OPTICS & IMAGE CREATION

- Professor: Rubén Alvarez

Tecnológico de Monterrey

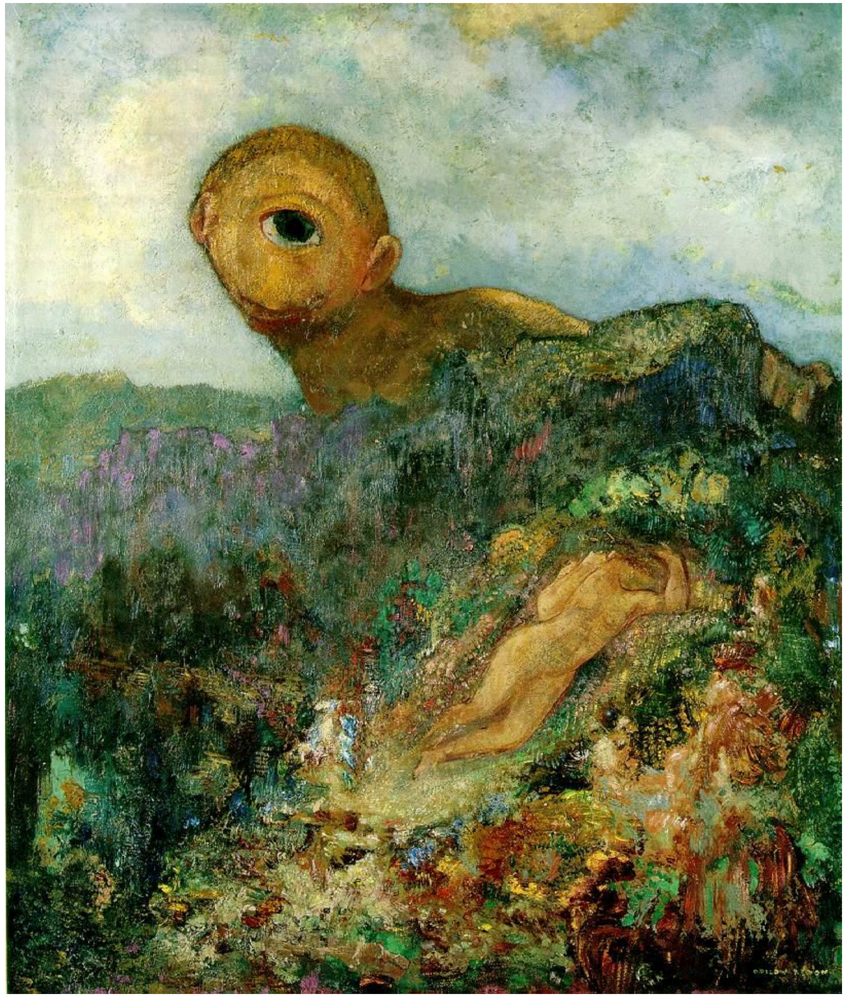
CONTENT

- 3D perception
- Lenses
- Image construction
- CCD vs CMOS sensors
- Camera calibration

3D PERCEPTION

COMPUTER VISION

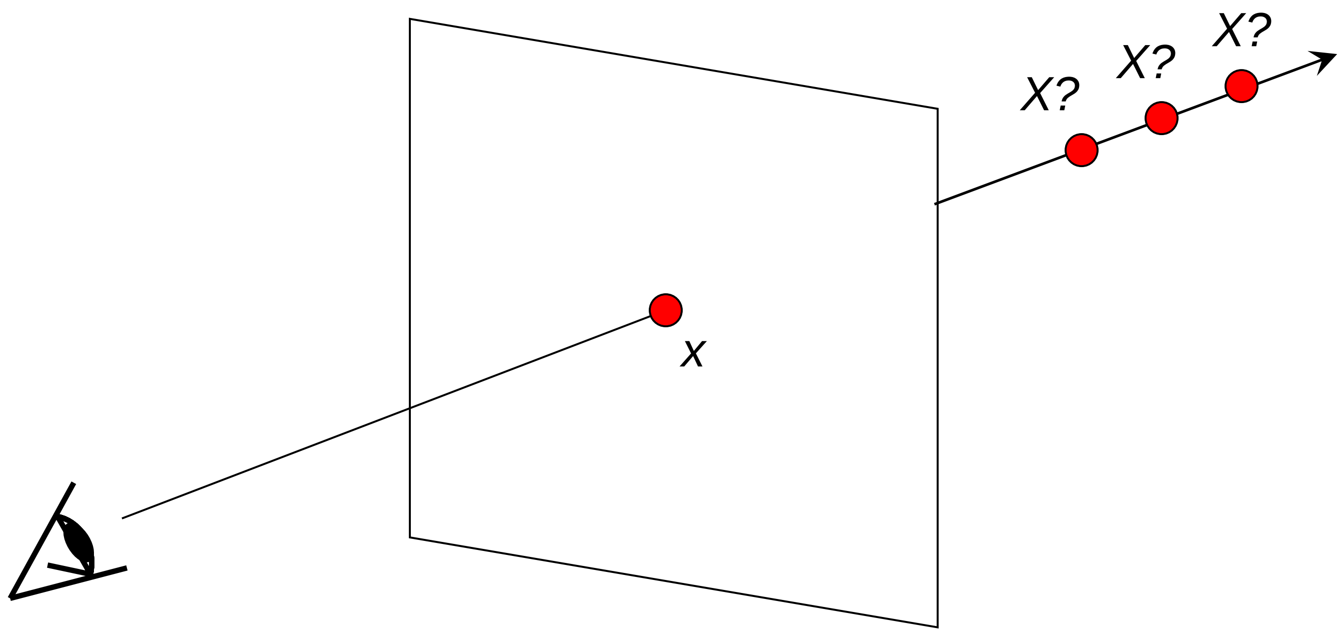
SINGLE-VIEW GEOMETRY



Odilon Redon, *Cyclops*, 1914

OUR GOAL: RECOVERY OF 3D STRUCTURE

- Is recovering the structure of an image unambiguous?



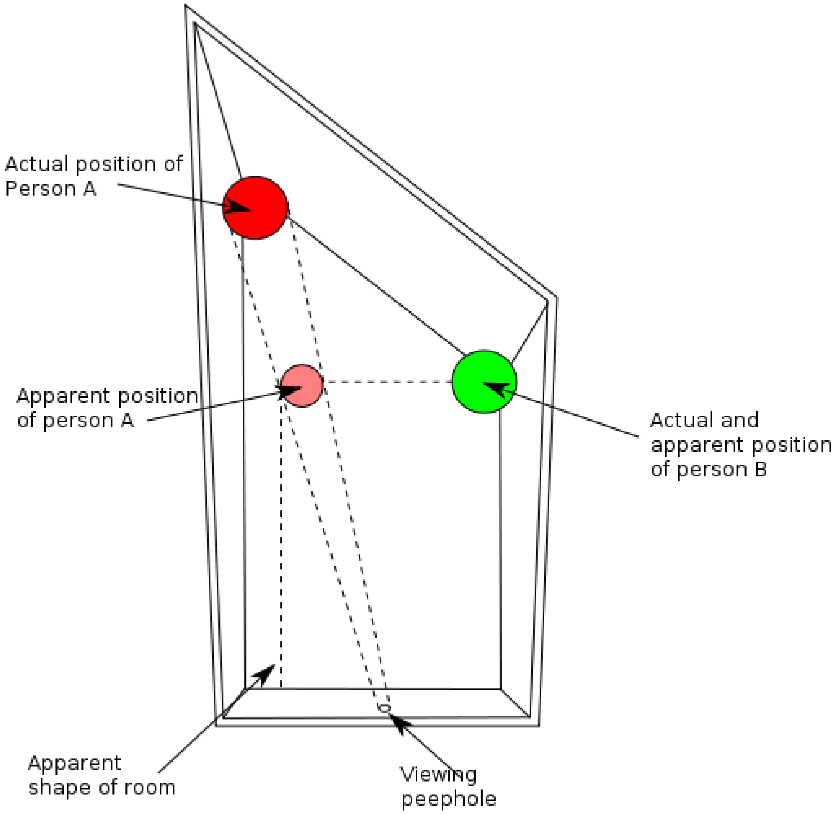
OUR GOAL: RECOVERY OF 3D STRUCTURE

- What about perspective?

OUR GOAL: RECOVERY OF 3D STRUCTURE

- Optical illusions?

AMES ROOM



Actual position of
Person A
Apparent position
of person A
Actual and
apparent position
of person B
Apparent
shape of room
Viewing
peephole

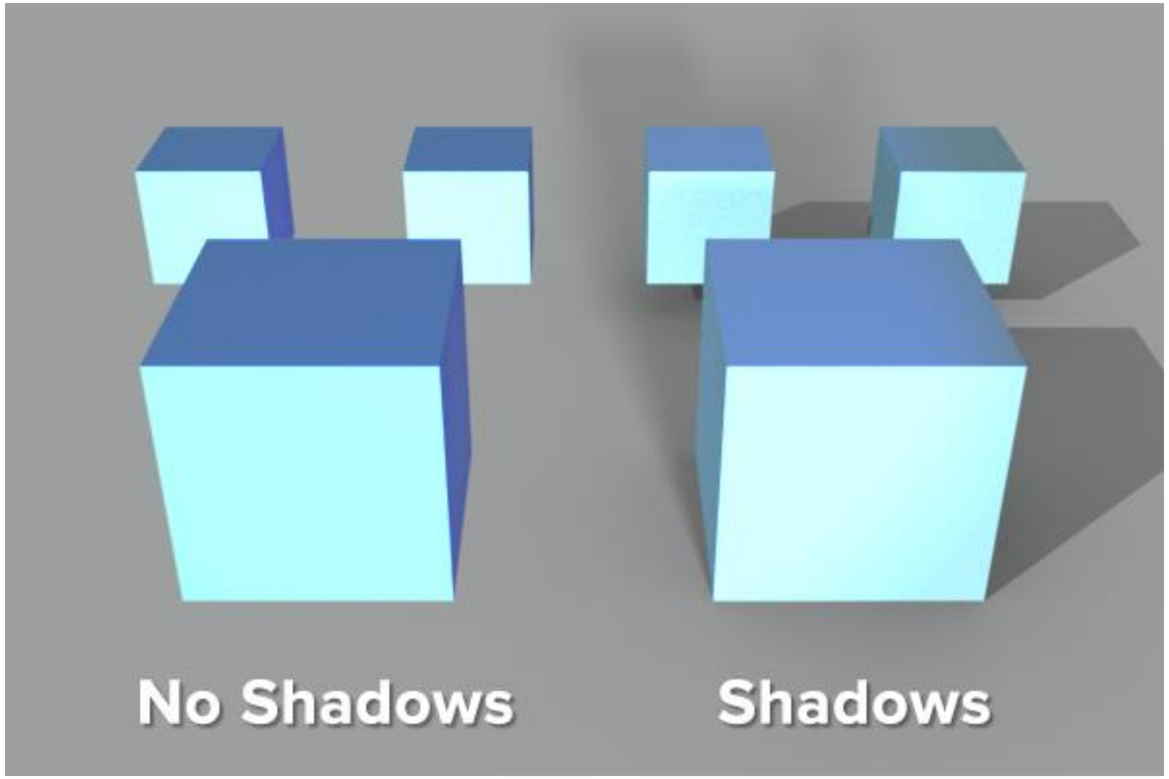
AMES ROOM

OUR GOAL: RECOVERY OF 3D STRUCTURE

- Will we need a multi-geometric view?



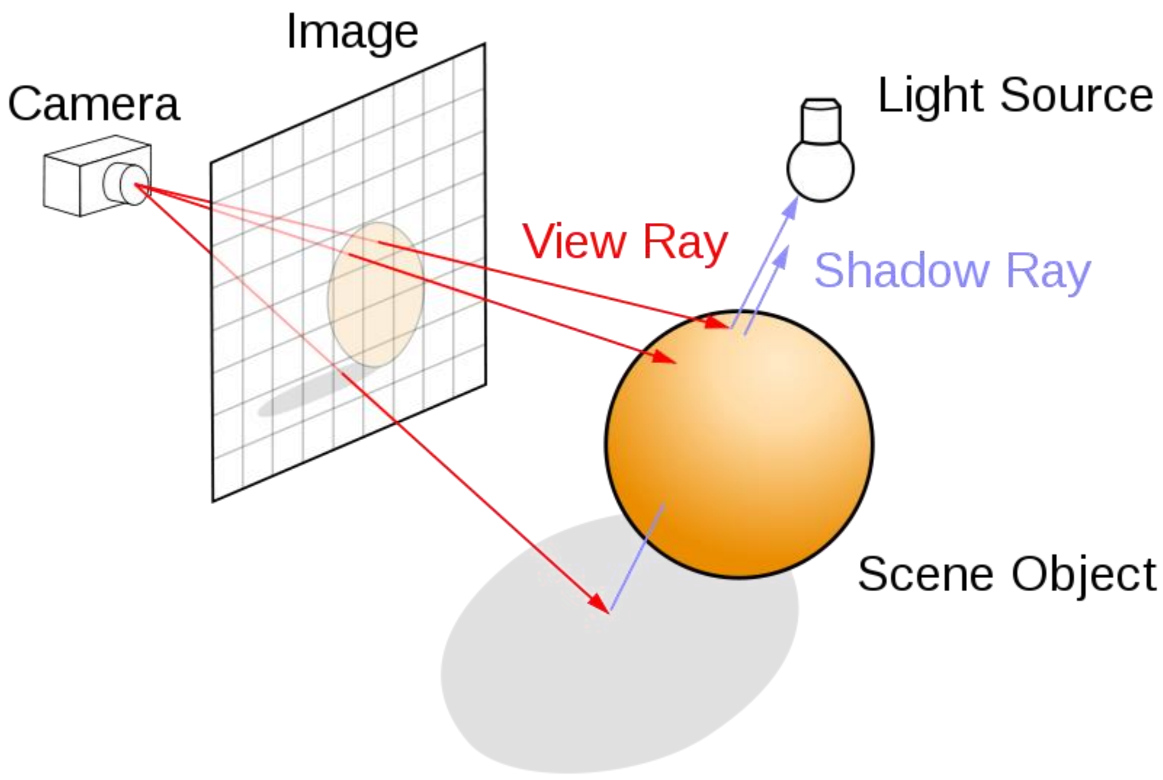
VIRTUAL REALITY LIGHTING



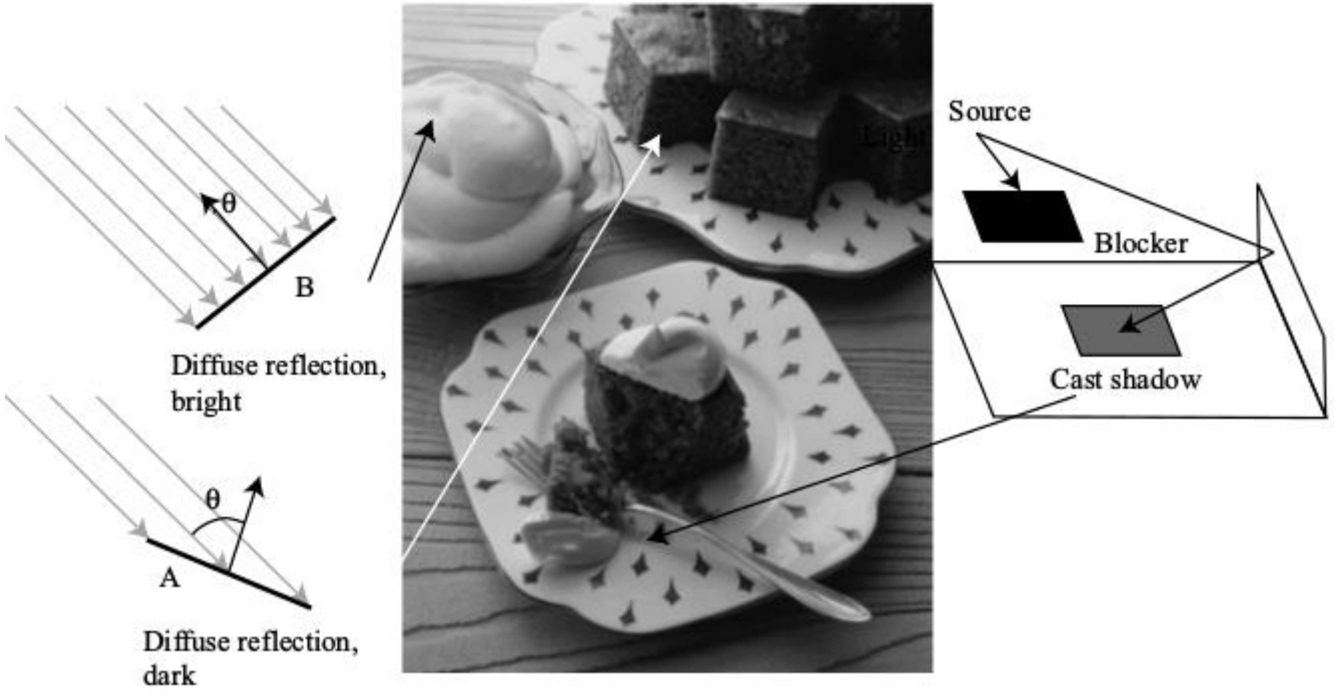
RAY TRACING

- It is a "rendering" technique for generating an image by tracing the path of light on an image plane and simulating its effects on virtual objects.

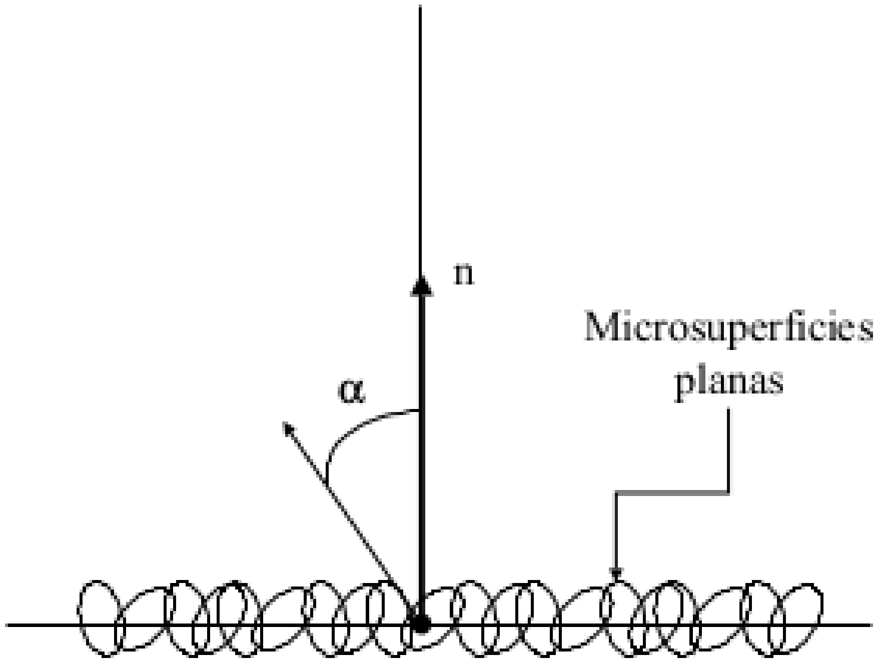
RAY TRACING

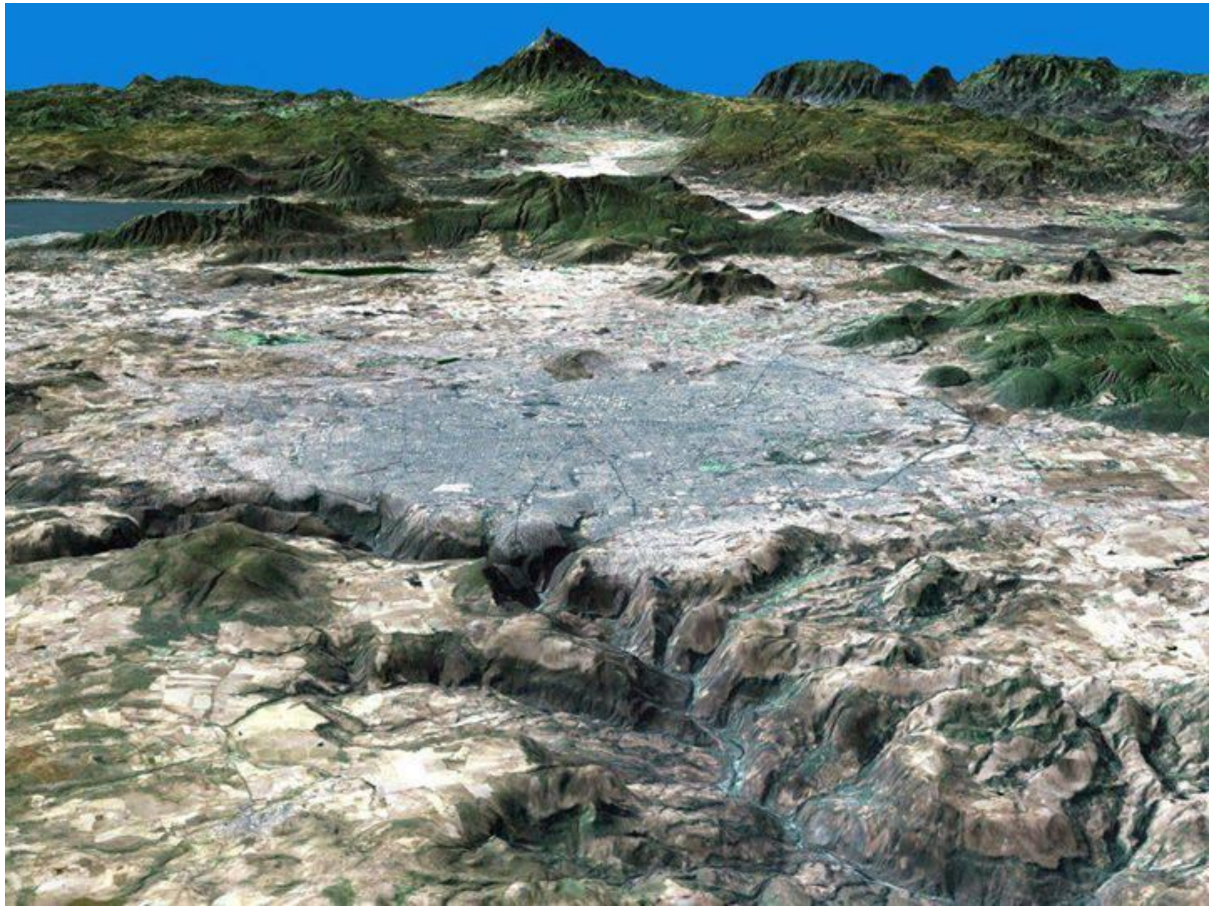


MAIN PROBLEM IN LIGHTING?



…SURFACE MODELS





LENSES

COMPUTER VISION

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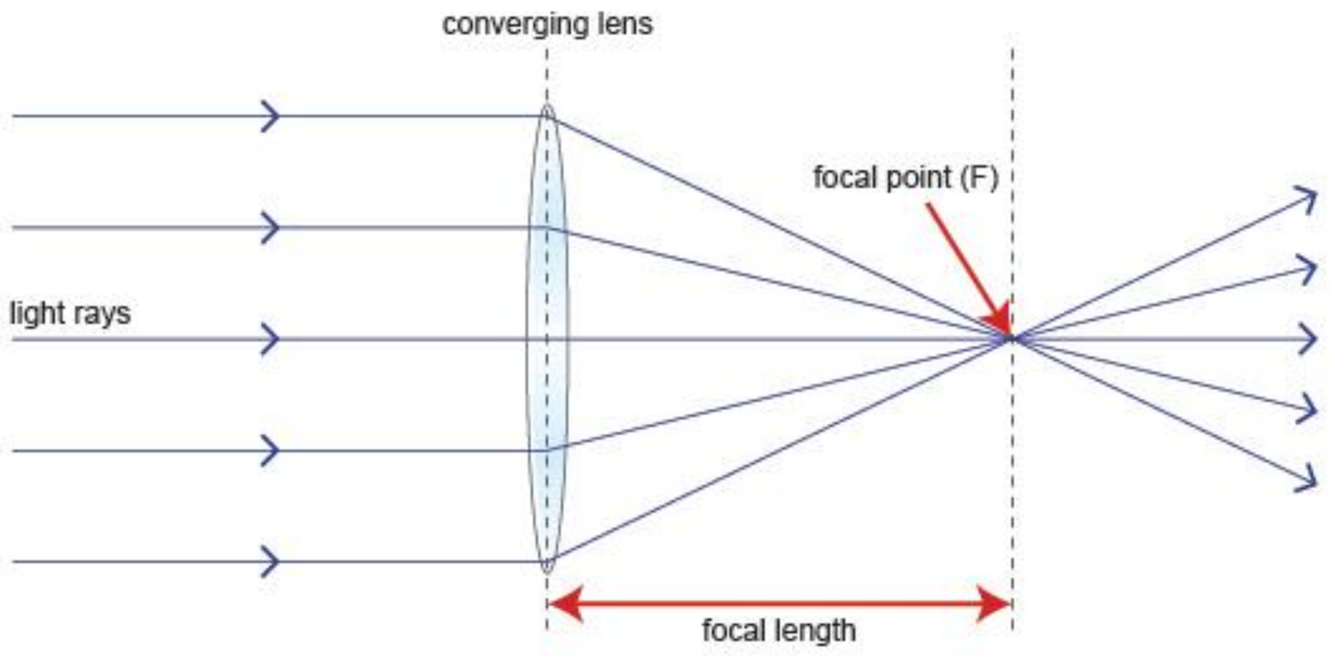
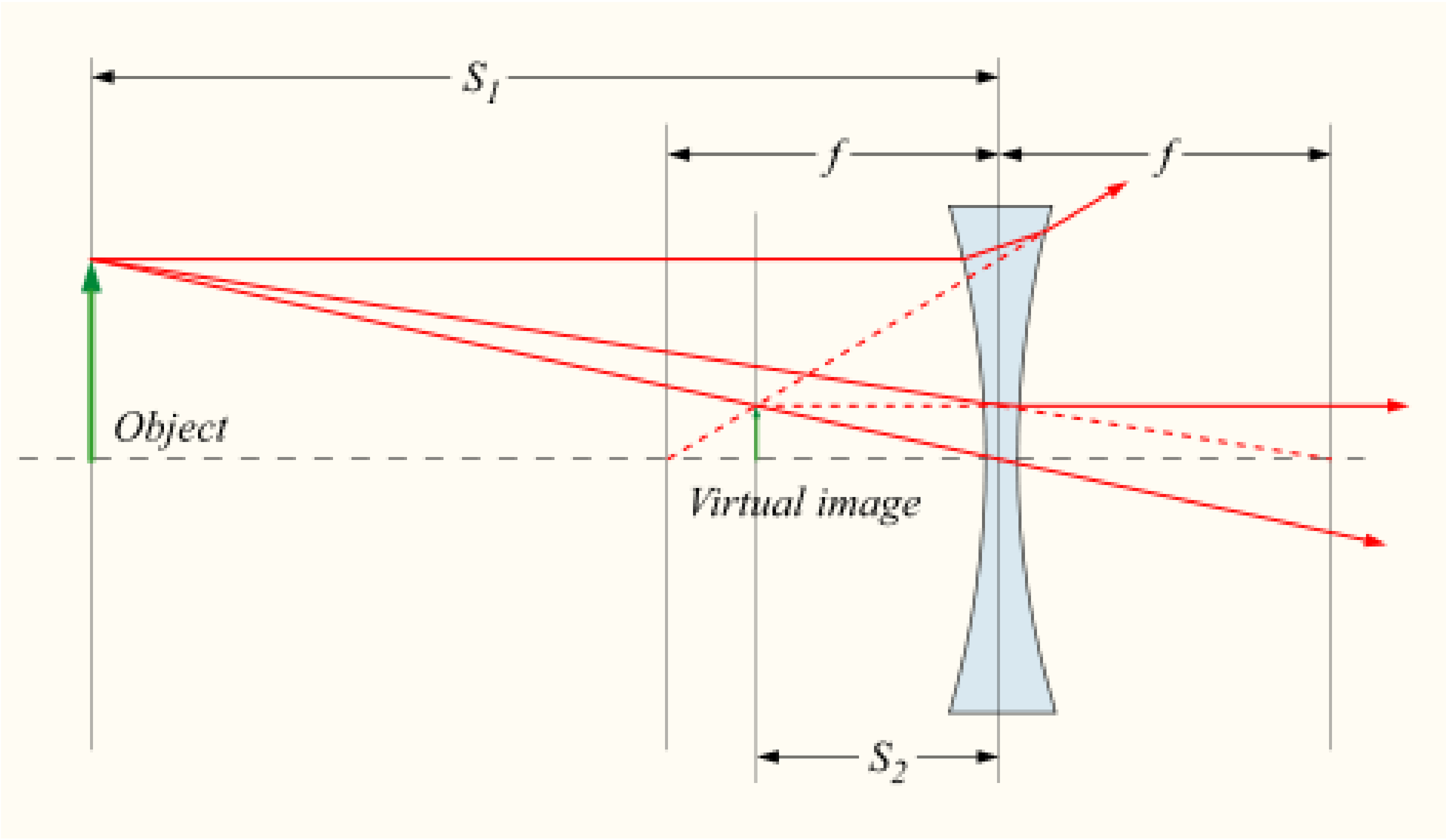
TYPES OF LENSES

CONVERGED LENSES



DIVERGENT LENSES

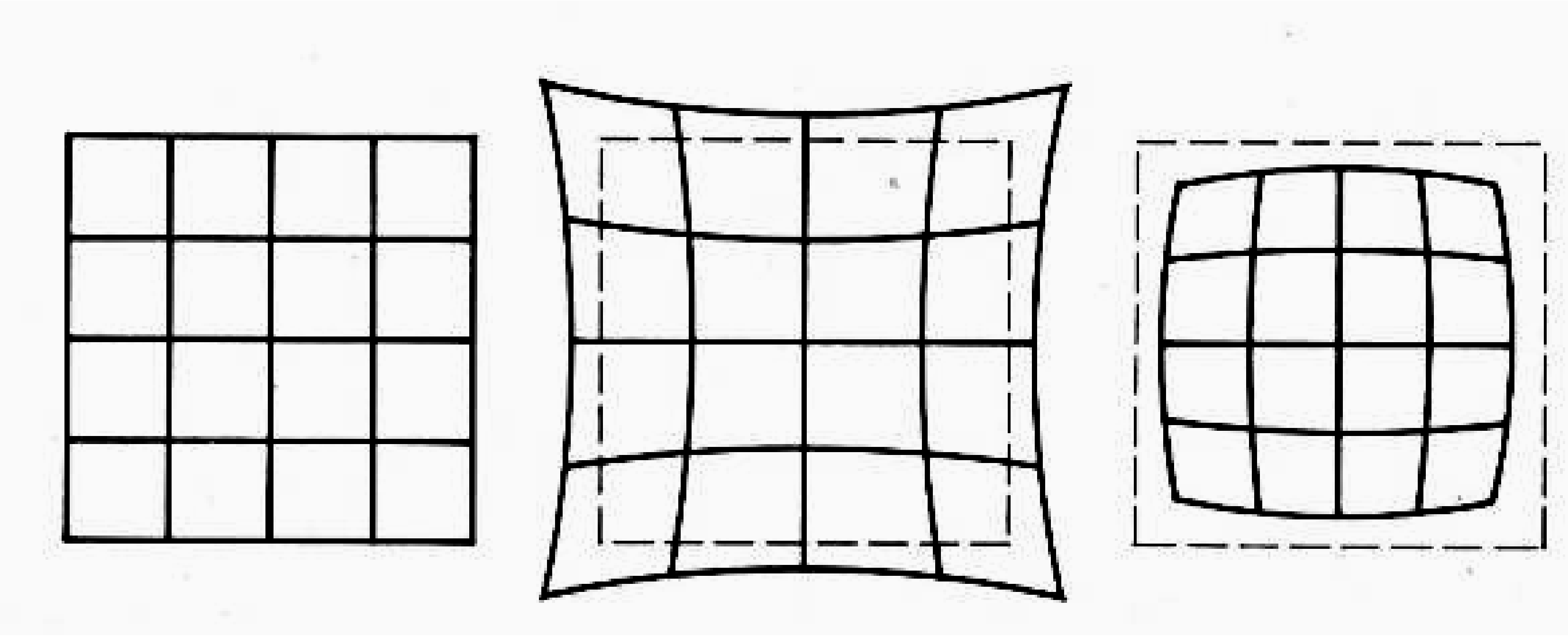


ARE THE LENSES PERFECT?

LENS PROBLEMS

- Physical world
- Radial distortion
- Distortion by perspective

RADIAL DISTORTION



WHAT IF WE JUST WORK WITH THE CENTER OF THE LENS?

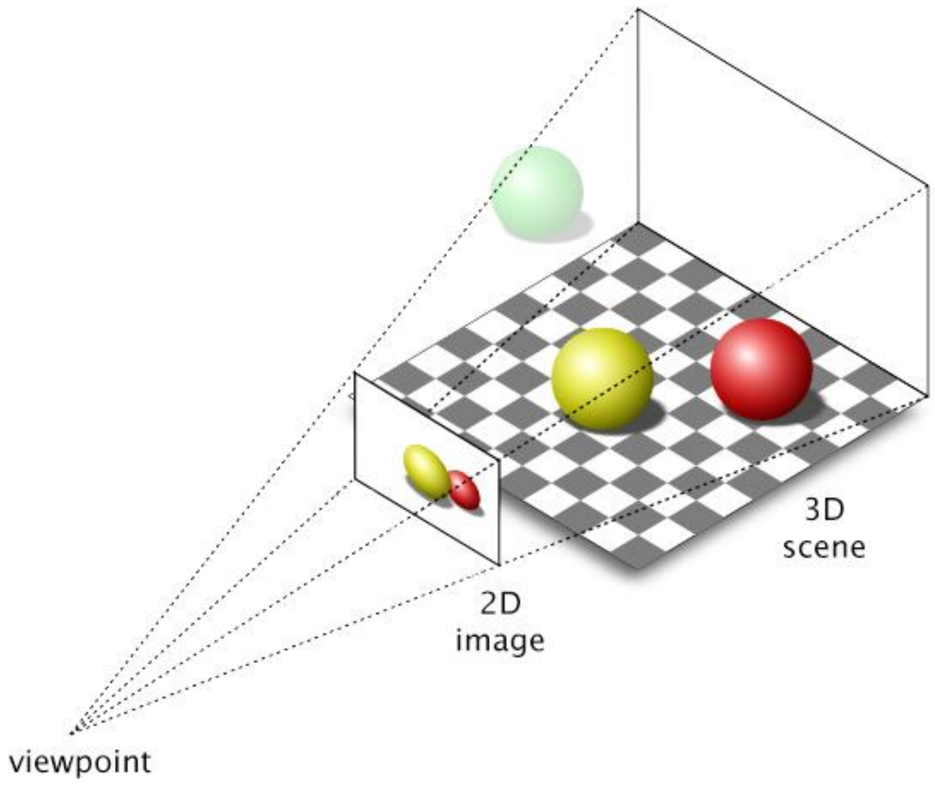
3D PERCEPTION IN 2D

COMPUTER VISION

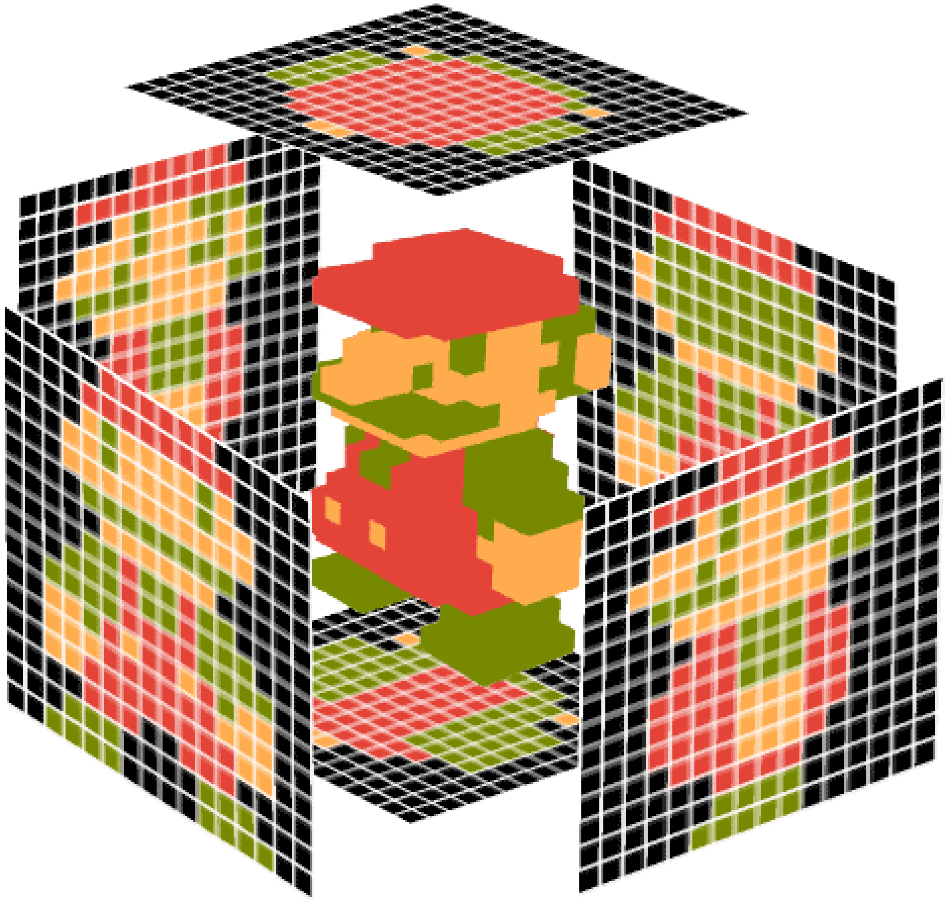
YOU CAN GET THE 3D PERCEPTION FROM AN 2D IMAGE?

COMPUTER VISION

MOVE INFORMATION FROM 3D TO 2D

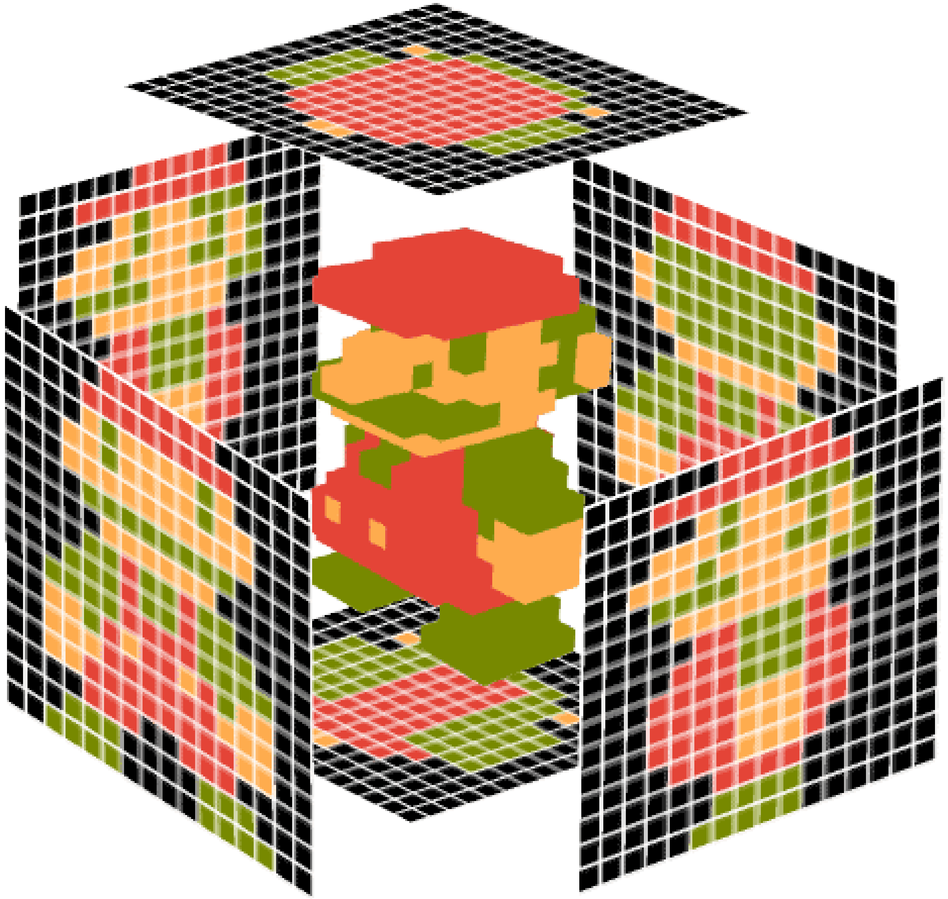


WHAT DO WE LOSE WITH THE DIMENSION REDUCTION?



WHAT DO WE LOSE WITH THE DIMENSION REDUCTION?

- Angles
- Distance



DISTORTION BY PERSPECTIVE

- What does a sphere look like in an image?

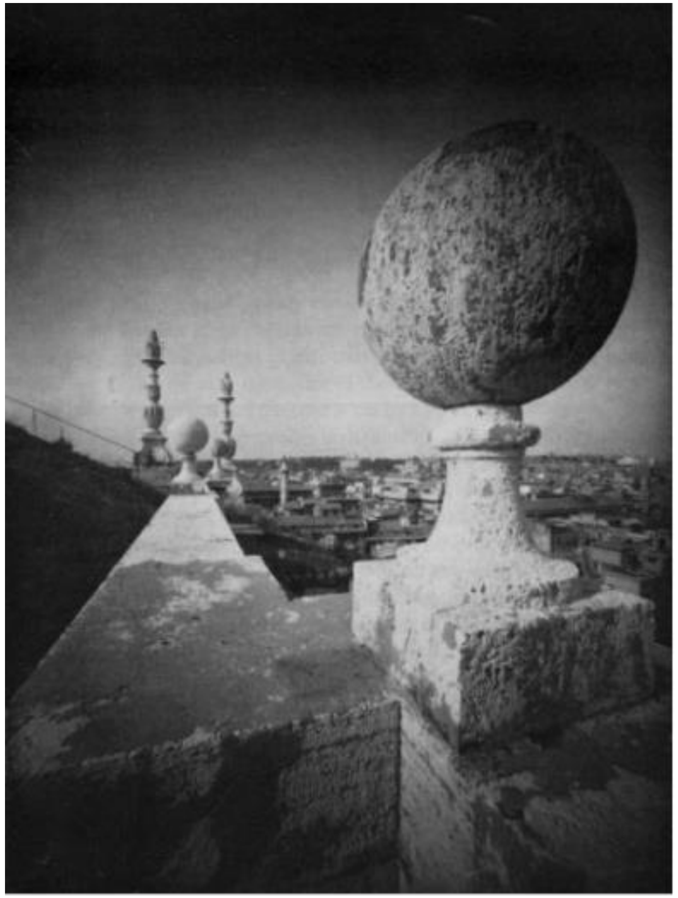
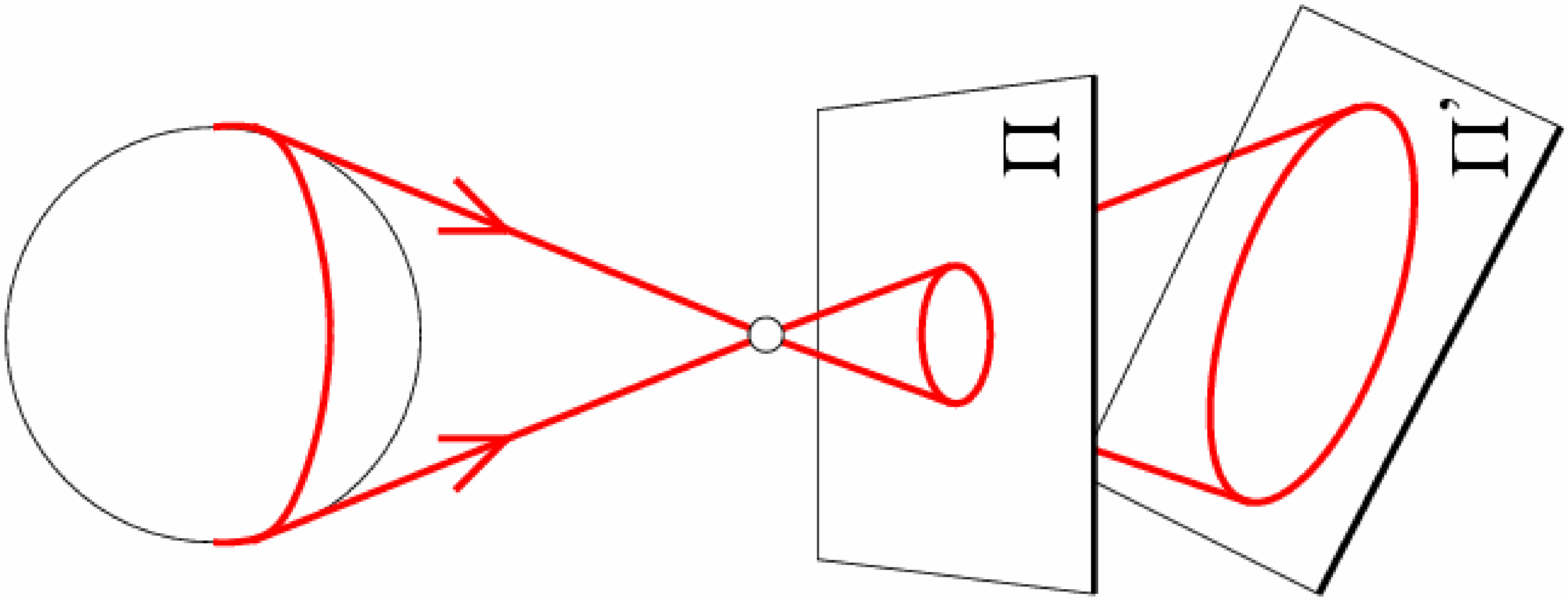


Image source: F. Durand

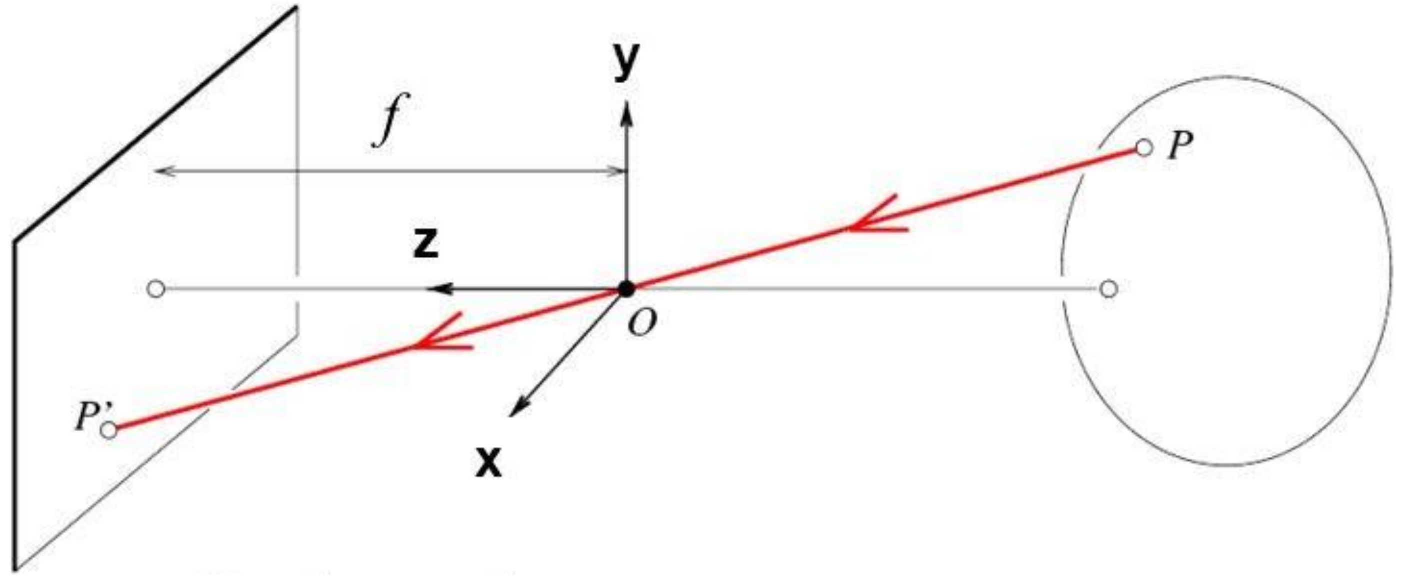
DISTORTION BY PERSPECTIVE

- It depends not only on the distance, but also on the projection angle!

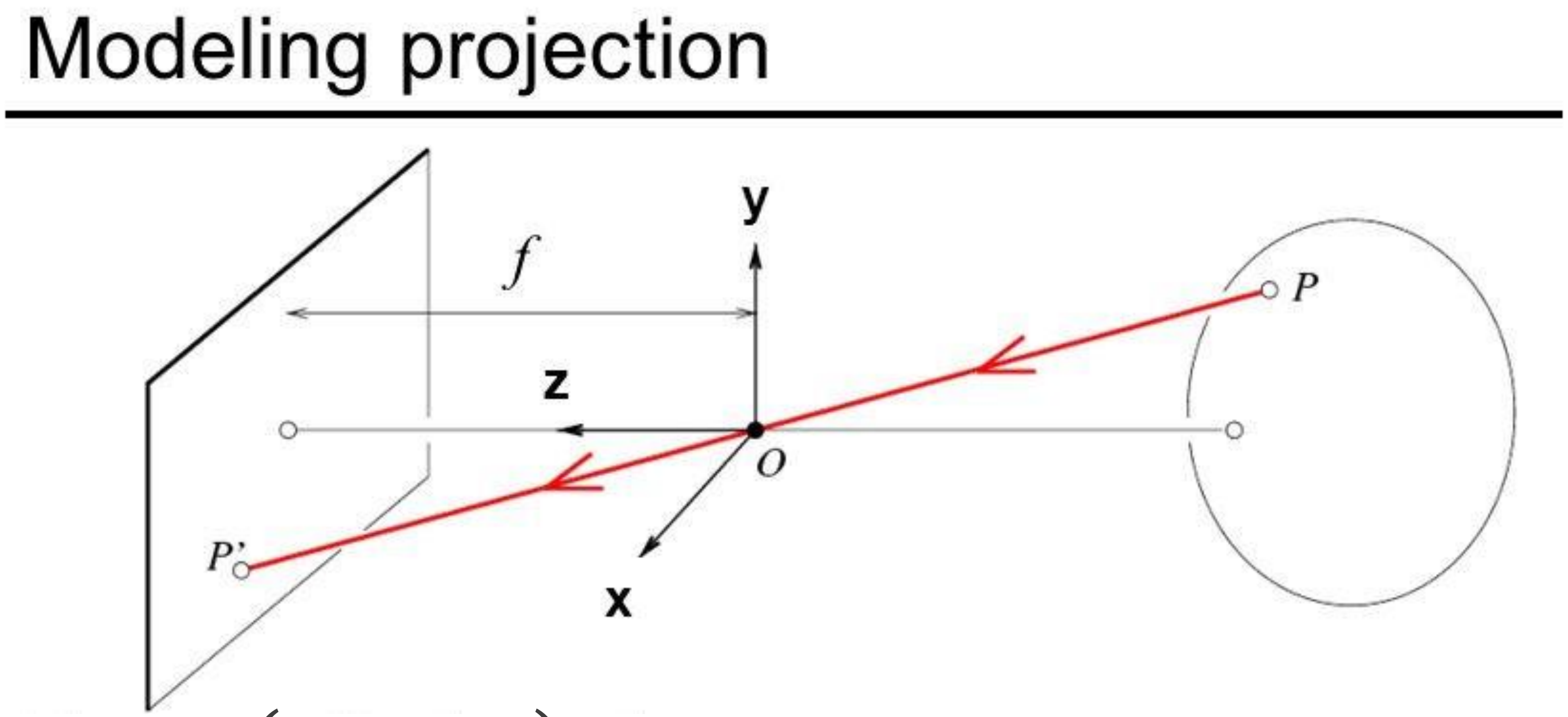


PROJECTION MODELING

Modeling projection



PROJECTION MODELING



- $(x, y, z) \rightarrow \left(f\frac{x}{z}, f\frac{y}{z}\right)$

HOMOGENEOUS COORDINATES

$$(x, y, z) \rightarrow \left(f\frac{x}{z}, f\frac{y}{z}\right)$$

Is it a linear transformation?

HOMOGENEOUS COORDINATES

$$(x, y, z) \rightarrow \left(f\frac{x}{z}, f\frac{y}{z}\right)$$

Is it a linear transformation?

- No, division between "z" is not linear.

VANISHING POINTS

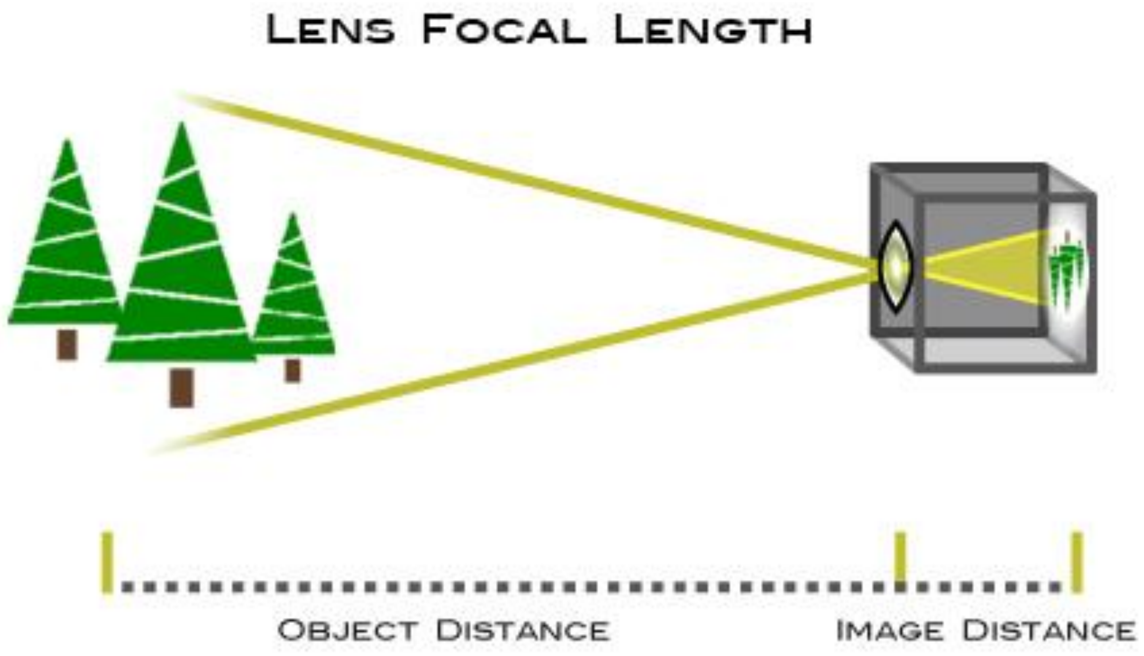
What do straight lines look like in an image?

VANISHING POINTS

LENSES PROPERTIES

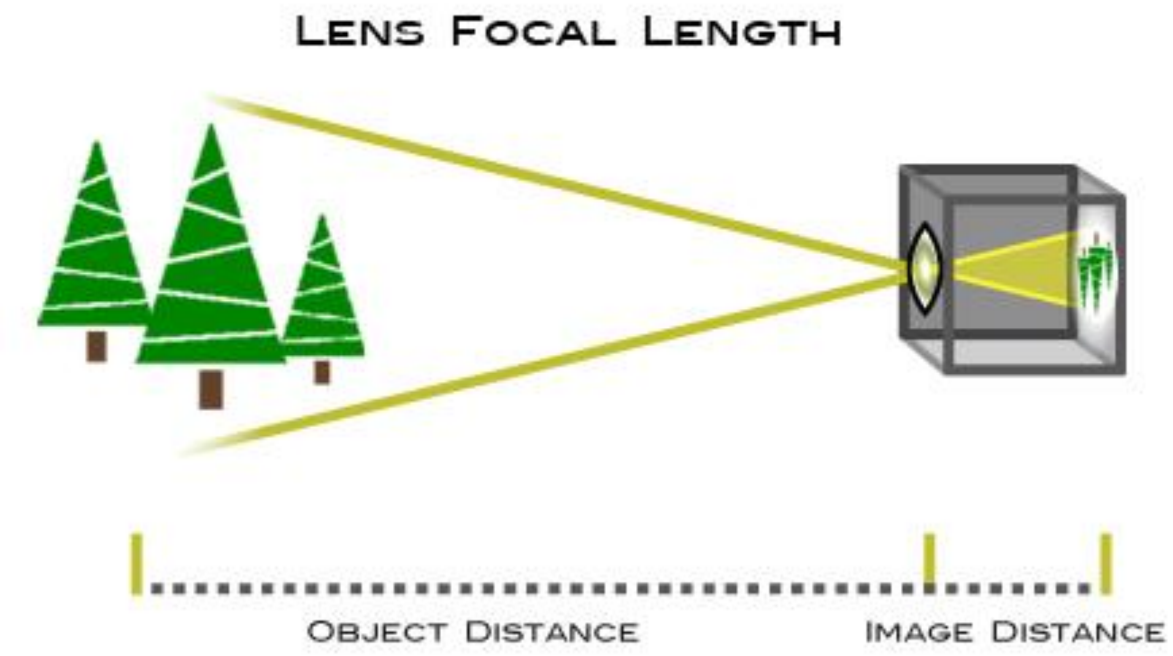
COMPUTER VISION

FOCAL DISTANCE

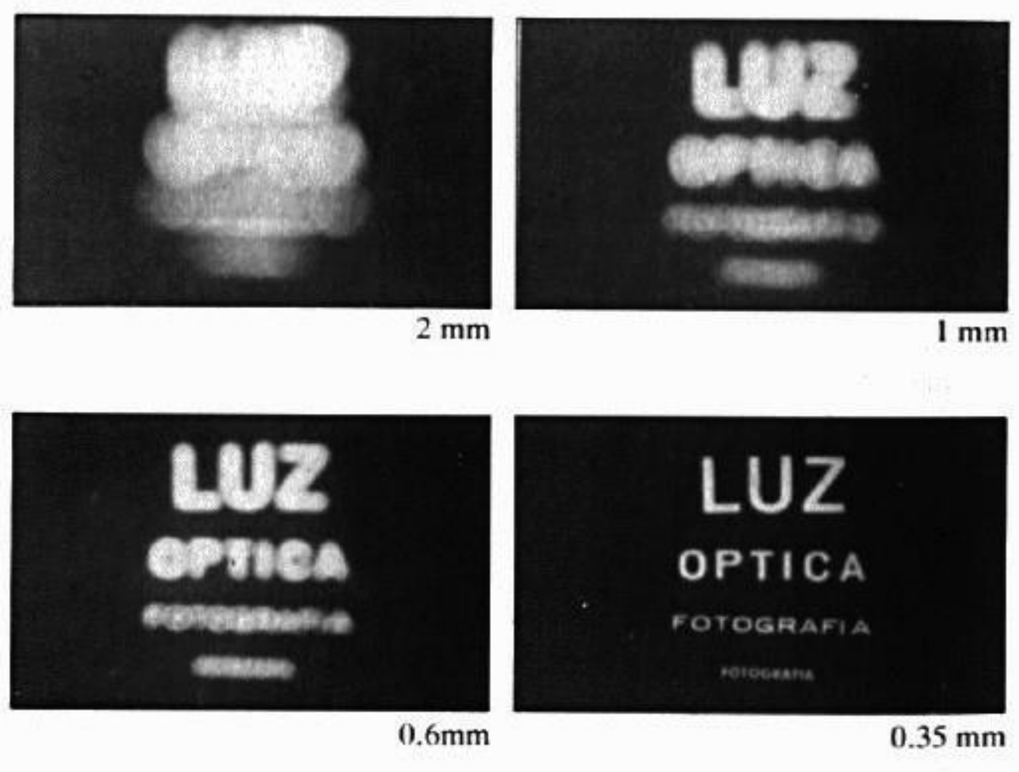


DOES OPENNESS MATTER?

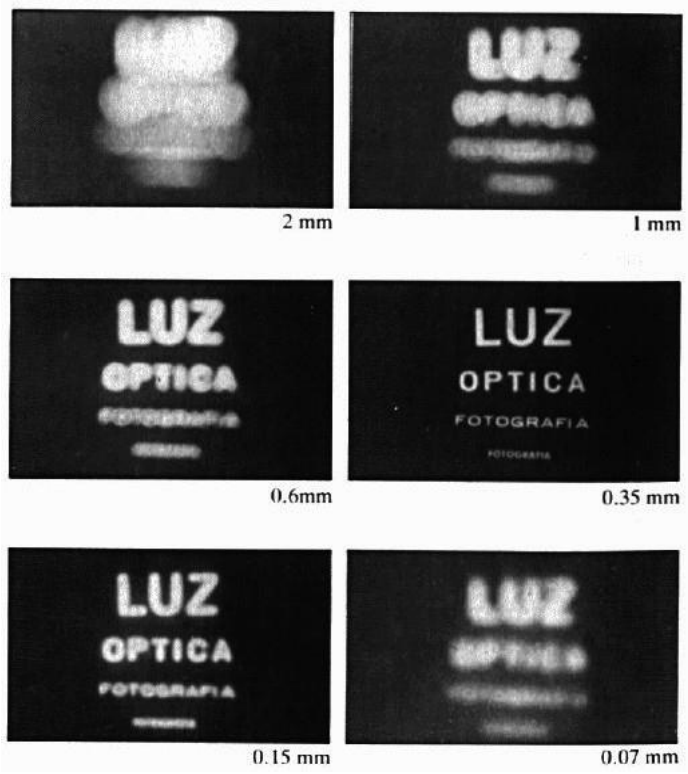
- In the case of the above drawing, is it important to enter the dimensions of that opening where the light enters the box?



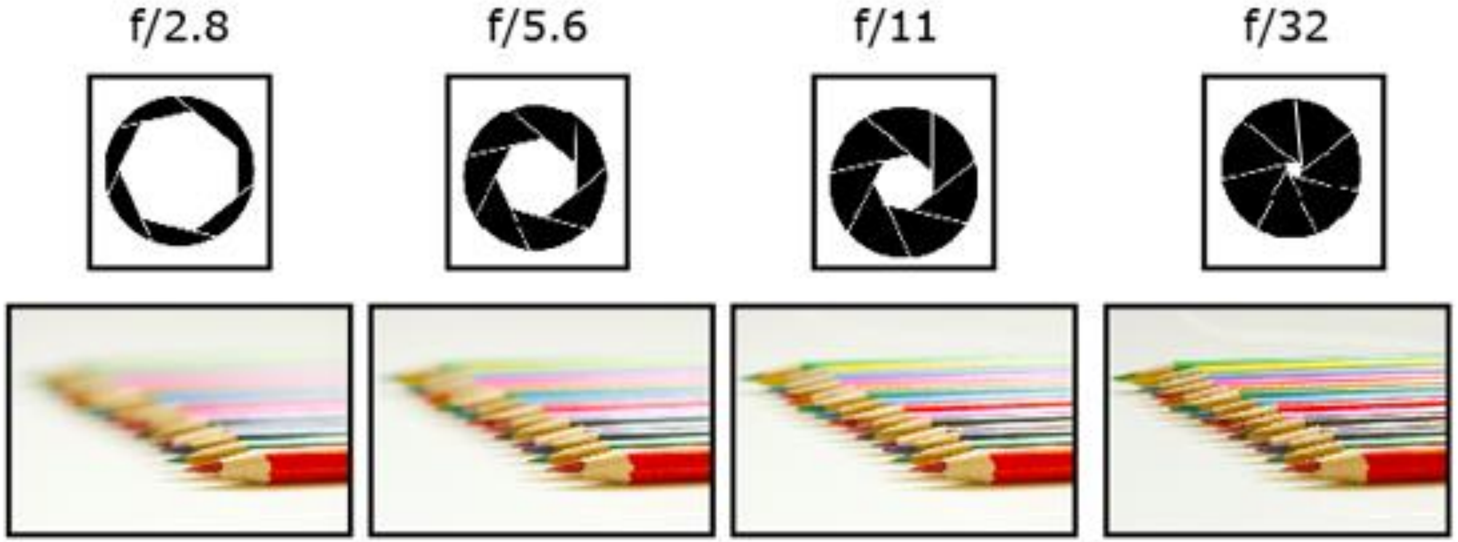
DOES OPENNESS MATTER?



THE SMALLER THE APERTURE, THE LESS LIGHT ENTERS



OPENNESS AND DEPTH ARE CORRELATED



HOW DO WE MODEL A LENS?

- The two main ones are:
  - Thin lenses
  - Pin hole model

OVERALL

- The cameras have:
  - Intrinsic parameters
  - Extrinsic parameters

THIN LENSES

- Gauss Law $\frac{1}{Z} + \frac{1}{z} = \frac{1}{f}$
- Where Z is the distance from the real world to the lens.
- z is the distance from the projected image to the lens.

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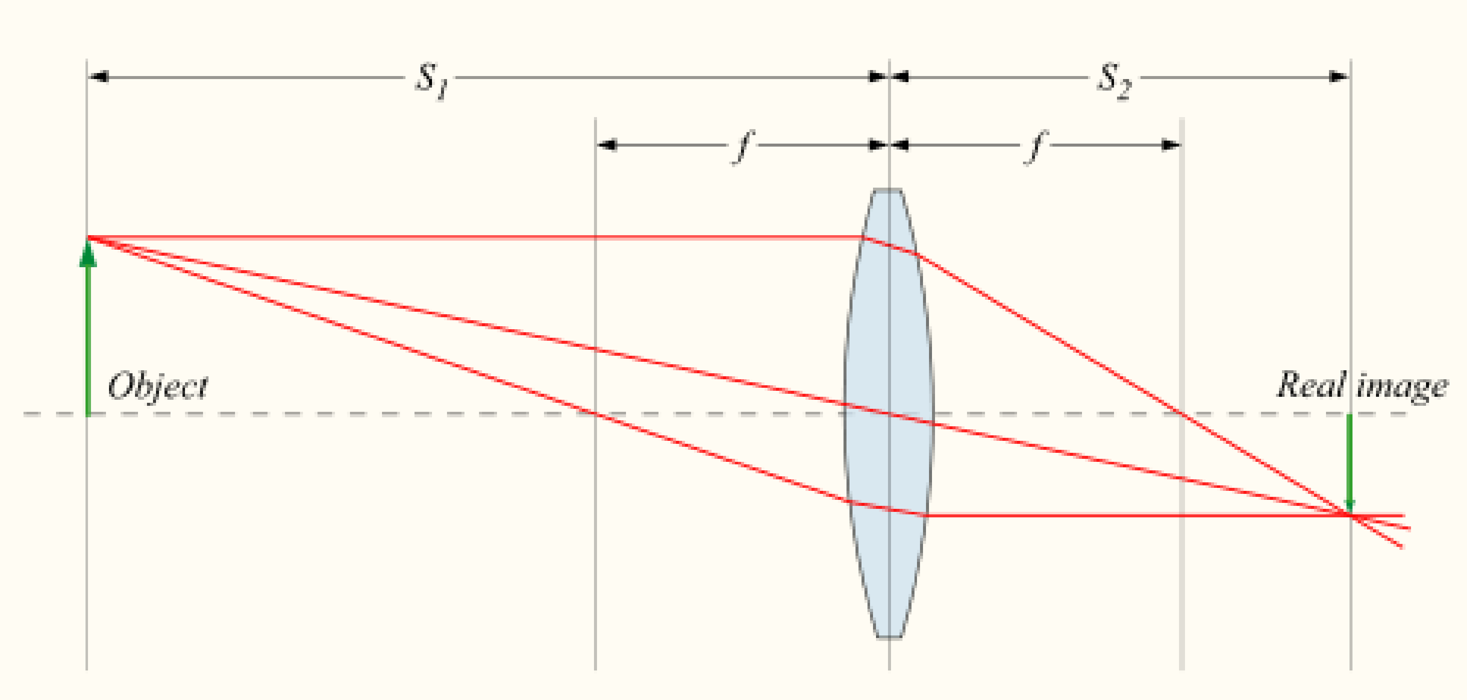
THIN LENSES

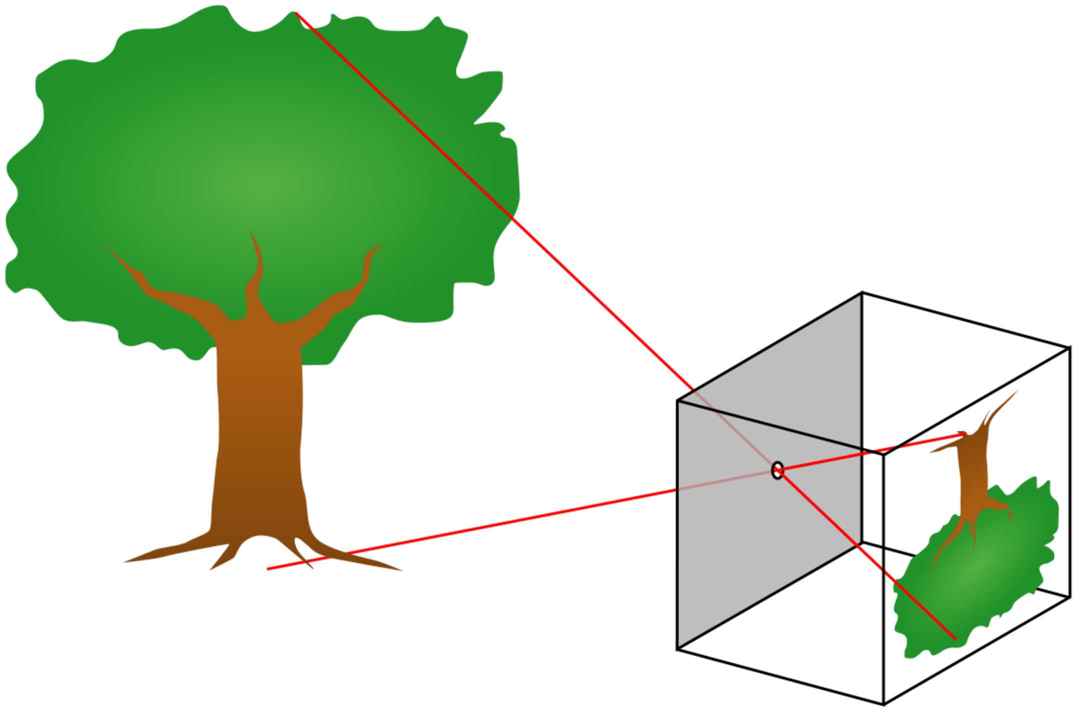
- Gaussian Law $\frac{1}{Z} + \frac{1}{z} = \frac{1}{f}$



PIN HOLE MODEL

- Capture all the rays of light through a simple point.
- The point is the "projection center" also known as the "focal point.
- The image is formed in the plane of the image.

PIN HOLE MODEL



PIN HOLE MODEL

- Does not contemplate the "focus"
- Tales Theorem
  - $x = \frac{f}{Z_W} X_W, \ y = \frac{f}{Z_W} Y_W$
  - Magnification
  - $M = \frac{x}{X_W} = \frac{y}{Y_W} = \frac{f}{Z_W}$

EXERCISE

- You need to calibrate a video camera. The camera's optics have a focal length of 3mm and the pixel size is $5.6\mu m \, x \, 5.6\mu m$. The effective number of pixels are $293(W) \, x \, 357(H)$.
- What is the minimum distance you need to put the calibration pattern (checkerboard) with respect to the camera so that the board is inside the image? If each square measures $27mm$ *on each side and you have 7x9 squares.*

EXERCISE

- You need to calibrate a video camera. The camera's optics have a focal length of 3mm and the pixel size is $5.6\mu m \; x \; 5.6\mu m$. The effective number of pixels are $293(W) \; x \; 357(H)$.

WHY CALIBRATE THE CAMERA?

- Solve 3D geometry
- Simplify 3D reconstruction
- Improving accuracy
- Eliminate ambiguities such as scale

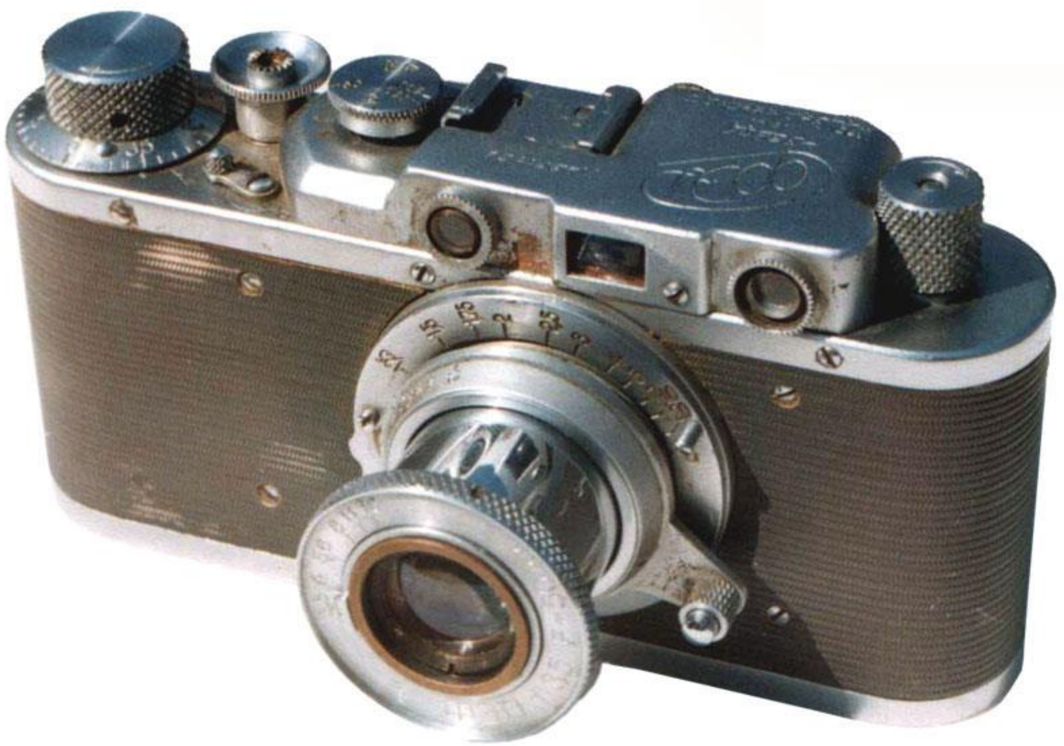
SOLVE GEOMETRY IN 3D WITHOUT KNOWING THE CAMERAS

- Structure from motion

CAMERA CALIBRATION

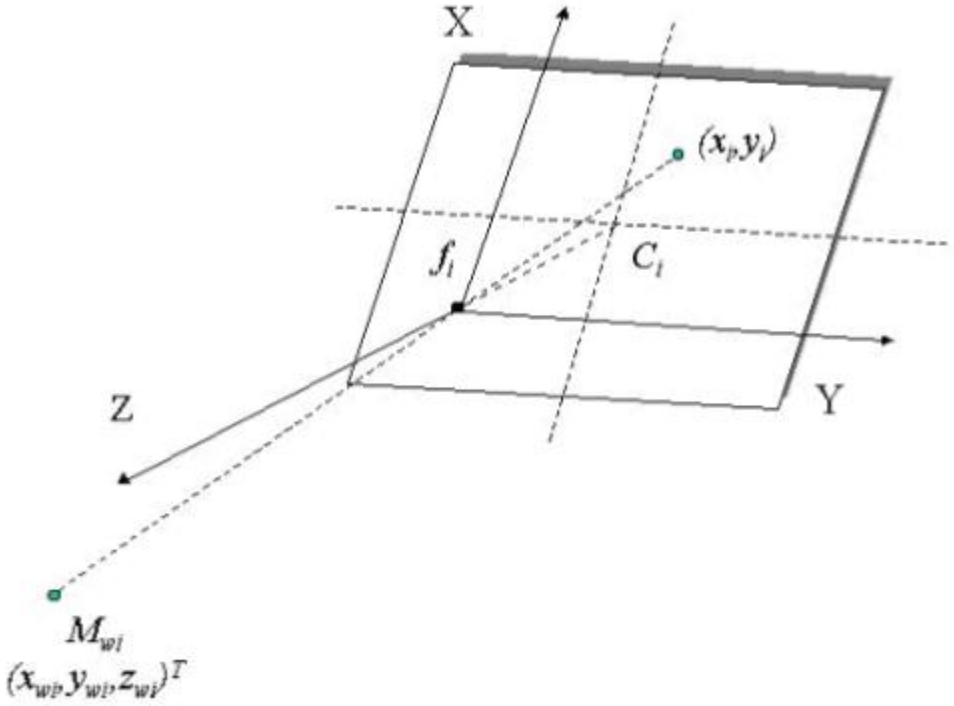
COMPUTER VISION

CAMERA CALIBRATION



SO… TO CALIBRATE THE CAMERA

- We need a sequence of images



CAMERA CALIBRATION

- $$\begin{pmatrix} p_{xi} \\ p_{yi} \\ 1 \end{pmatrix} = \begin{pmatrix} \frac{f}{dx} & 0 & c_{xi} \\ 0 & \frac{f}{d_y} & c_{yi} \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} X_w \\ Y_W \\ Z_W \end{pmatrix}$$

CAMERA CALIBRATION

- $$\begin{pmatrix} p_{xi} \\ p_{yi} \\ 1 \end{pmatrix} = \begin{pmatrix} \frac{f}{dx} & -\rho \frac{f}{dy} & c_{xi} \\ 0 & \frac{f}{d_y} & c_{yi} \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} X_w \\ Y_W \\ Z_W \end{pmatrix}$$

CCD VS CMOS

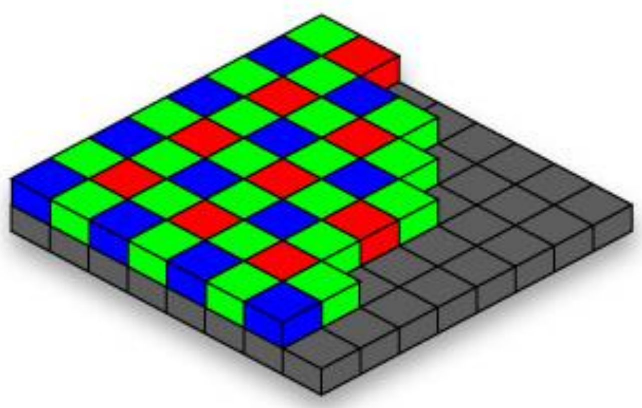
COMPUTER VISION

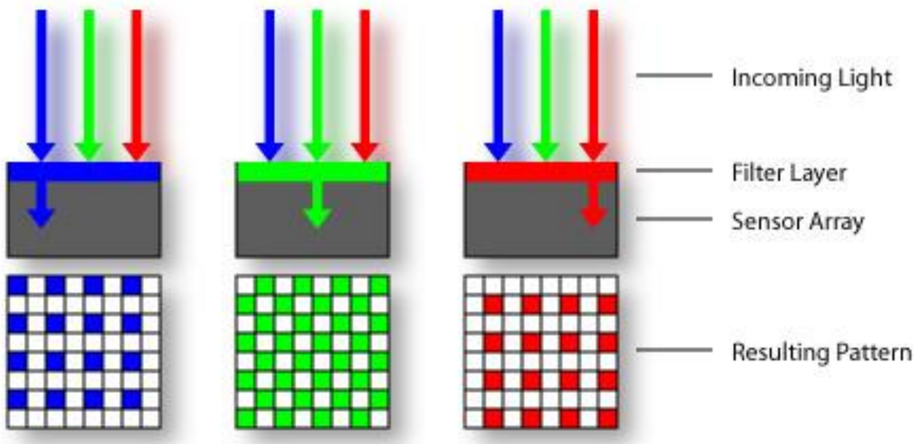
CCD VS CMOS

- **CCD**
- Mature technology
- High production cost
- High power consumption
- Higher fill rate
- Lower noise
- Higher resolution
- Blooming
- Sequential readout

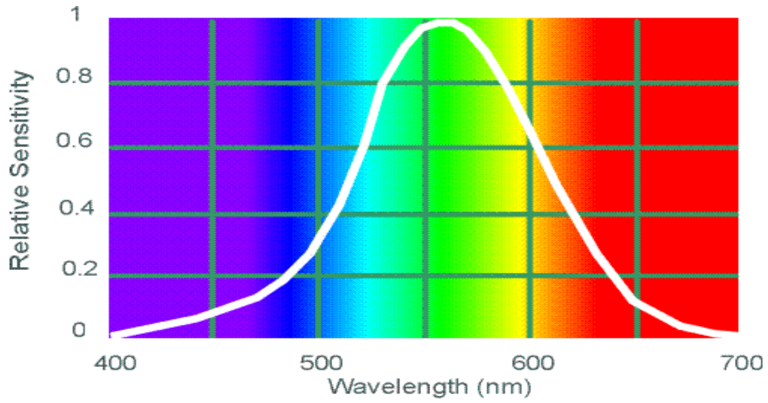
- **CMOS**
- Recent technology
- Lower production cost (but…)
- Low power
- Lower fill rate (less sensitive)
- Higher noise
- Lower resolution
- Per pixel amplification
- Random pixel access
- Smart pixels
- On chip integration
  with other components

COLOR SENSING IN CAMERA: COLOR FILTER ARRAY





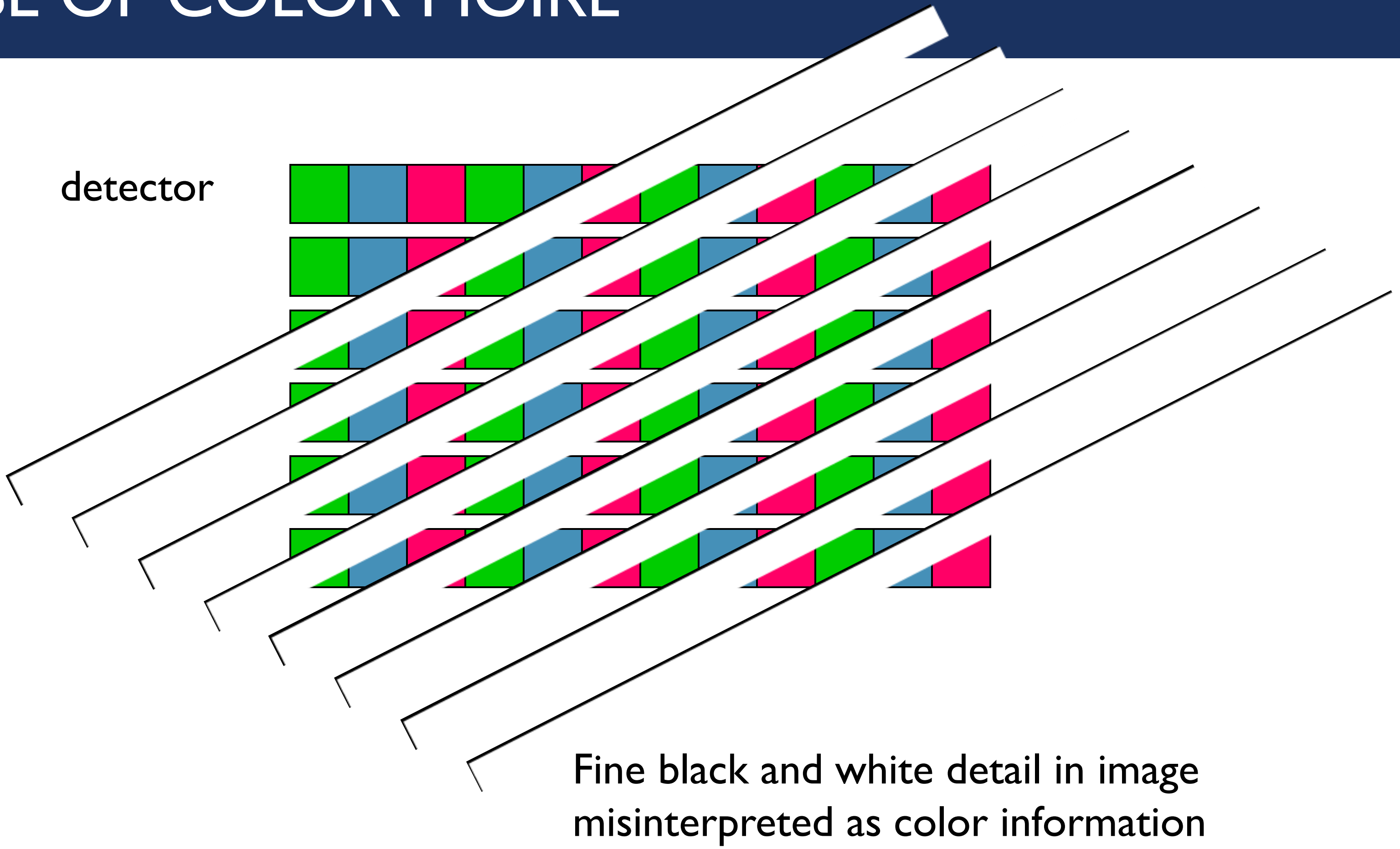
Estimate missing components from neighboring values (demosaicing)



Human Luminance Sensitivity Function

THE CAUSE OF COLOR MOIRE

THE CAUSE OF COLOR MOIRE



PRACTICE 1.1

- On canvas

Questions?