



# UNIVERSITÀ DEGLI STUDI DI PADOVA

## Camera calibration

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- Calibration: advantages and applications
- Calibration process outline



- Recall:
  - What are the intrinsic parameters? What is their meaning?
  - What are the extrinsic parameters? What is their meaning?
- How can we know them?

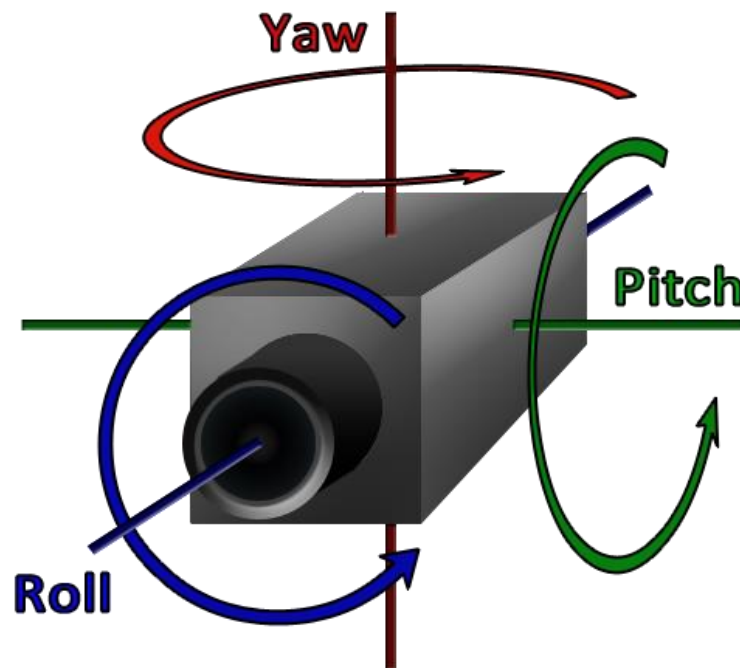


- Camera calibration is the process of estimating the camera parameters
  - Intrinsic calibration only
    - Including distortion parameters
  - Intrinsic+extrinsic calibration
- Calibration is needed if we want to measure the projection characteristics of a camera



- Reference with world coordinate system is not needed, but
  - The calibration process anyway links 3D object and projection
  - Only intrinsic parameters are provided
- A dedicated process can be used to evaluate the camera position and orientation in world coordinates

- Camera orientation is expressed by means of three angles
  - Yaw, pitch, roll
- Other names are used (e.g., pan and tilt)

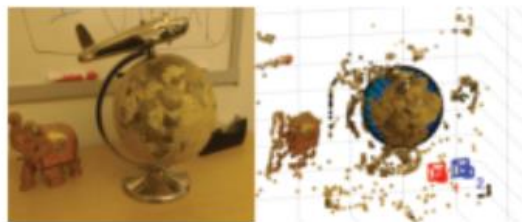


# Why calibrating?

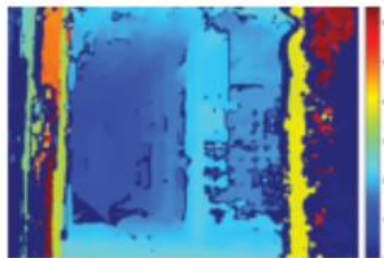
Examples of what you can do after calibrating your camera:



Remove Lens Distortion



Estimate 3-D Structure from Camera Motion

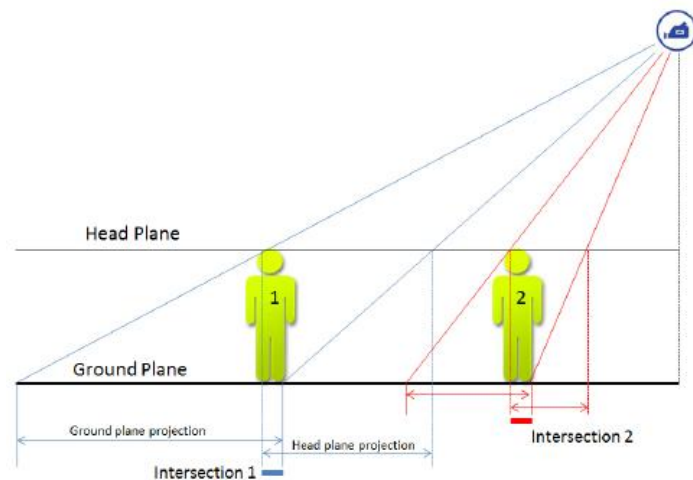


Estimate Depth  
Using a Stereo Camera



Measure Planar Objects

- Other applications include relating points in the image with the real world
- Example: determining distances with respect to the camera with additional constraints (e.g. ground plane)







- Let's develop a first approach to calibration
- How would you define a process for calibrating a camera?
  - Hint: you should find a method for evaluating the matrix  $K$  by observing how rays are projected

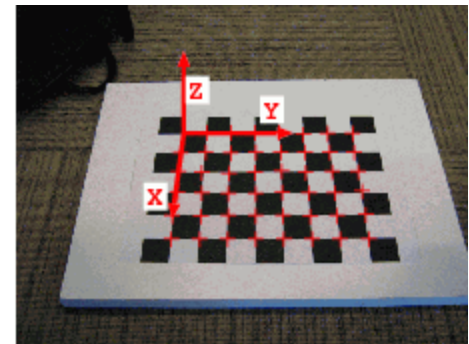


- Anti spoiler 😊

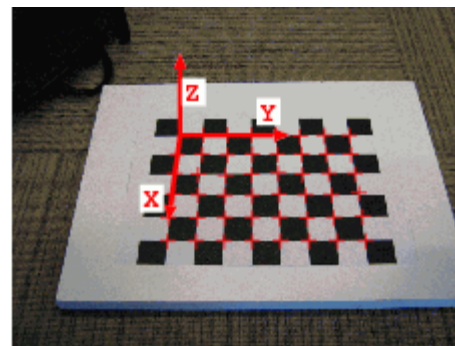


- Several methods exist for calibrating a camera
- General process:
  - Take an object of known shape and appearance
  - Take pictures of the object
  - Analyze the projection process

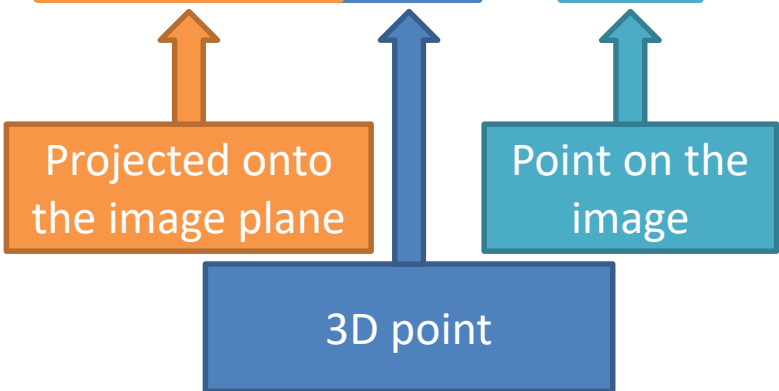
- In principle, the calibration pattern can be any object of **known shape and dimensions**
- The object shall be found in the image: a shape that is easily recognizable
  - Example: a checkerboard
  - The points used for calibration are the square corners



- Collect  $N$  images of the pattern
- For each image
  - List the  $M$  3D corner positions in the pattern reference system
  - Find the corner positions in the image reference system
- Initialize the intrinsic calibration parameters to *default values*
  - For  $K$ :  $f_u, f_v, u_0, v_0 \rightarrow \theta_K$
  - For distortion:  $k_1, k_2, k_3, p_1, p_2 \rightarrow \theta_d$



- Initialize the extrinsic parameters to *default values*
- Solve the non-linear least squares problem:

$$\min_{\theta_K, \theta_d} \sum_{i=0}^{N-1} \sum_{j=0}^{M-1} \left\| K[I|\mathbf{0}]T_i \tilde{\mathbf{P}}_{i,j} - \tilde{\mathbf{p}}_{i,j} \right\|^2$$


- Initialize the extrinsic parameters to *default values*
- Solve the non-linear least squares problem:

$$\min_{\theta_K, \theta_d} \sum_{i=0}^{N-1} \sum_{j=0}^{M-1} \|K[I|\mathbf{0}]T_i \tilde{\mathbf{P}}_{i,j} - \tilde{\mathbf{p}}_{i,j}\|^2$$

Recall:  $N$  images,  $M$  points per image



- Do you see any problem in the process described?





- Anti spoiler 😊

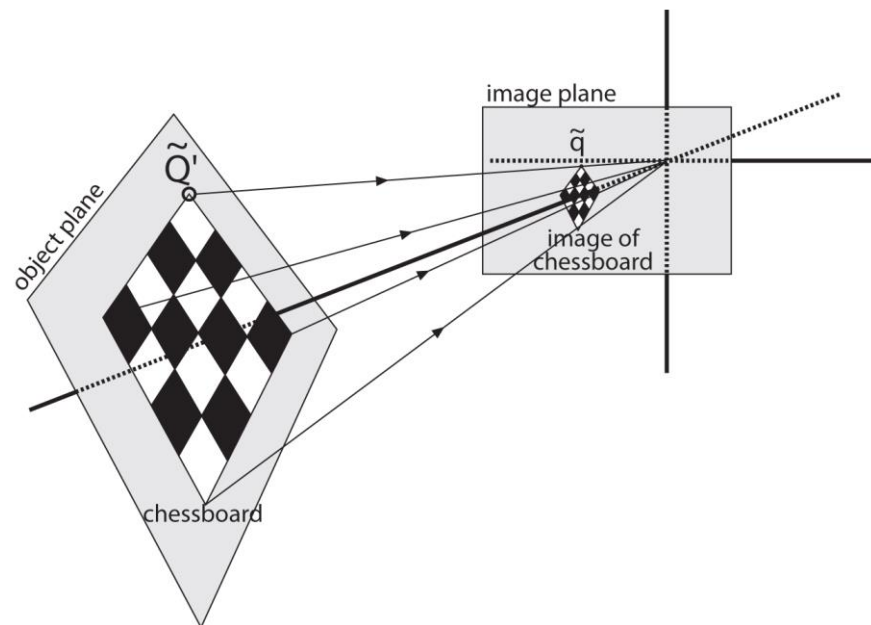


- The minimization process is done over a large set of parameters
- The minimization process can hardly provide a good result
  - Good initial guesses would be very desirable

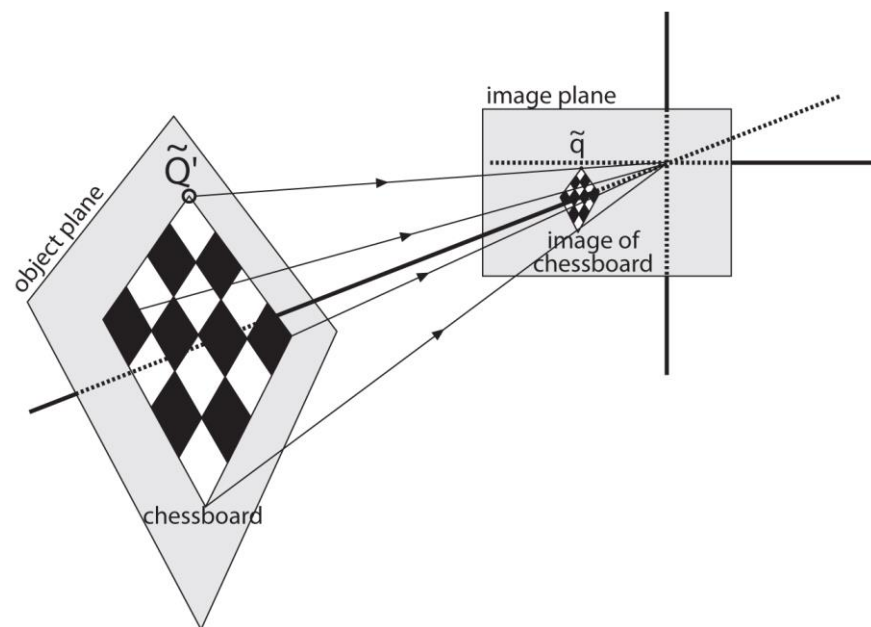


- To help the calibration process with a good initial guess we can exploit homography
  - Recall: homography – what is it?

- The transformation from object to image plane can be represented by a homography
  - Possible only if the object is **planar**
  - Possible only if we neglect distortion



- Using a homography simplifies the mathematical description
  - A good initial guess
- Details about this
  - "Learning OpenCV 3" – p. 664
  - 3D data processing course (Prof. A. Pretto)





- How many views are needed to calibrate a camera?
- Each view of a planar object can be represented by a homography
  - The checkerboard corners are constrained by the homography: only four points per view are "free"
    - 8 constraints (x and y) for each view
    - More points are useful for measuring distortion



- Considering the number of intrinsic and extrinsic parameter, how many images are needed?



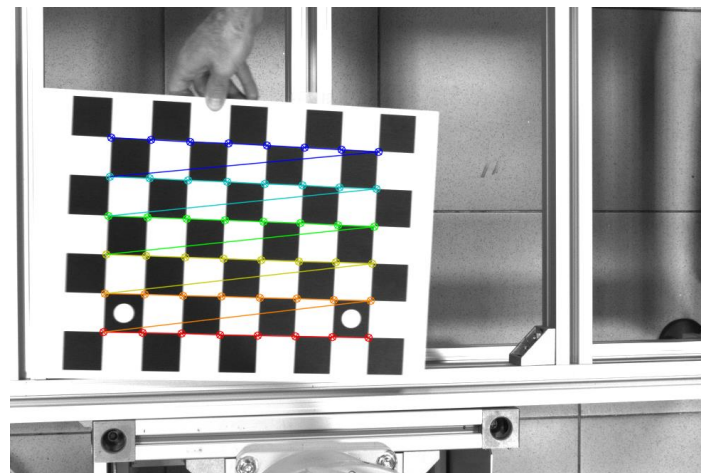
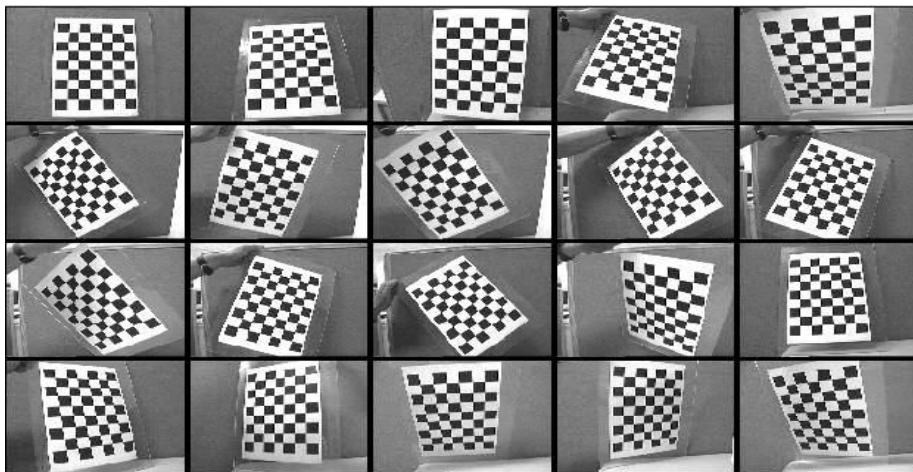
- Anti spoiler 😊





- Neglecting distortion, we have
  - 4 or 5 intrinsic parameters
  - 6 extrinsic parameters
- A minimum of 2 views are needed
- The calibration process is handled by a minimization – and it is unstable!
  - A larger number of views is needed in practice (e.g., 10 views or more)

- A typical calibration image set





- Have a look at the OpenCV calibration tutorial  
[https://docs.opencv.org/4.x/dc/dbb/tutorial\\_py\\_calibration.html](https://docs.opencv.org/4.x/dc/dbb/tutorial_py_calibration.html)
- You will be requested to go perform a calibration in the next lab



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