UNIVERSITÀ DEGLI STUDI DI PADOVA

Cameras and lenses

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DELL'INFORMAZIONE

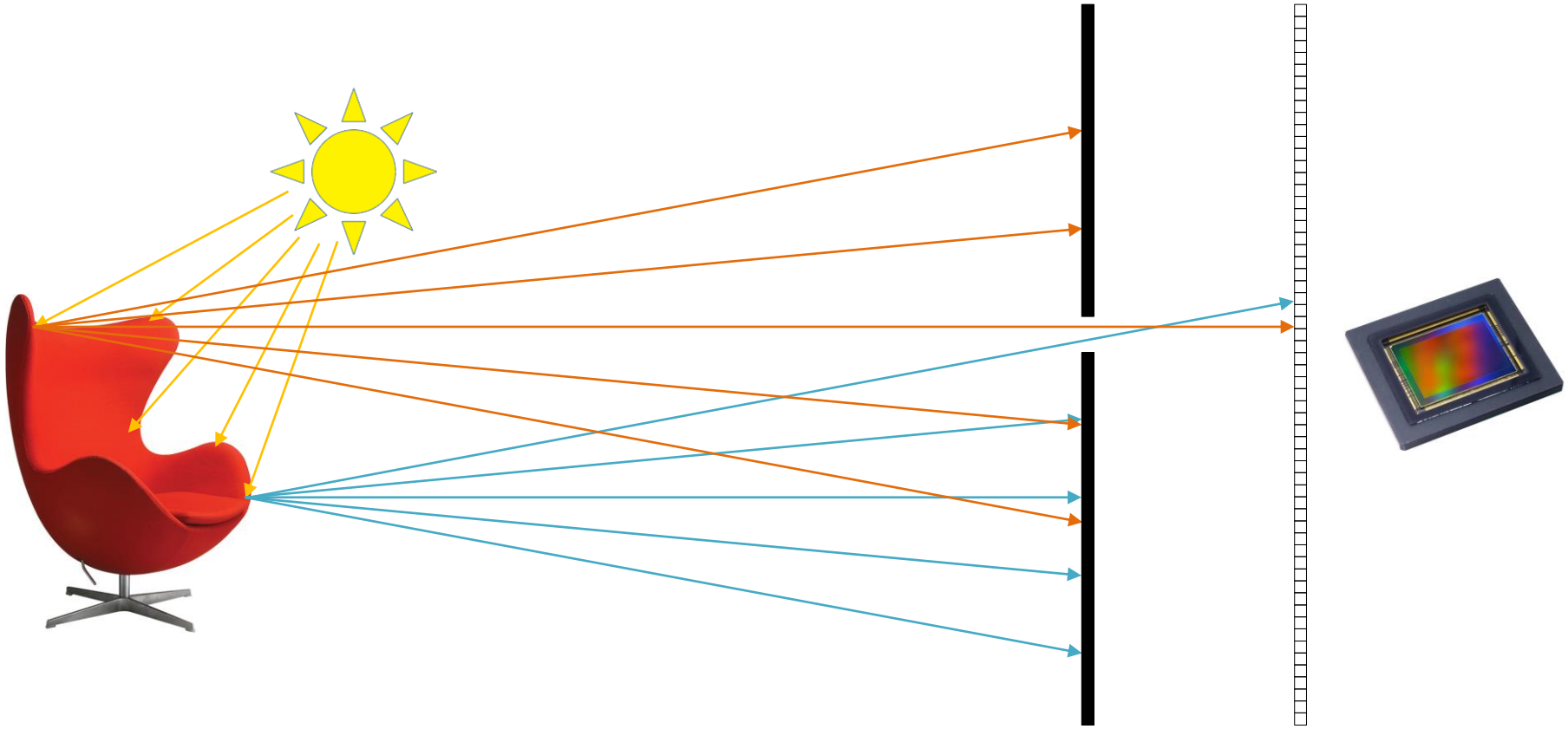
INTELLIGENT AUTONOMOUS SYSTEMS LAB

Agenda

- Thin lens model
  - Effect of adding a lens
- Non-ideal lenses
  - Mathematical formulation

Pinhole limitation

- Recall the pinhole model



- What is a major limit of this model?

- Anti spoiler ☺

Adding a lens

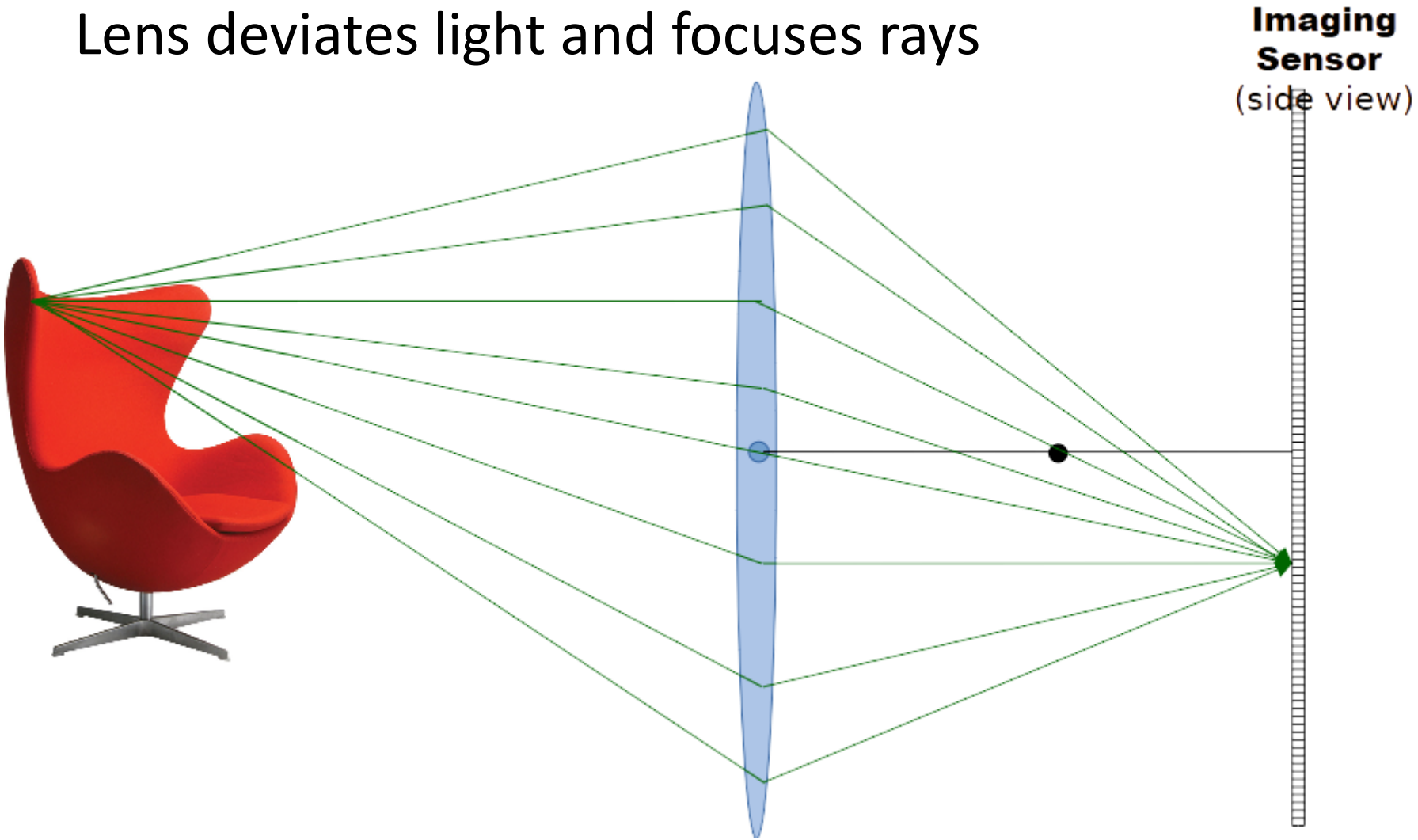
- Trade-off:
  - Sharp images vs
  - Light intensity
- A more complex system can provide sharp images without needing a pinhole

Thin lens camera model

- Let's introduce the **thin lens model**
  - A lens is added, centered on the pinhole
- The lens has
  - The main axis lying on the optical axis
  - A center lying in place of the pinhole
- The lens is thin because we can neglect the lens width with respect to the curvature radius
  - The lens is modeled as a 2D plane where every deviation occurs

Effect of lens

Lens deviates light and focuses rays

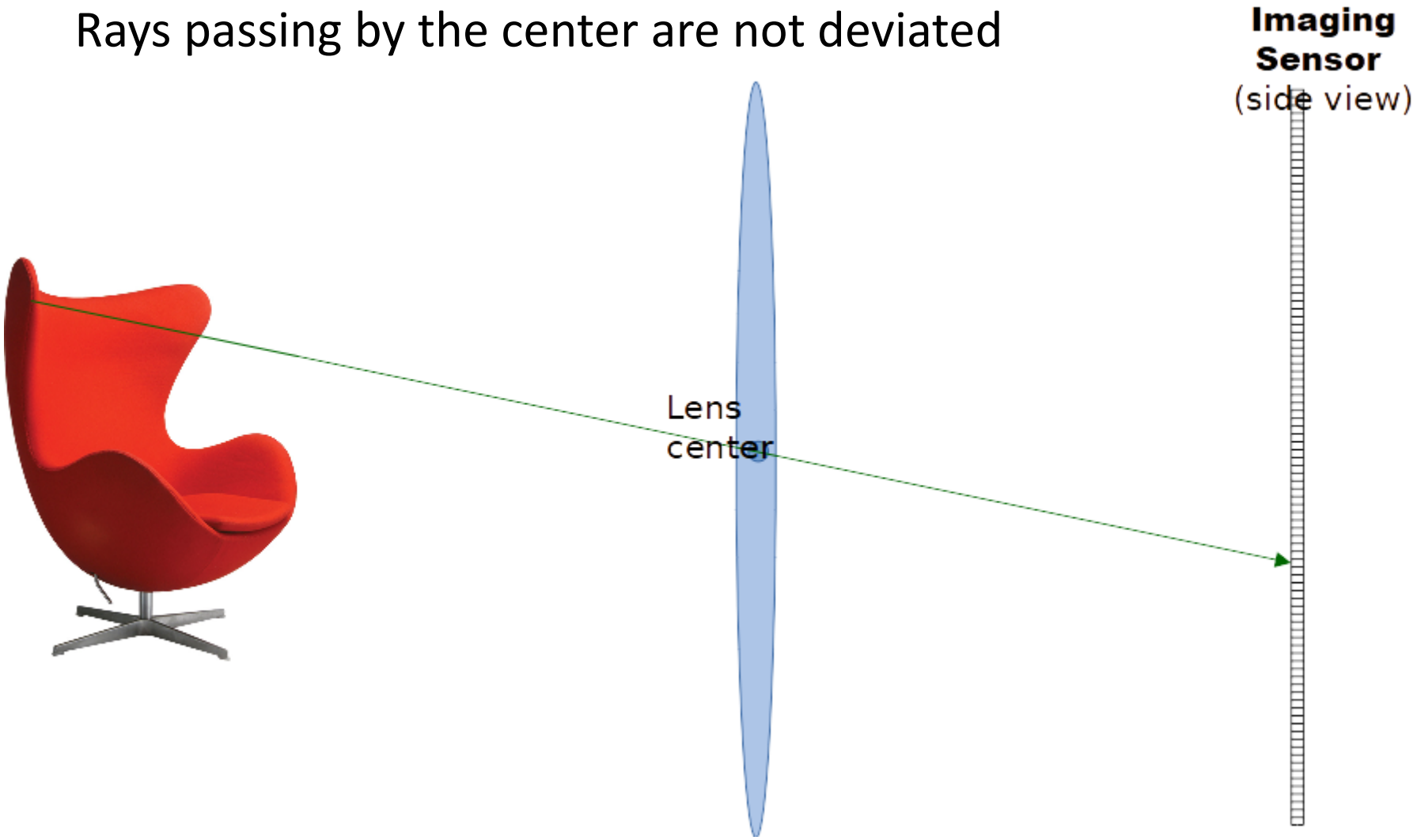


Effect of lens

- How to evaluate where the rays are deviated?
  - Some rays are deviated following simple rules

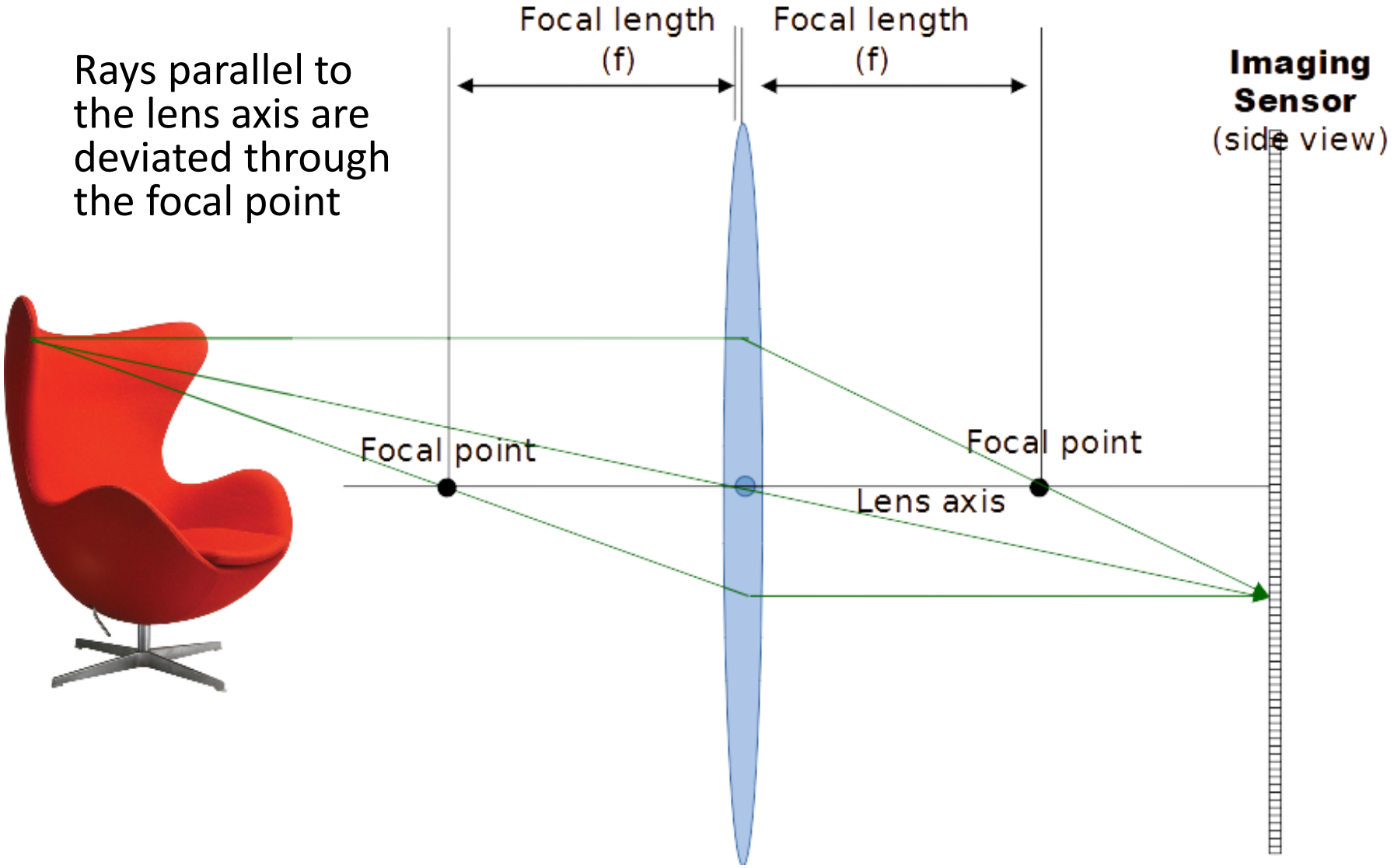
Effect of lens

Rays passing by the center are not deviated



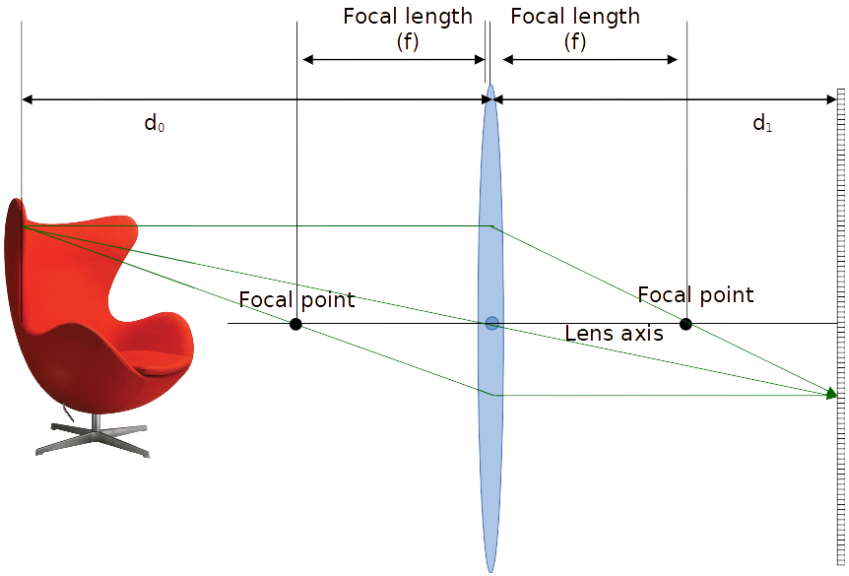
Focal length

Rays parallel to the lens axis are deviated through the focal point



Thin lens equation

- By tracing the two rays, we can determine the location of the image point
- Is there any link connecting
  - The position of the object, and
  - The position of the image?

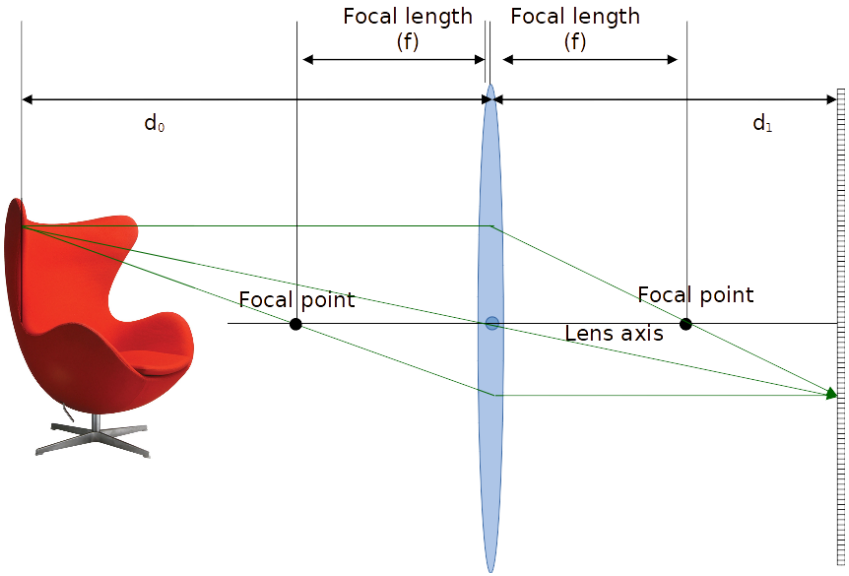


Thin lens equation

- The **thin lens equation** relates the distances
  - Between object and lens, d_0
  - Between lens and image, d_1

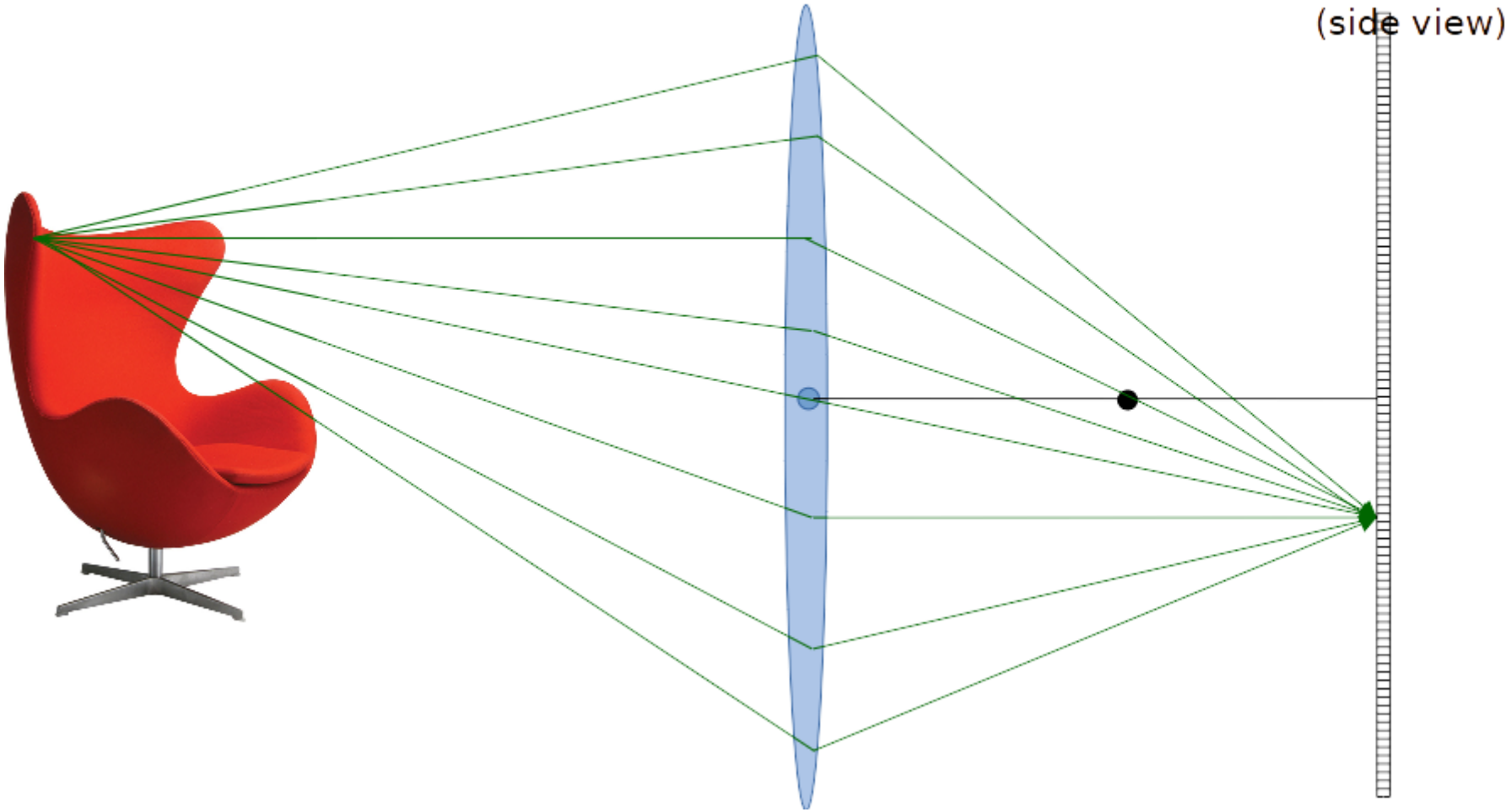
  depending on the lens focal length, f

$$\frac{1}{d_0} + \frac{1}{d_1} = \frac{1}{f}$$



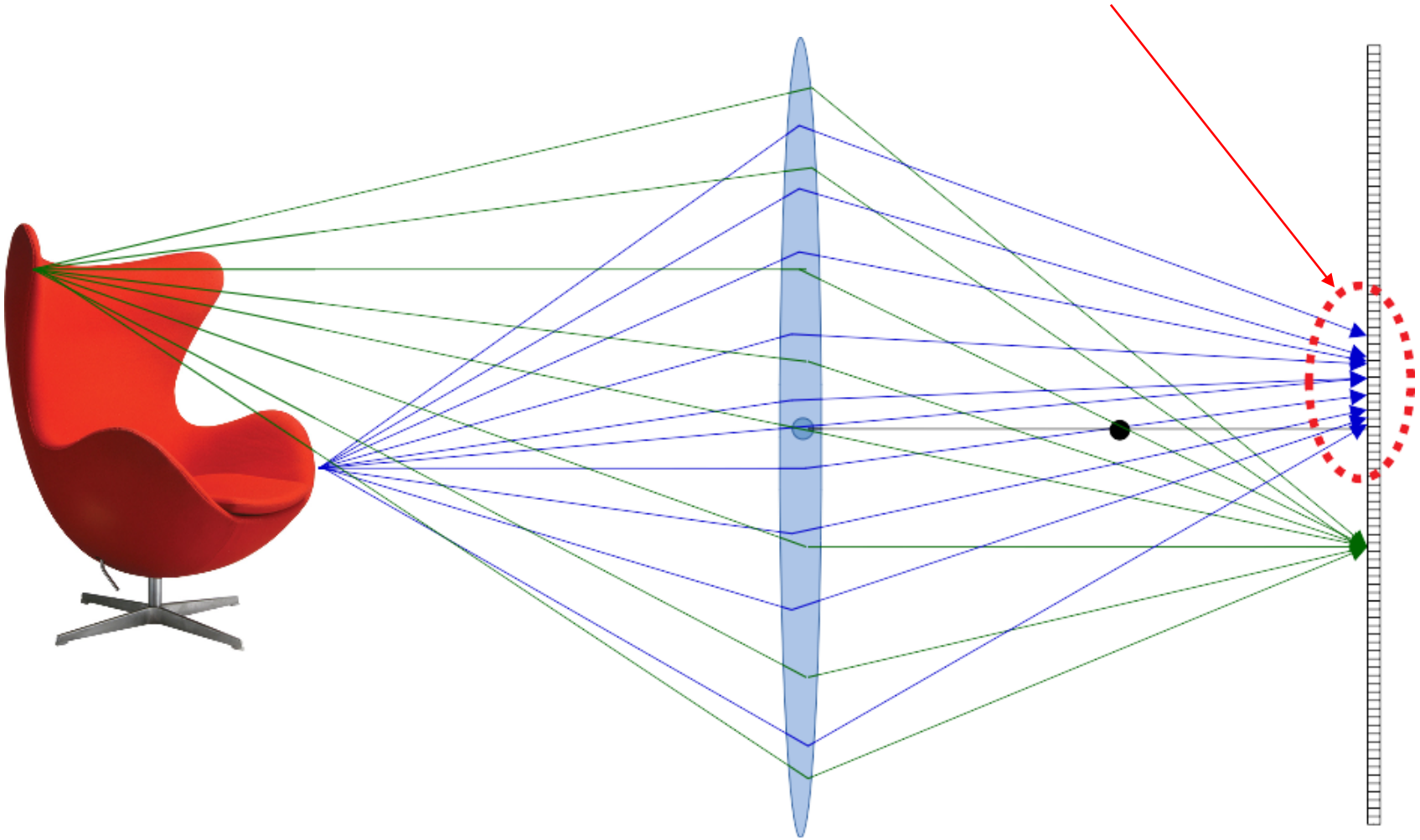
Focus

Points at a given distance are in focus



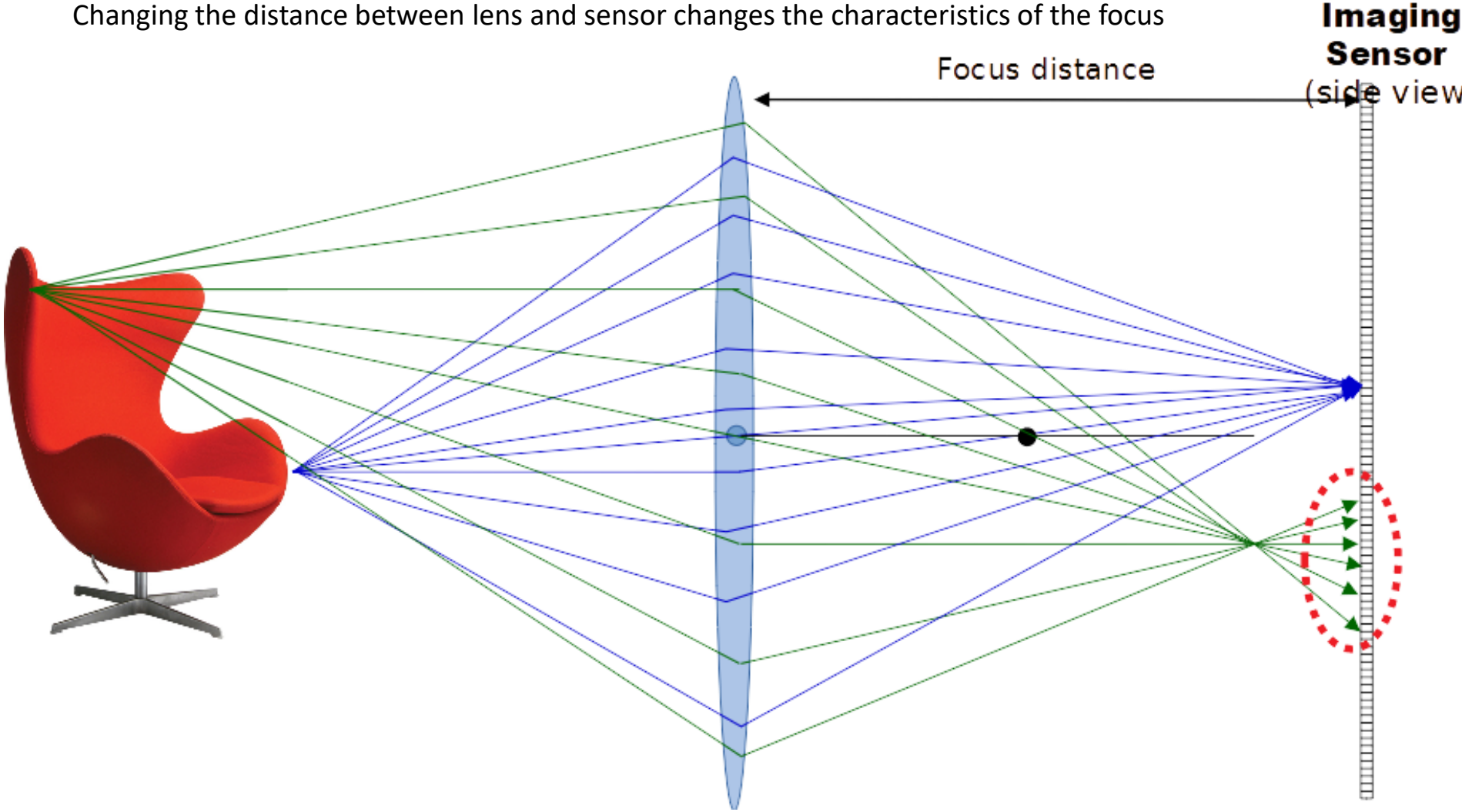
Focus

All other distances are not in focus and generate a **circle of confusion**



Focus

Changing the distance between lens and sensor changes the characteristics of the focus



Focus

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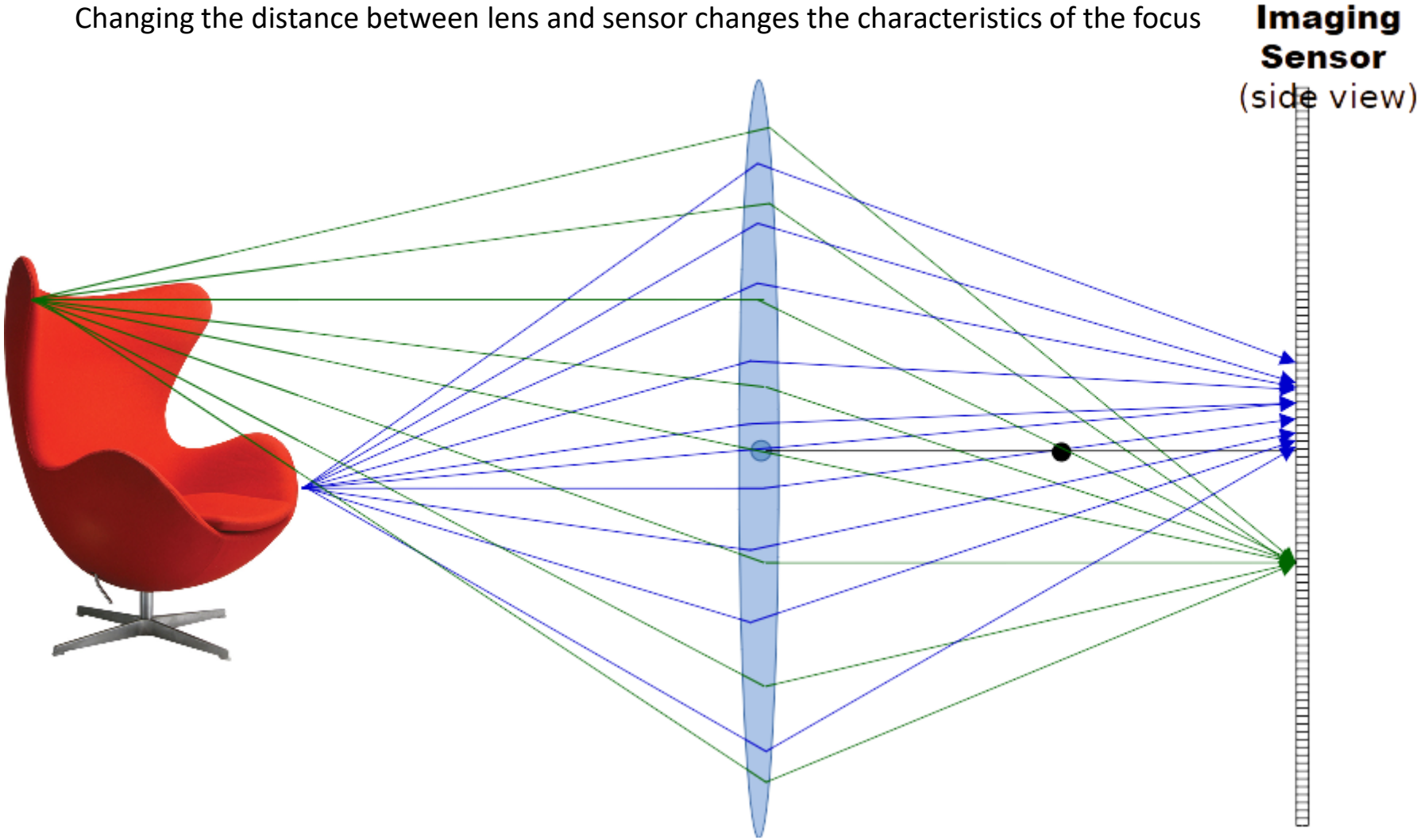
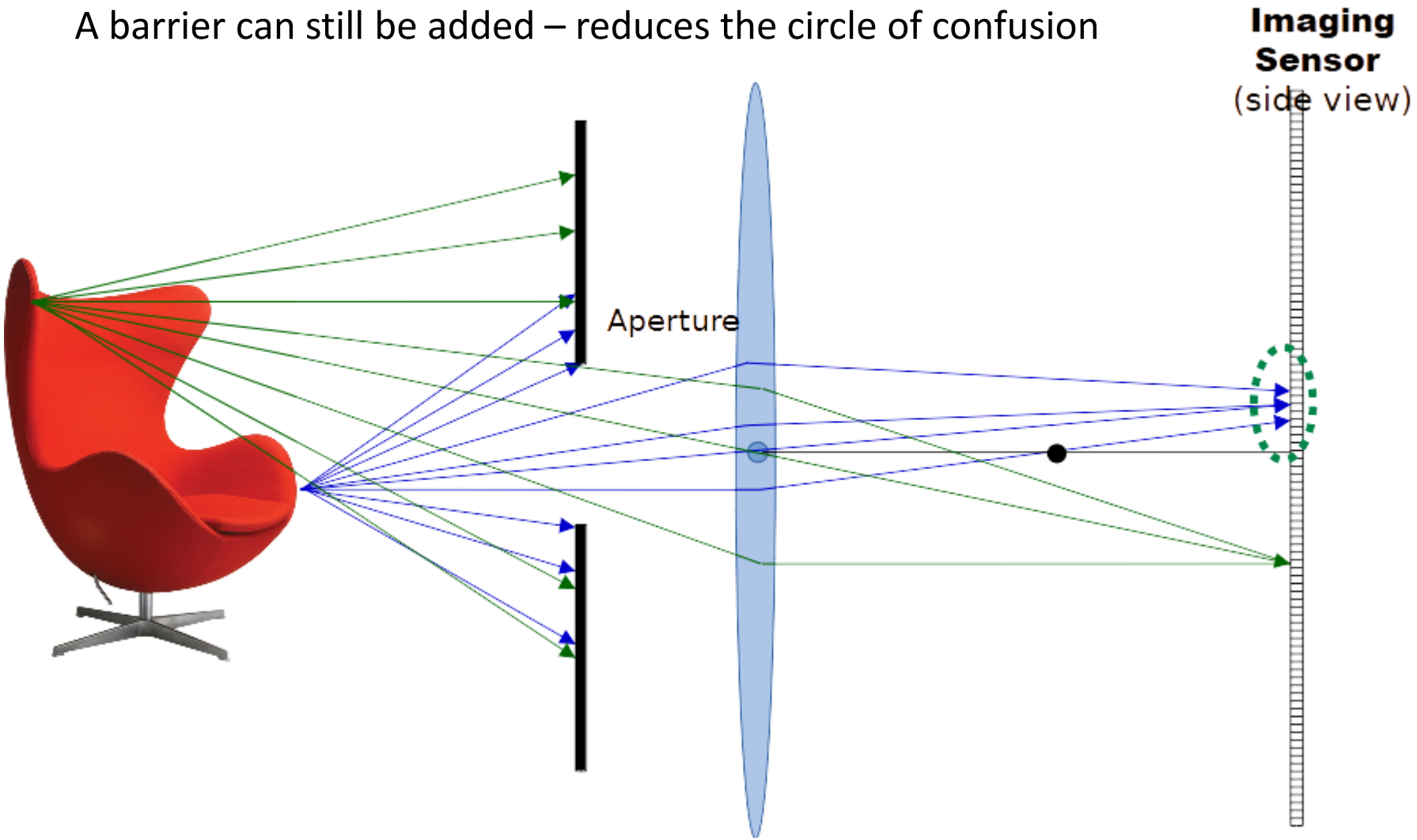


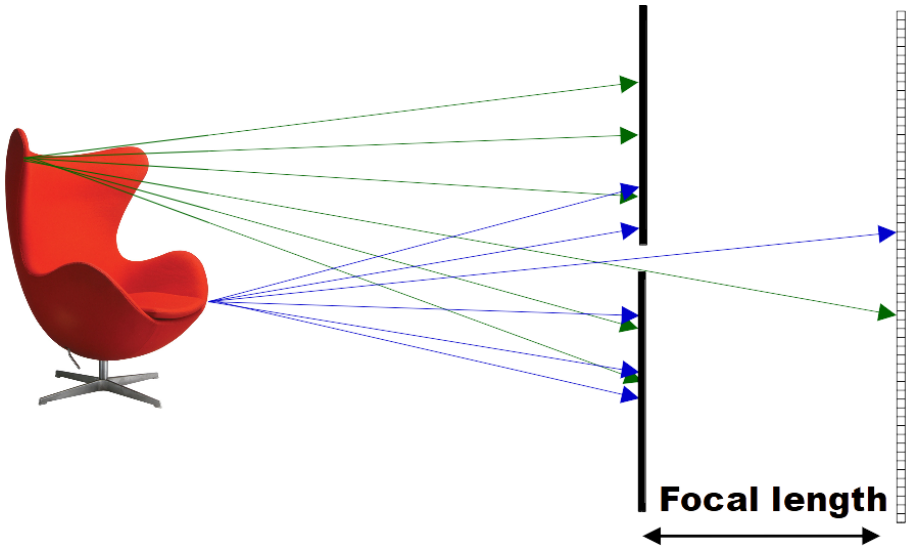
Focus

A barrier can still be added – reduces the circle of confusion



Focal length comparison

- The expression **focal length** has several meanings now:
  - Thin lens: distance at which parallel rays intersect
  - Pinhole camera model: distance between pinhole and sensor

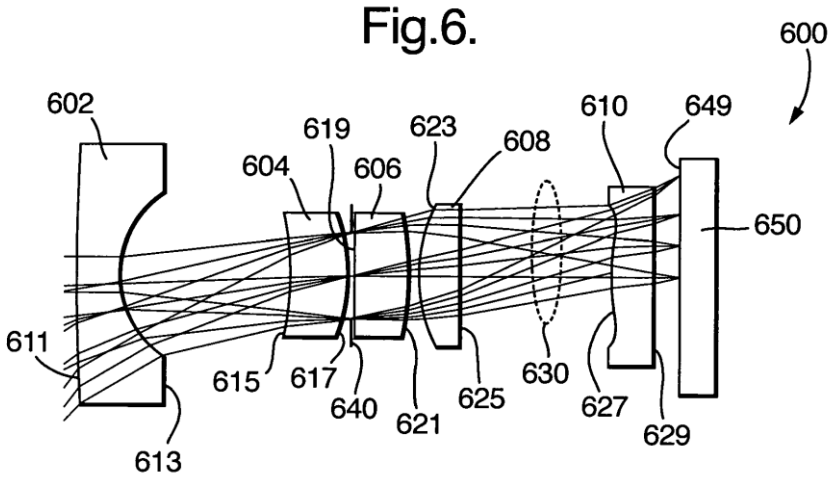


Non ideal lenses

- The lens used so far is:
  - Thin
  - Ideal
- Real lenses are affected by additional effects
  - Distortion
  - Chromatic aberrations
  - Other minor effects

Non ideal lenses

- Lens manufacturer keep under control distortions
- A non-distortion lens is often complex to design and to build



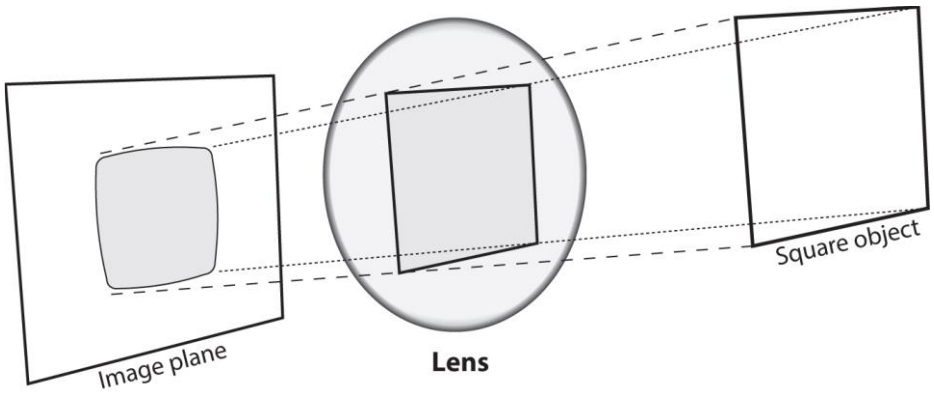
LCM-5MP-08MM-F2.0-1.8-ND1
LENS C-MOUNT 5MP 08MM F2.0
1/1.8" NON DISTORTION

Distortion

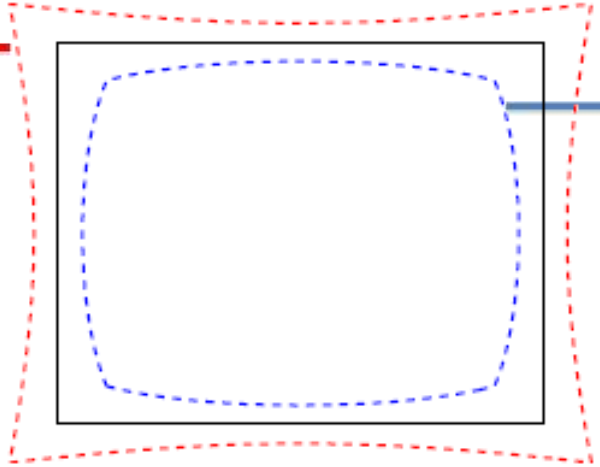
- Distortion is a deviation from the ideal behavior described so far
- Such deviation undergoes a pattern that can be:
  - **Radial**
  - **Tangential**

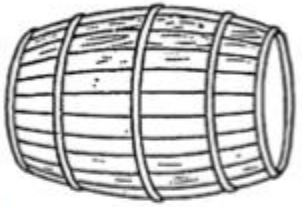
Radial distortion

- **Radial** distortion: the entity of the distortion depends on the distance of the distorted point from the image center



Radial distortion



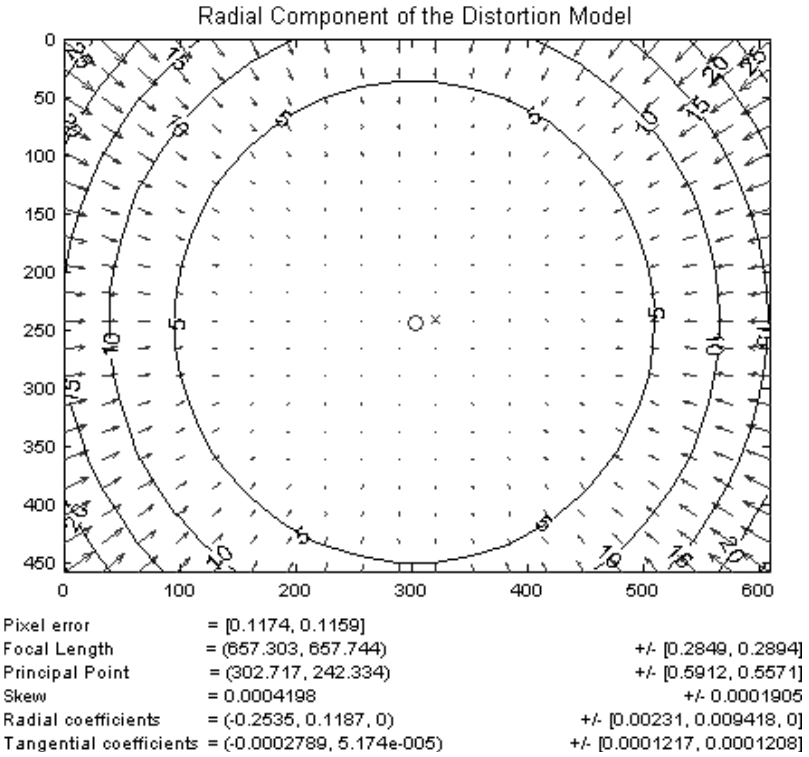


Pincushion distortion

Barrel distortion

Radial distortion

- The radial distortion can be analyzed by means of distortion patterns
  - Can be experimentally measured
  - Can be analytically described if the lens structure is known in detail
  - Distortion chart - the arrows represent the displacements



Radial distortion

- Camera models commonly consider a polynomial approximation for the radial distortion
  - Just a mathematical model, not a physical one
  - Often modeled* as a *correction*: the corrected point (x_{corr}, y_{corr}) depending on the distorted point (x, y):

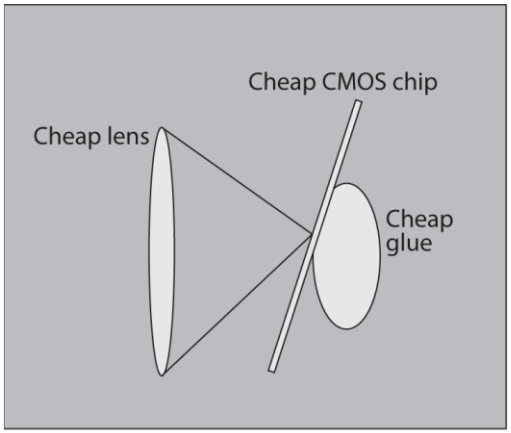
$$x_{corr} = x \cdot \left(1 + k_1 r^2 + k_2 r^4 + k_3 r^6\right)$$
$$y_{corr} = y \cdot \left(1 + k_1 r^2 + k_2 r^4 + k_3 r^6\right)$$

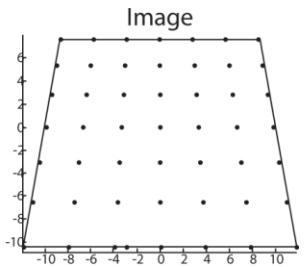
LE EQUAZIONI NON SERVE SAPERLE

*Model used in OpenCV

Tangential distortion

- Tangential distortion is caused by the non-ideal alignment between lens and sensor
- Looks similar to a "perspective" effect on the sensor
  - Usually negligible





Tangential distortion

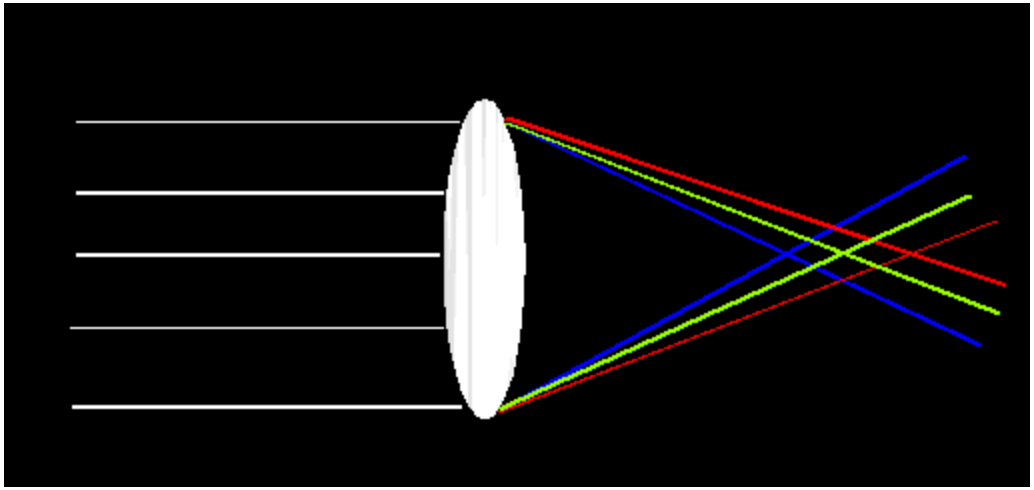
- Tangential distortion is also modeled in terms of (x_{corr}, y_{corr})

$$x_{corr} = x + \left[2p_1xy + p_2\left(r^2 + 2x^2\right)\right]$$

$$y_{corr} = y + \left[p_1\left(r^2 + 2y^2\right) + 2p_2xy\right]$$

Chromatic aberration

- Dispersion: refractive index depends on wavelength
- Modifies ray blending and lens focal length: f(λ)
- Color fringes near the image edges



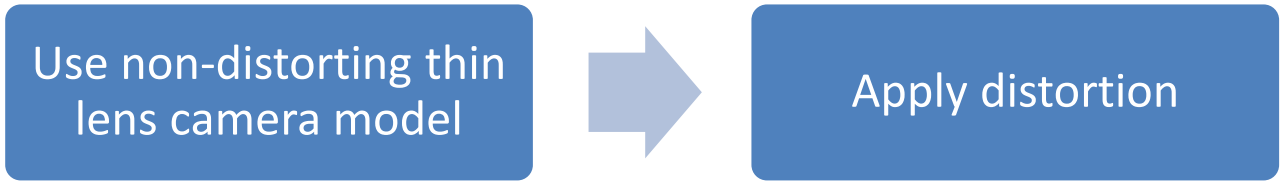
Chromatic aberration

Close to the lens center

Close to the outer edge

Distortion and camera models

- A thin lens camera model can be coupled with distortion estimation
  - Projection



  - Inverse projection

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