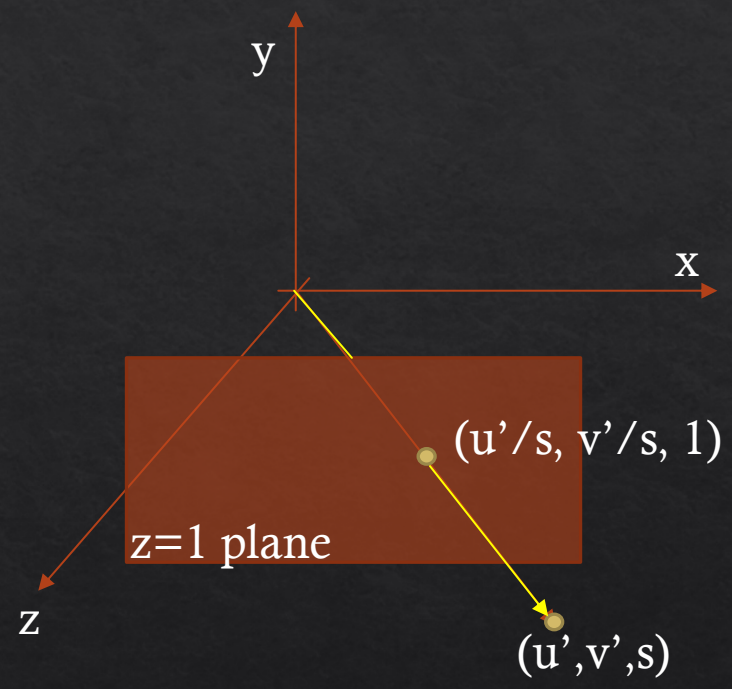
$$\begin{bmatrix} u' \\ v' \\ s \end{bmatrix}$$

point in 3D homogenous space

equivalent to

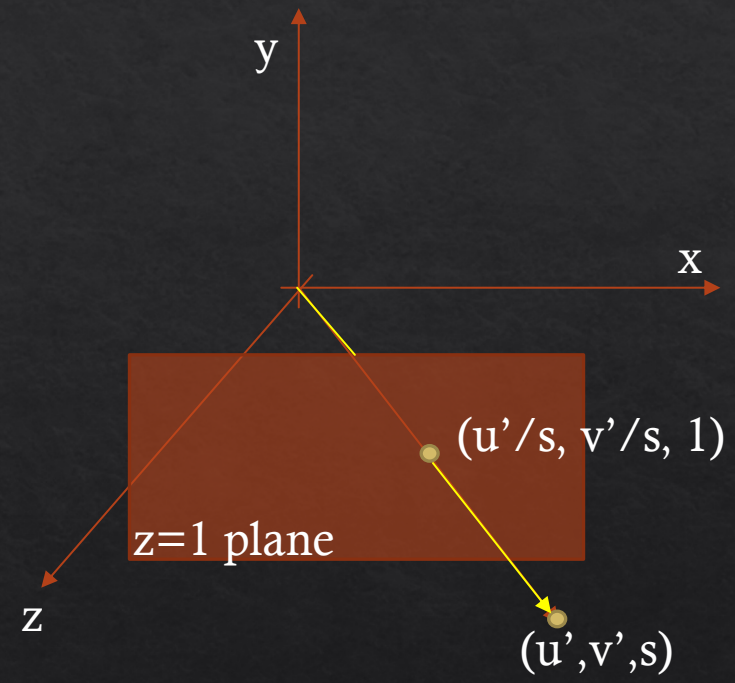
$$\begin{bmatrix} u'/s \\ v'/s \\ 1 \end{bmatrix}$$

point in 2D space



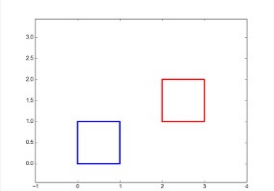
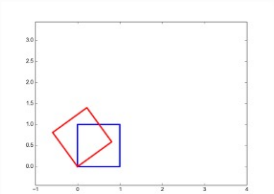
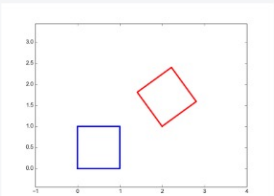
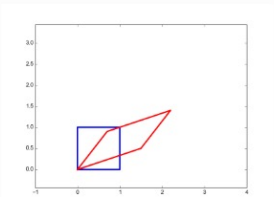
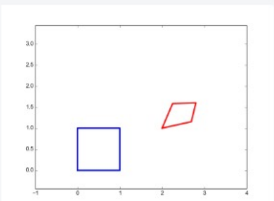
Homogeneous coordinates are useful!

$$\begin{bmatrix} u' \\ v' \\ s \end{bmatrix} \quad \text{equivalent to} \quad \begin{bmatrix} u'/s \\ v'/s \\ 1 \end{bmatrix}$$



$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} 2x \\ 2y \\ 2 \end{bmatrix} = \begin{bmatrix} 3x \\ 3y \\ 3 \end{bmatrix} = \begin{bmatrix} 4x \\ 4y \\ 4 \end{bmatrix} \cdots$$

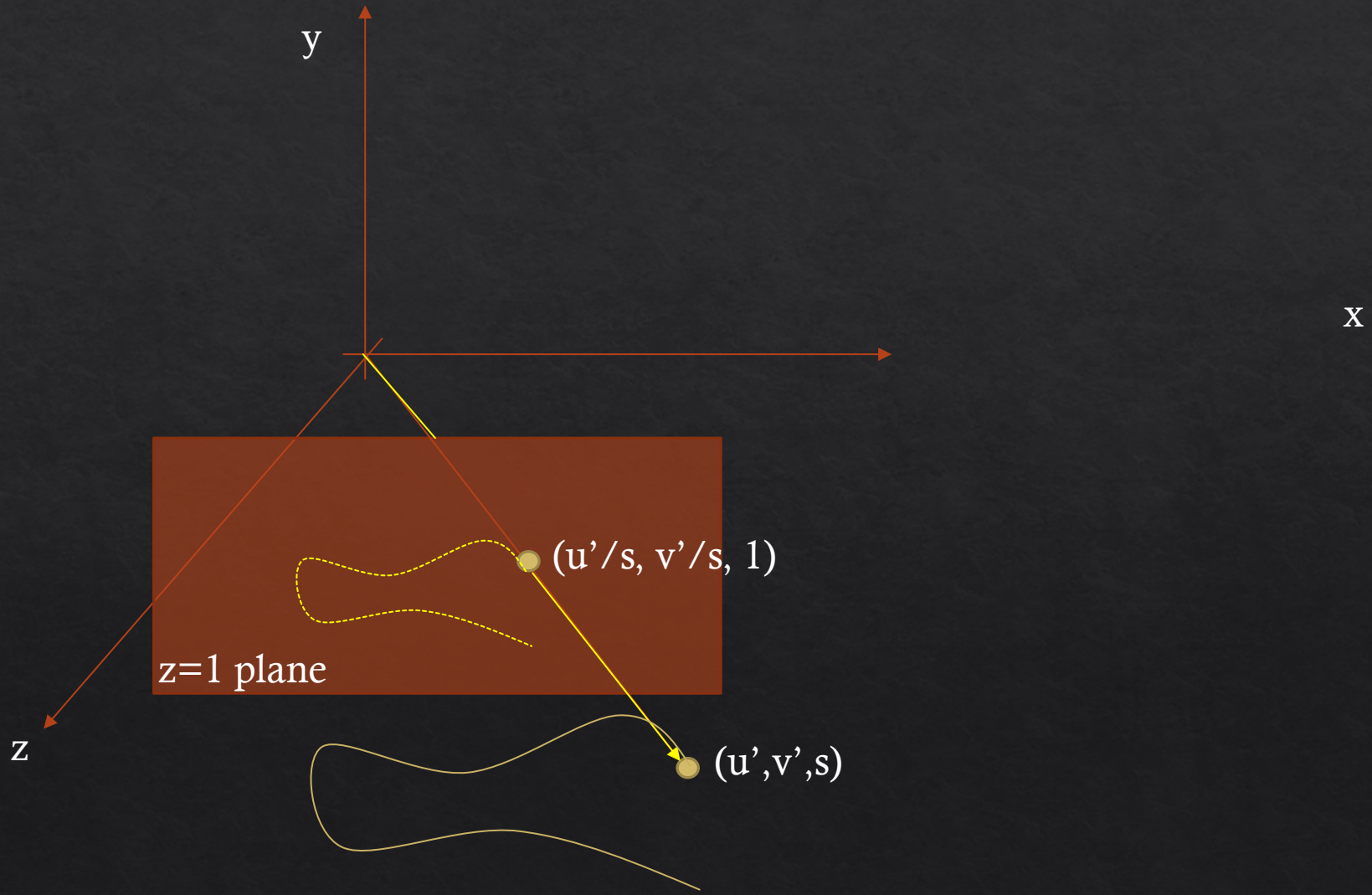
What operations are possible now?

	Translation	$\begin{pmatrix} 1 & 0 & t_1 \\ 0 & 1 & t_2 \\ 0 & 0 & 1 \end{pmatrix}$
	Rotation	$\begin{pmatrix} \cos(\phi) & -\sin(\phi) & 0 \\ \sin(\phi) & \cos(\phi) & 0 \\ 0 & 0 & 1 \end{pmatrix}$
	Rigid Body	$\begin{pmatrix} \cos(\phi) & -\sin(\phi) & t_x \\ \sin(\phi) & \cos(\phi) & t_y \\ 0 & 0 & 1 \end{pmatrix}$
	Affine	$\begin{pmatrix} a & b & c \\ d & e & f \\ 0 & 0 & 1 \end{pmatrix}$
	Projective Transform	$\begin{pmatrix} a & b & c \\ d & e & f \\ g & h & 1 \end{pmatrix}$

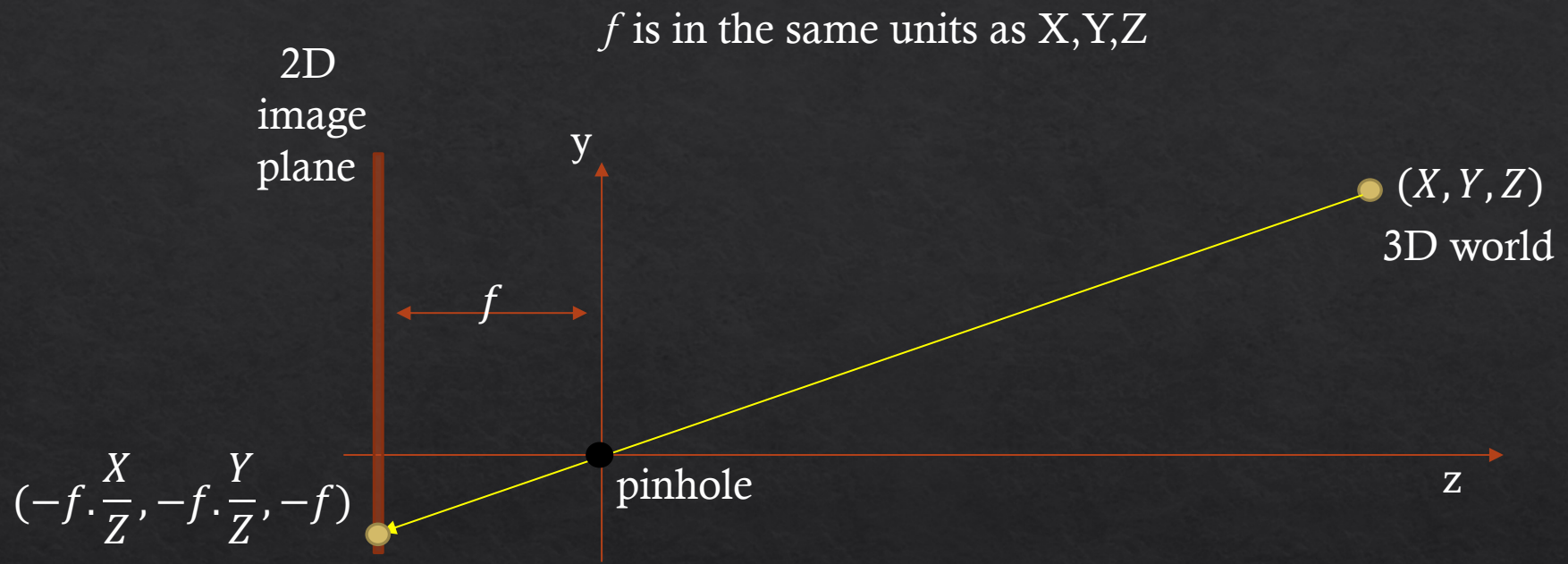
https://staff.fnwi.uva.nl/r.vandenboomgaard/IPCV20162017/LectureNotes/MATH/homogenous.html#sec-homogeneous

Remind you of a camera sensor plane?

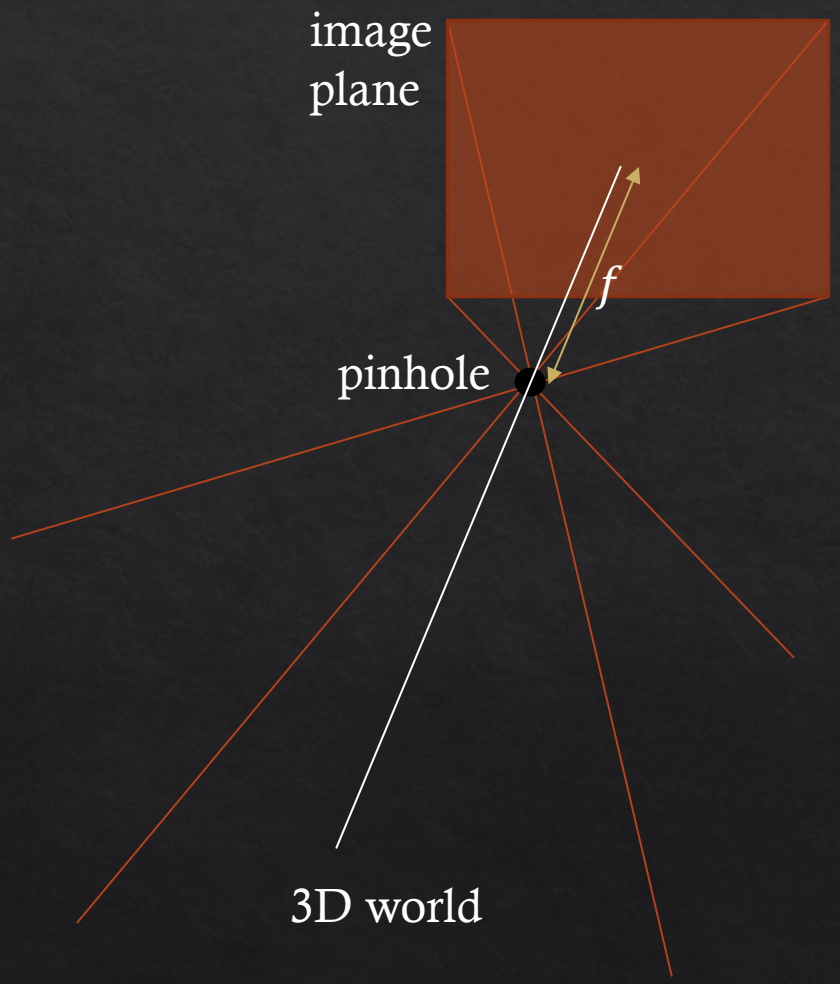
Yes, if the camera is at the origin looking down the Z-axis

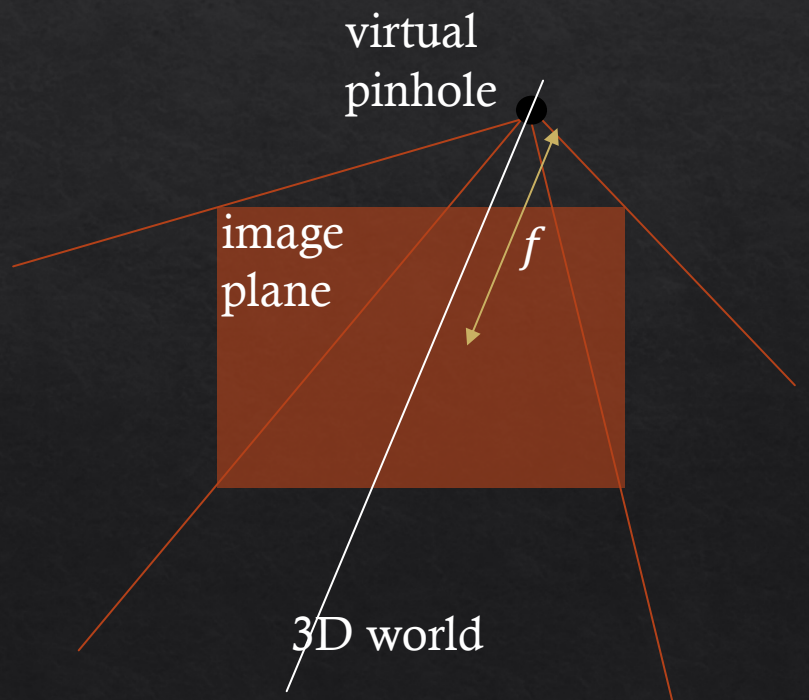


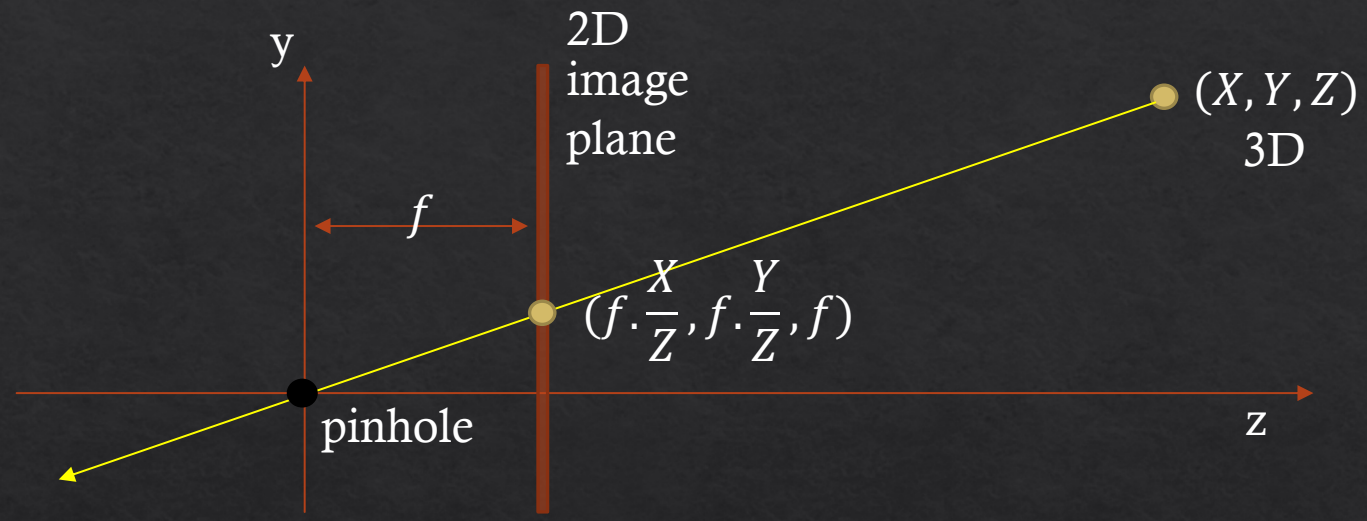
Ideal pinhole camera 3D



Ideal vs virtual pinhole model







$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} \begin{bmatrix} fX \\ fY \\ Z \end{bmatrix} = \begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

Pixel coordinates
(u,v)
on z=1 plane

Pixel coordinates from 3D point

1. Projection from 3D to 2D

$$\begin{pmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

2. Scaling pixels by pixel resoln.

$$\begin{pmatrix} s_x f & 0 & 0 & 0 \\ 0 & s_y f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

3. Translation to positive quadrant

$$\begin{pmatrix} f_x & 0 & u & 0 \\ 0 & f_y & v & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

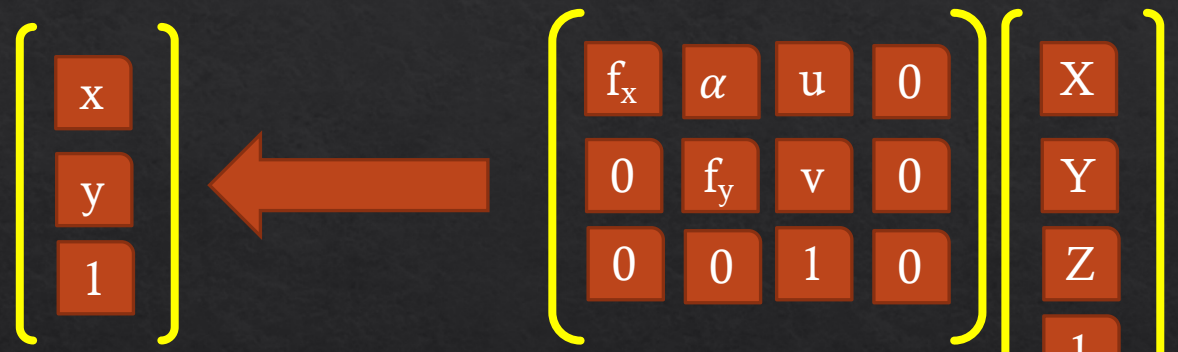
4. Skew, if sensor not perpendicular to optic axis

$$\begin{pmatrix} f_x & \alpha & u & 0 \\ 0 & f_y & v & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

More details here

Pixel coordinates from 3D point

When the camera is at the origin looking towards Z

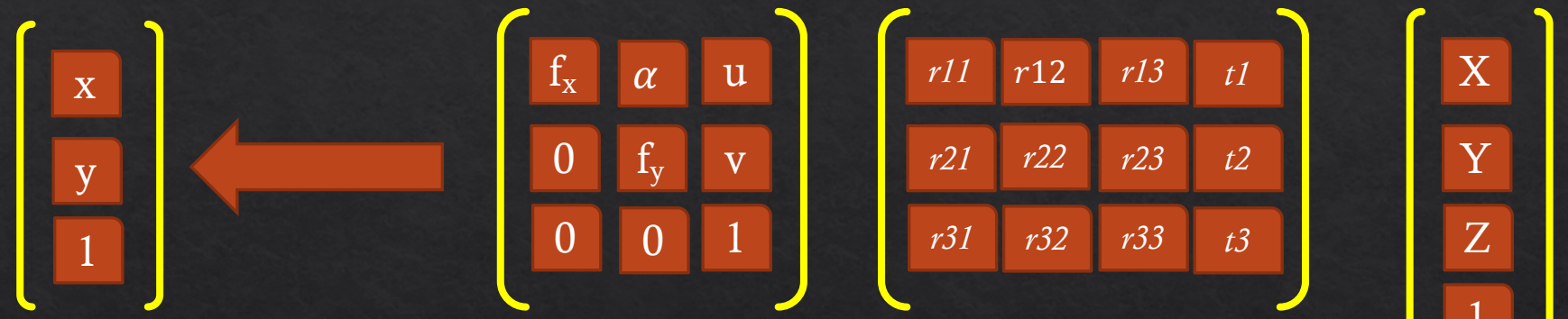


2D pixel coordinates

3D world coordinates

Pinhole camera matrix

When the camera is at an arbitrary location



2D pixel coordinates

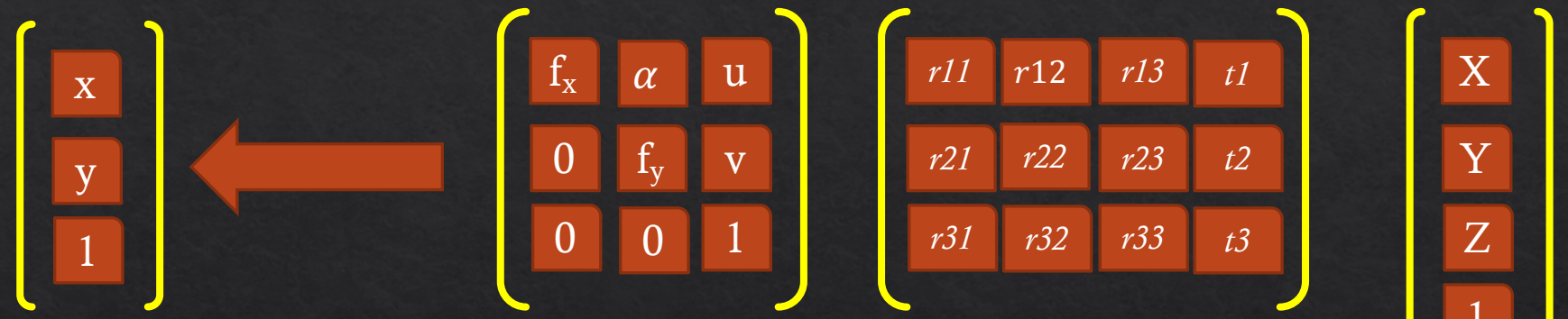
intrinsic

extrinsic

3D world coordinates

Pinhole camera matrix

When the camera is at an arbitrary location



2D pixel coordinates

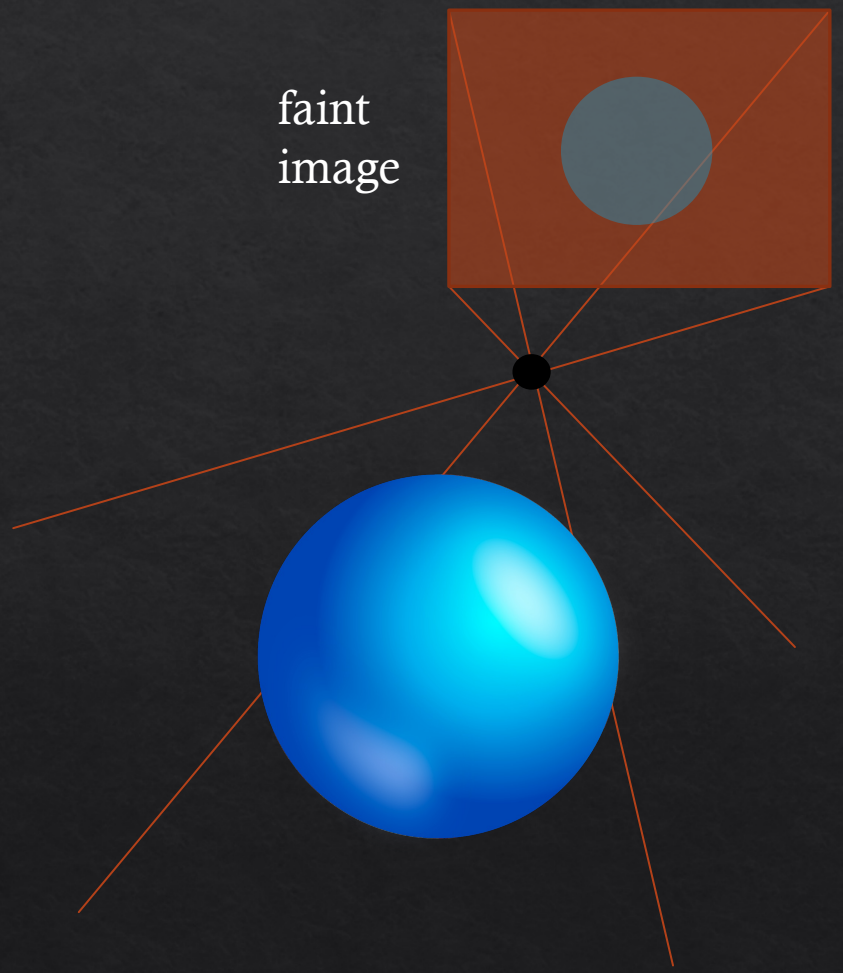
intrinsic

extrinsic

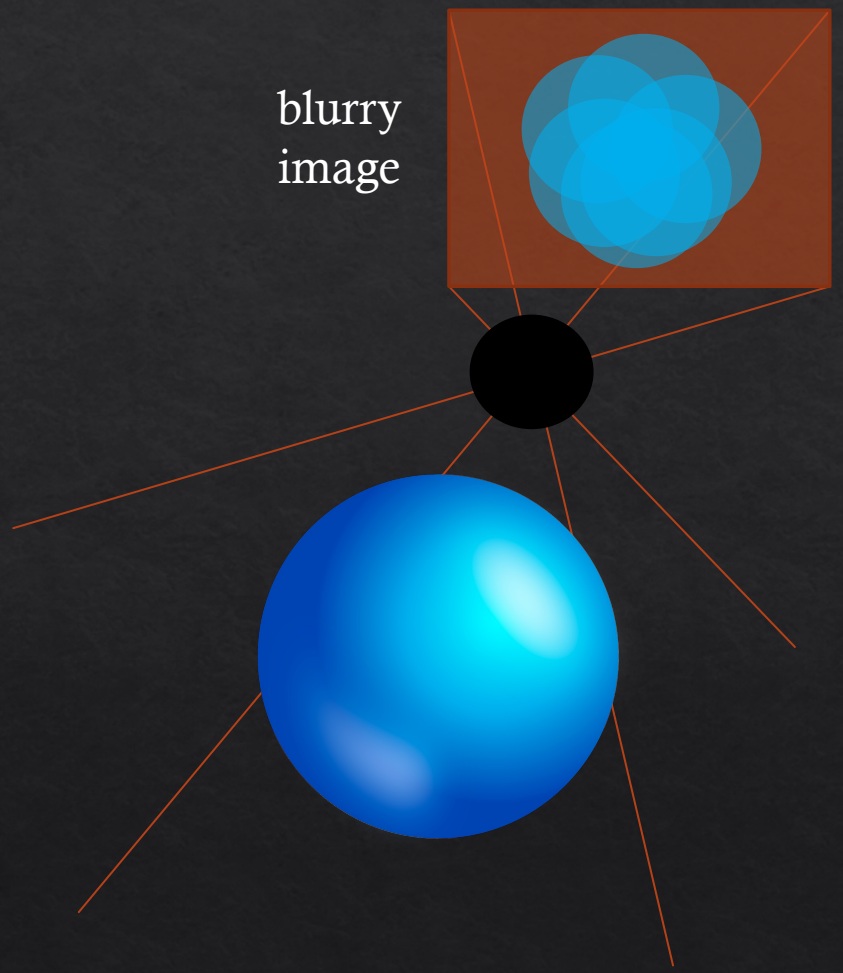
3D world coordinates

Problems with pinhole camera?

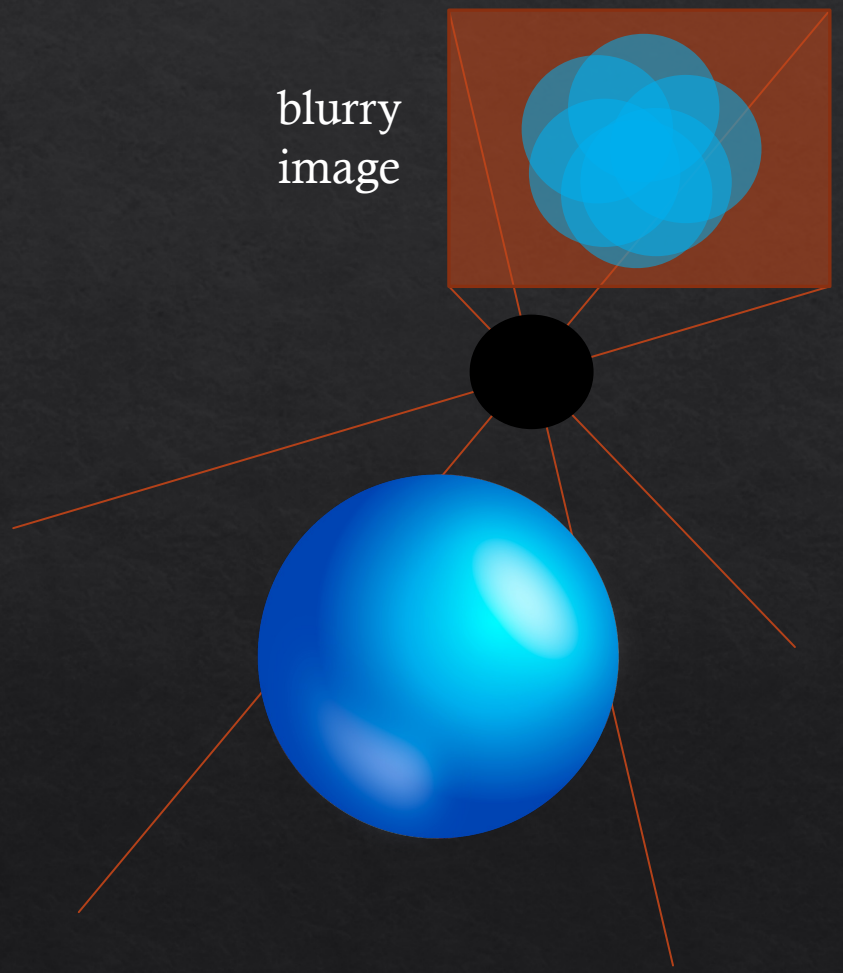
Pinhole only allows little light through



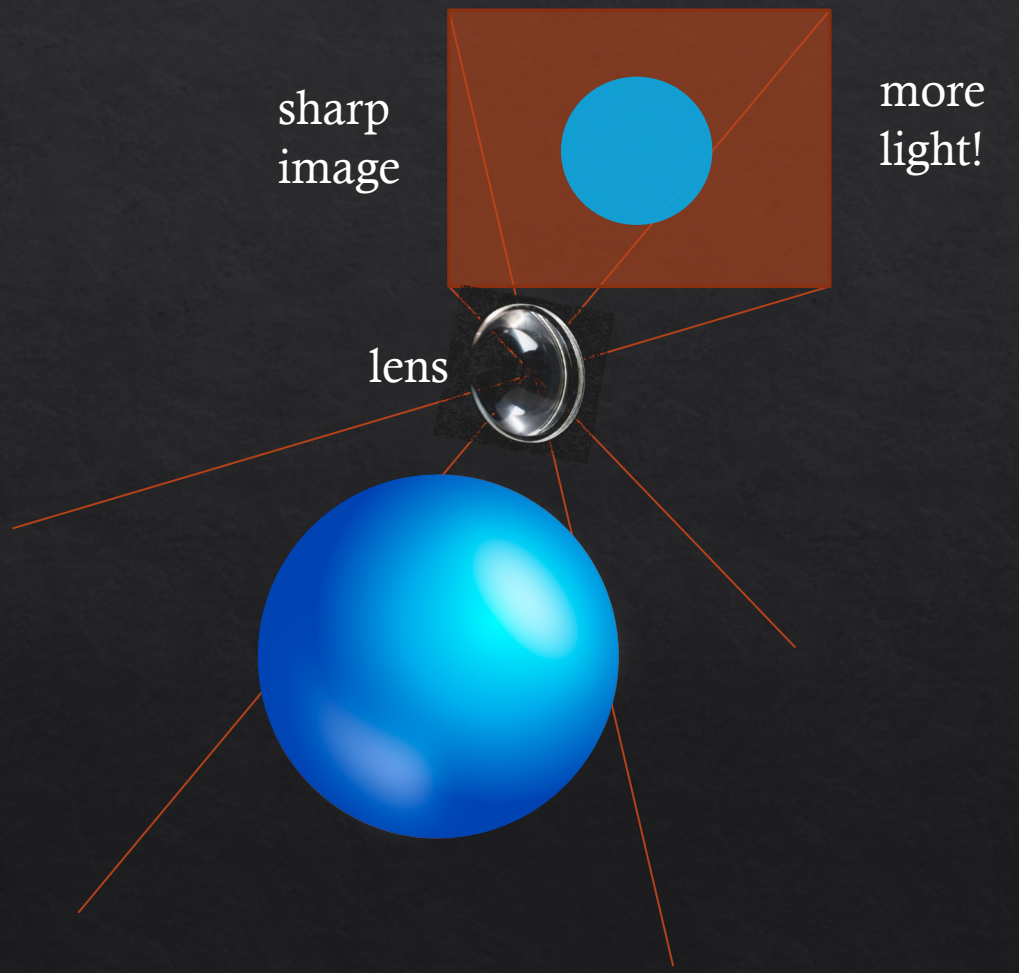
Large hole: many superposed images



Can we improve light and avoid blur?

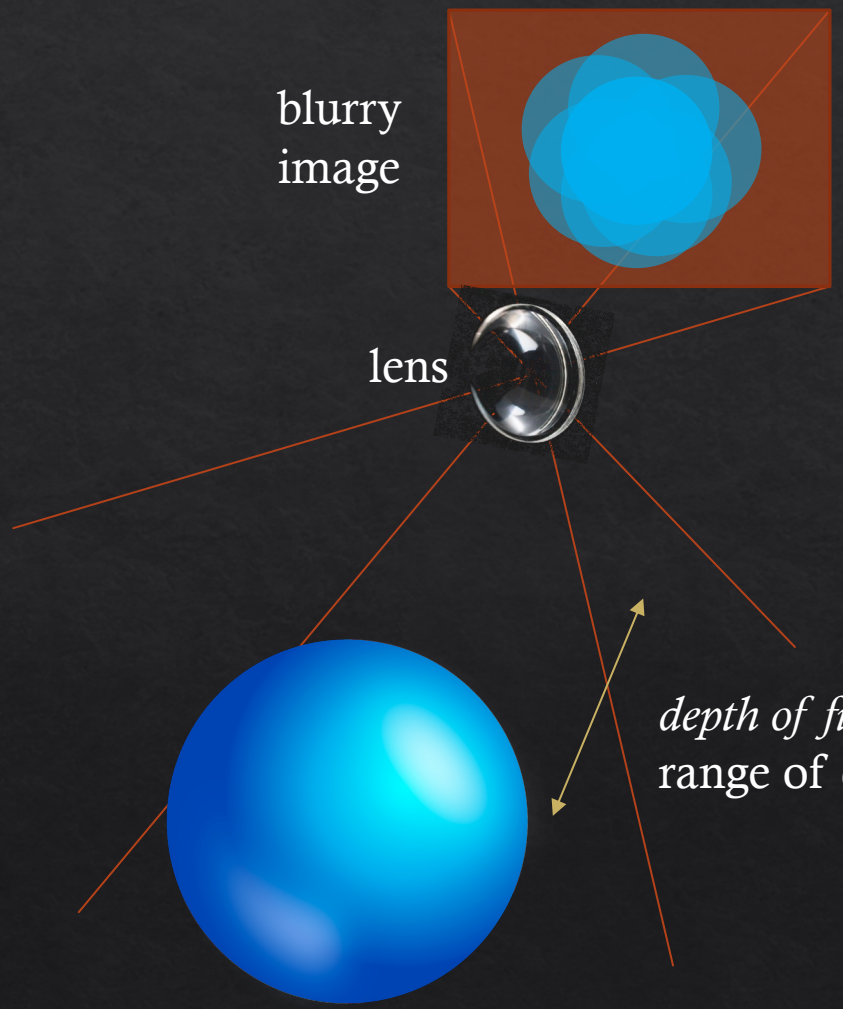


Lens improves light efficiency, but …



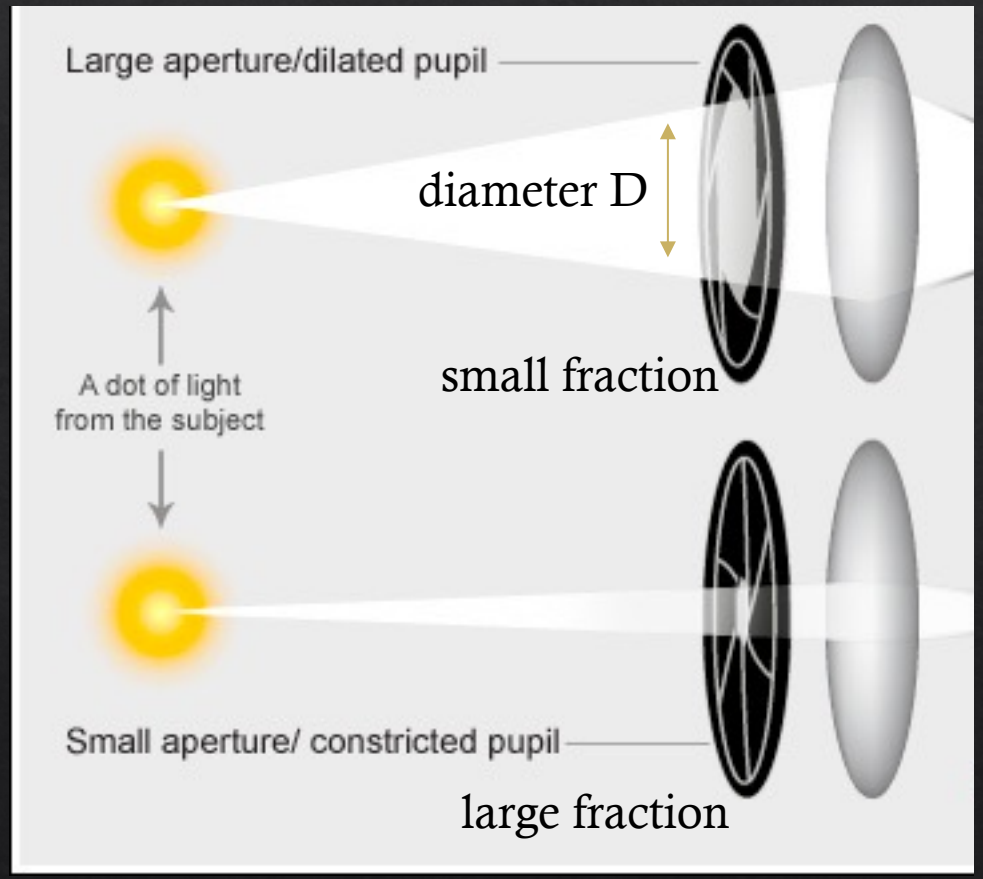
https://phydemo.app/ray-optics/simulator/

… only focusses part of the world



depth of field
range of depths for which image is sharp

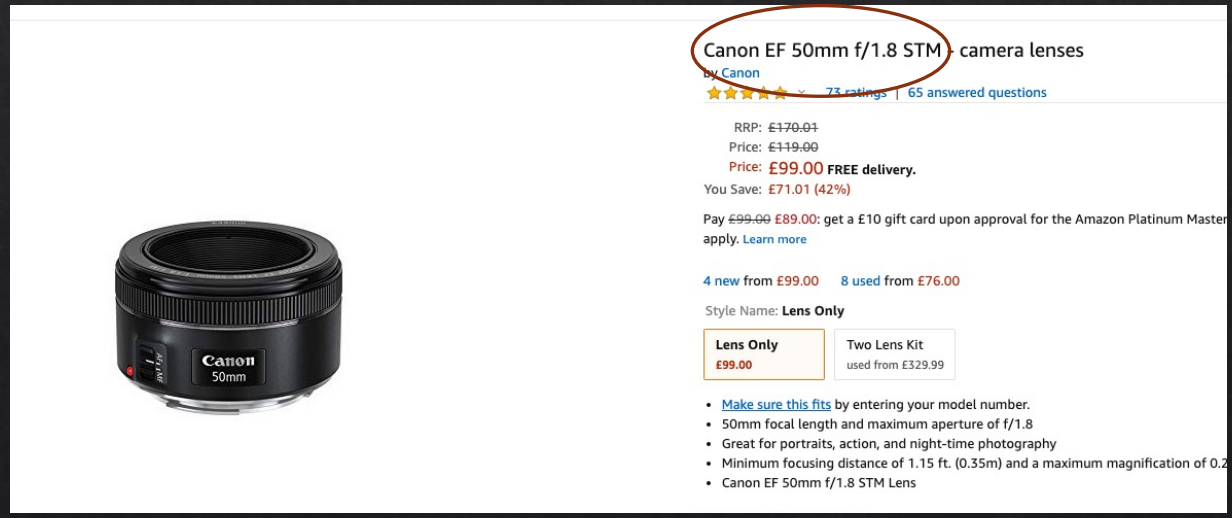
Finite-sized pinhole = aperture



https://www.dpreview.com/forums/post/59717839

aperture specification is a fraction: $\frac{f}{D}$

called f-number of a lens

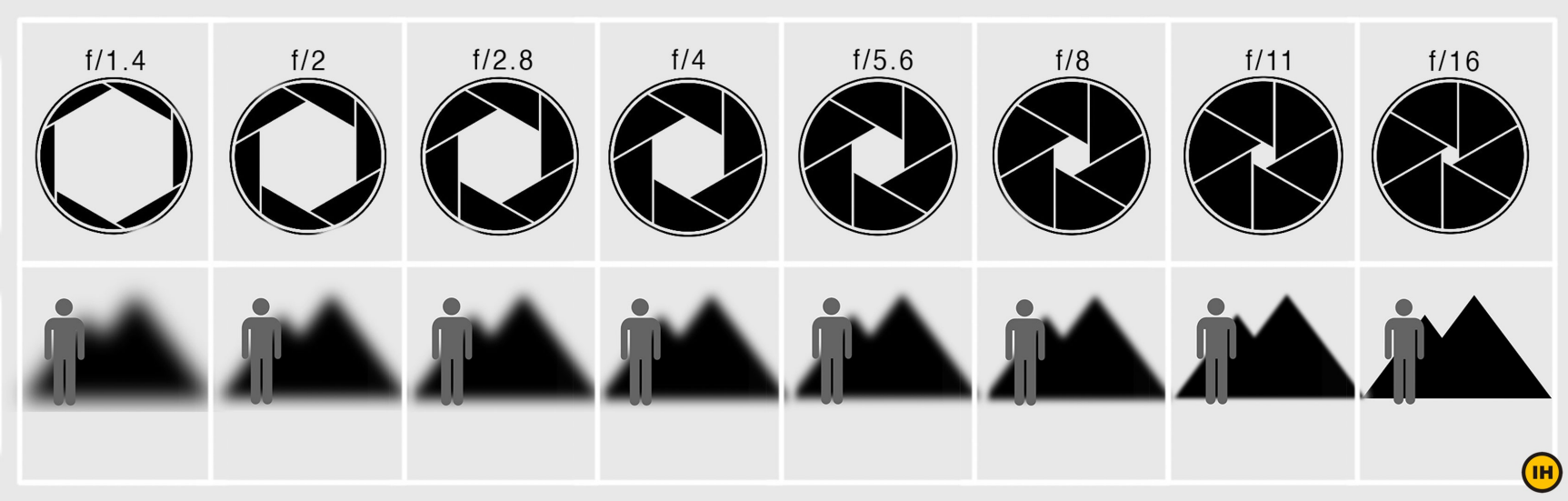


amazon purchase

Depth of field depends on aperture size

more light allows
fast shutter speed –
good for dark scenes

less light but large
depth of field –
good for landscape

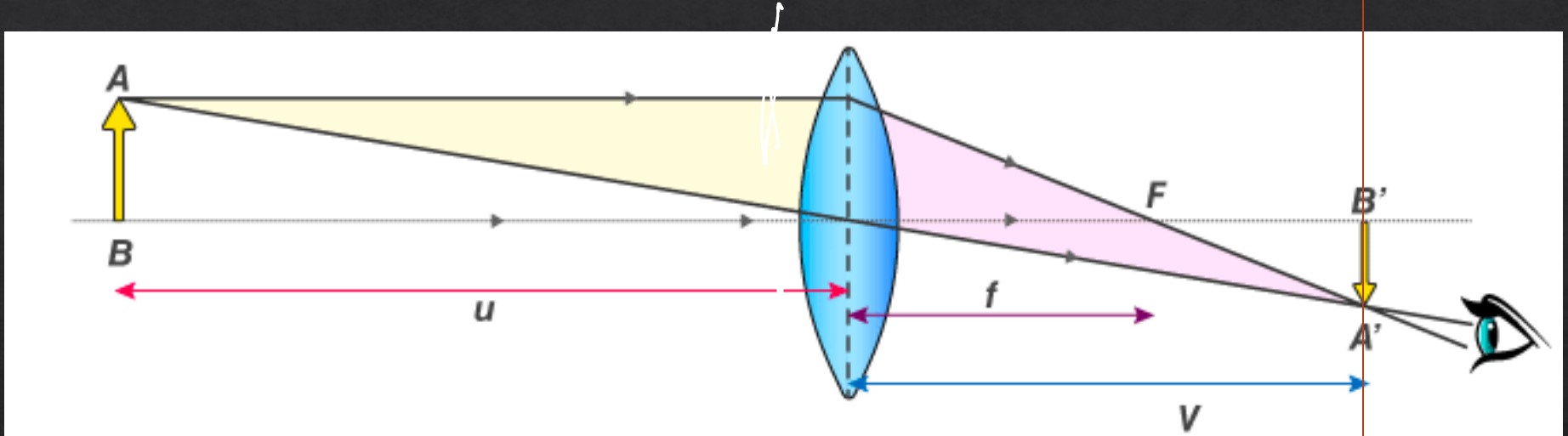


'fast lens'

'slow lens'

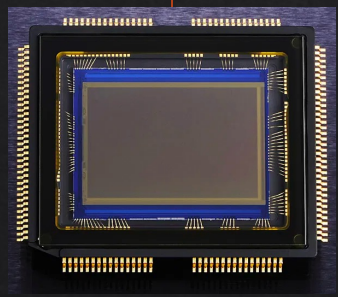
https://www.zippi.co.uk/thestudio/landscape-photography/aperture-diagram-indiahikes/

Thin lens formula, independent of aperture

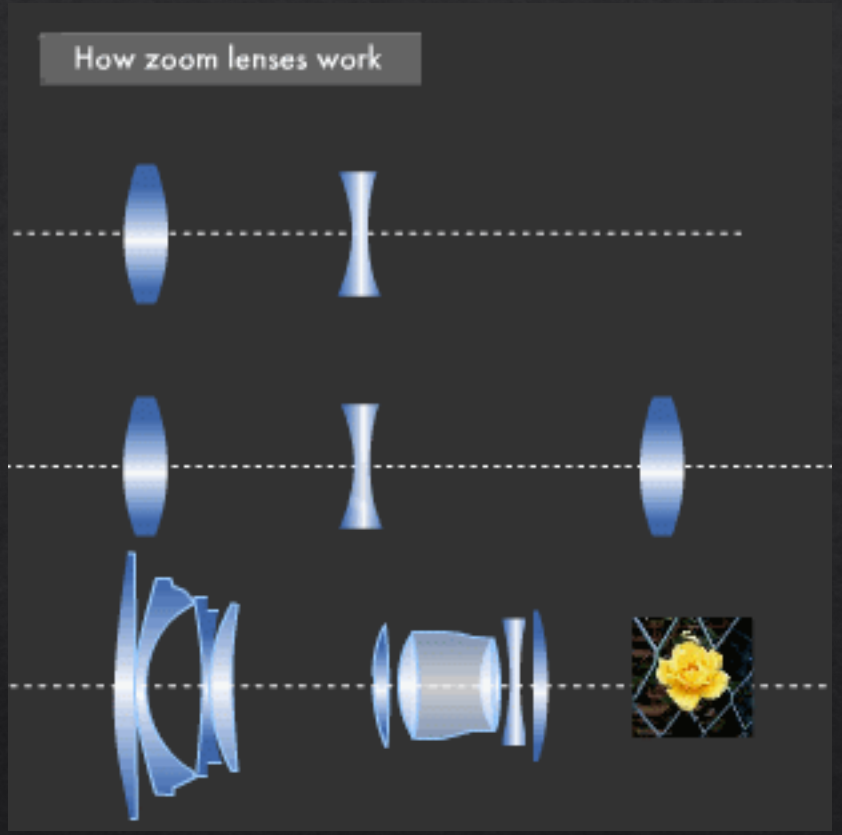


https://byjus.com/physics/derivation-of-lens-formula/

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$



Zooming-- changing f



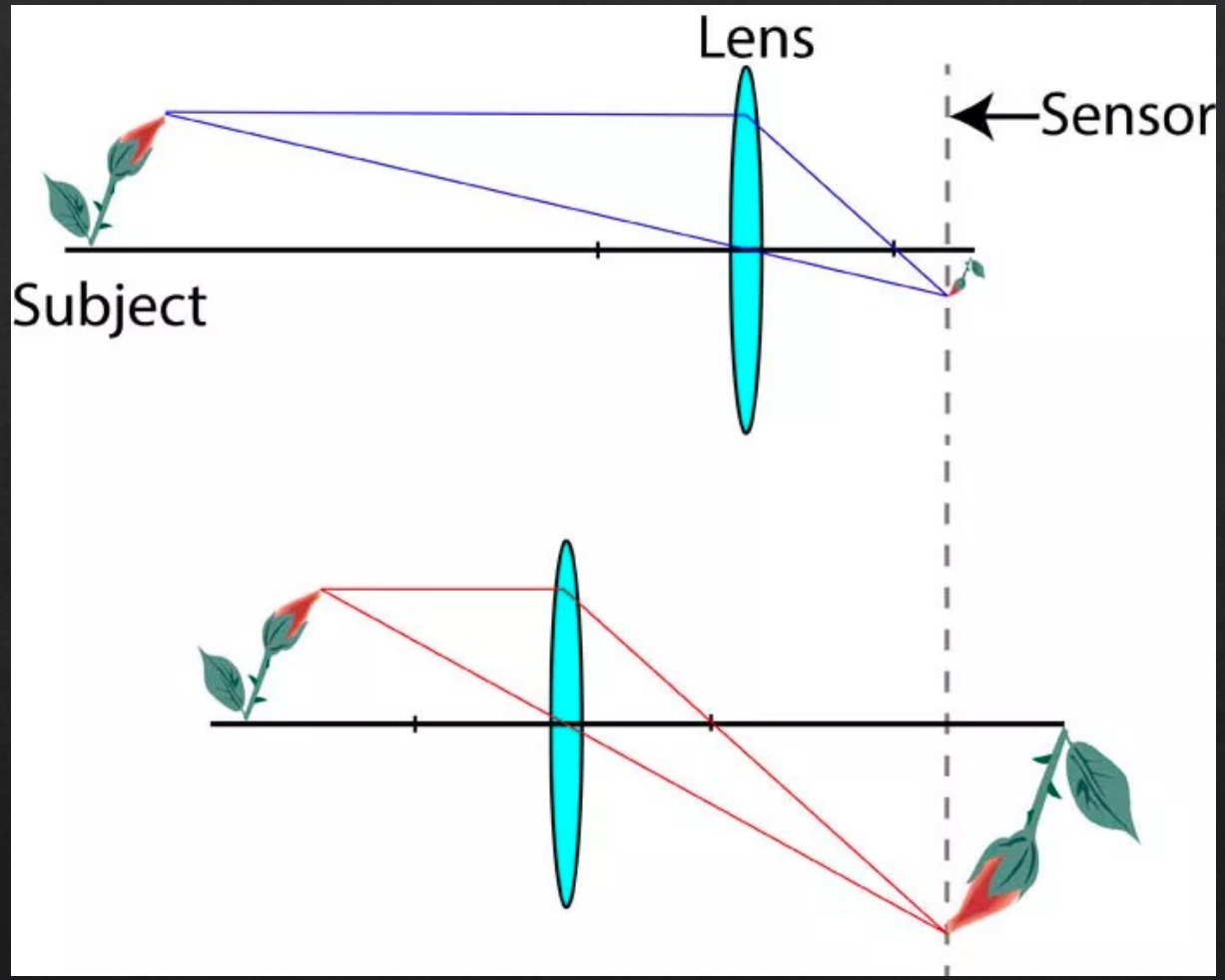
https://global.canon/en/technology/s_labo/light/003/02.html

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

effective
focal
length

Same lens (fixed f), increase v

extension tube



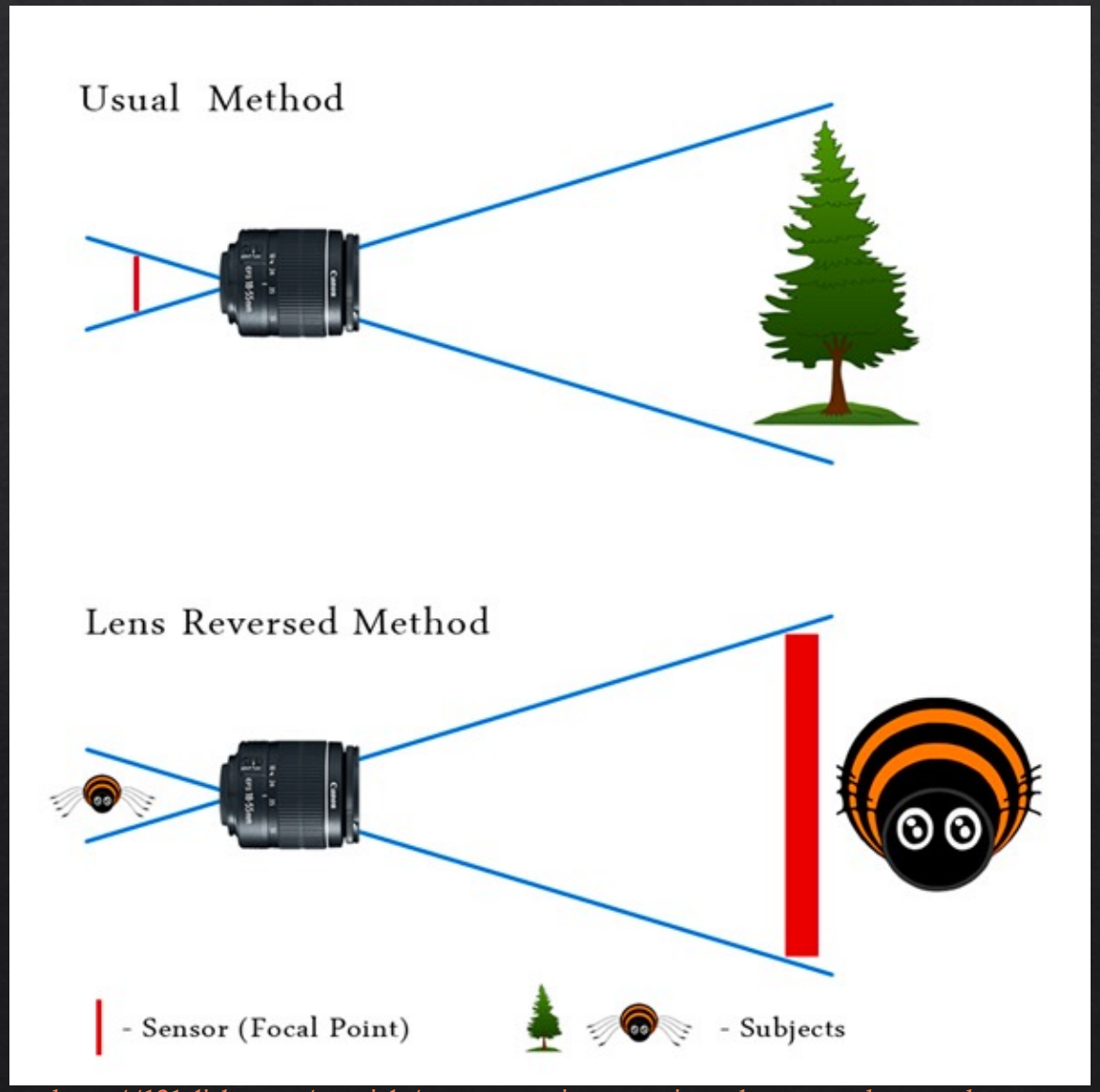
$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

larger image!

https://expertphotography.com/difference-between-macro-micro-and-close-up-photography/

Also achieved by swapping subject and sensor!

reverse ring extension tube

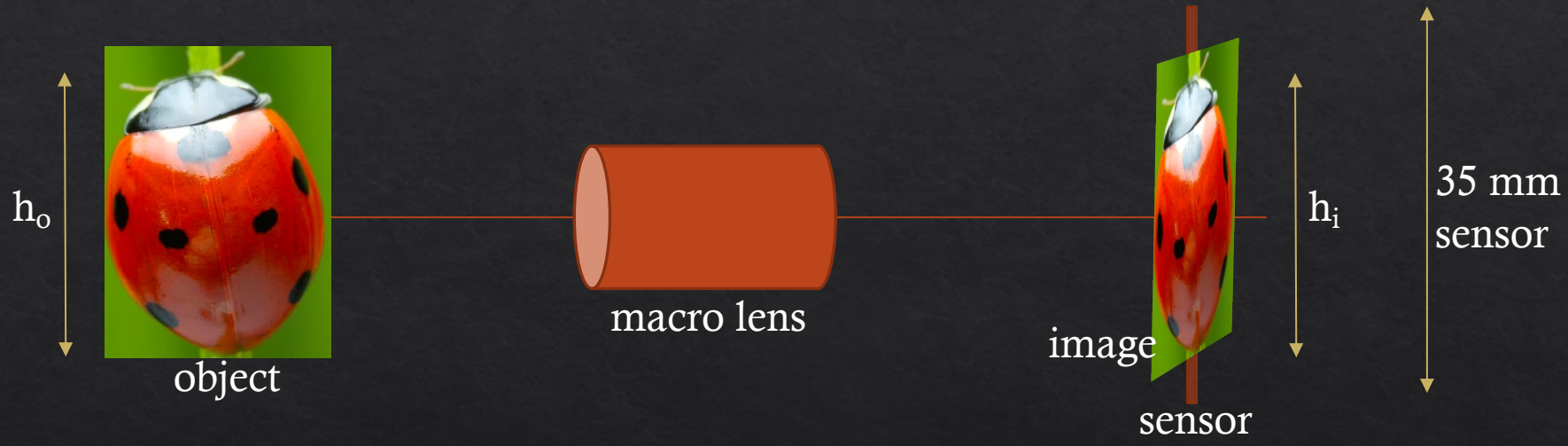


$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

https://121clicks.com/tutorials/use-reverse-ring-extension-tube-macro-photography

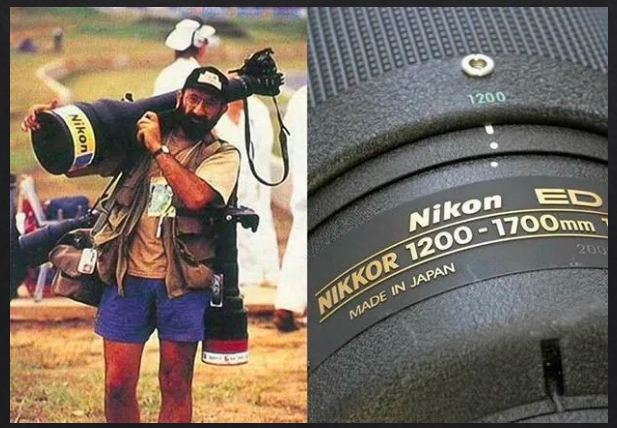
Macro photography

high magnification ratio $\frac{h_i}{h_o}$



Types of lenses

telephoto
- f larger than length of lens construction
- useful to zoom
- compresses range of depths
- usually variable focal lengths
- and variable f-number (depending on f)



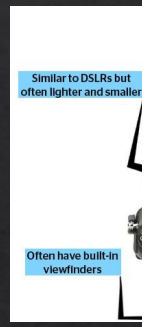
standard/prime
- f fixed
- no zoom capability
- usually high quality build = better image quality

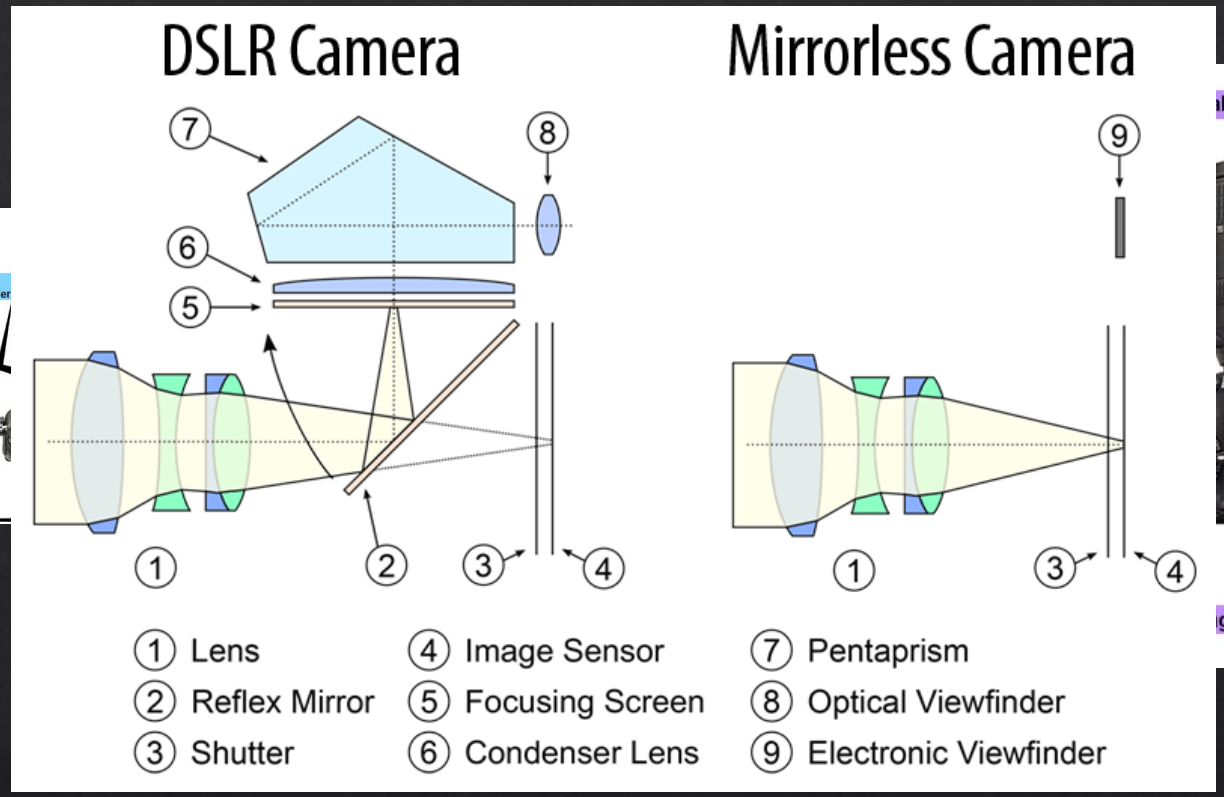
wide angle
- f shorter than lens construction
- good for landscape
- could introduce more distortion

Types of cameras

Read more here…

Types of cameras



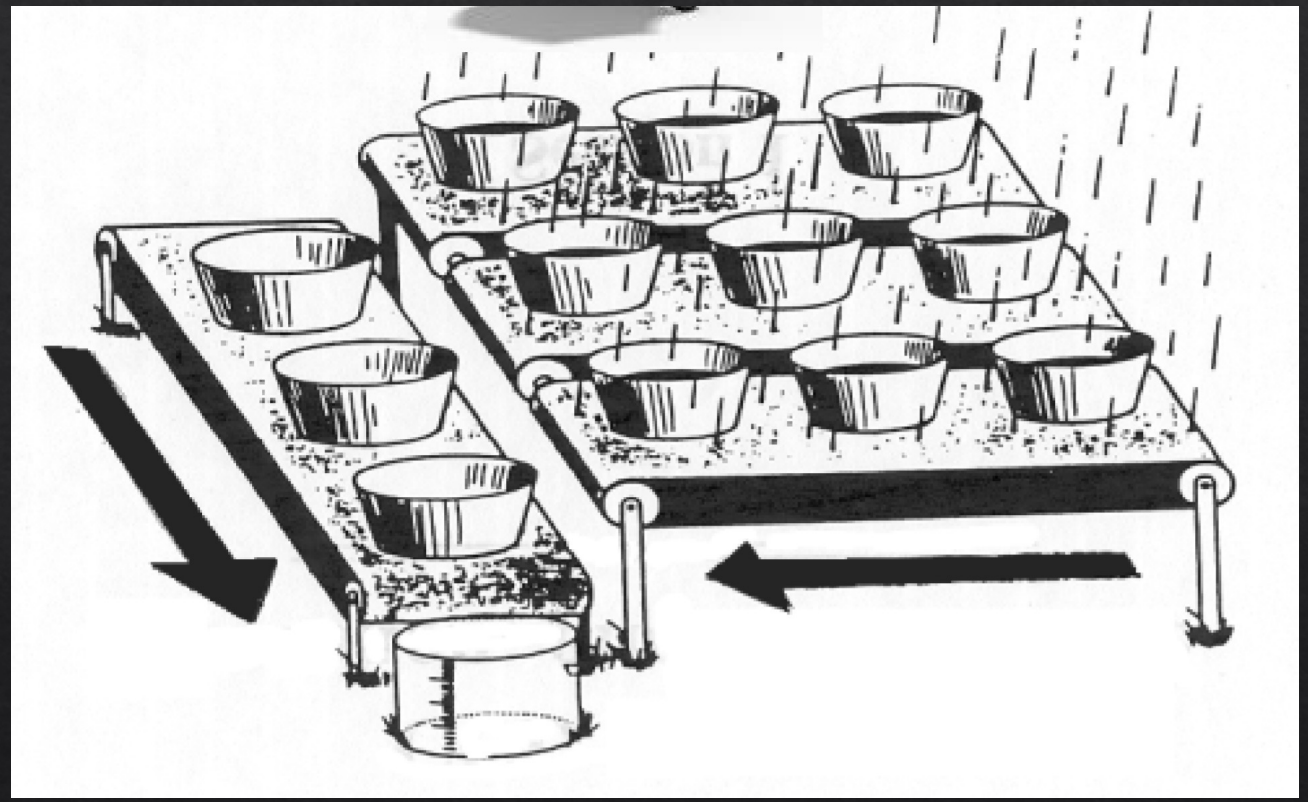


Read more here…

Types of cameras

Read more here…

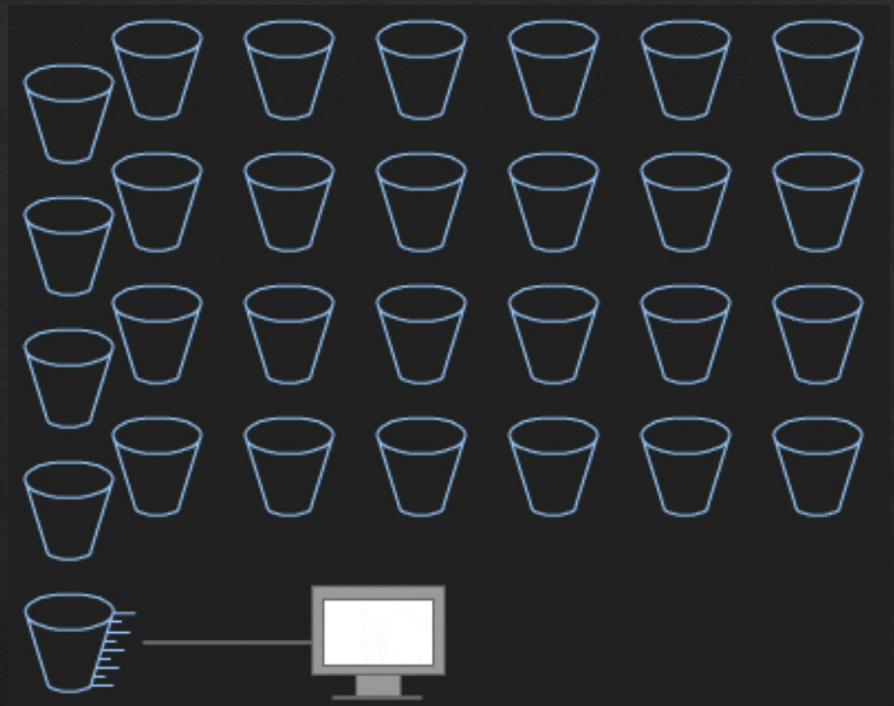
Cameras – sensors



https://www.visiononline.org/userassets/aiauploads/file/cvp_the-fundamentals-of-camera-and-image-sensor-technology_jon-chouinard.pdf

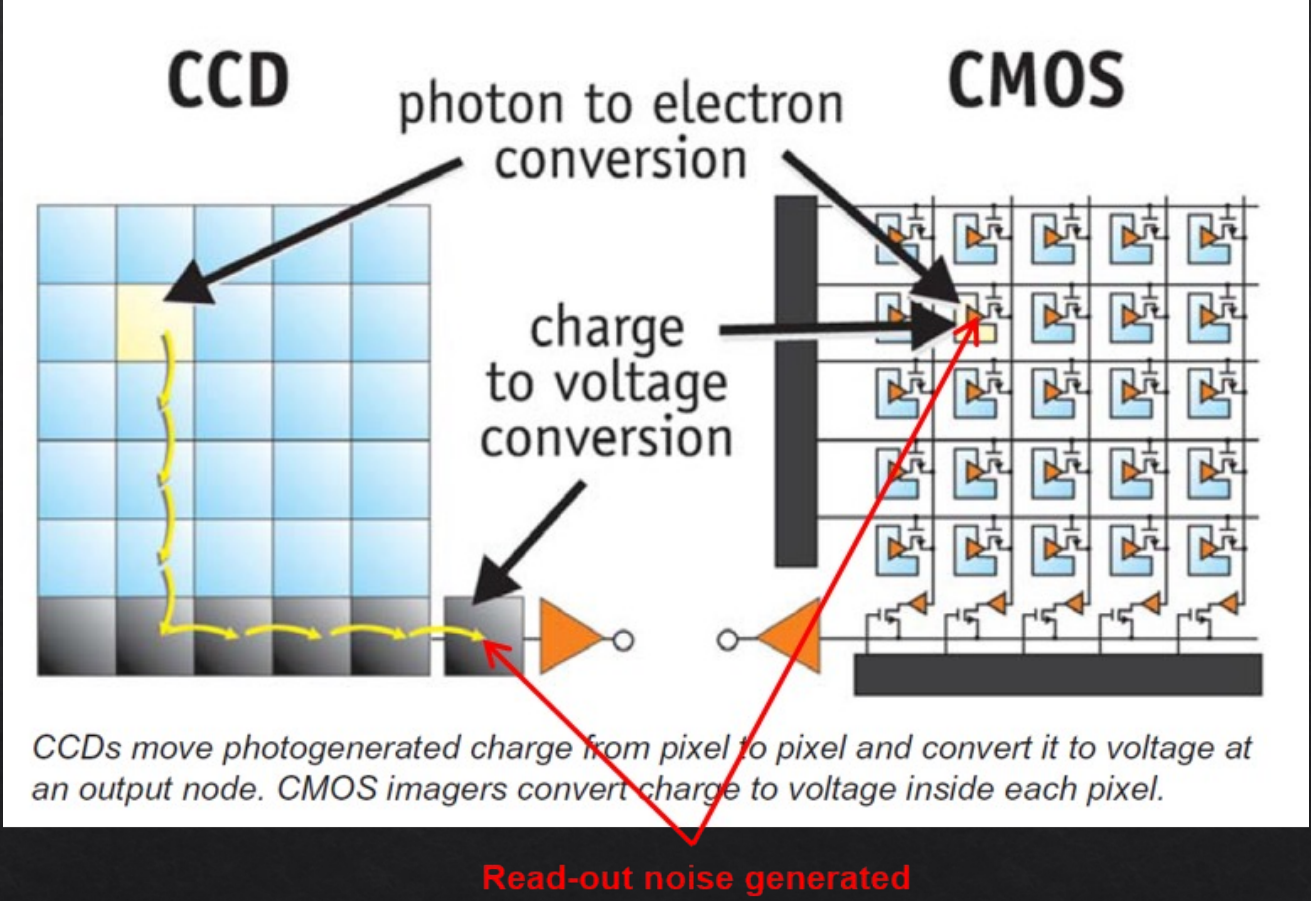
Sensor sensitivity and response

Types of sensors



Link to gif

Types of sensors

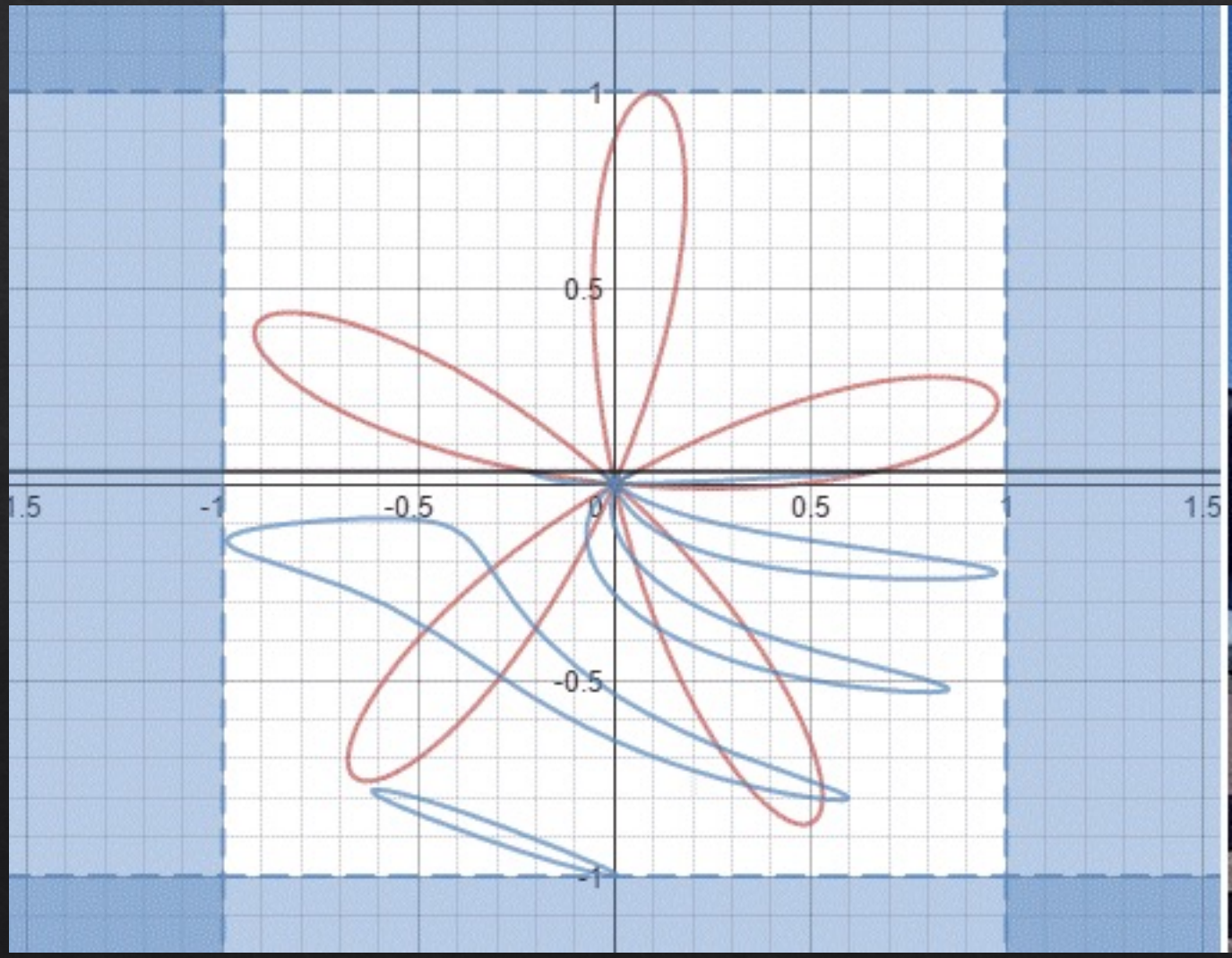


Read more here, and on this canon website (marketing-speak alert)

Link to gif

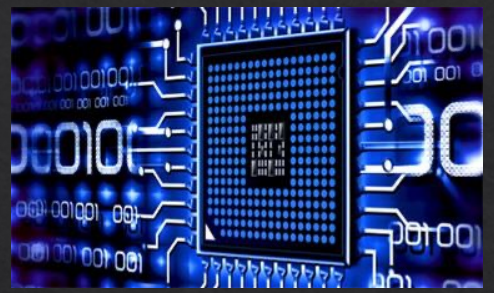
Link to gif

Rolling shutter



Link to gif

The big picture!



CG – account for all factors!