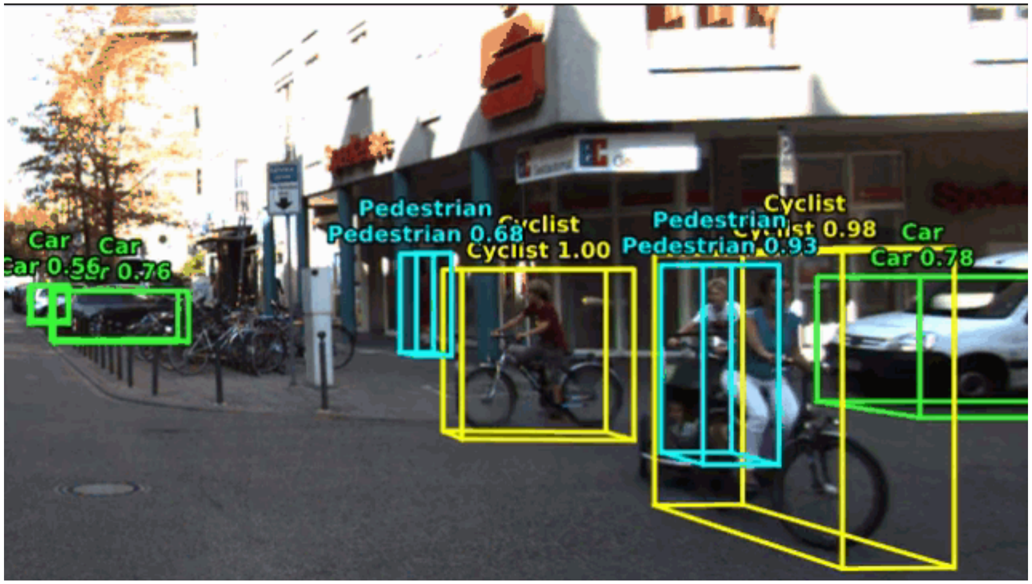
The Camera Sensor

Course 3, Module 1, Lesson 1 – Part 1

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE & ENGINEERING

The Camera Sensor



The Camera Sensor

- Captures detailed appearance information
- High rate of information capture
- Relatively inexpensive

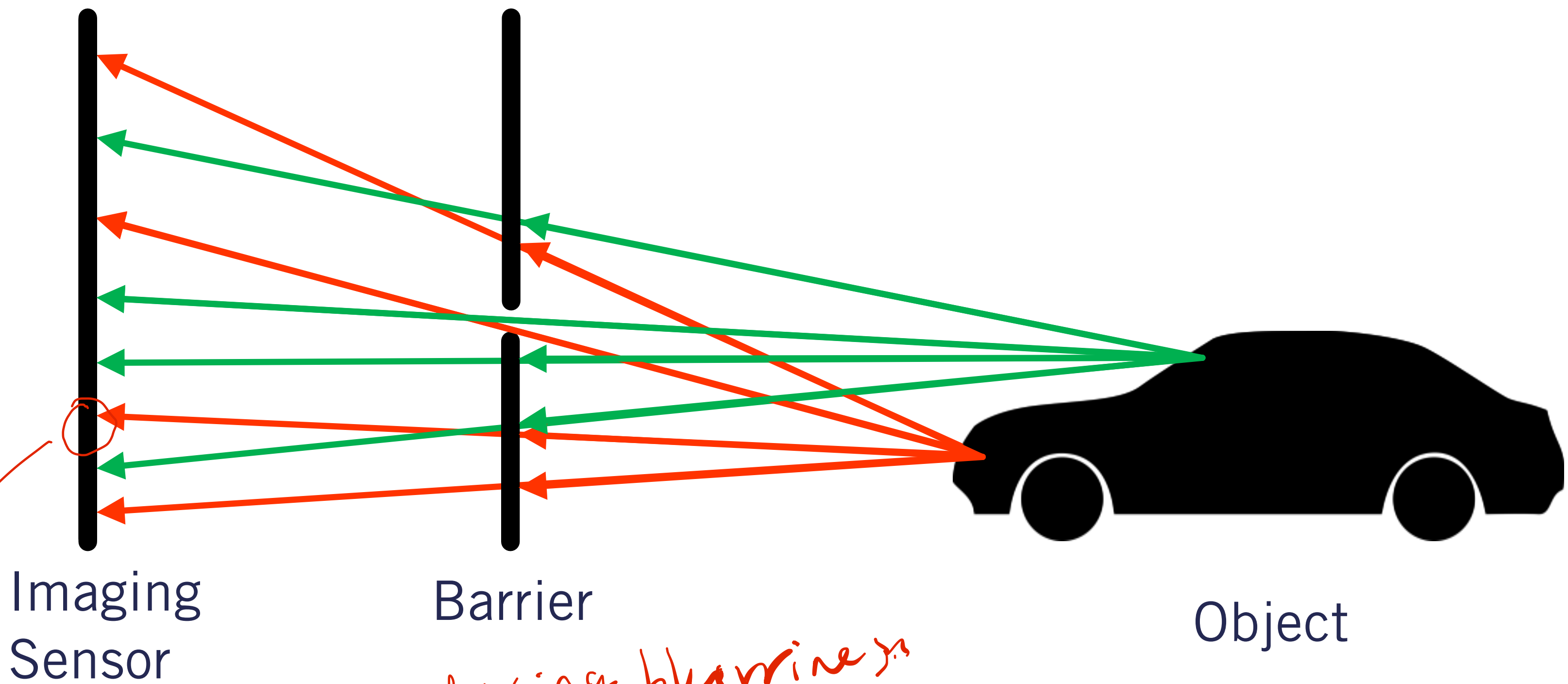
More information

object detection, segmentation & identification

Sam: Can we add this video of a camera sensor here? https://www.shutterstock.com/video/clip-1022389735-camera-repair-sensor-digital-close-up-matrix

Sam: This image of driving with lots of signs and lights for click 1: https://www.shutterstock.com/image-photo/busy-traffic-during-rush-hour-amsterdam-1069610642?src=bLnVCTgF8bcUNe81sHDIVw-1-39

Image Formation

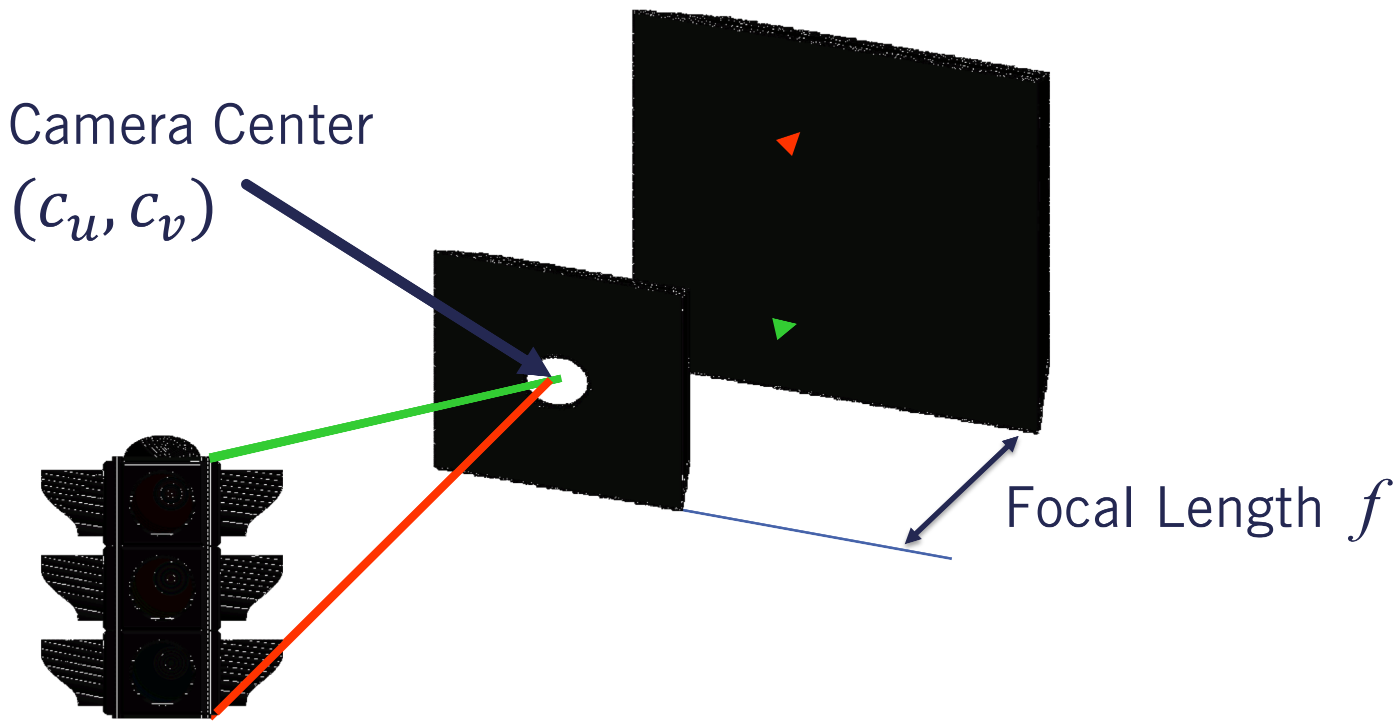


reducing blurriness

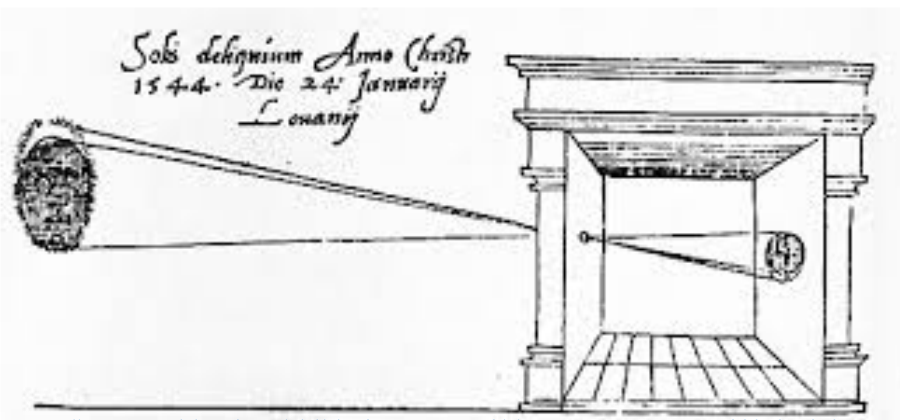
same location on sensor

multi light sources

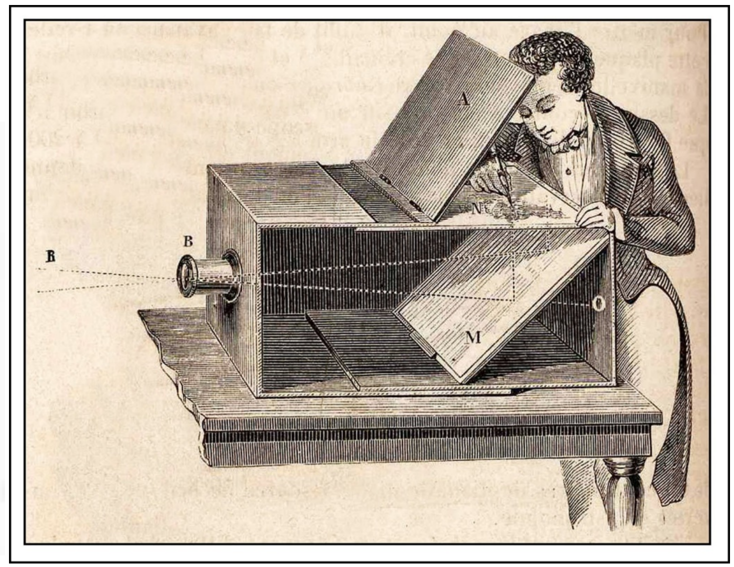
Pinhole Camera Model



Camera Obscura: 1544 A.D.

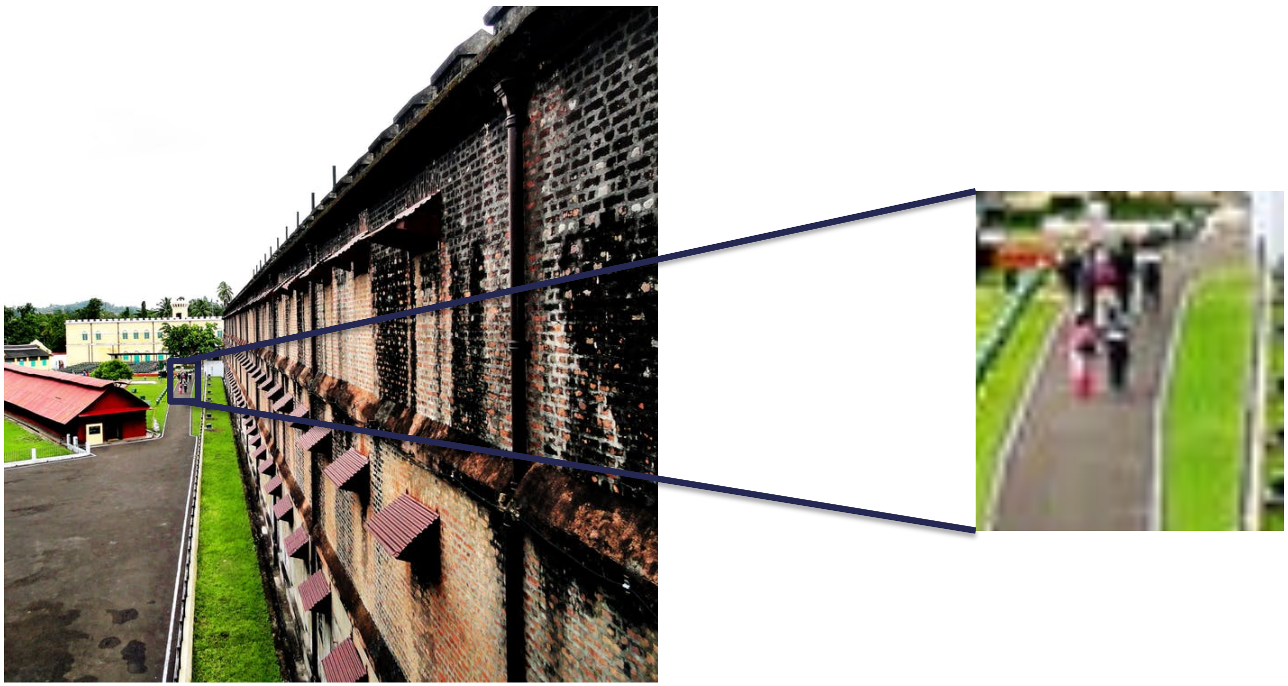


https://commons.wikimedia.org/wiki/File:1545_gemma_frisius_-_camera_obscura_-_121704_1_1.png



https://commons.wikimedia.org/wiki/File:Camera_Obscura_box18thCentury.jpg

Modern Day Cameras



https://www.pexels.com/photo/4k-alone-andaman-and-nicobar-black-774343/

Summary

- The camera is important as a sensor due to the amount of information it can capture, and its relatively small price tag
- The basic camera model has existed since the 1500s!

- **Next: Projective Geometry**

Camera Projective Geometry

Course 3, Module 1, Lesson 1 – Part 2

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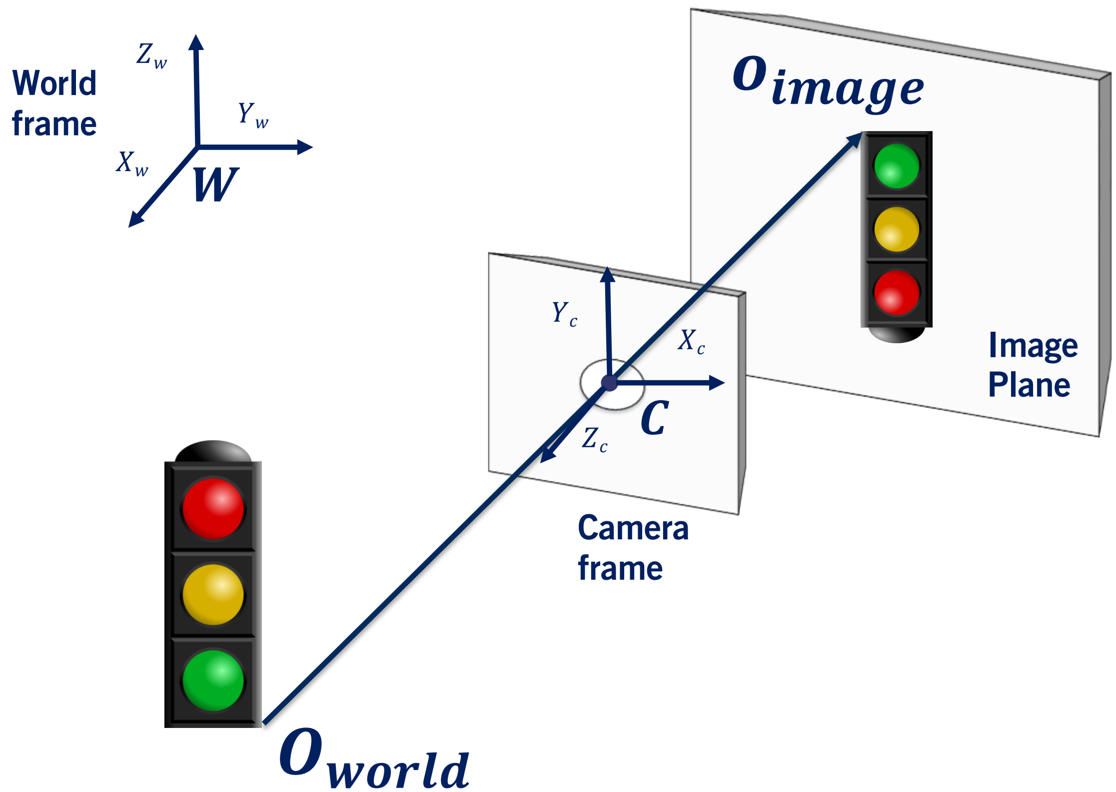
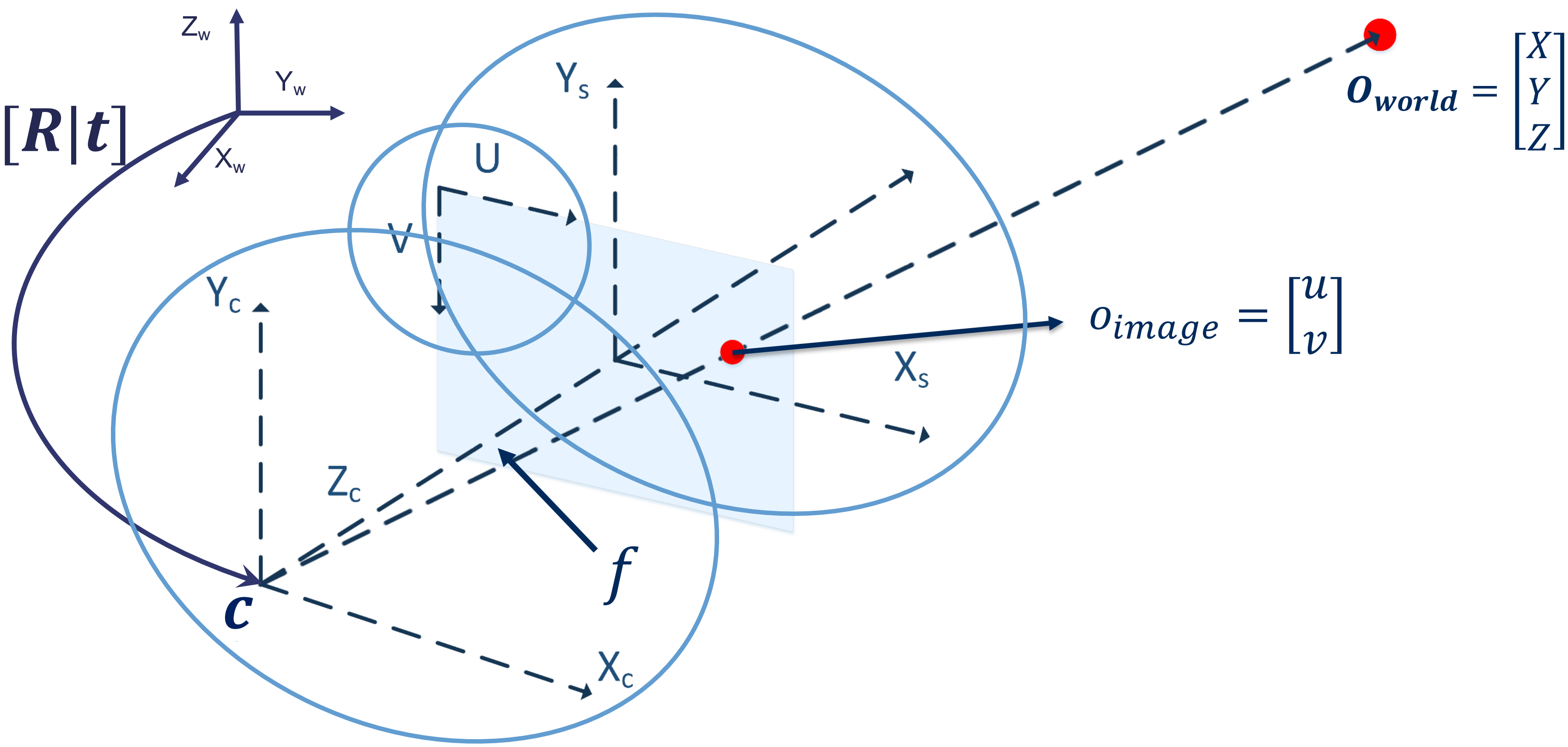
Projection: World → Image (Real Camera)

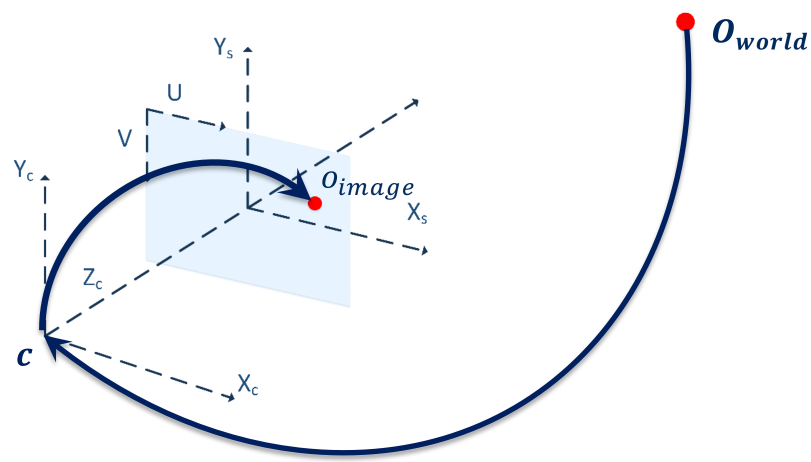


Projection: World → Image (Simplified Camera)



Computing the Projection

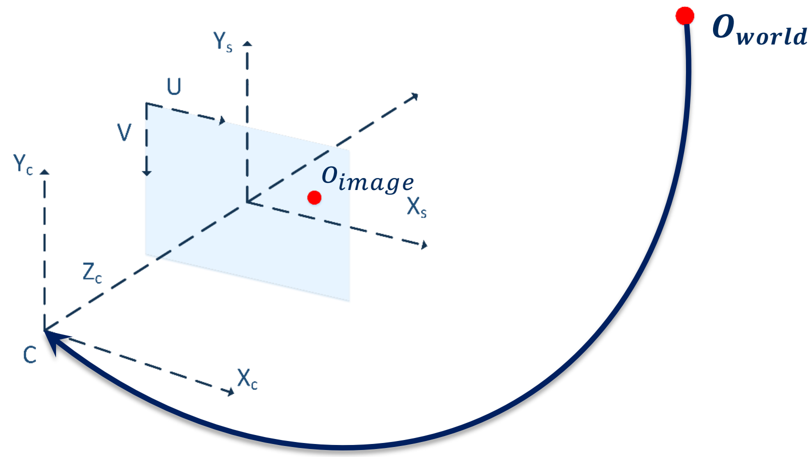
- Projection form World coordinates → Image coordinates:
    1. Project from World coordinates→ Camera coordinates
    2. Project from Camera coordinates to Image coordinates



Computing the Projection

- World → Camera:

$$o_{camera} = [R|t]O_{world}$$

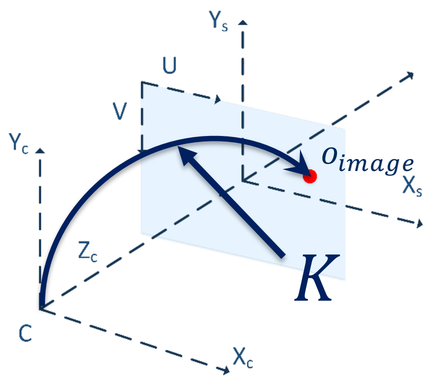


Computing the Projection

- Camera → Image:

$$o_{image} = \begin{bmatrix} f & 0 & u_0 \\ 0 & f & v_0 \\ 0 & 0 & 1 \end{bmatrix} o_{camera} = K o_{camera}$$

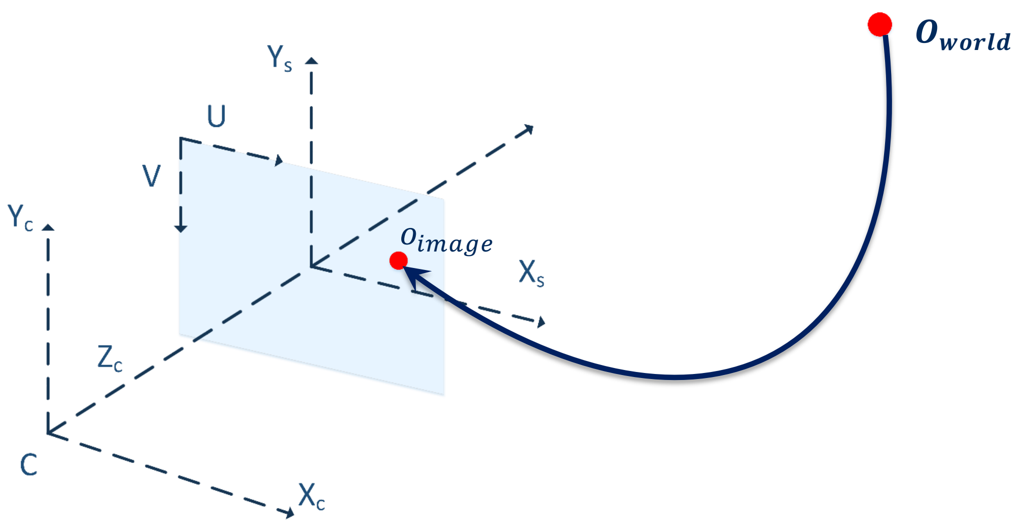
$\boldsymbol{o_{world}}$



Computing the Projection

- World → Image:

$$P = K\,[R|t]$$



Computing the Projection

- Projection from World Coordinates → Image Coordinates:

$$o_{image} = PO_{world} = \underbrace{\underset{3x3}{K}\,\underset{3x4}{[R|t]}}_{3x4}\,\underset{4x1}{O_{world}} \rightarrow \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

Computing the Projection

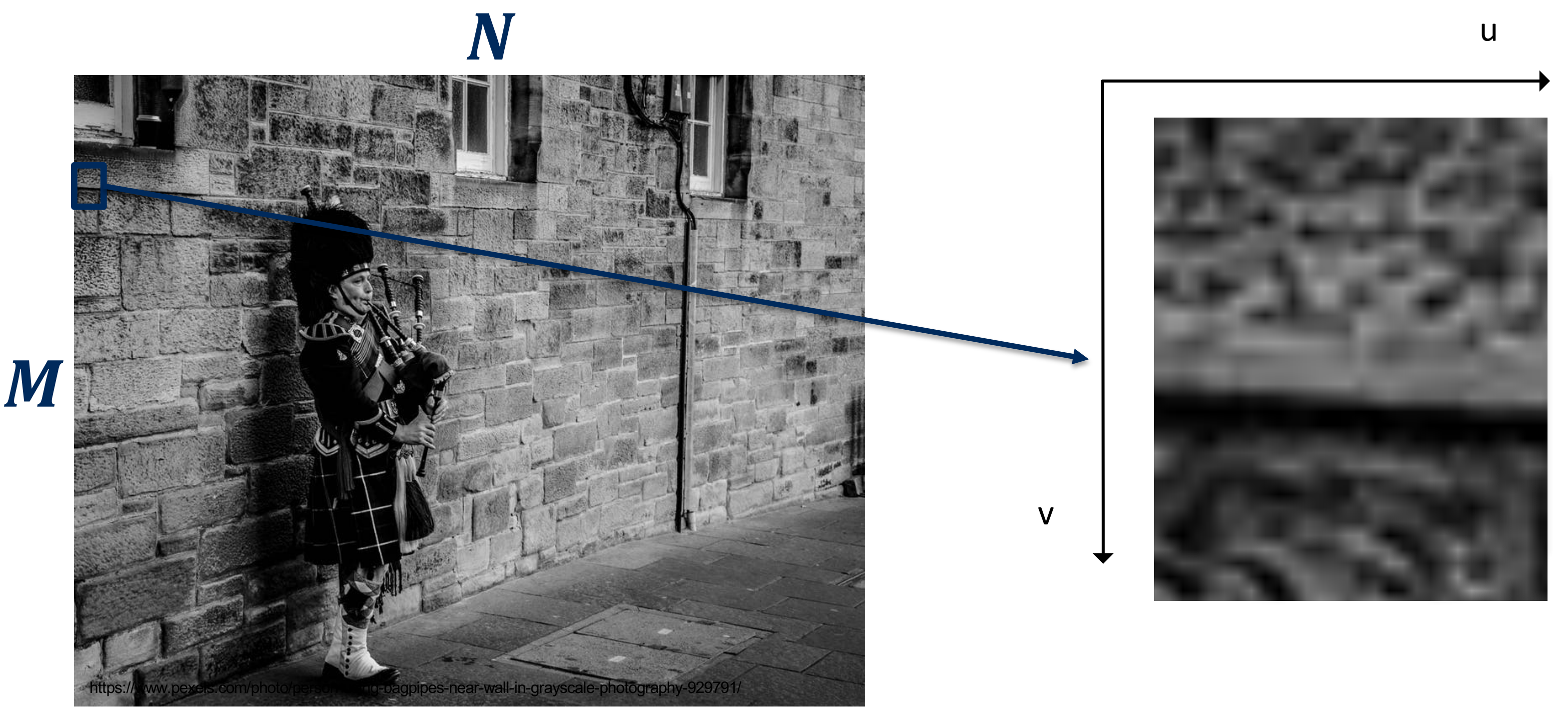
- **World** coordinates to **Image** coordinates:

$$o_{image} = \begin{bmatrix} x \\ y \\ z \end{bmatrix} = K[R|t] \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

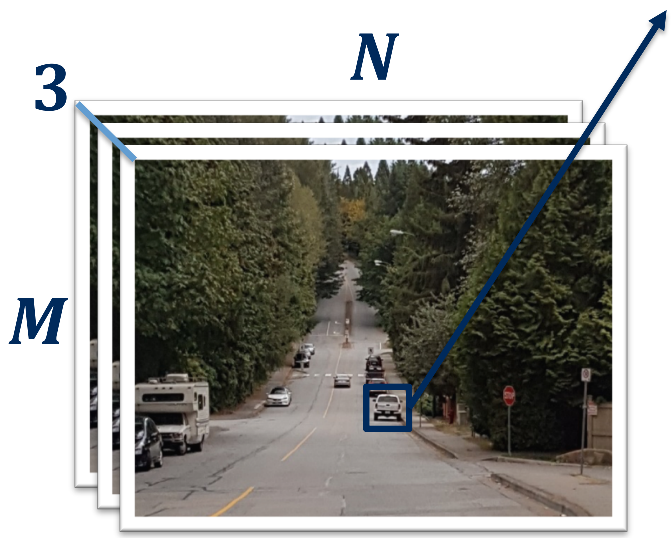
- **Image** coordinates to **Pixel** coordinates:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} \rightarrow \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \frac{1}{z} \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

The Digital Image: Greyscale



The Digital Image: Color



u

v

128	127	127	23
127	255	127	25
41	41	0	0
42	43	0	0

R

124	4	144	153
4	4	12	12
4	4	4	4
1	1	0	0

G

0	1	1	2
255	255	2	2
255	255	23	62
233	233	56	52

B

Summary

- 3D points in the world coordinate frame can be projected to 2D points in the image coordinate frame using projective geometry equations
- These equations rely on the camera intrinsic parameters, as well as its extrinsic location in the world coordinate frame
- A color camera image is represented digitally as an MxNx3 array of unsigned 8 bit or 16 bit integers

- **Next: Camera Calibration**