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Korea Institute of Energy Technology

Advanced Computer Vision
Week 03

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Image Debugging with Python

Summary of Previous Lesson

Basics of Python functions

→ How to define and use

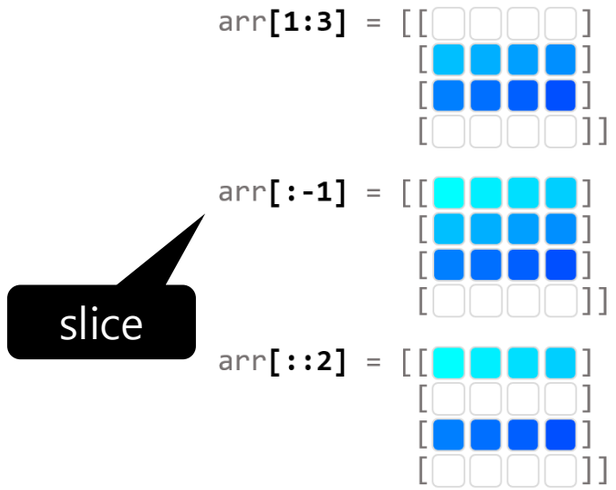
Basics of NumPy arrays

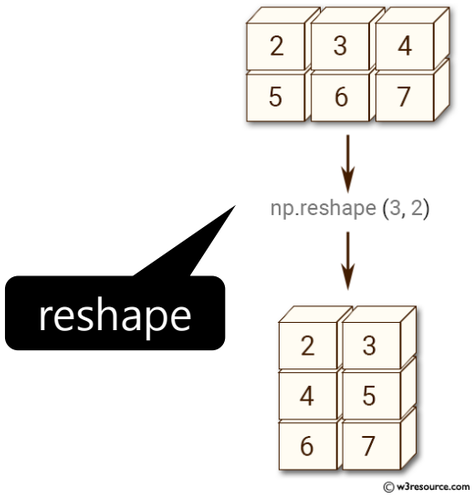
→ Many useful operations for multi-dimensional arrays

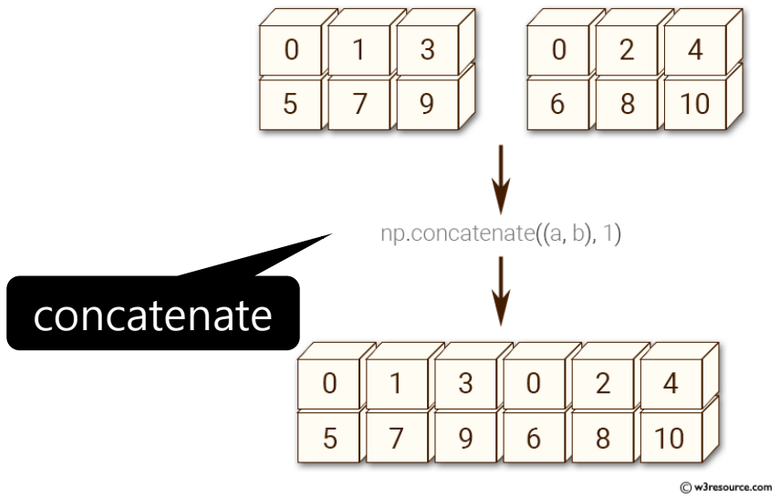
→ Please always check the current shape of arrays using the **shape** method!

→ Basic math operations: add, subtract, min, max, mean, etc. along different axis

→ Basic transformations: slicing, reshape, concatenate, stack, append, etc.







[1] w3resource.com

Now, Let's Play with Images!

Solve image processing puzzles.

→ Multiple image processing missions to make specific images.

→ If you need, please refer below pages.

Numpy: https://numpy.org/doc/stable/reference/

Scikit-learn image: https://scikit-image.org/

PIL image: https://pillow.readthedocs.io/en/stable/reference/Image.html

Codes are available at:

https://view.kentech.ac.kr/a6fac1a2-7304-409e-85f0-78b1d527034f

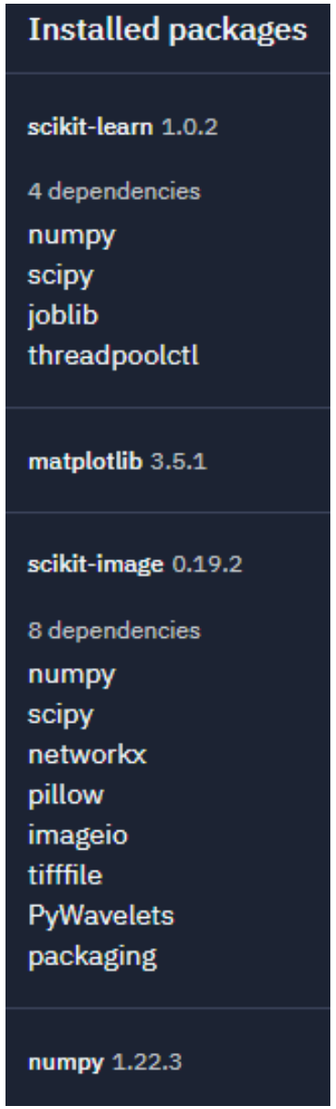


Image Processing Puzzle

Now we will try visualization

→ Enables image debugging

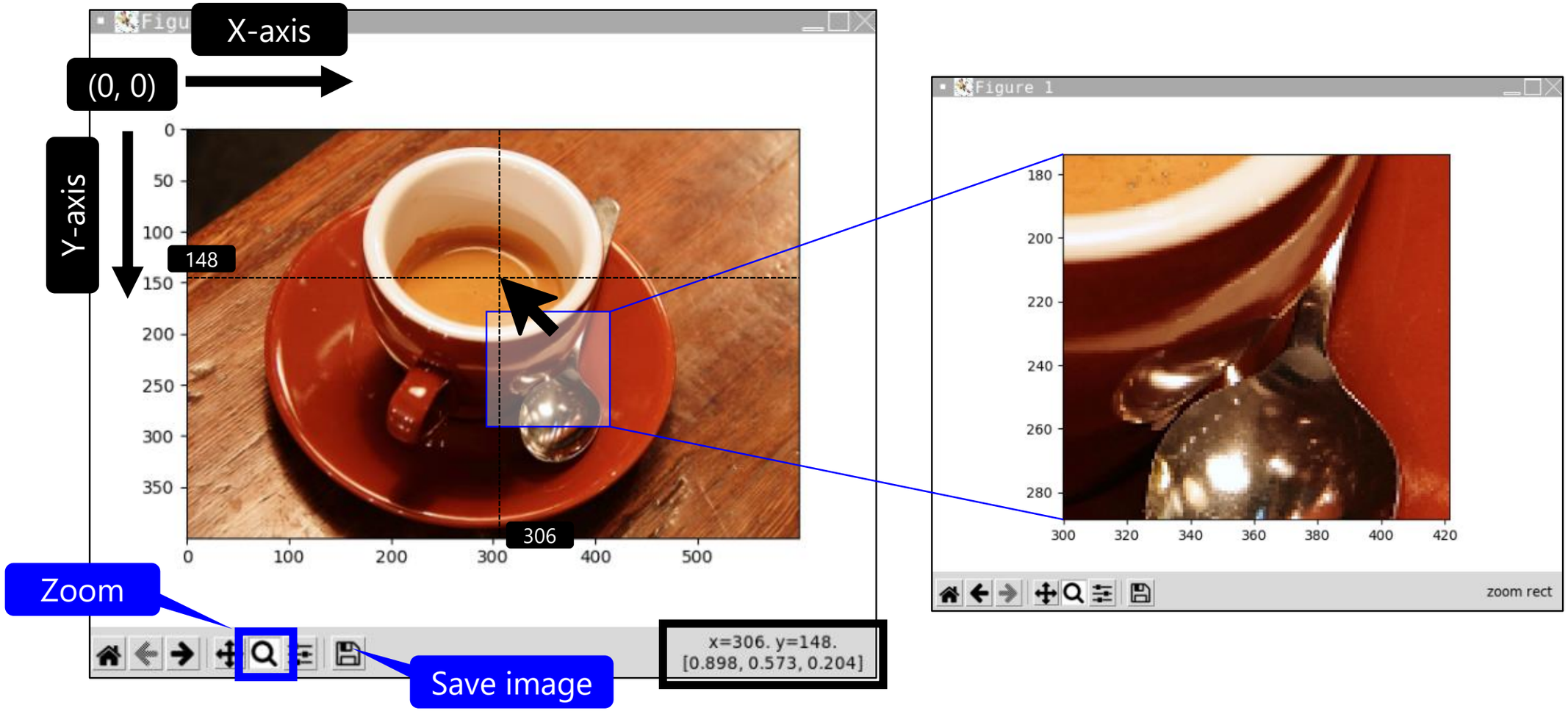
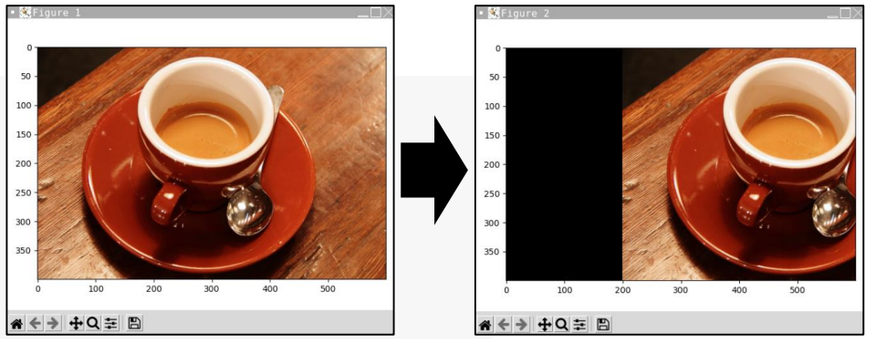


Image Processing Puzzle

Discussion 2: shifting image over x-axis

→ Use loop to generate the target image




```
hh, ww, ch = im.shape

for i in range(ww):
        print('index:', i)
        im1 = np.zeros(im.shape)
        im1[:, i:, :] = im[:, :ww-i, :]
        if (im1 == gt1).all():
                break;

check_same(gt1, im1)
```

Check the shape

Search space: maximum width

Initialize

Assign

Break the loop if the target is matched

Check if the output is correct

Image Processing Puzzle

Discussion 2-2: shifting over both x- and y-axis

→ Use loop to generate the target image → Too slow!

```
flag = False
hh, ww, ch = im.shape
for i in range(hh):
  for j in range(ww):
    print('index:', i, j)
    im1 = np.zeros(im.shape)
    im1[i:, j:, :] = im[:hh-i, :ww-j, :]
    error = np.abs(im1 - gt1).mean()
    if error == 0:
      flag = True
      break;
  if flag:
    break;
check_same(gt1, im1)
```

Search space: both maximum height + width
Use "**nested loop**"

You can check the processing time using the below code lines:

```
import time
start = time.time()
…
print(time.time() - start)
```

Image Processing Puzzle

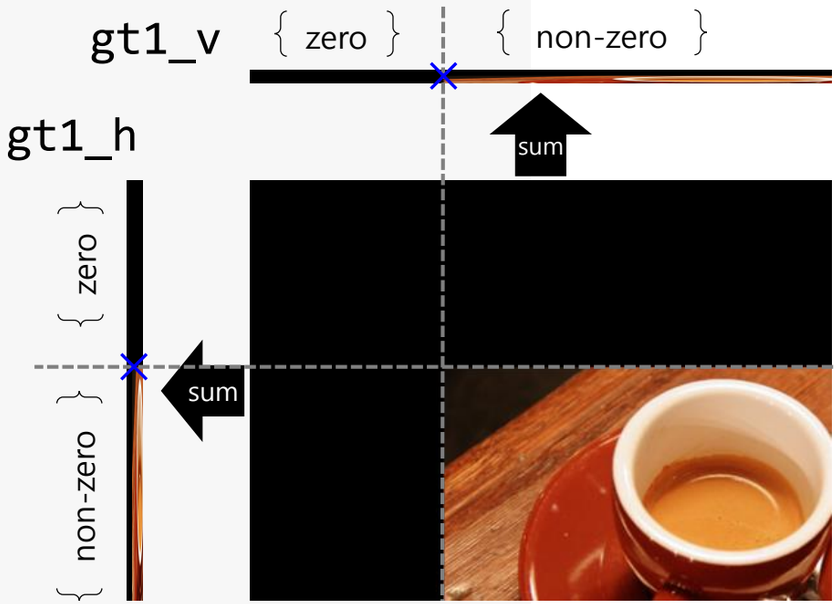
Discussion 2-2: shifting over both x- and y-axis

→ Dimension reduction. Please discuss this code in your report!

```
hh, ww, ch = im.shape

gt1_h = gt1.sum(axis=(0,2))
gt1_v = gt1.sum(axis=(1,2))

jj = (gt1_h == 0).sum()
ii = (gt1_v == 0).sum()

im1[ii:, jj:, :] = im[:hh-ii, :ww-jj, :]

check_same(gt1, im1)
```

Dimension reduction

Automatic binary sum
(= count the number of zeros)



→ Once you are familiar with the "for-loop" statement,

Try to implement your code **efficiently** through **dimension reduction!**

Image Processing Puzzle

Discussion 4: Image multiplication

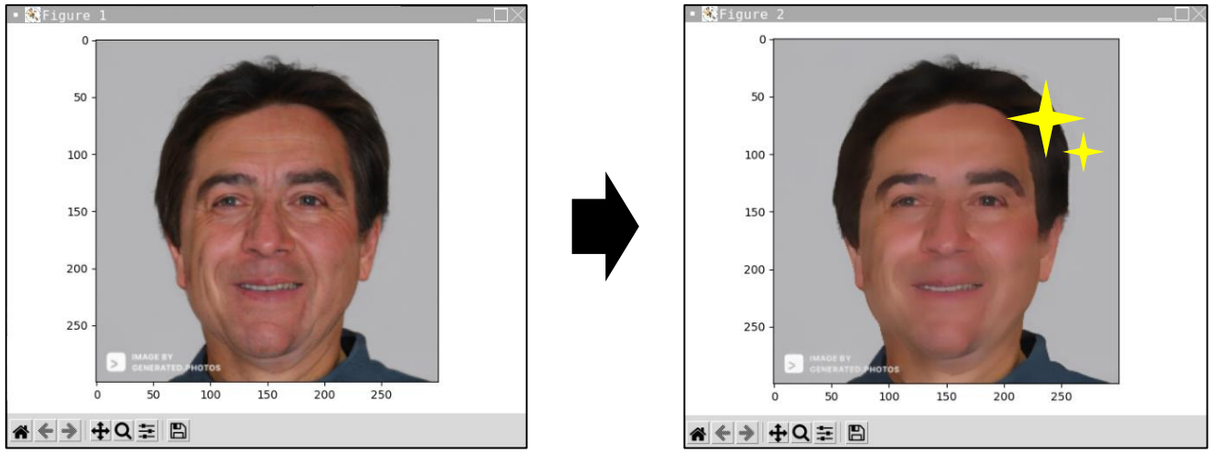
→ Multiply a binary mask to black out unnecessary parts.

Discussion 5: Image cropping and resizing

→ Crop a specific region with slicing, and resize the image.

Discussion 6: Photoshop - bilateral filter

→ Let's see how to do “photoshop” with a basic filtering algorithm.



Randomly generated face image (AI model) from https://generated.photos/face-generator/new

Discussion

<Image Processing Puzzle 2>
Please paste your result images (screenshot or save) in this report if needed.

Discussion 2-3: Shifting image
2.7. Try yourself! Please try to use “dimension reduction”.

2.8. Please visualize your output image.

Discussion 4 - Image multiplication
4.1. Please load a ground truth (GT) array from 'samples/puzzle2/gt1.npy'

4.2. Please convert 'im' to look like 'gt1' by multiplying the binary mask.

4.3. What is broadcasting?

4.4. What are the rules for allowing broadcasting?

Discussion 5: Image cropping and resizing
5.1. Crop the image (cat's eye) by array slicing.

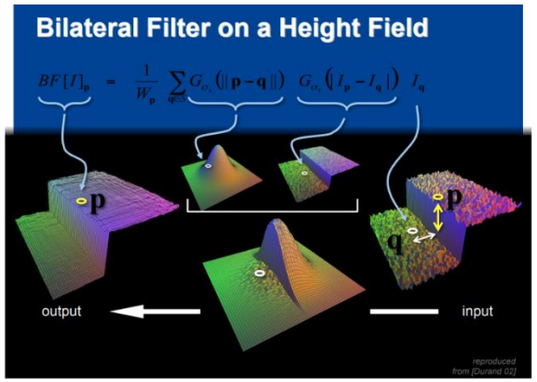
5.2. Increase the size of the "cat's eye" image to 400 x 400. Please discuss the difference between "rescale" and "resize".

Discussion 6: Photoshop - bilateral filter
6.1. Please capture random faces from "https://generated.photos/face-generator/new"

6.2. Please apply a "bilateral filter" on the image.

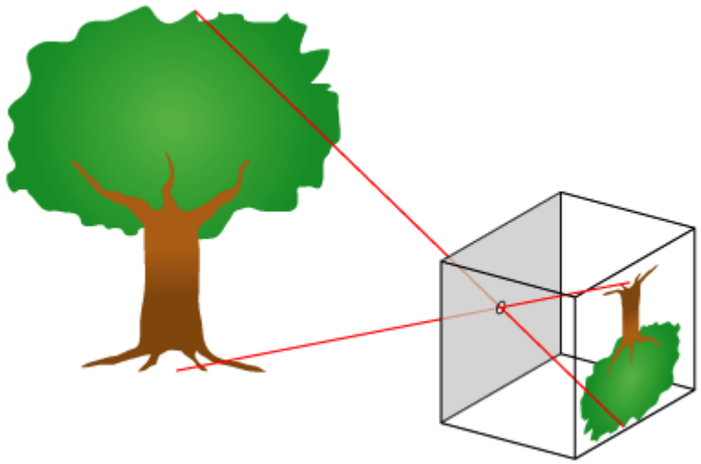
6.3. Please analyze the effect of the bilateral filter by changing the input parameters.

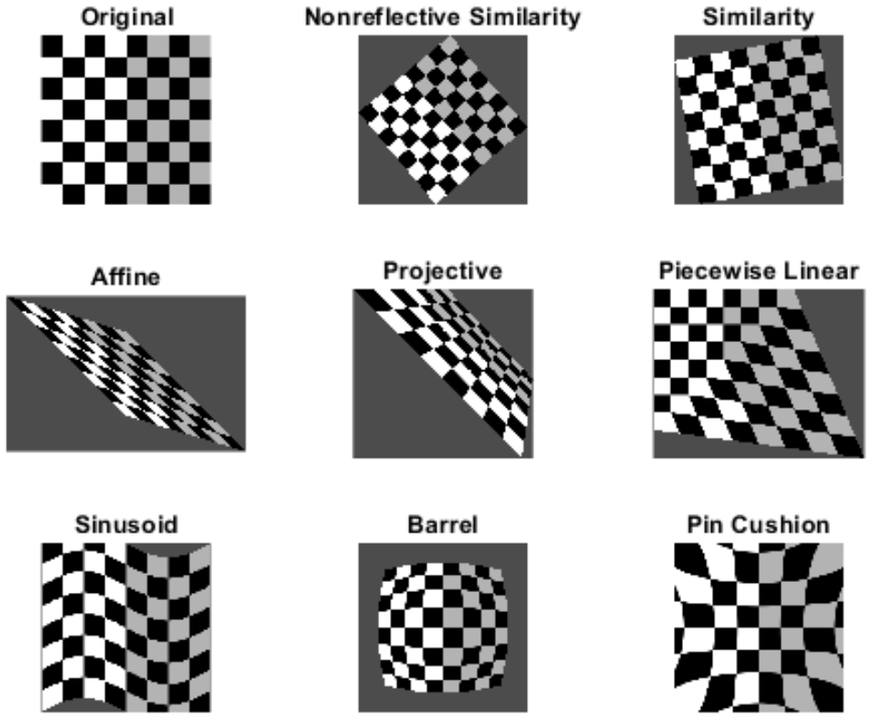
6.4. What are the pros and cons of filtering?



Next Contents

- Basic camera theory
  - Pinhole camera model
- Camera geometry





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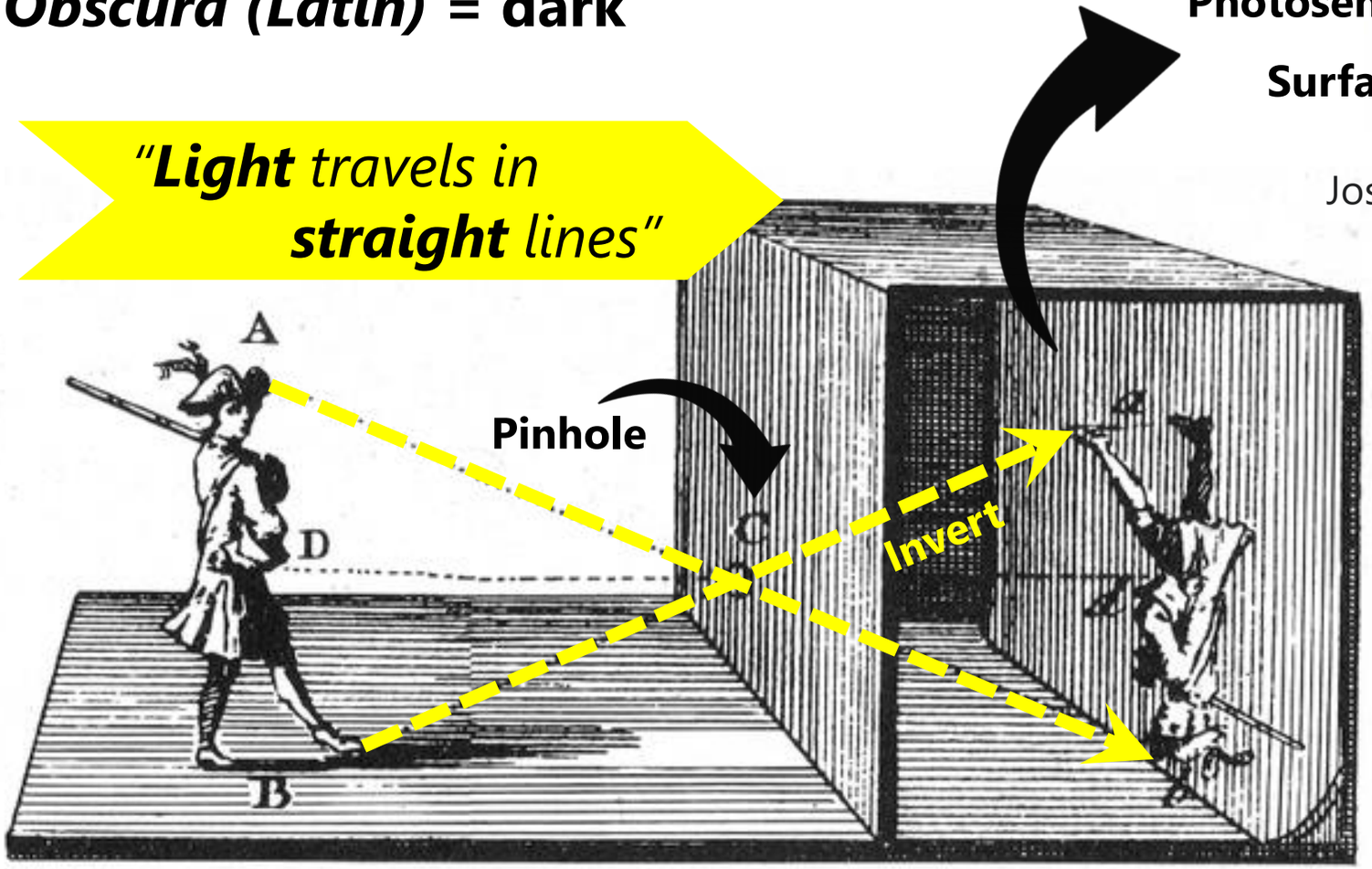
Brief Overview of Pinhole Camera Model

Camera Obscura – *Darken Room*

Camera (Latin) **= room or chamber**

Obscura (Latin) **= dark**

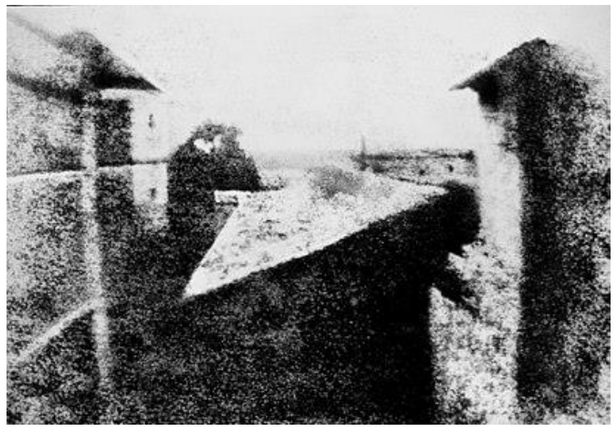
*"**Light** travels in **straight** lines"*



Photosensitive Surface

Joseph Nicéphore Niépce
(1765 – 1833)

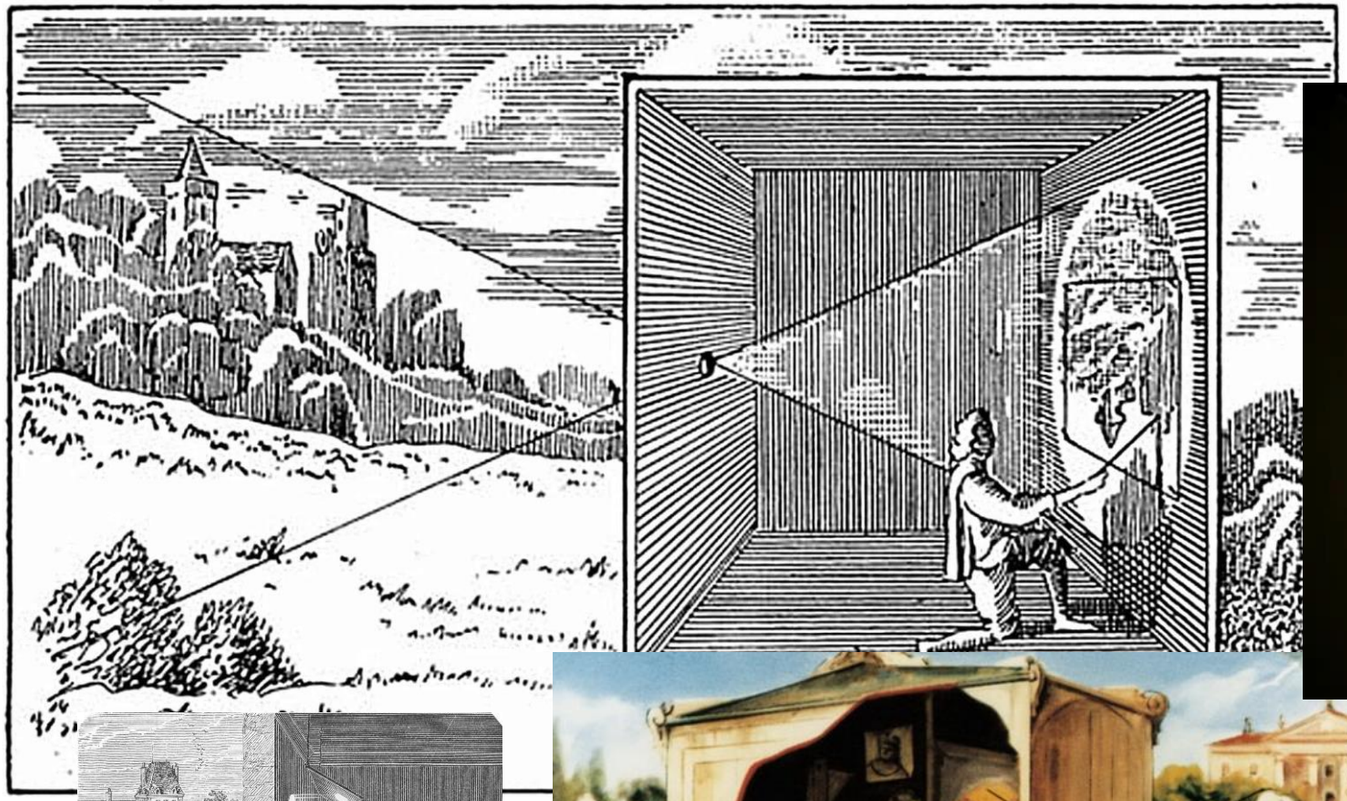
The inventor of photography

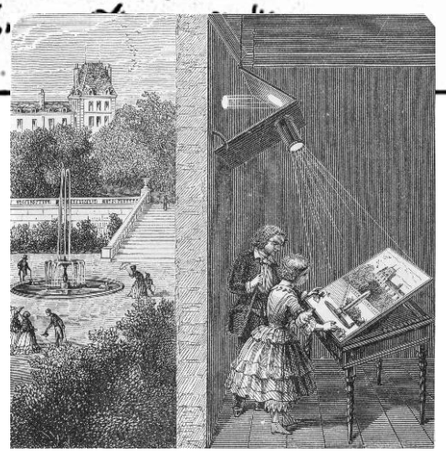


The first photograph

→ It took 8 hours

Camera Obscura – Based on *Art*





Amazing, cheap, fun way to experiment during COVID-19 quarantine

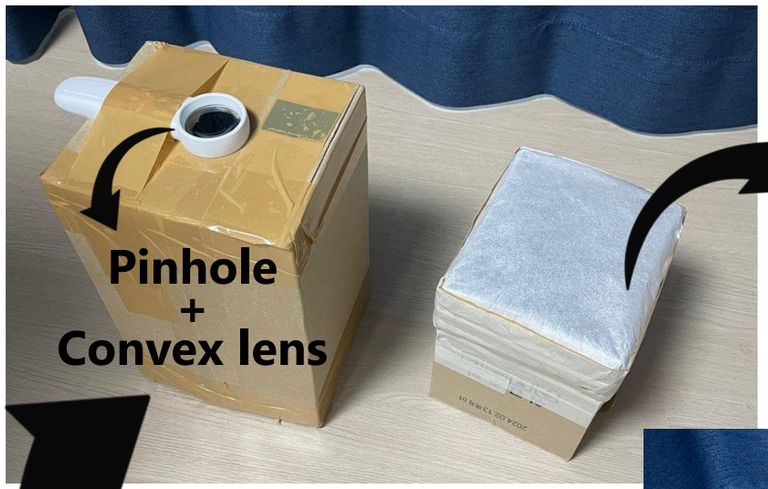
By Mathieu Stern

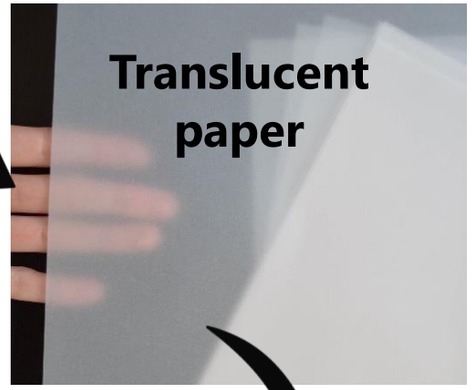
Inviting nature into your home!

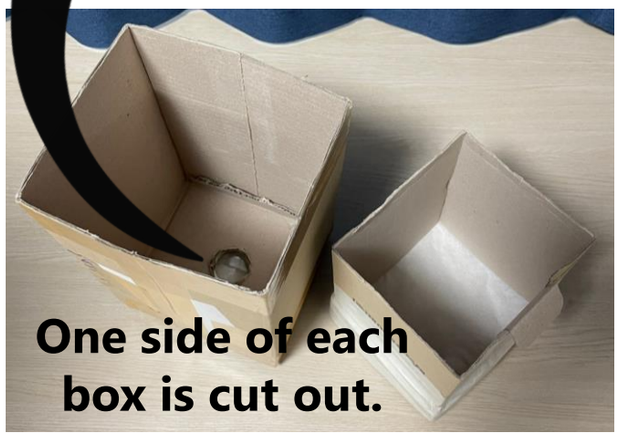
Agents of Change: Camera Obscura (Art Land Magazine)

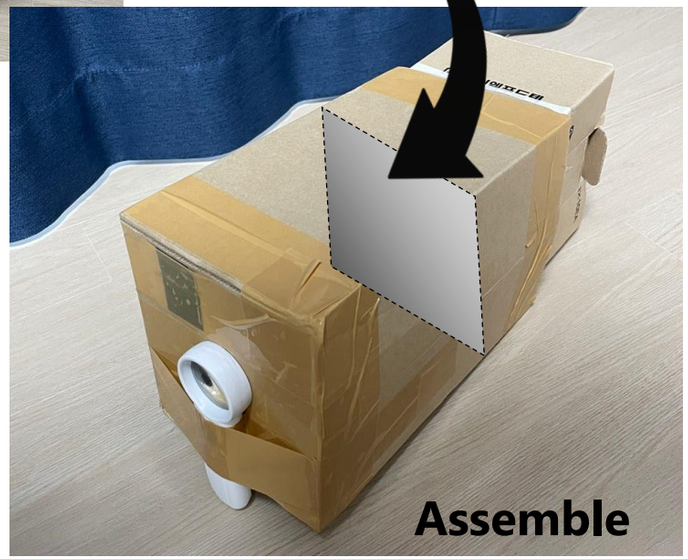
Camera Obscura – Making

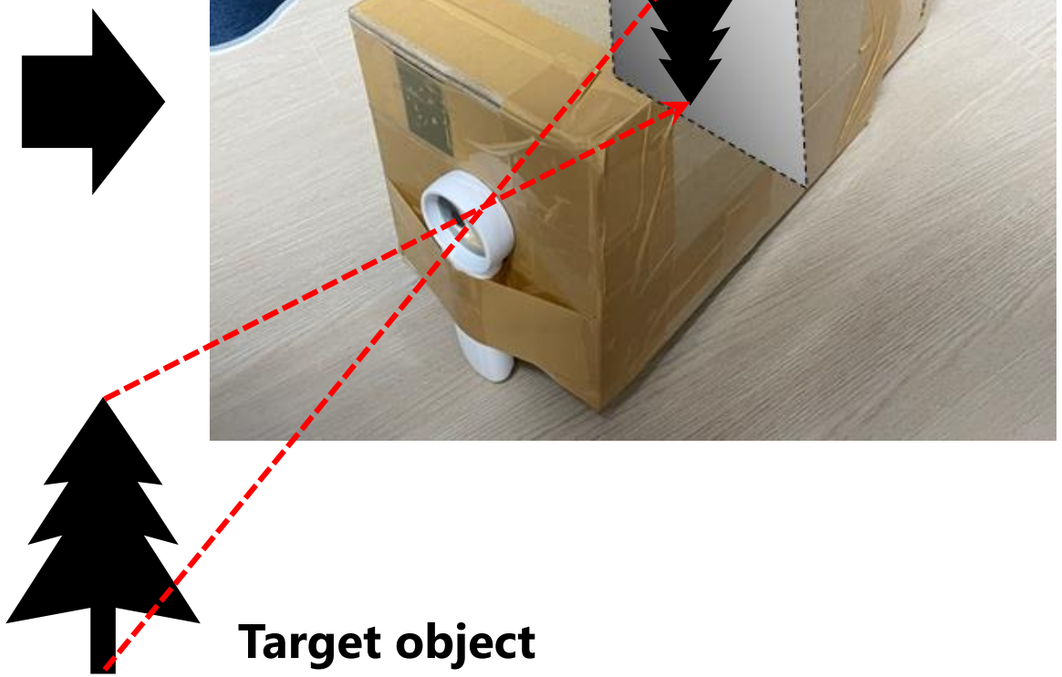
Preparation: two boxes, convex lens, translucent paper







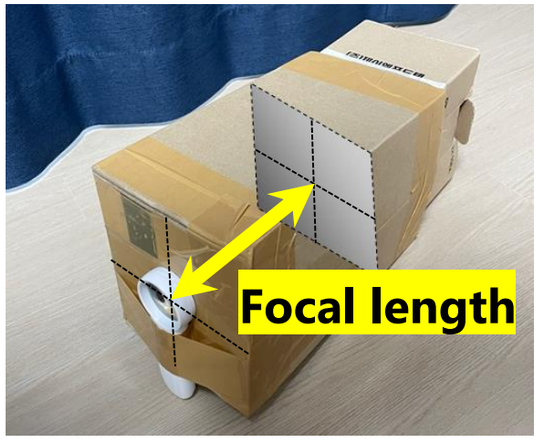




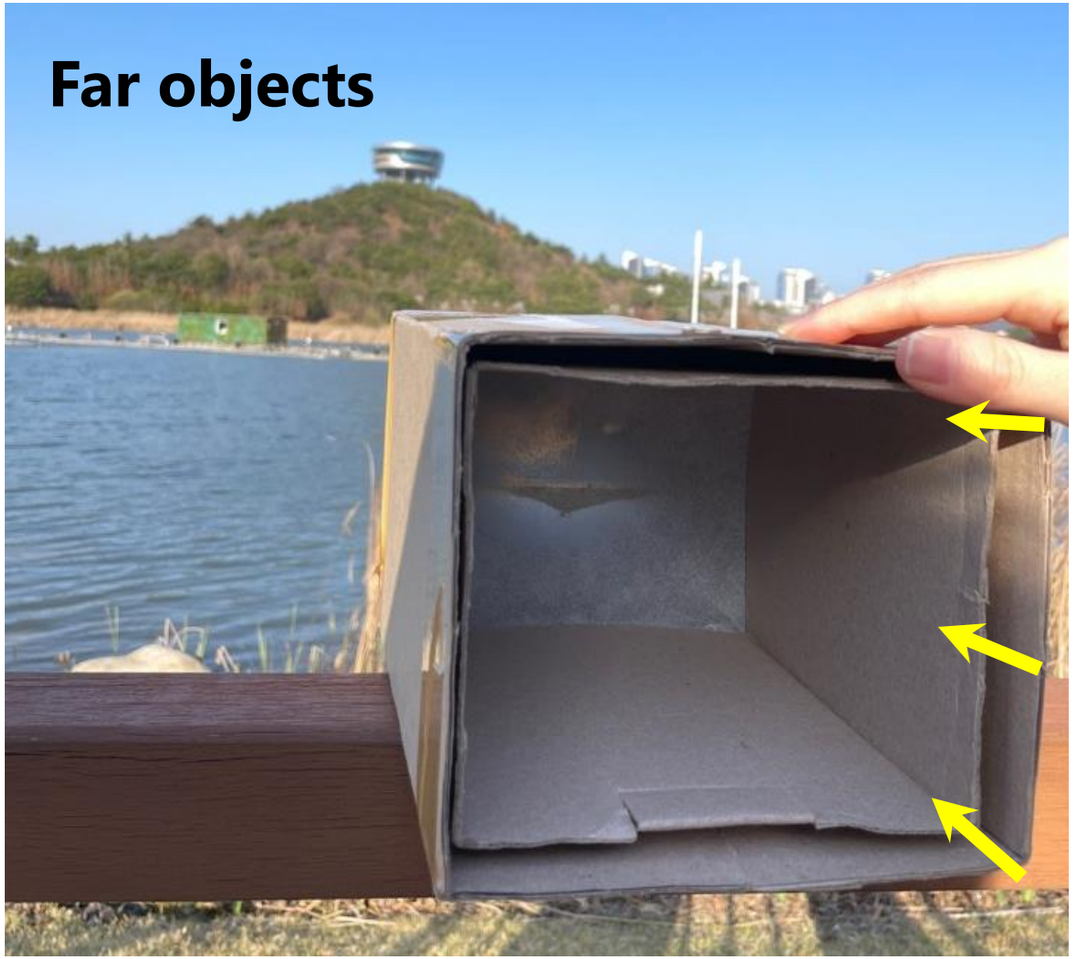
Camera Obscura – Experiments

Camera Obscura – About Focal Length

Near objects



Far objects

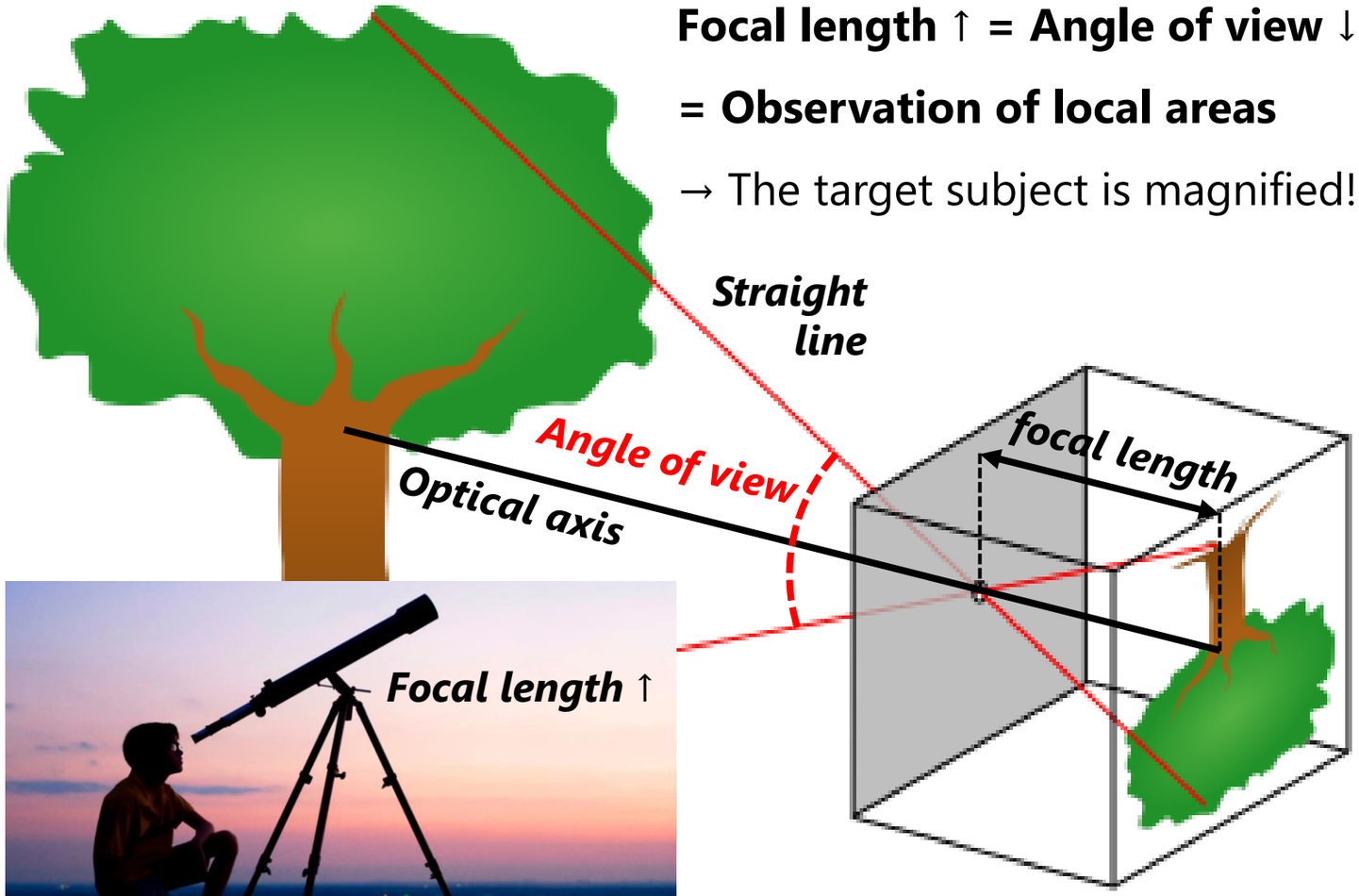


→ **Near** objects: focal length ↑

→ **Far** objects: focal length ↓

Pinhole Camera Model

Simplified example of ray optics



Focal length ↑ = Angle of view ↓

= Observation of local areas

→ The target subject is magnified!

We will make it!

***Resolution** (for image, “spatial”)

→ The number of pixels in each dimension

***Frame rate** (for video, “temporal”)

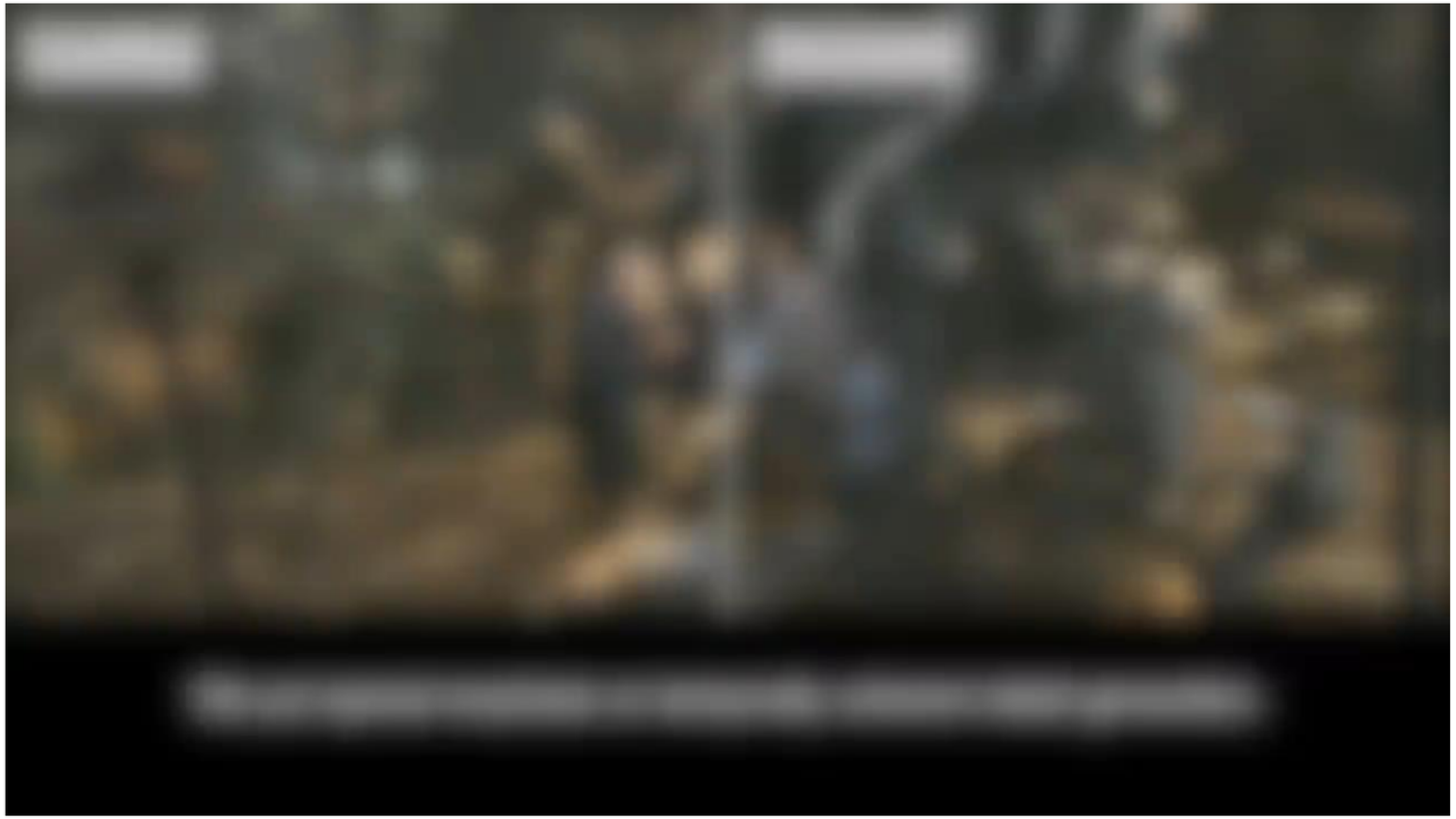
→ The number of image frames per second

Screen = Photographic film = CCD sensor

About Resolution

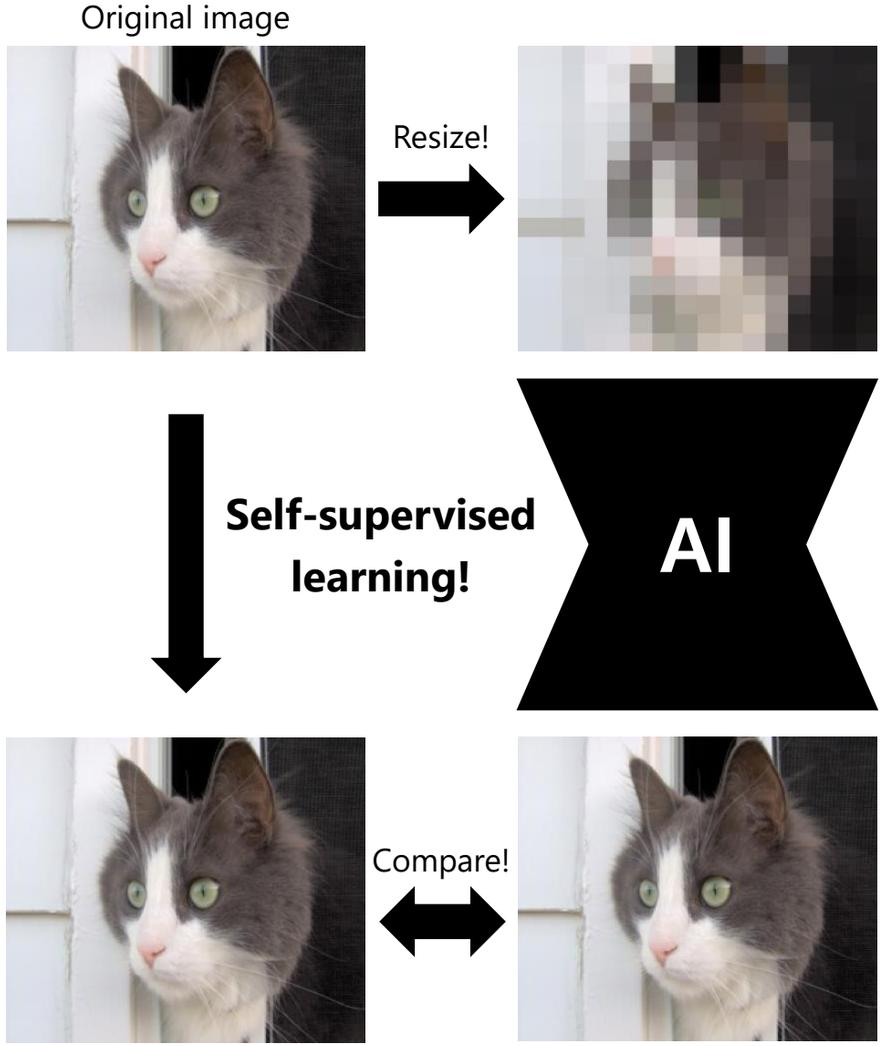
Example of deep learning application:

→ Image super resolution, "**spatial** processing"



TecoGAN (*SIGGRAPH'19*)

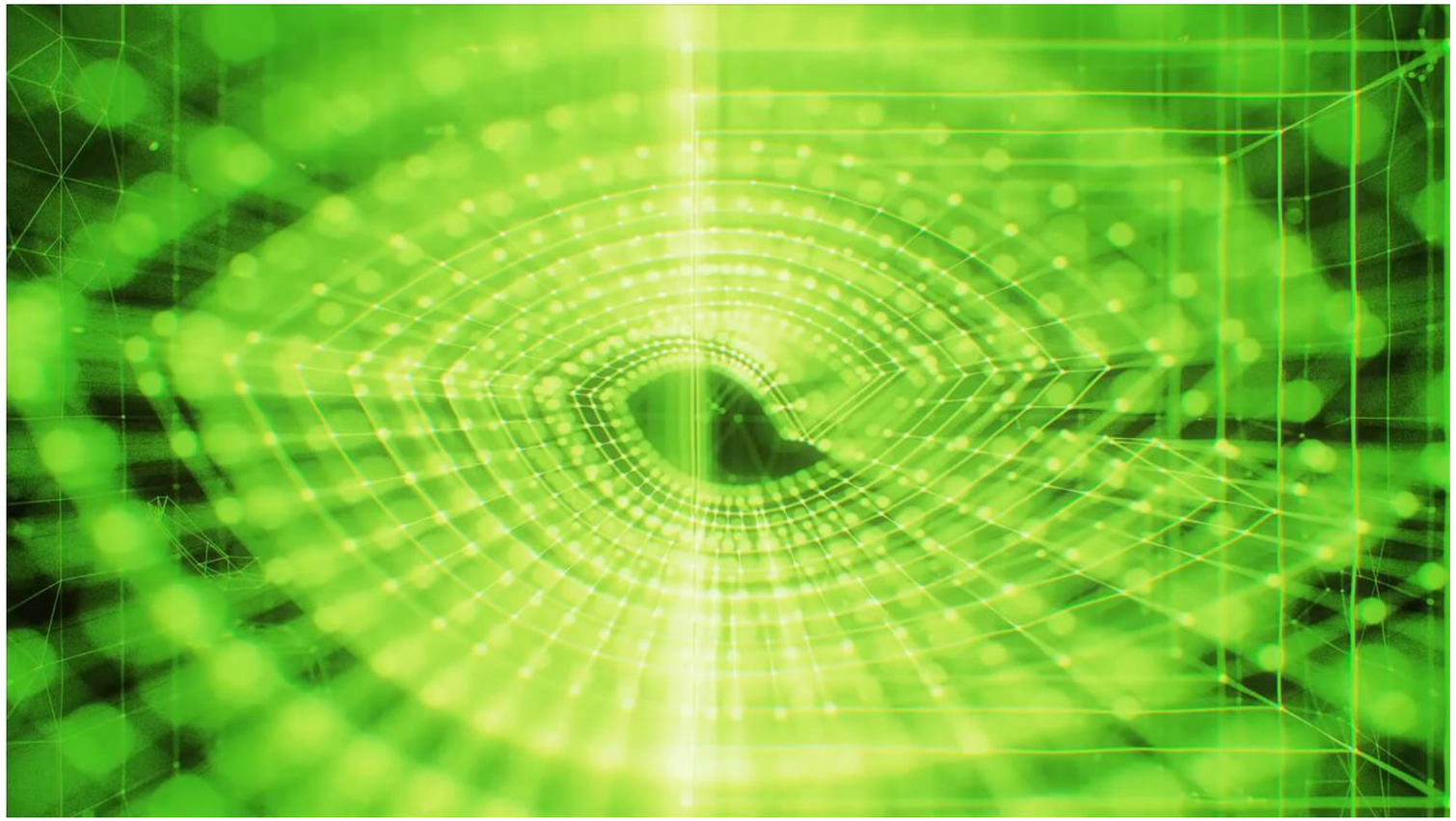
How to train?



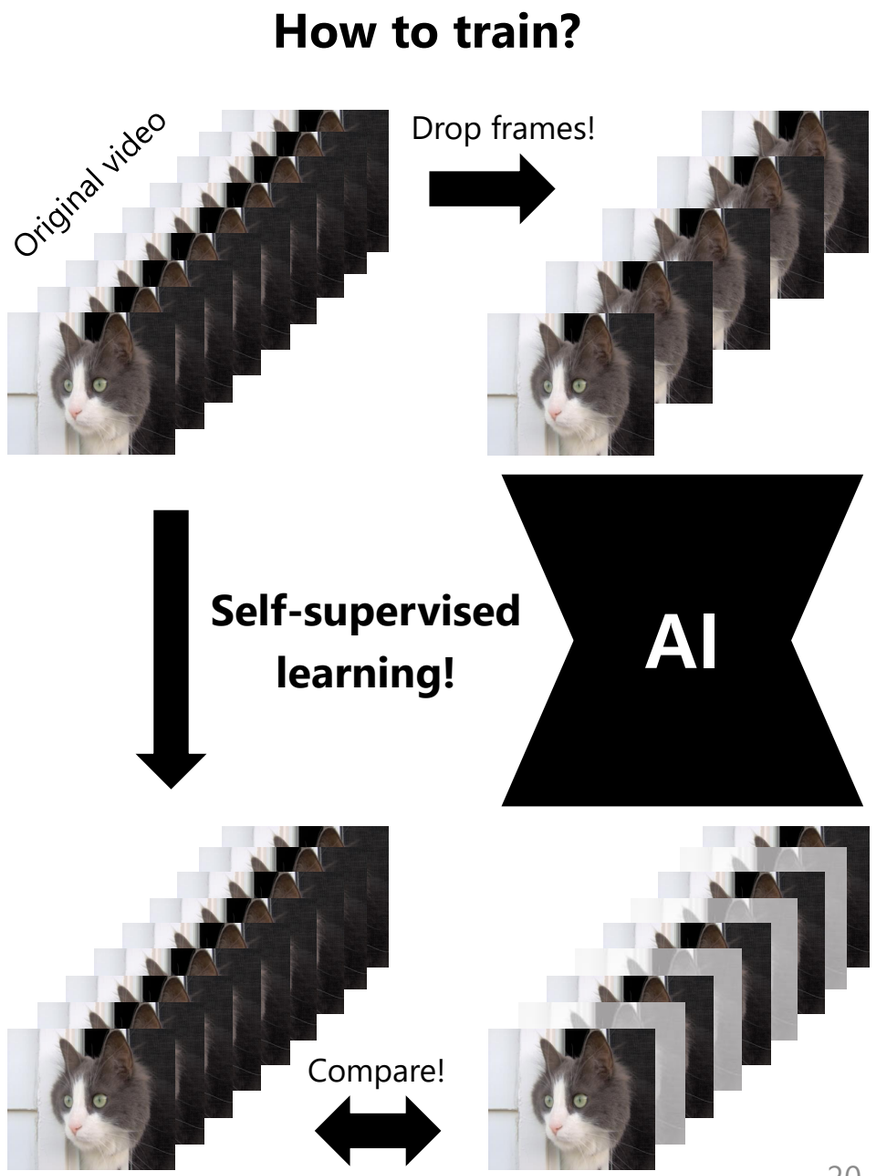
About Frame Rate

Example of deep learning application:

→ Video frame interpolation, "**temporal** processing"



Transforming Standard Video Into Slow Motion with AI
(Research at NVIDIA, 2018)



About Shutter Speed

A.k.a., exposure time:

The length of time that the digital sensor inside the camera is exposed to light

→ **How shutter speed affects motion.**

"The faster your shutter speed,
the sharper your image will be."

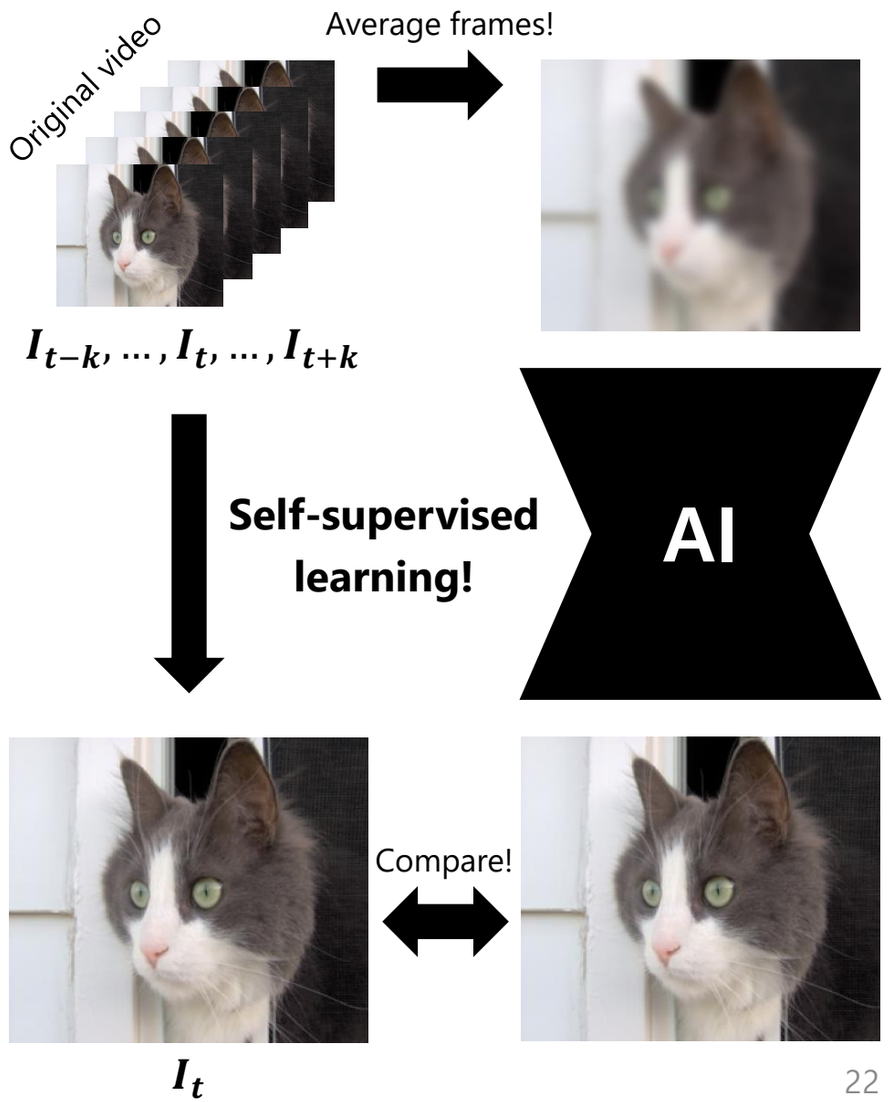
mrs-cook.weebly.com

About Shutter Speed

Example of deep learning application:

→ Motion deblurring

Fix Blurry Photos with Motion Deblur AI (by AKVIS, 2021)

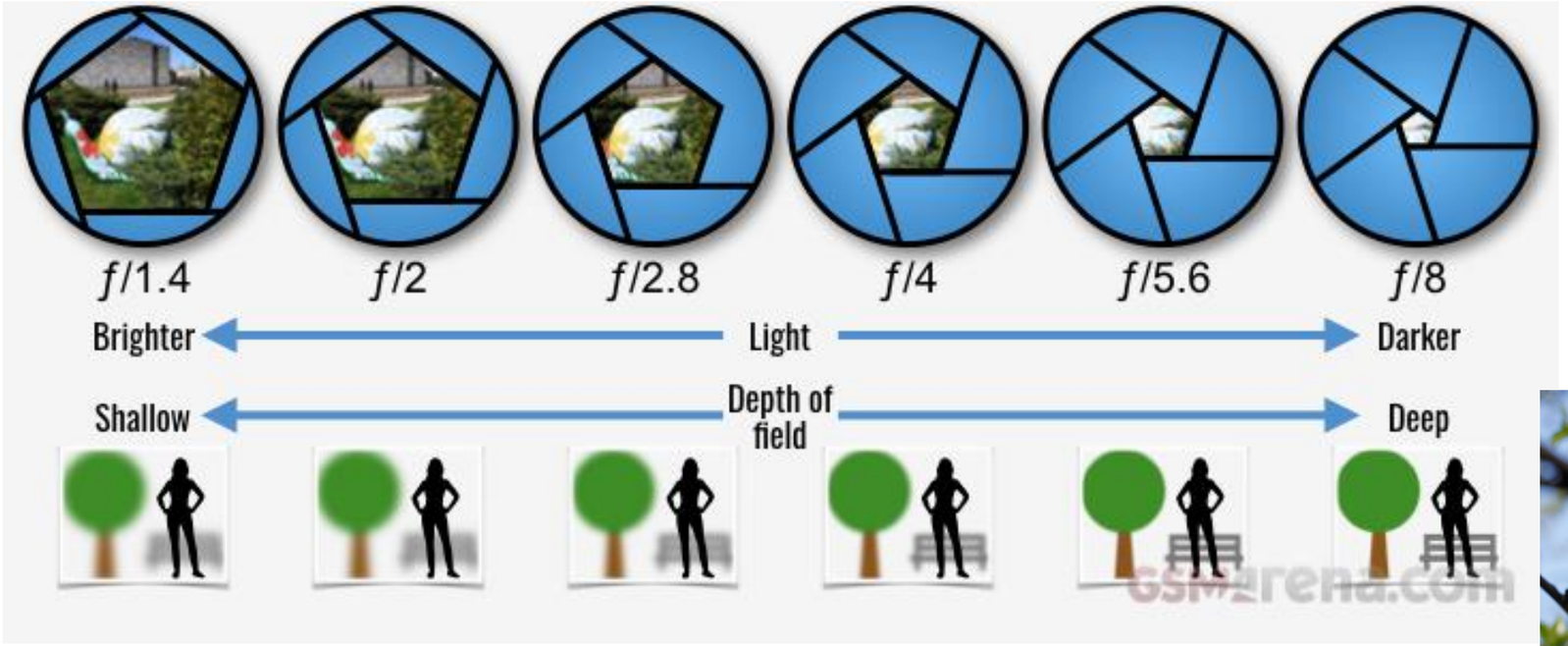


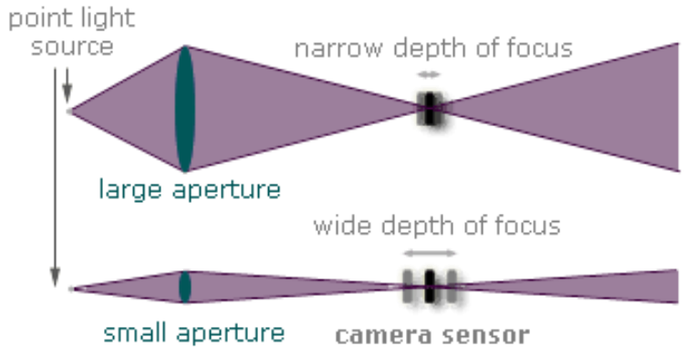
Aperture

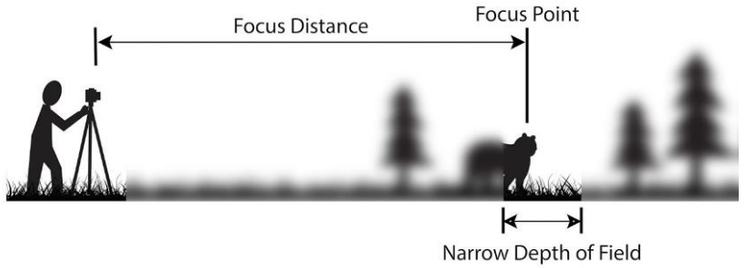
A hole through which light travels

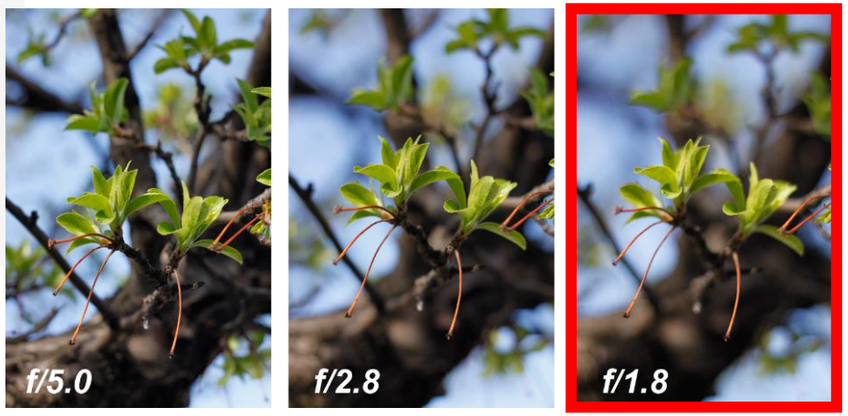
→ Controls the amount of the light

→ Controls depth-of-field (DoF)









Out focus
= **shallow** depth of field

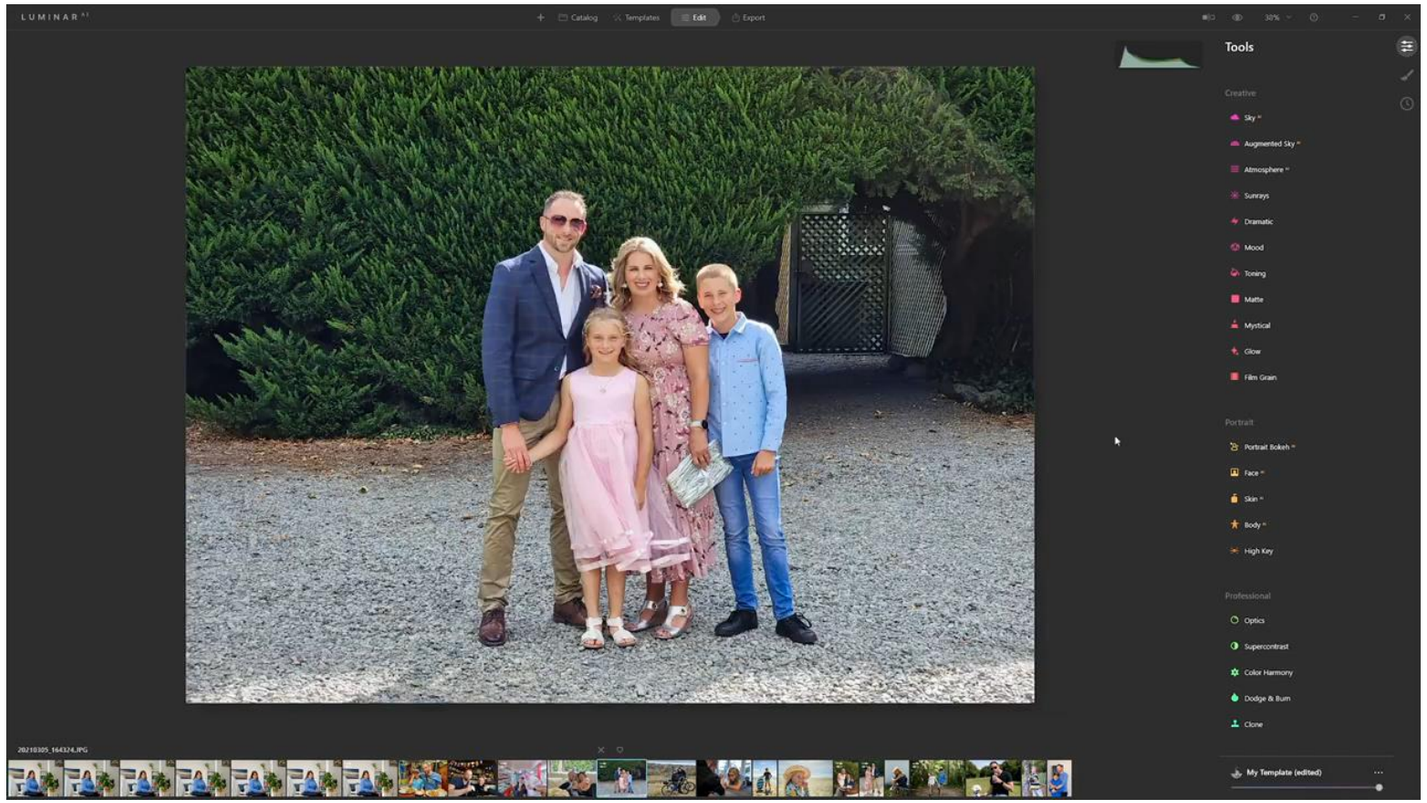
→ Helps concentrate on the subject!

[1] gsmarena.com [2] boostyourphotography.com [3] cambridgeincolour.com

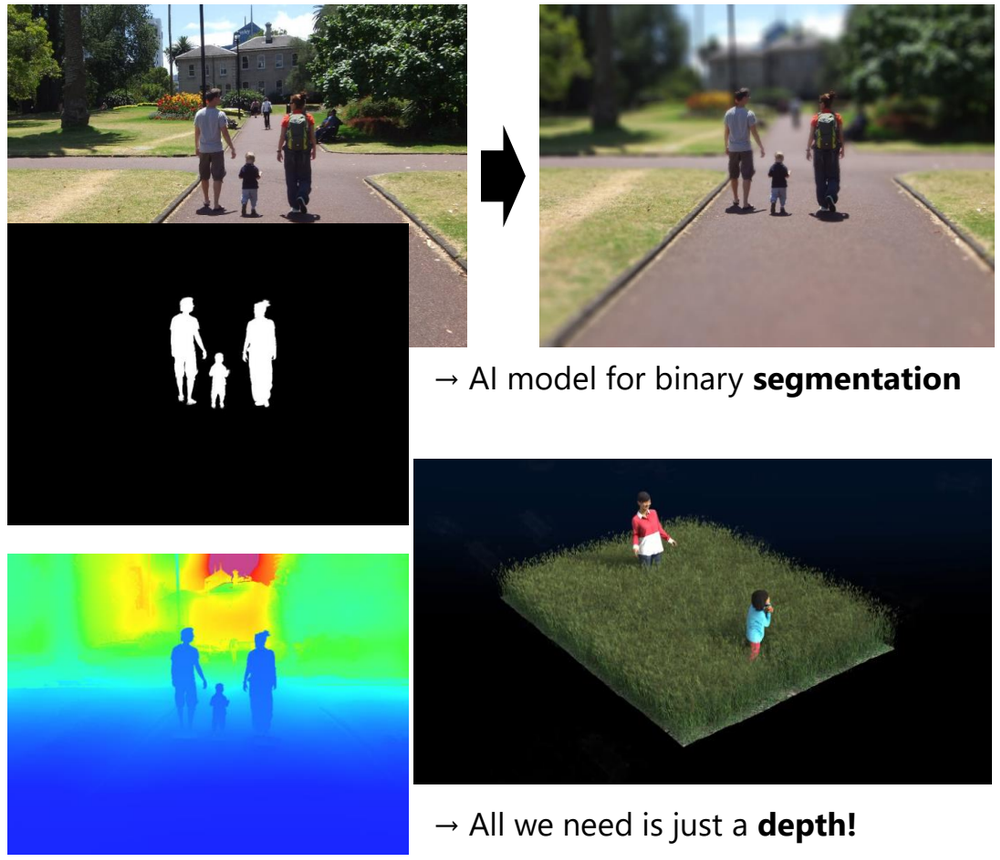
Out Focusing

Technically difficult for smartphone cameras 🤔

→ Computer vision & AI make this possible!



Automatic bokeh by Luminar AI (2021)



→ AI model for binary **segmentation**

→ All we need is just a **depth!**

[1] Liu, et al., “Bokeh Effects Based on Stereo Vision” (2015)

Summary of a Basic Camera Model

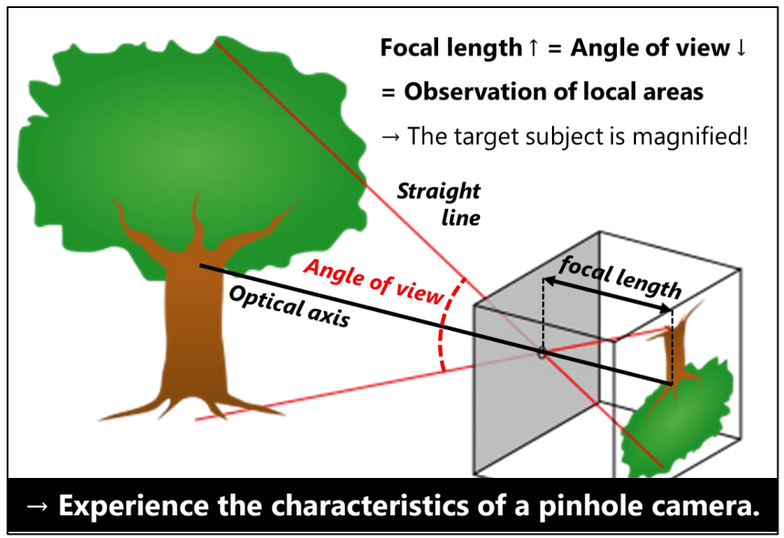
Characteristics of a pinhole camera

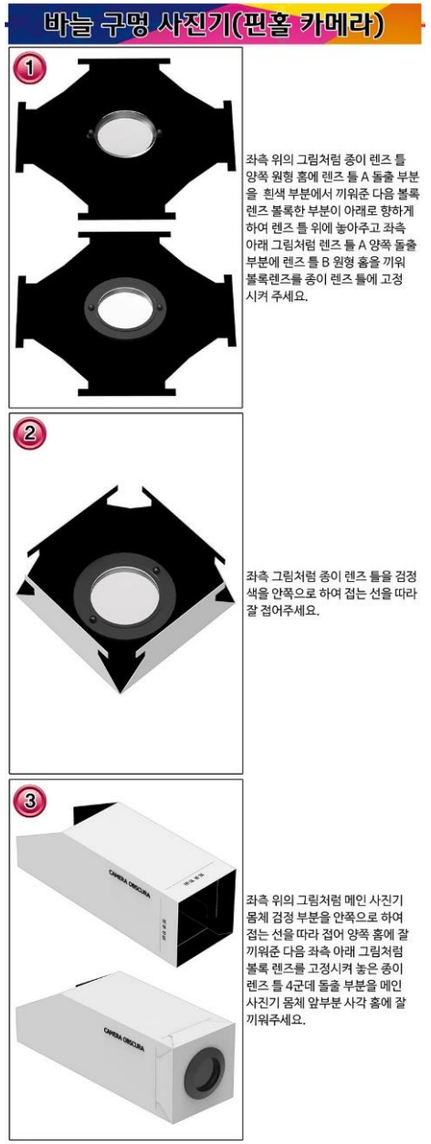
- Camera obscura
- Focal length
- Aperture & depth of field
- Shutter speed & exposure time

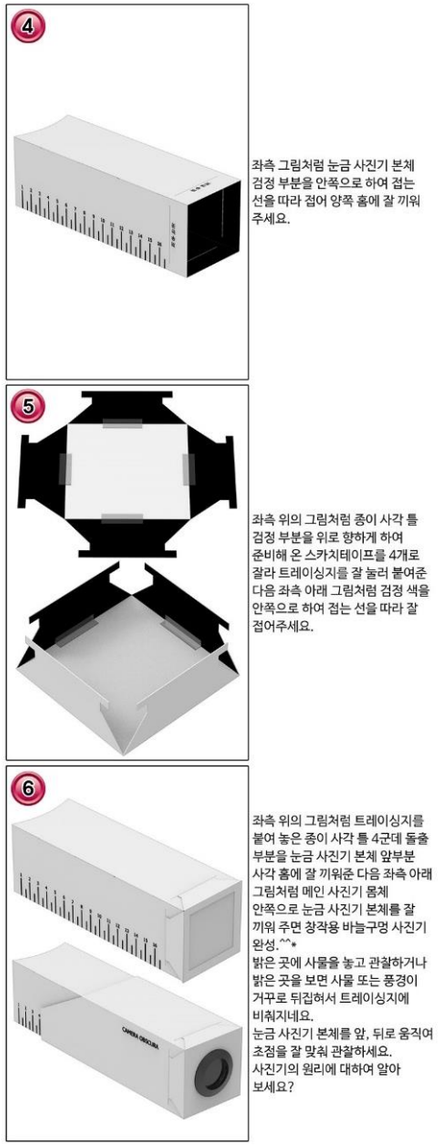
What AI can enhance images and videos

- Self-supervised learning
  - Image super resolution
  - Video frame interpolation
  - Motion deblurring
- Segmentation and depth
- 3D photography

Let's Make a Pinhole Camera







Discussion

<Pinhole Camera Quiz>
True or False?

Q1. Decreasing the focal length makes the object smaller. [True / False]

Q2. Increasing the focal length makes the field-of-view smaller. [True / False]

Q3. Increasing the size of aperture makes the photo darker. [True / False]

Q4. Increasing the size of aperture makes the depth-of-field shallower. [True / False]

Q5. Decreasing the shutter speed makes the photo sharper. [True / False]

Q6. Increasing the exposure time makes the photo brighter. [True / False]

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Camera Calibration

Camera Calibration?

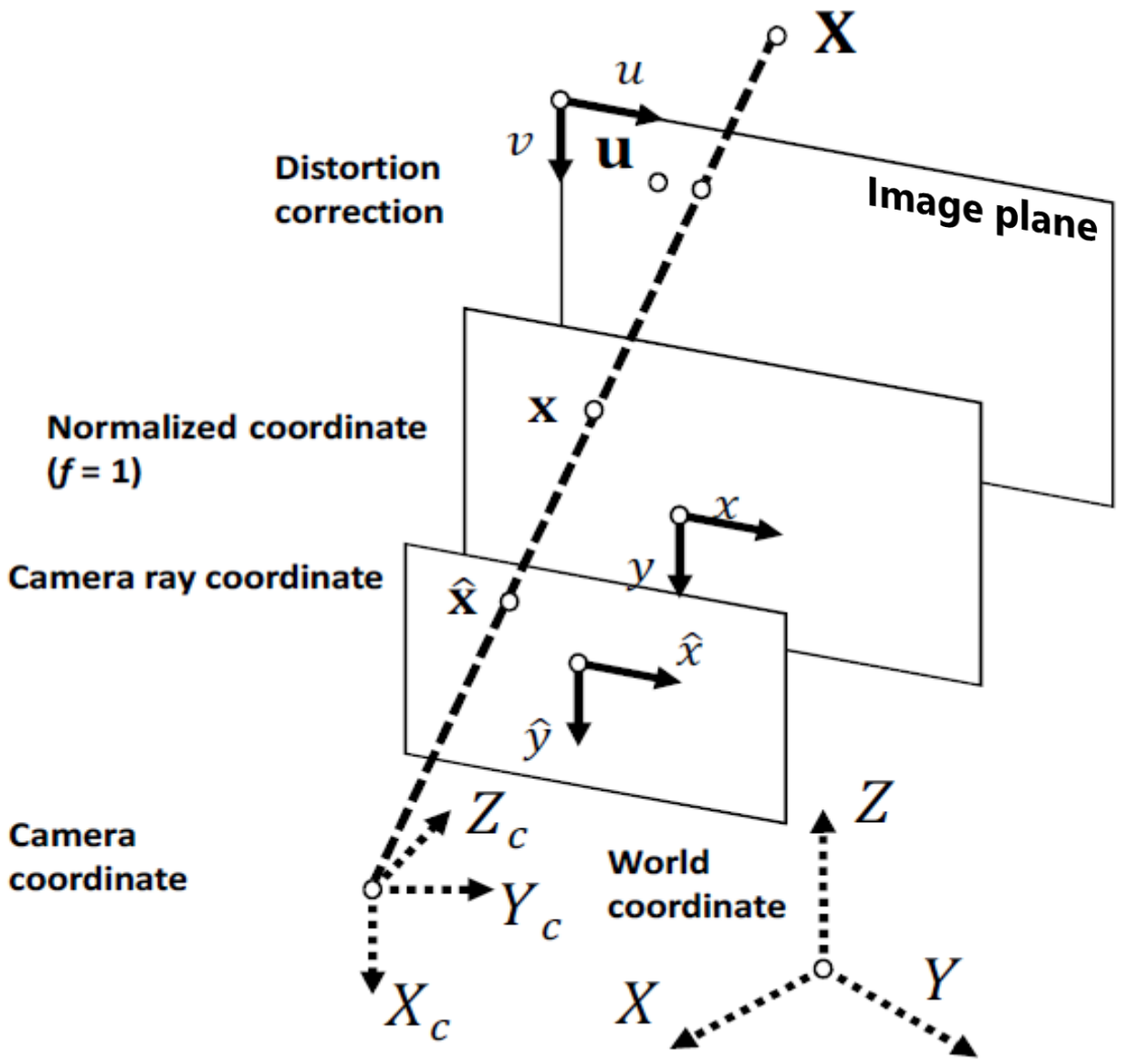
- ✓ Process of estimating the **parameters** of a pinhole camera model.
- ✓ Determines which **incoming light (3D)** is **associated with** each pixel on the resulting **image (2D)**.
- ✓ In an ideal pinhole camera, **a simple projection matrix** is enough to do this.
- ✓ The camera projection matrix is derived from the **intrinsic** and **extrinsic** parameters of the camera.

$$s\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & \text{skew\_c}f_x & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

$$= K[R|t] \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

- (X, Y, Z): 3D point in the world coordinate
- $[R|t]$: extrinsic parameters to convert the world coordinate into the camera coordinate
- K: intrinsic parameters to represent the camera characteristics
- $K[R|t]$: camera projection matrix
- (x, y): 2D pixel location in the image plane
- s: scale factor

Camera Geometry: 3D → 2D



$$\mathsf{X}_C = \begin{bmatrix} R & T \\ 0^T & 1 \end{bmatrix} \mathsf{X}$$

$$(X_C, Y_C, Z_C)^T \mapsto (\hat{x}, \hat{y}) = \left(\frac{fX_C}{Z_C}, \frac{fY_C}{Z_C}\right)^T$$

$$\hat{\mathbf{x}} = \begin{bmatrix} \hat{x} \\ \hat{y} \\ f \end{bmatrix} = \frac{1}{Z_C} \begin{bmatrix} f & & 0 \\ & f & 0 \\ & & f \quad 0 \end{bmatrix} \begin{bmatrix} \mathsf{X}_C \\ 1 \end{bmatrix}$$

$$f = 1$$

$$\mathsf{x} = \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = [R \mid T]X$$

$$\mathbf{u} = \mathsf{K}\mathsf{x}$$

$$\mathbf{u} = \mathbf{K}[\mathbf{R}|\mathbf{T}]\mathbf{X}$$

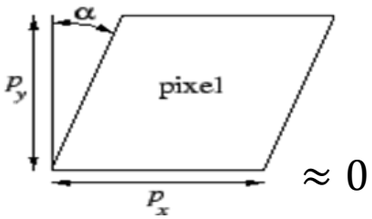
Intrinsic Parameters

✓ The intrinsic matrix $\boldsymbol{K}$ contains 5 intrinsic parameters of the specific camera model.

→ Focal length: f_x, f_y

→ Principal point: c_x, c_y

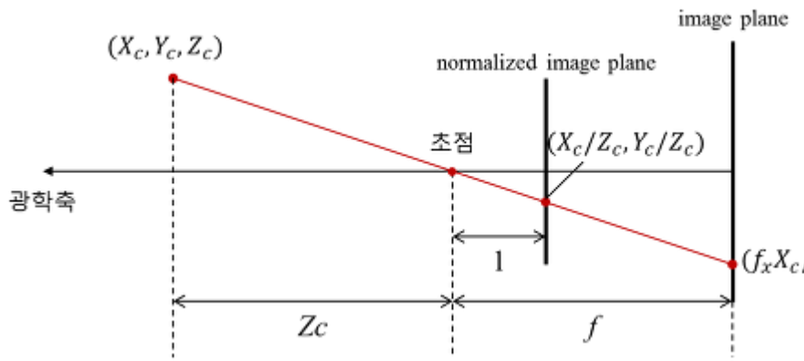
→ Skew coefficient (y-axis slope of the image sensor): $skew_c = \tan(\alpha)$



≈ 0

$$s\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & \text{skew\_c}f_x & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

$$= K[R|t] \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$



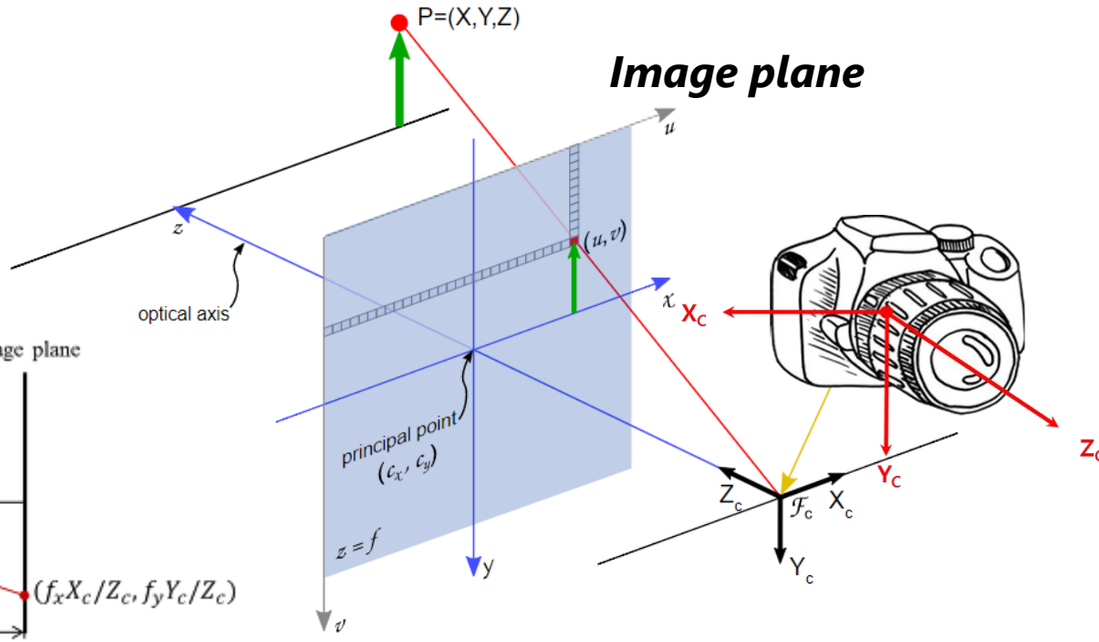


Figure by NVIDIA

Extrinsic Parameters

✓ Transformation matrix from 3D world coordinates to 3D camera coordinates

→ Rotation ($\boldsymbol{R}$, 3×3 matrix) + Translation ($\boldsymbol{t}$, 3×1 matrix)

$$s\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & \text{skew\_c}f_x & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

$$= K[R|t] \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

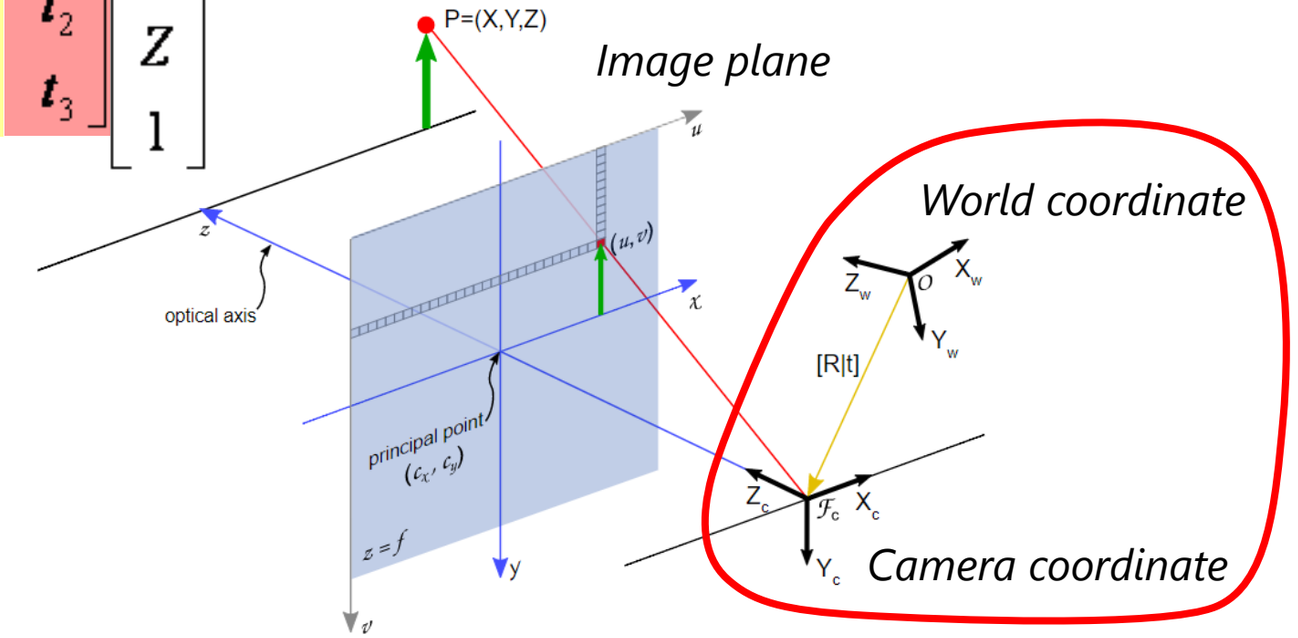
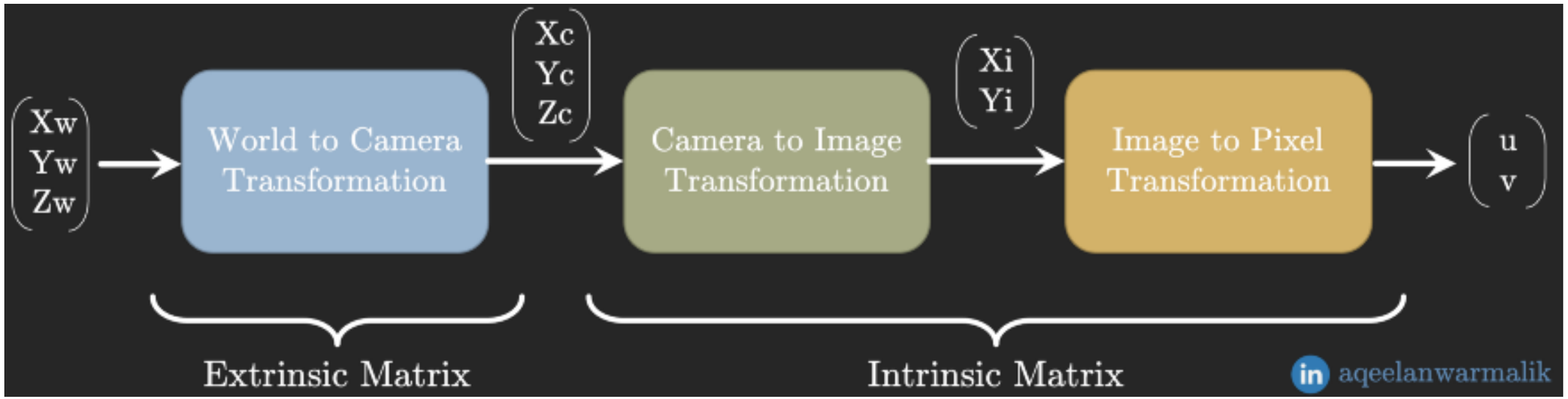


Figure by NVIDIA

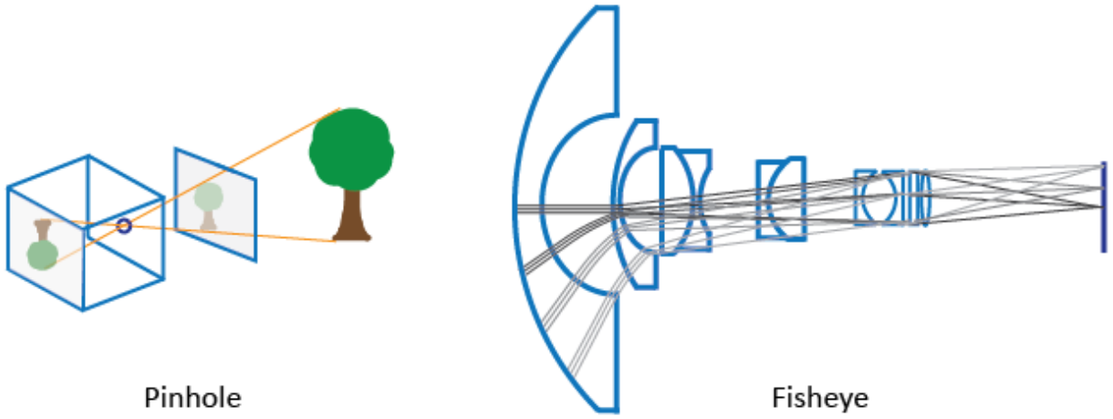
Summary: 3D to 2D Projection

1. **World-to-Camera**: 3D-3D projection. Representation of Rotation + Scaling + Translation.
   → **Camera extrinsic matrix**: depends on the position and orientation of the camera.
2. **Camera-to-Image**: 3D-2D projection. Loss of information. Requires pinhole camera model and its parameters.
   → **Camera intrinsic matrix**: depends on camera properties (e.g., focal length, pixel dimensions, resolution, etc.)
3. **Image-to-Pixel**: 2D-2D projection. Continuous to discrete. Quantization + Origin shift.



+ Camera Lens Distortion

✓ For the wider Field-of-View (FoV), various types of lens are used.



Different types of the distortion

Distorted image with wide FoV

+ Camera Lens Distortion → Undistortion

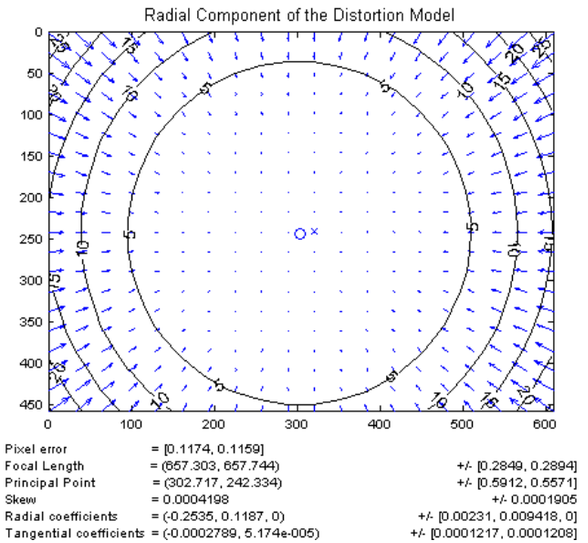
✓ Before camera calibration, we need to correct the image distortion.

Undistortion

Radial distortion model

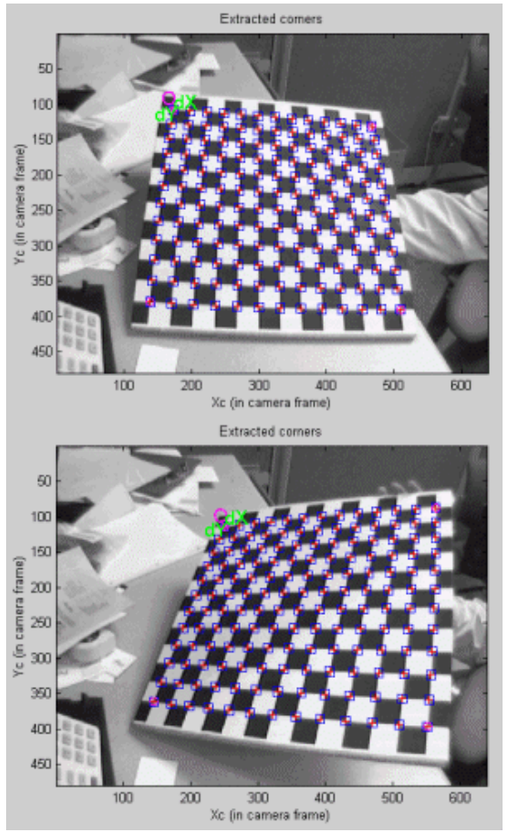
$$x_{\text{distorted}} = x\left(1 + k_1^* r^2 + k_2^* r^4 + k_3^* r^6\right)$$

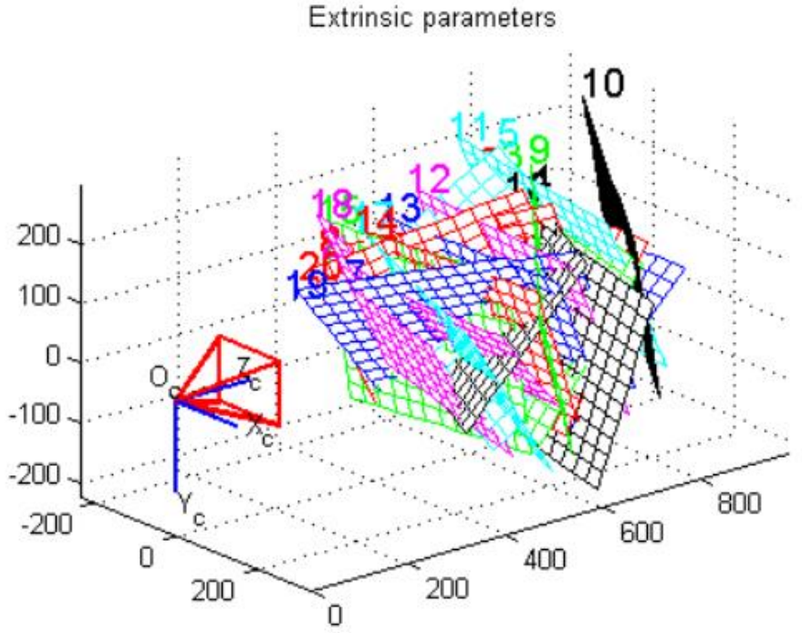
$$y_{\text{distorted}} = y\left(1 + k_1^* r^2 + k_2^* r^4 + k_3^* r^6\right)$$



How to Calibrate Pinhole Camera?

✓ Camera Calibration Toolbox [1]






```
Calibration results after optimization (with uncertainties):

Focal Length:          fc = [ 665.77415   665.77415 ] ± [ 2.42637   2.42637 ]
Principal point:       cc = [ 319.50000   239.50000 ] ± [ 0.00000   0.00000 ]
Skew:             alpha_c = [ 0.00000 ] ± [ 0.00000 ]   => angle of pixel axes = 90.00000 ± 0.00000 degrees
Distortion:            kc = [ 0.00000   0.00000   0.00000   0.00000  0.00000 ]
Pixel error:          err = [ 1.09184   0.99454 ]

Note: The numerical errors are approximately three times the standard deviations (for reference).
```

[1] http://robots.stanford.edu/cs223b04/JeanYvesCalib/htmls/example.html

Next Contents

- ✓ Python practice for basic camera geometry & image transformation
- ✓ Basic feature extraction & matching

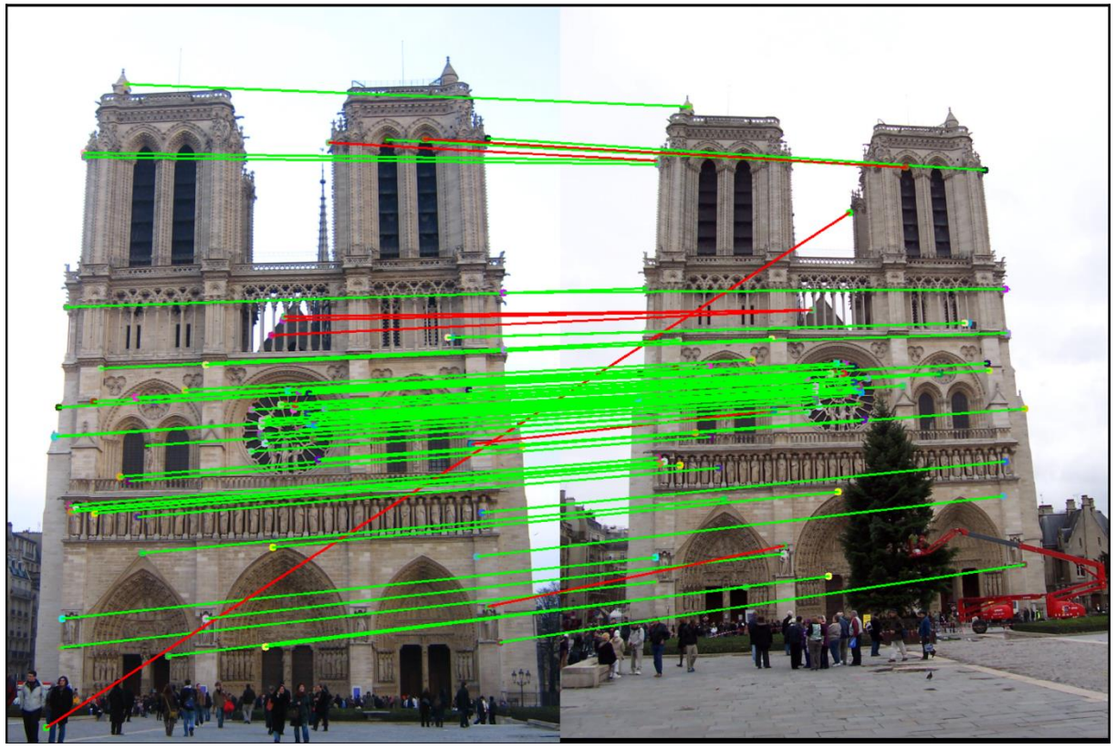


Figure by James Hays