March 5, 2026 Introduction to Internet of Things Course

Augmented reality on your knees

👀

Seminar by Nikita Ligostaev

What a heck why AR?

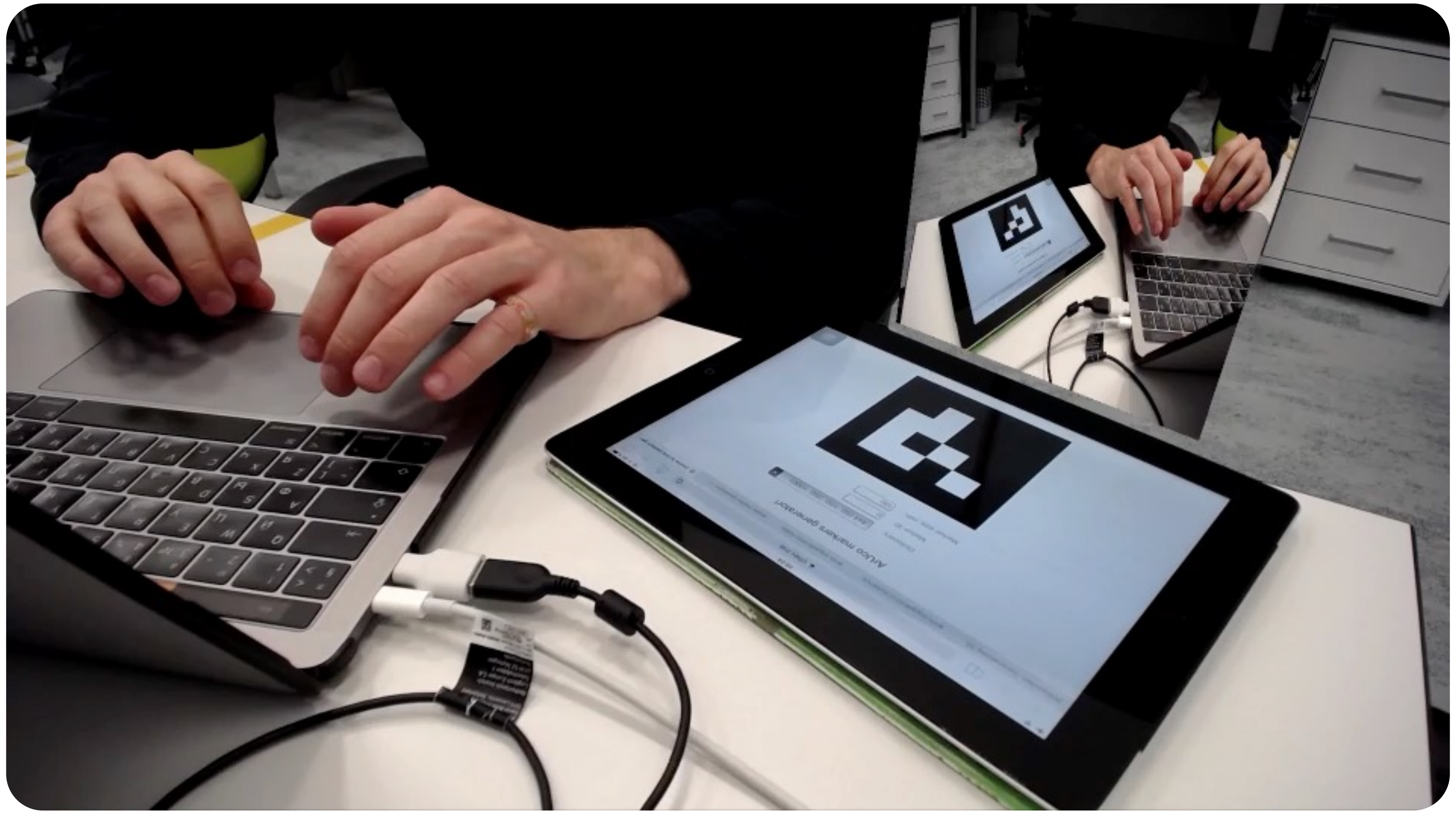
Web-camera is a sensor by construction, image formation is crucial for any kind of visualization.
We will consider very basic principles of linear algebra used in computer vision without going into details.
AR is just a straightforward application for today’s seminar.

⚠️

By the end of the seminar you will be able to use monocular camera for projection of anything in the camera frame.
Hopefully, it will be useful for common understanding and your research (in ideal case).

⚠️ Spoilers for seminar

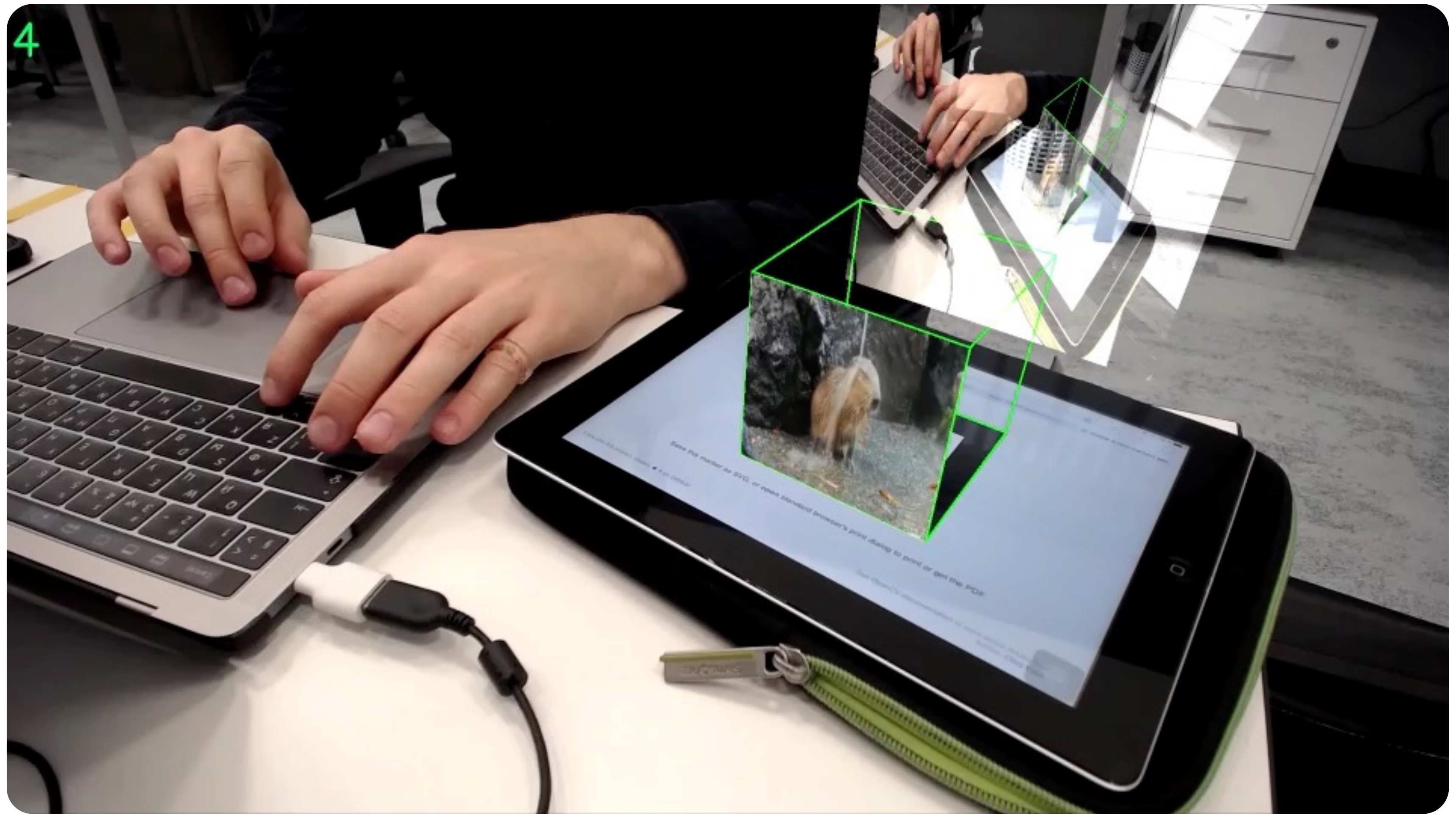
numero uno



Web-camera feed projection on the plane

⚠️ Spoilers for homework

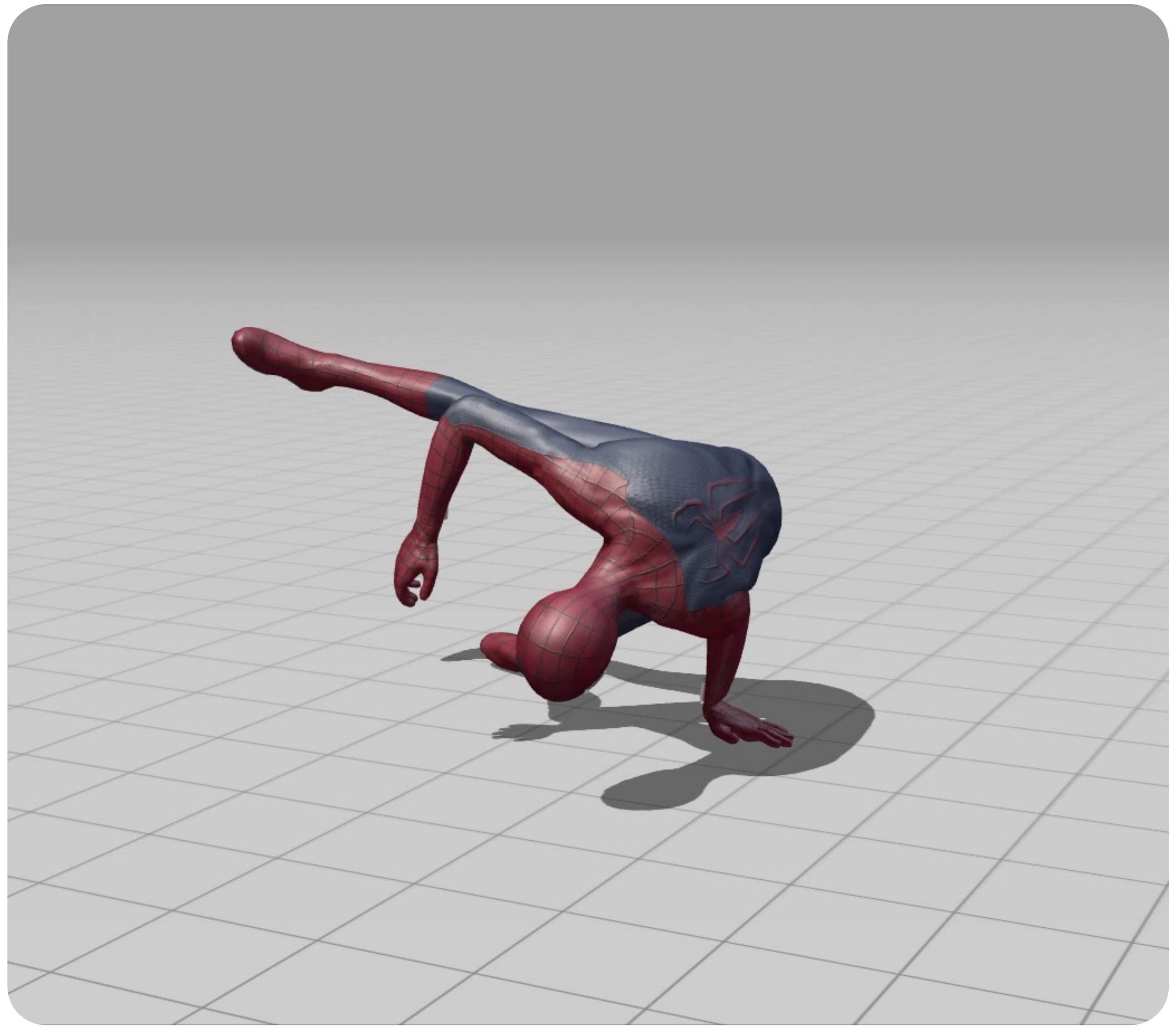
numero due

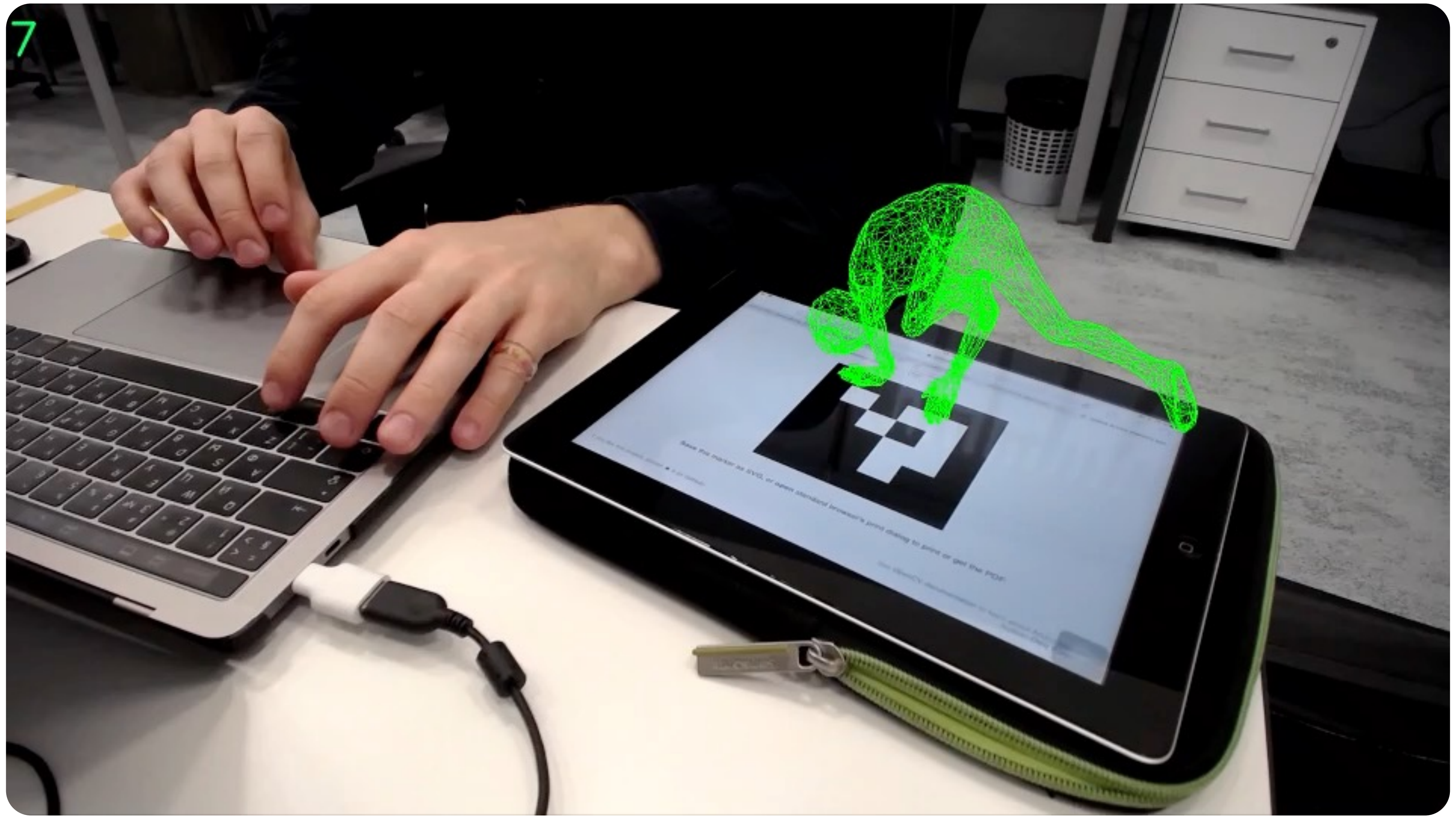


Video projection on the cube plane
and web-camera feed projection functionality

⚠️ Spoilers for bonus

numero tre





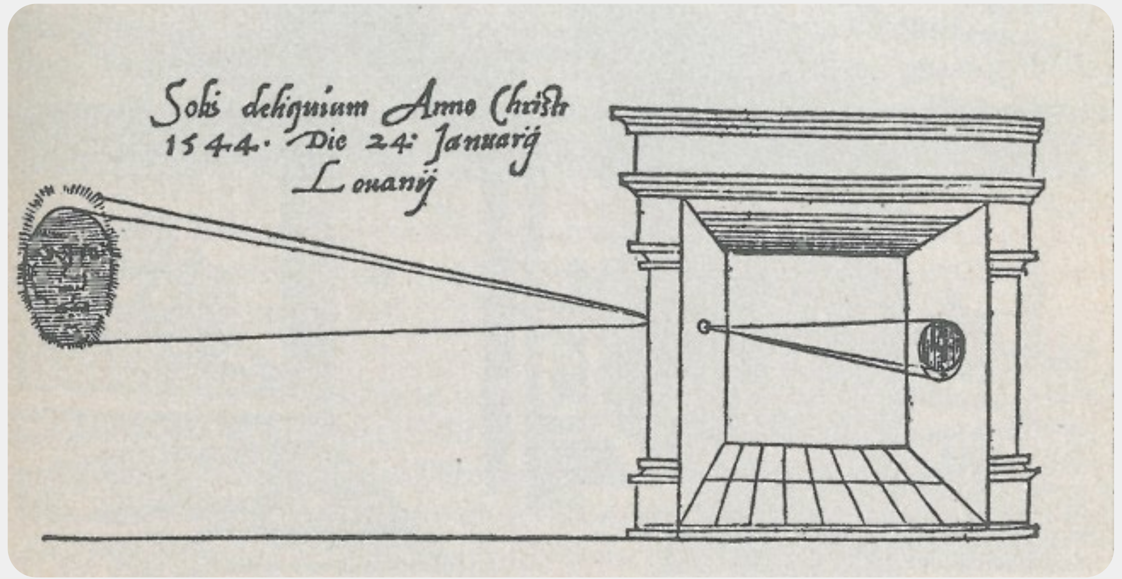
Animated .obj model projection

Instructions

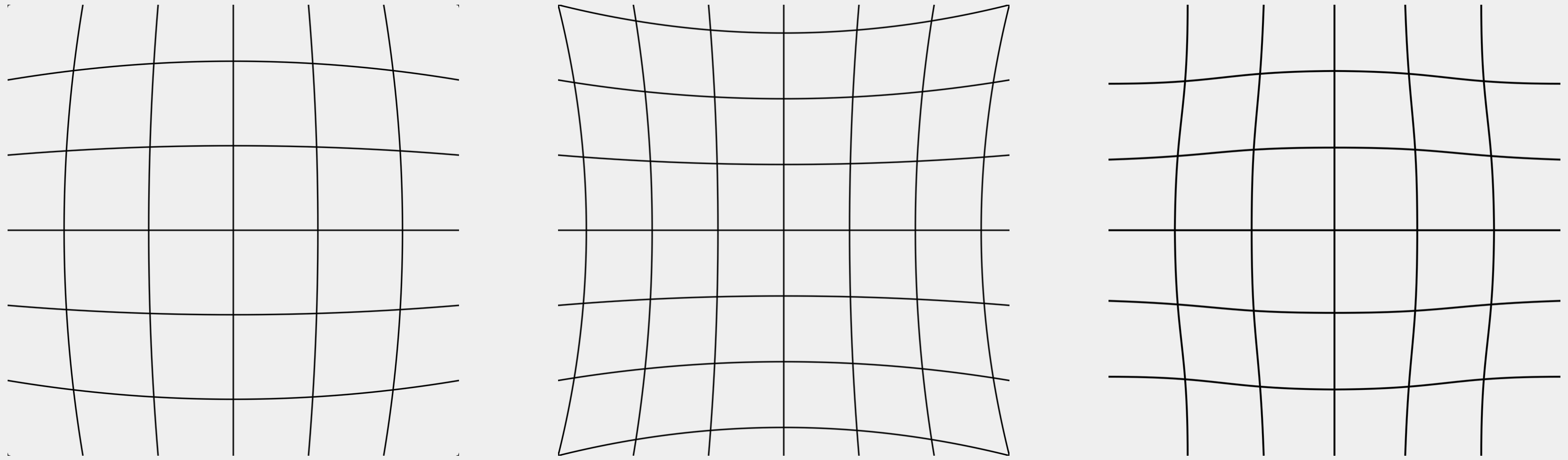
All tasks and their description are available in Github repository (the same repository you used for conda setup)

- solve all tasks from **seminar.ipynb**
- solve homework from **hw.ipynb**
- solve **bonus.ipynb** for additional points
- in case you are done with tasks you are free and can go home
- **do not forget to submit report in Canvas for seminar, homework** or/and **bonus** (make video recordings of your solution, archive copy of repository, include your videos in **./data/solutions/** folder, put your name in the beginning of **hw.ipynb** or/and **bonus.ipynb**)

Plan for today



Pinhole camera model



Lens/camera distortion

$$\begin{bmatrix} \hat{x}_s \\ \hat{y}_s \\ \hat{z}_s \end{bmatrix} = \mathbf{K}\left[\mathbf{R}|t\right] \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix}$$

Projective transformation

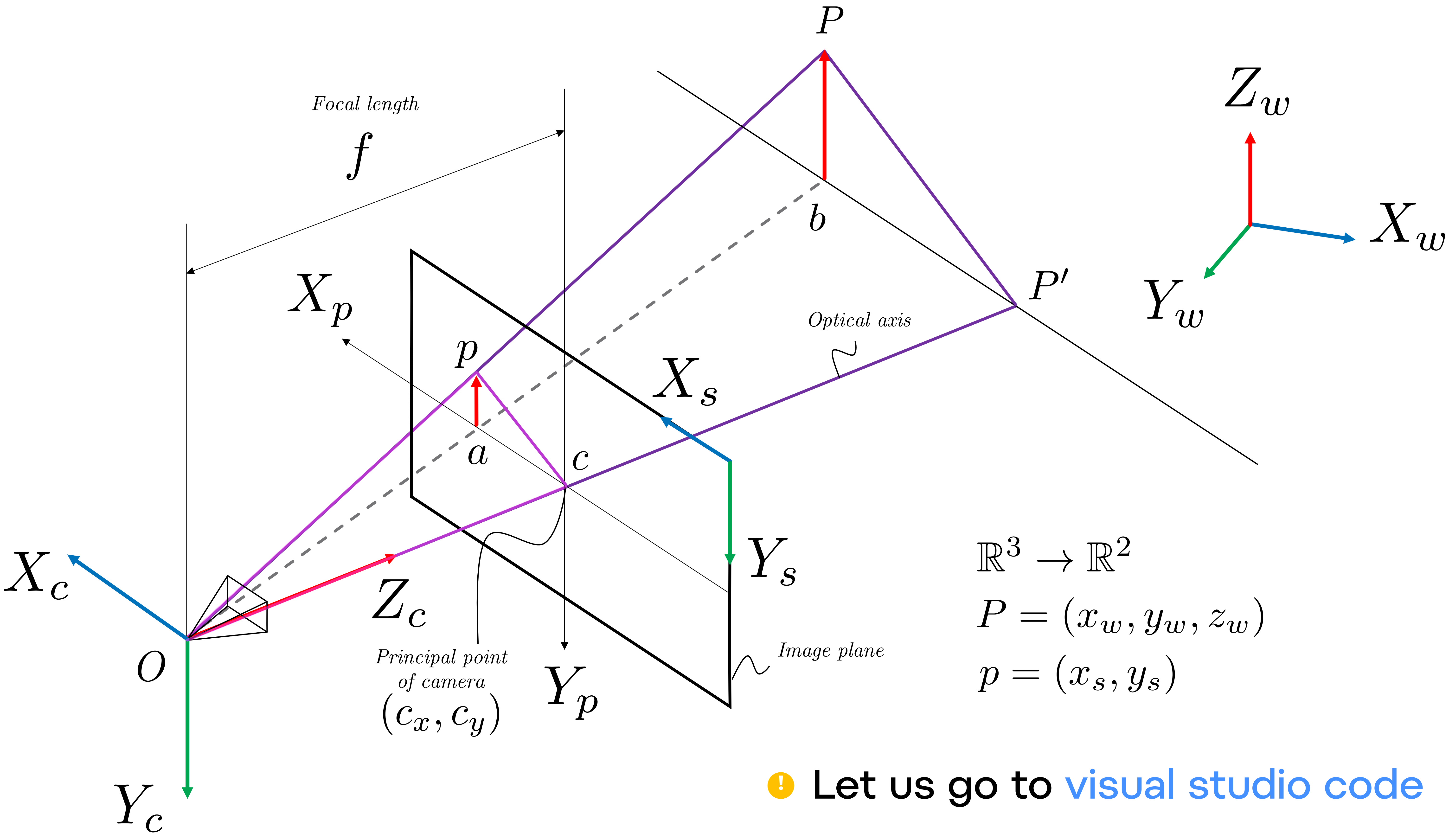
Markers

Hands-on
AR demo

Pinhole camera model

or how camera perceives the world

Pinhole camera model



$\mathbb{R}^3 \rightarrow \mathbb{R}^2$

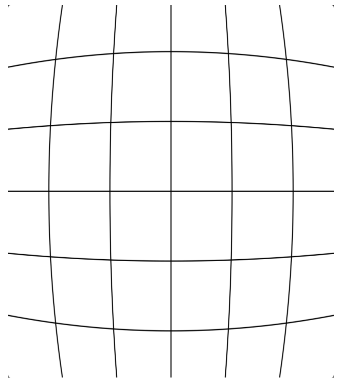
$P = (x_w, y_w, z_w)$

$p = (x_s, y_s)$

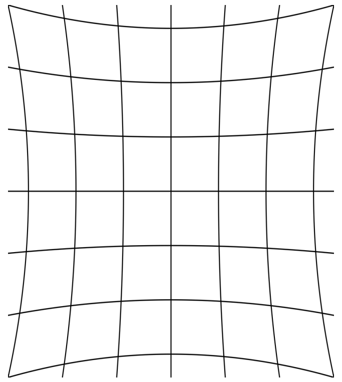
Let us go to visual studio code

Camera/lens distortion

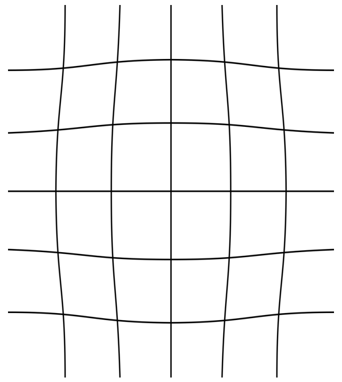
and what we can do with it



Barrel



Pincushion



Moustache

$k_1 < 0$ $\quad$ $k_1 > 0$ $\quad$ $k_1 < 0 \quad k_2 > 0$

$$L(x_c, y_c) = L_r(x_c, y_c) + L_t(x_c, y_c)$$

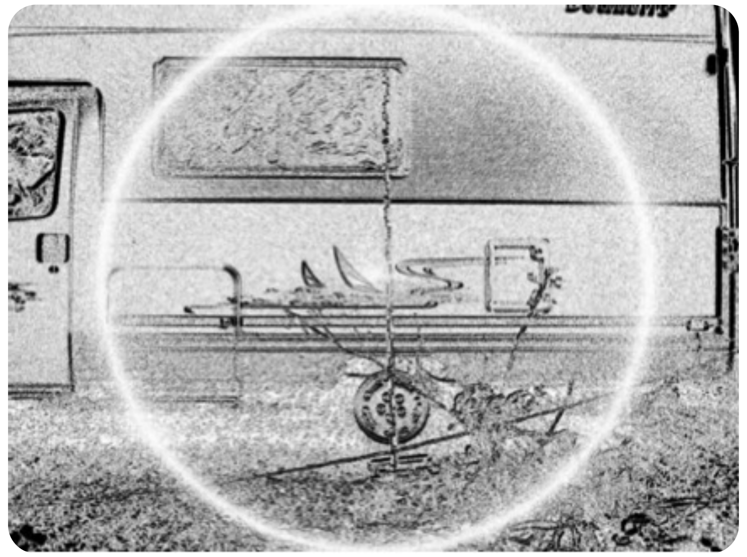
$$r^2 = x_c^2 + y_c^2$$

$$L_r(x_c, y_c) = (1 + k_1 r^2 + k_2 r^4 + k_3 r^6) \begin{bmatrix} x_c \\ y_c \end{bmatrix}$$

$$L_t(x_c, y_c) = \begin{bmatrix} 2p_1 x_c y_c + p_2(r^2 + 2x_c^2) \\ p_1(r^2 + 2y_c^2) + 2p_2 x_c y_c \end{bmatrix}$$

Original

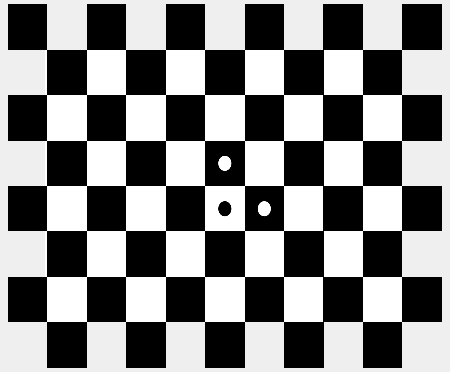
Corrected



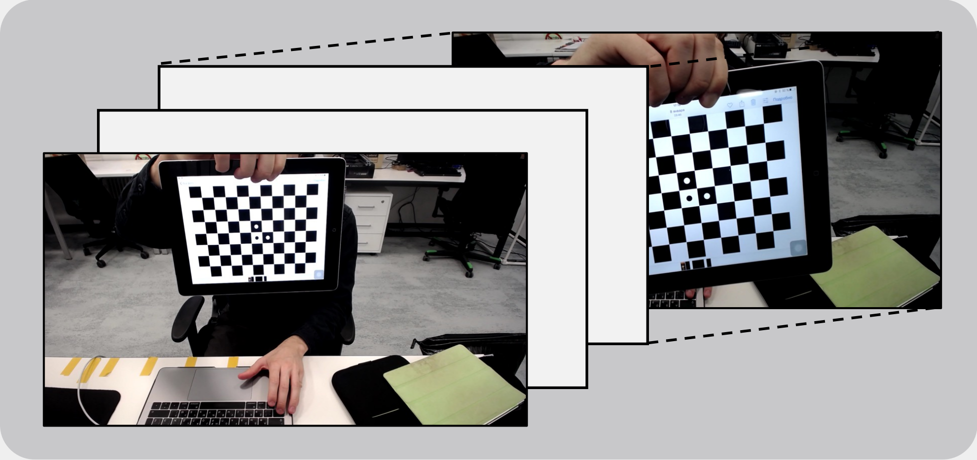
Difference between grayscale versions of original and corrected images

Projective transformation

Intrinsic camera matrix



Known-size checkerboard pattern



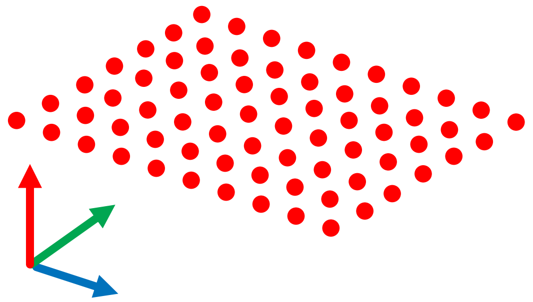
Set of calibration samples

Camera calibration algorithm

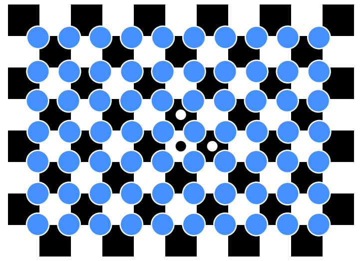
all parameters in px units

$$\mathbf{K} = \begin{bmatrix} f_x & \gamma & c_x \\ 0 & f_x & c_y \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 858.212 & 0 & 574.698 \\ 0 & 845.243 & 394.842 \\ 0 & 0 & 1 \end{bmatrix}$$

3D to 2D mapping



3D model of pattern (3D points in WCS)



2D object points (2D points in CCS)

$$\mathbf{K} = \begin{bmatrix} f_x & \gamma & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$$

Intrinsic camera matrix

$$\mathbf{R} = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \quad t = \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix}$$

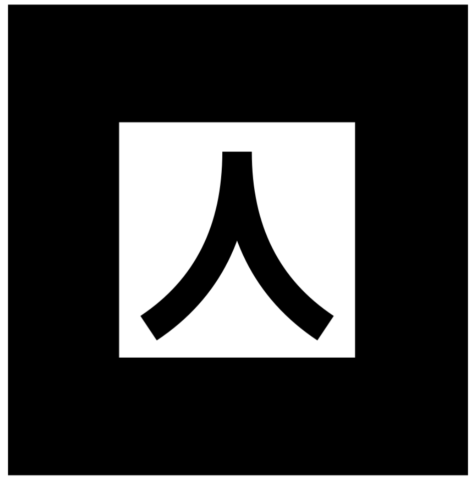
Rotation matrix and translation vector

$$\begin{bmatrix} \hat{x}_s \\ \hat{y}_s \\ \hat{z}_s \end{bmatrix} = \mathbf{K}\,[\mathbf{R}|t] \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix}$$

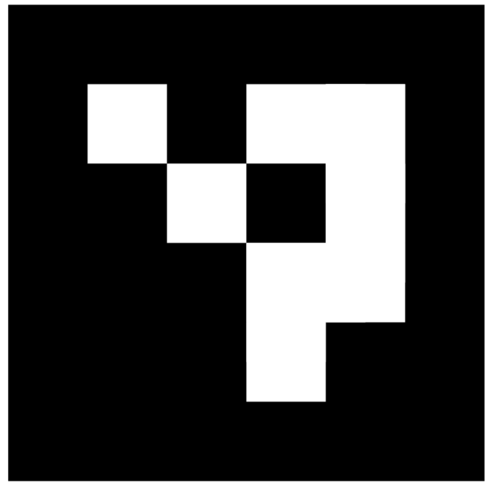
Solution

Markers

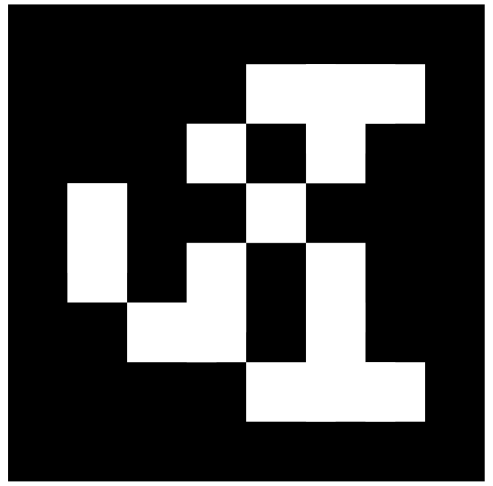
Fiducial markers use the same idea as calibration pattern (known geometry object), but mostly for detection and pose estimation purposes (e.g. in robotics, PCB manufacturing).



ARToolKit



Aruco



ApriTag

Intersense

reacTIVision

There a lot of them

Hands-on session

is on

❗ Let us go to visual studio code

Augmented reality on your knees

Ciao cacao. Thank You.

Seminar by Nikita Ligostaev