MECS 6616

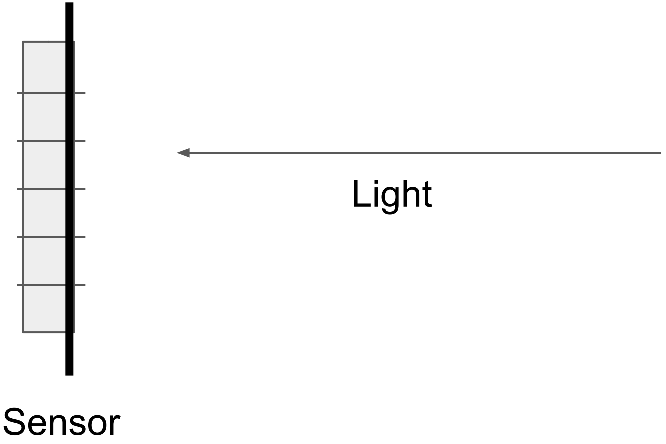
Computer Vision I: Why is Computer Vision Hard?

Spring 2020

Matei Ciocarlie

How do cameras work?

- A pixel measures the amount of light that hits it over a given time period
    - … can almost think of it as “counting photons”...



How do cameras work?

- A pixel measures the amount of light that hits it over a given time period
  - … can almost think of it as “counting photons”...
- Then, the result is digitized: **digital images are arrays of numbers**

128	144	120	130	128	165	184
131	152	128	114	180	200	230
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100	40	42	20	34	50	98
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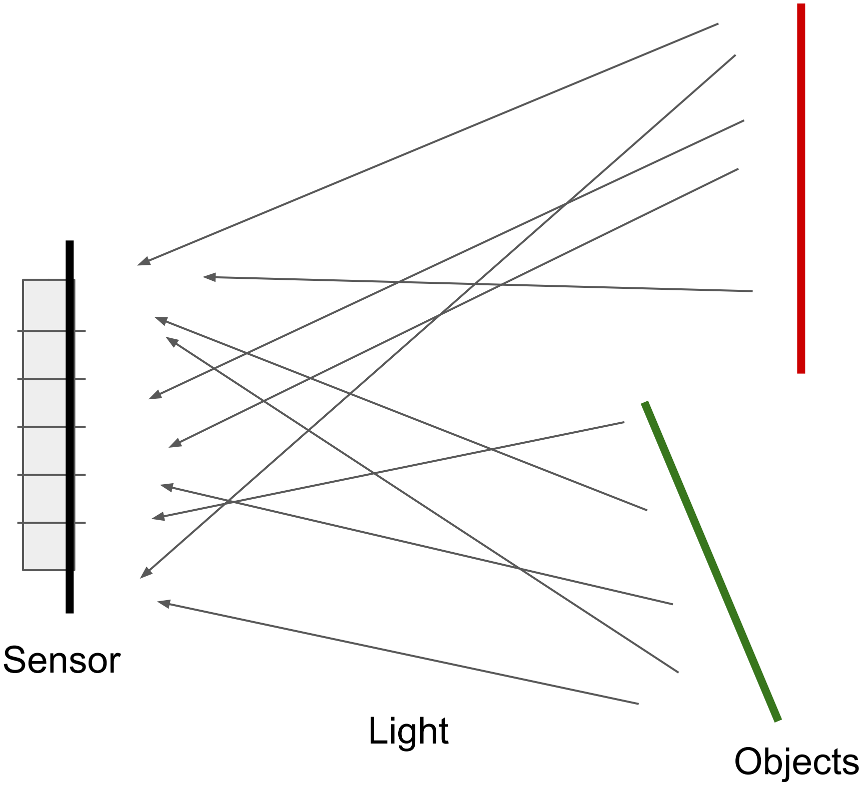
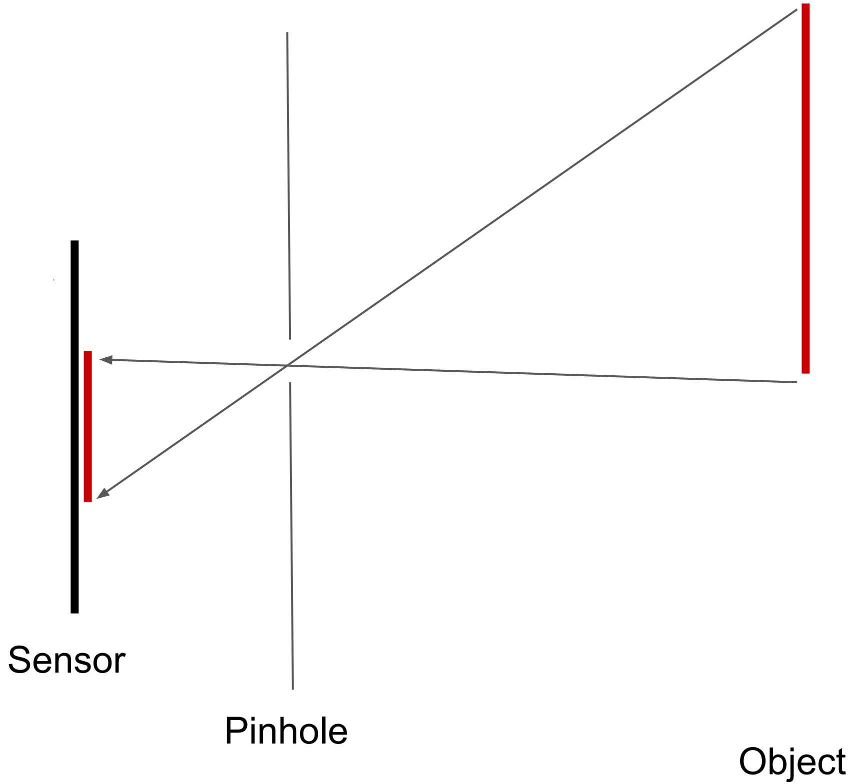
How do cameras work?

Light transport

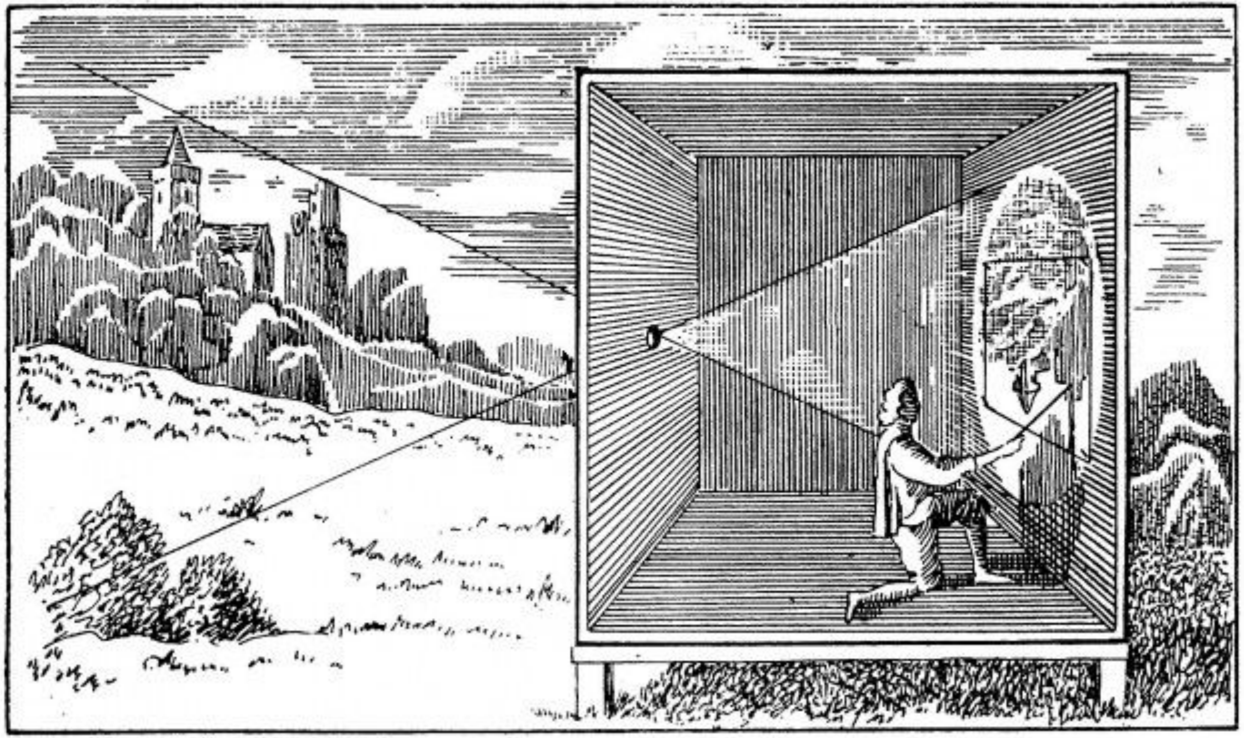


How do cameras work?

Pinhole camera



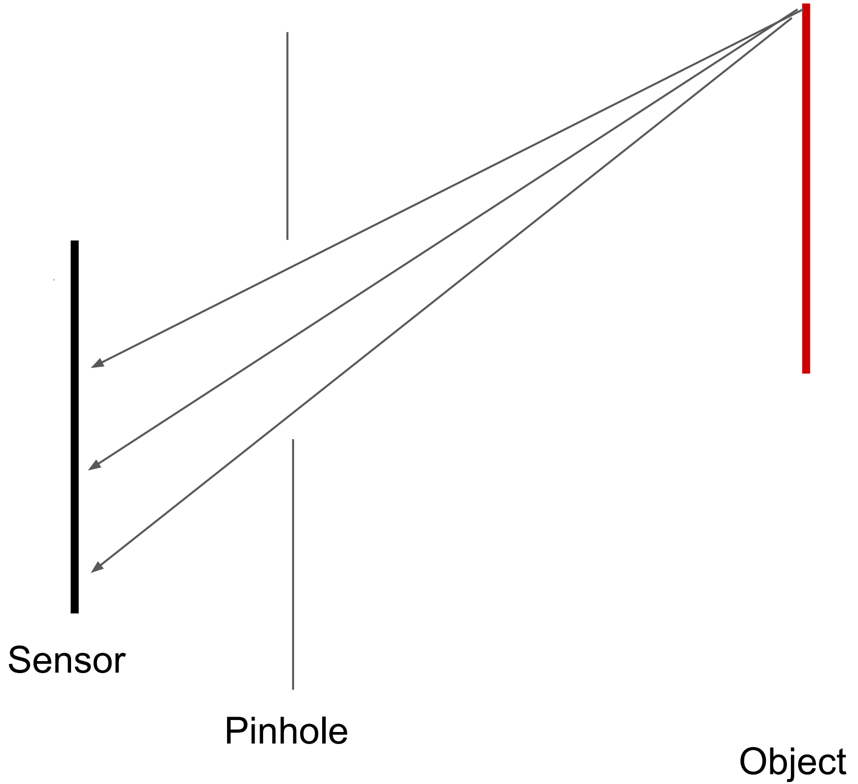
Camera obscura



http://pixsylated.com/blog/pix/Camera-Obscura-diagram-630x375.jpeg

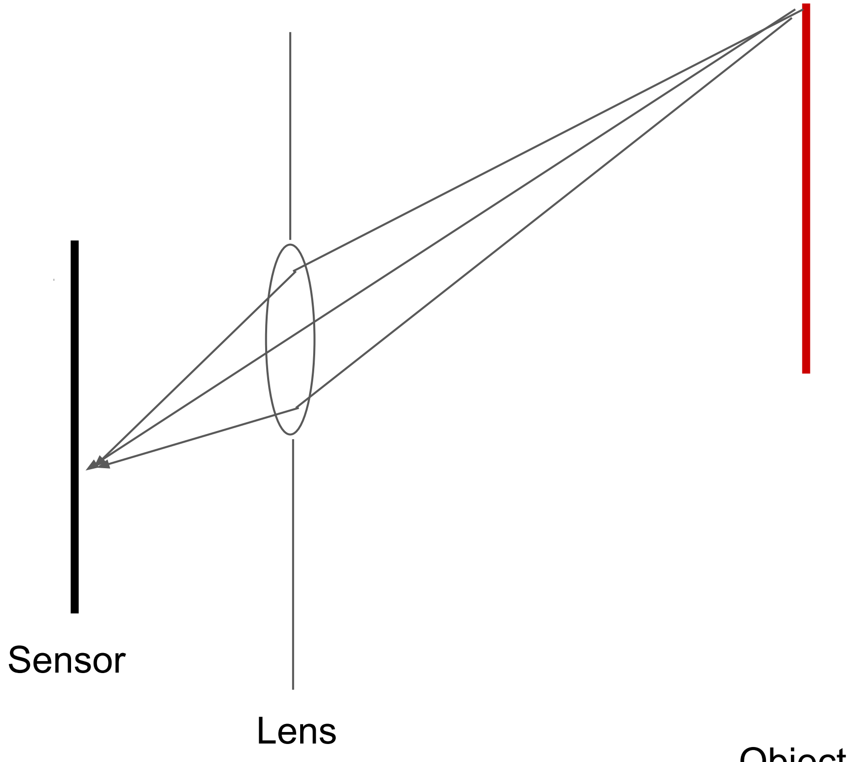
How do cameras work?

Pinhole camera



How do cameras work?

Lens camera



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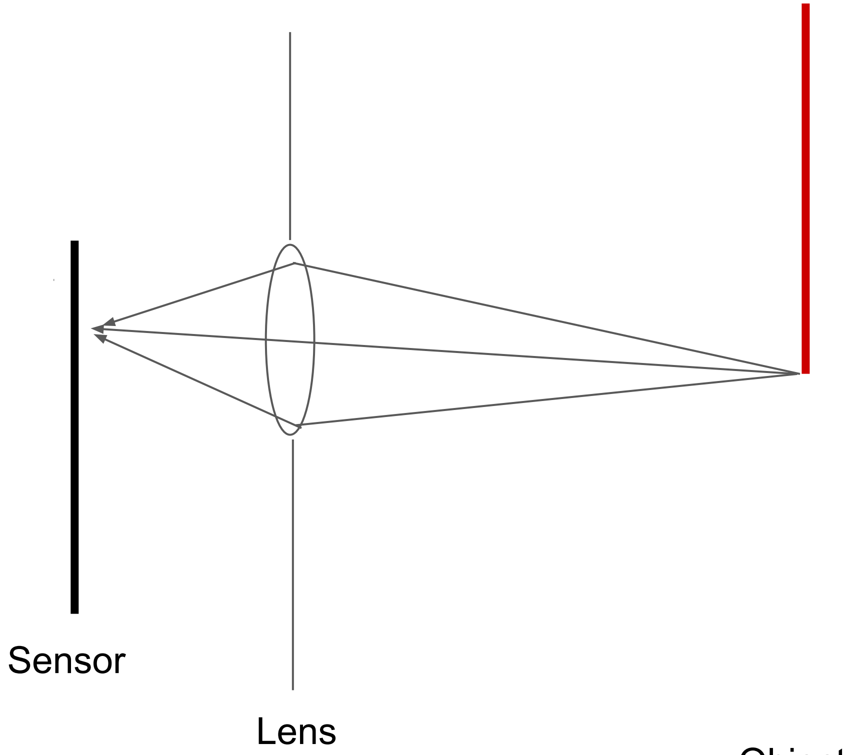
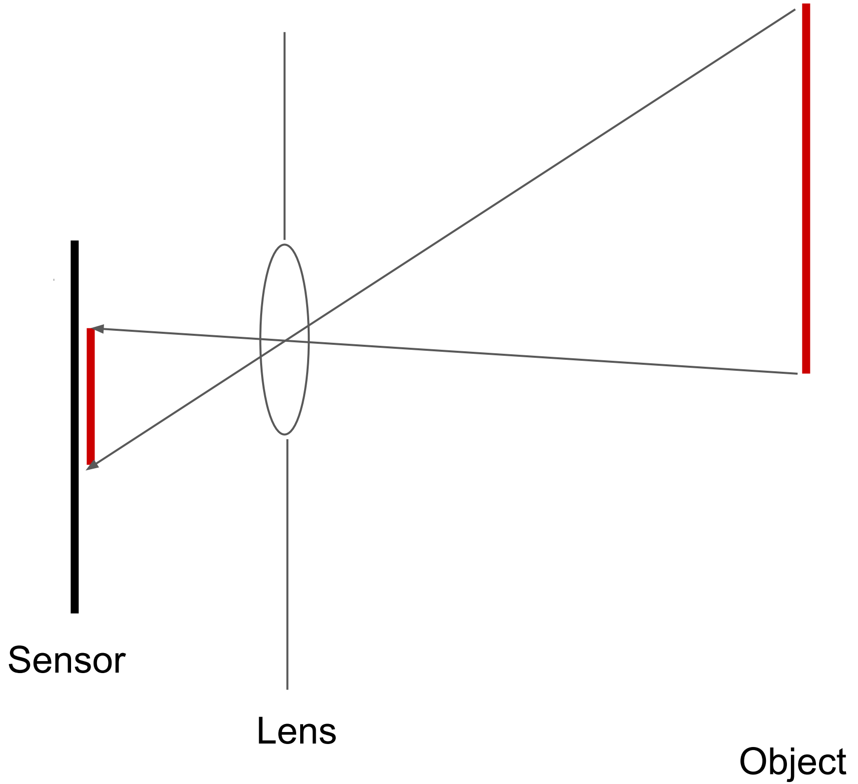
Lens camera



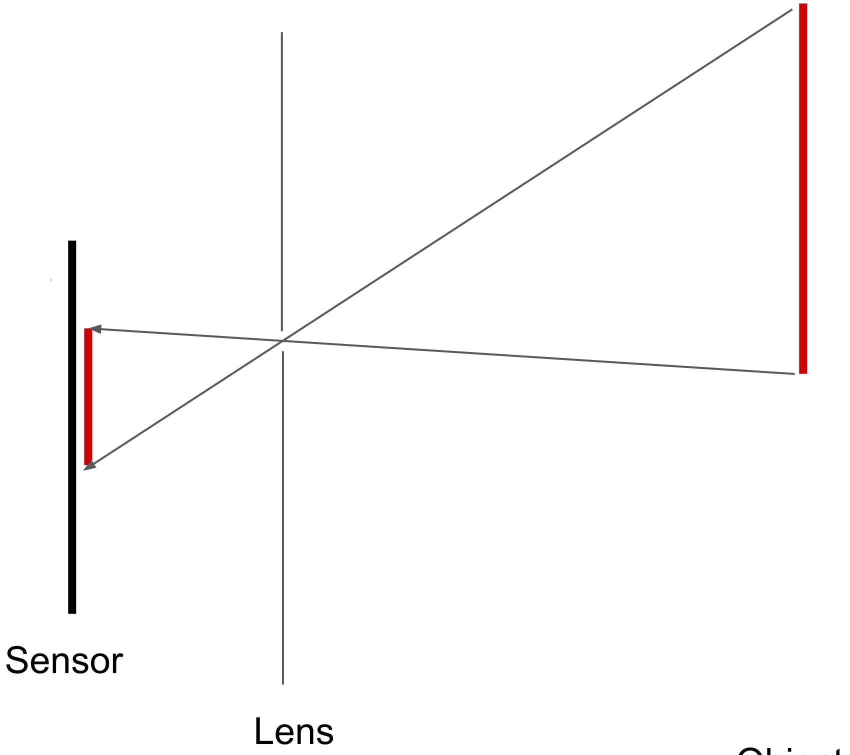
How do cameras work?

Lens camera

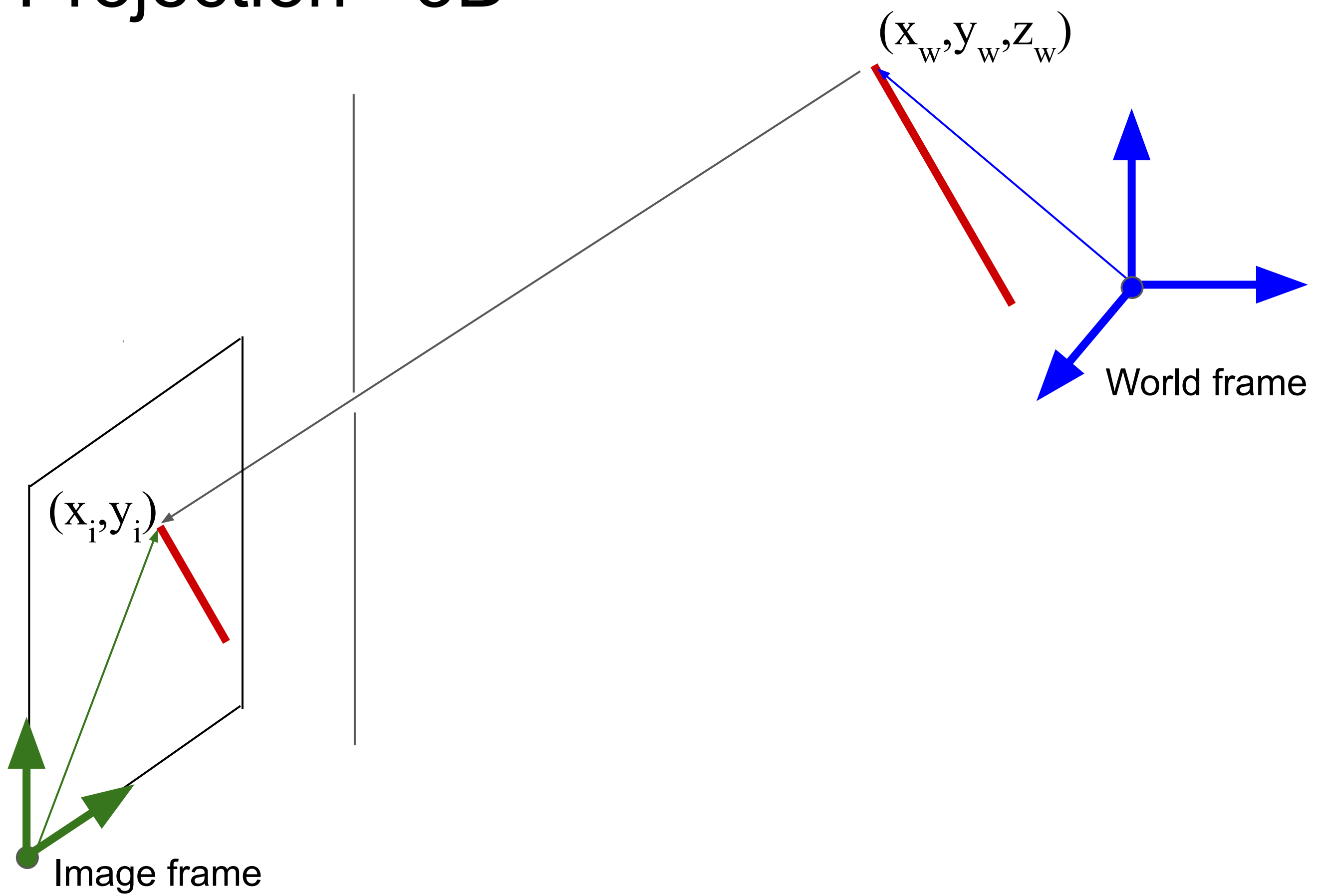


Lens cameras

- Lenses gather light and focus it on image plane
- Distance from lens to image plane is critical for sharp images
- However, for simplicity, in geometrical reasoning one can often assume simpler pinhole model
- Introduces **Perspective Projection**



Perspective Projection - 3D



Perspective Projection

A few properties:

- lines always project to lines
- parallel lines appear to be intersecting (unless parallel to image plane)
    - all the lines in a parallel set appear to meet at the same **vanishing point**
- objects further away appear smaller
- angles are generally **not** preserved

Camera Matrix

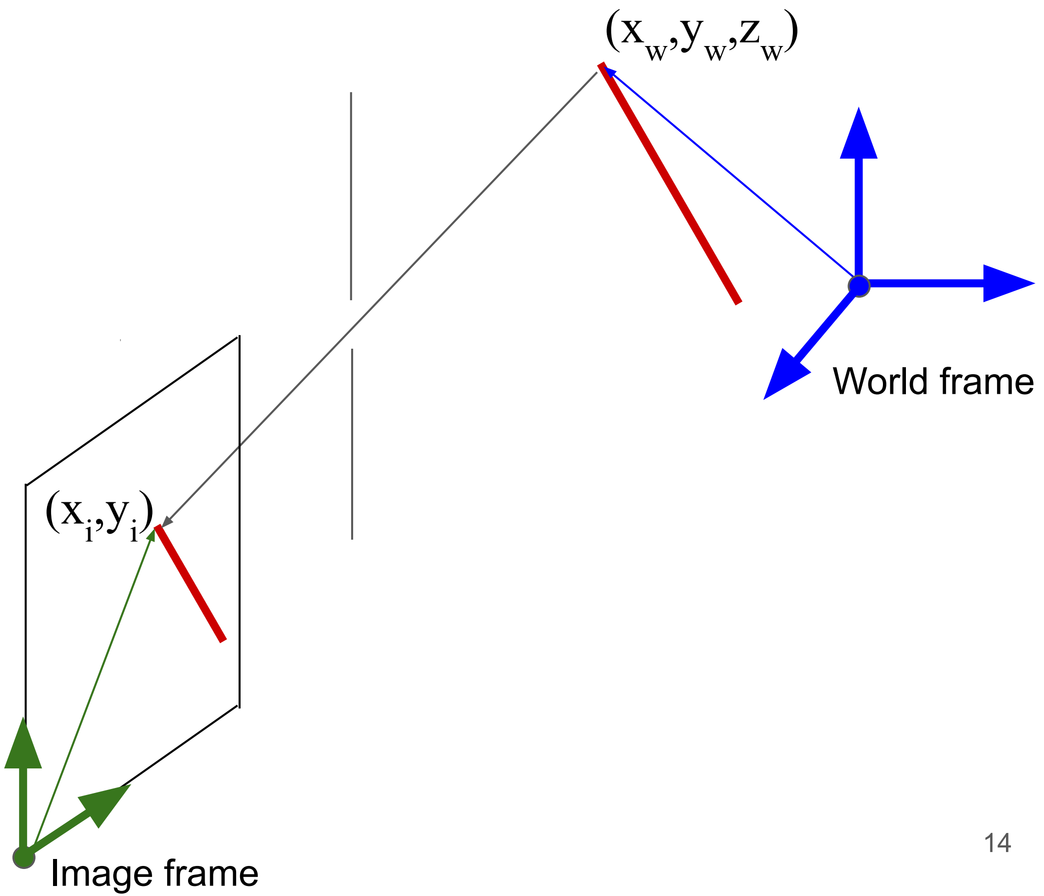
World point $\mathbf{x}_\mathrm{w} = [x_\mathrm{w}, y_\mathrm{w}, z_\mathrm{w}, 1]^\mathrm{T}$

Image point $\mathbf{x}_\mathrm{c} = [x_\mathrm{i}, y_\mathrm{i}, 1]^\mathrm{T}$

Camera matrix $\mathbf{P} \subset \Re^{3\mathrm{x}4}$:

$$\mathbf{x}_\mathrm{c} = \mathbf{P}\ \mathbf{x}_\mathrm{w}$$

… for any point in scene.



Camera Matrix

- Can be computed if enough correspondences are known:

$$\mathbf{x}_c^{\,j} = \mathbf{P}\,\mathbf{x}_w^{\,j}$$

- In theory, at least 6 points are needed
- In practice, use more to reduce error

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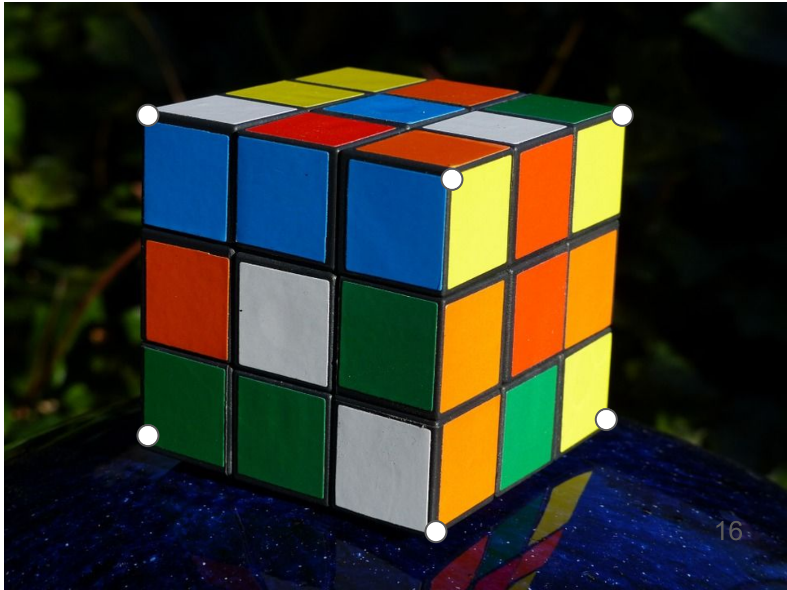
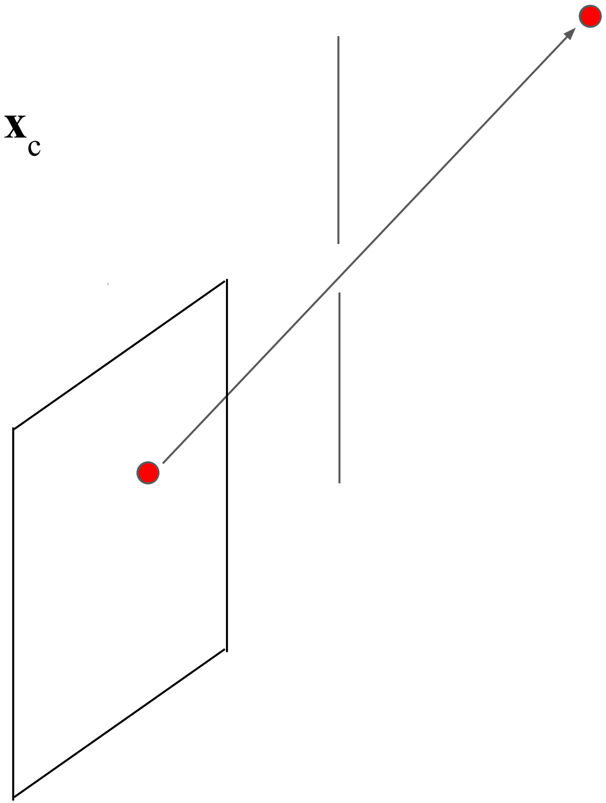


Calibration problem: compute the matrix $\mathbf{P}$ for a given camera.

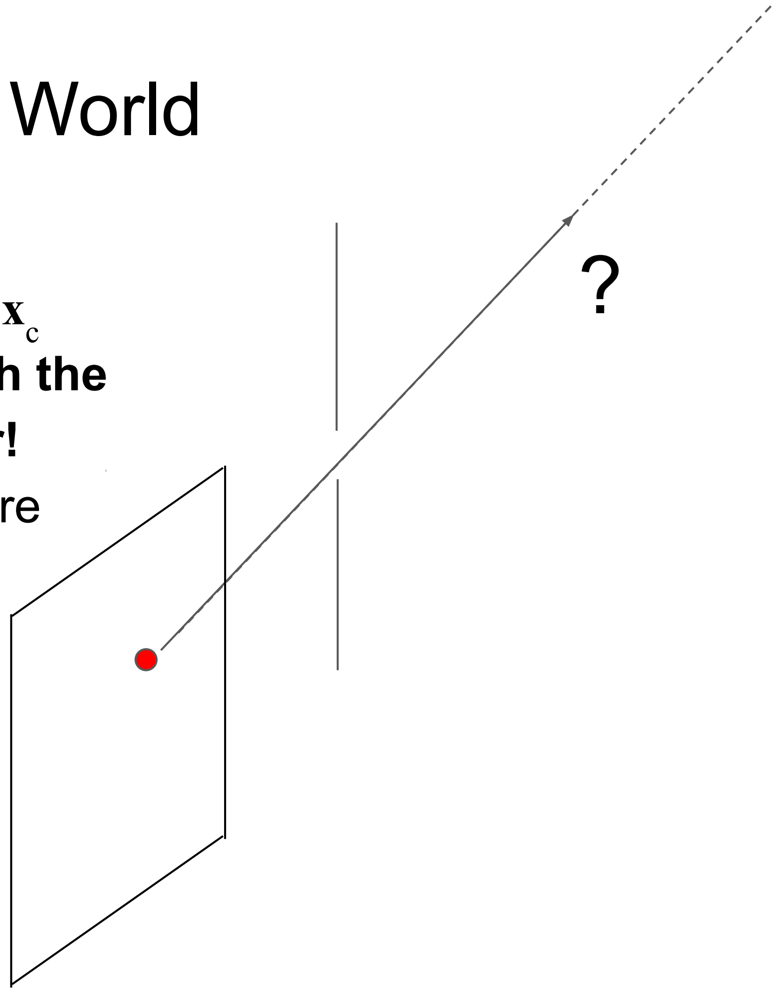
Projecting Back into the World

- Into the image: $\mathbf{x}_c = \mathbf{P}\,\mathbf{x}_w$
- Into the world: compute $\mathbf{x}_w$ given $\mathbf{x}_c$



Projecting Back into the World

- Into the image: $\mathbf{x}_c = \mathbf{P}\,\mathbf{x}_w$
- Into the world: compute $\mathbf{x}_w$ given $\mathbf{x}_c$
  - **can not be fully solved with the information we have so far!**
  - we just know $\mathbf{x}_w$ is somewhere along **a ray**



Intensity and Color

Recall once more: images are arrays of numbers!

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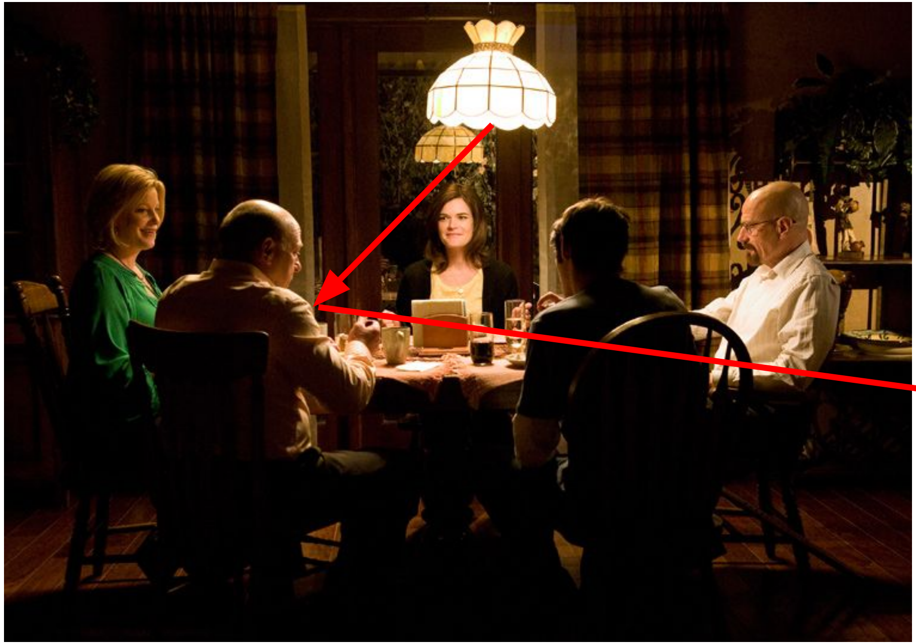
Intensity and Color

Light leaves the **source**, bounces of the **object**, and is captured by the **sensor**



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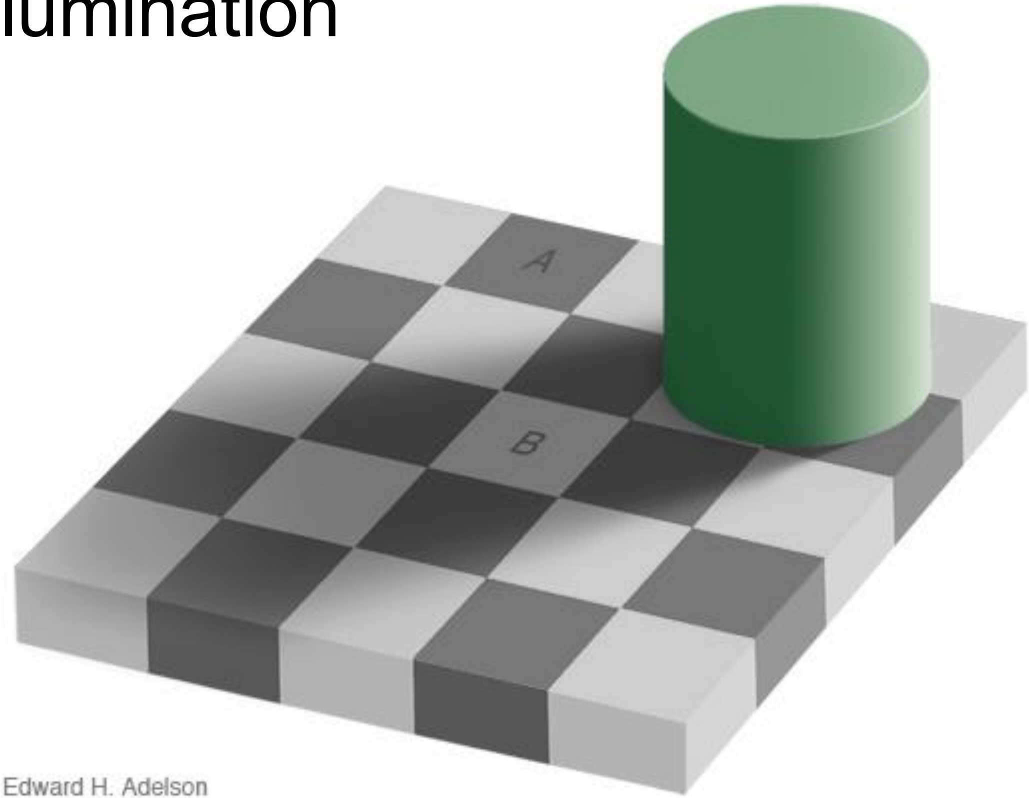
Intensity and Color

Light leaves the **source**, bounces of the **object**, and is captured by the **sensor**

- what the sensor sees depends on the characteristics of both the light source and the object that is captured (without accounting for multiple bounces…)
- main light source characteristic: spectral distribution
- main object characteristics:
    - geometry
    - albedo (color)
    - “shiny” vs. “dull”

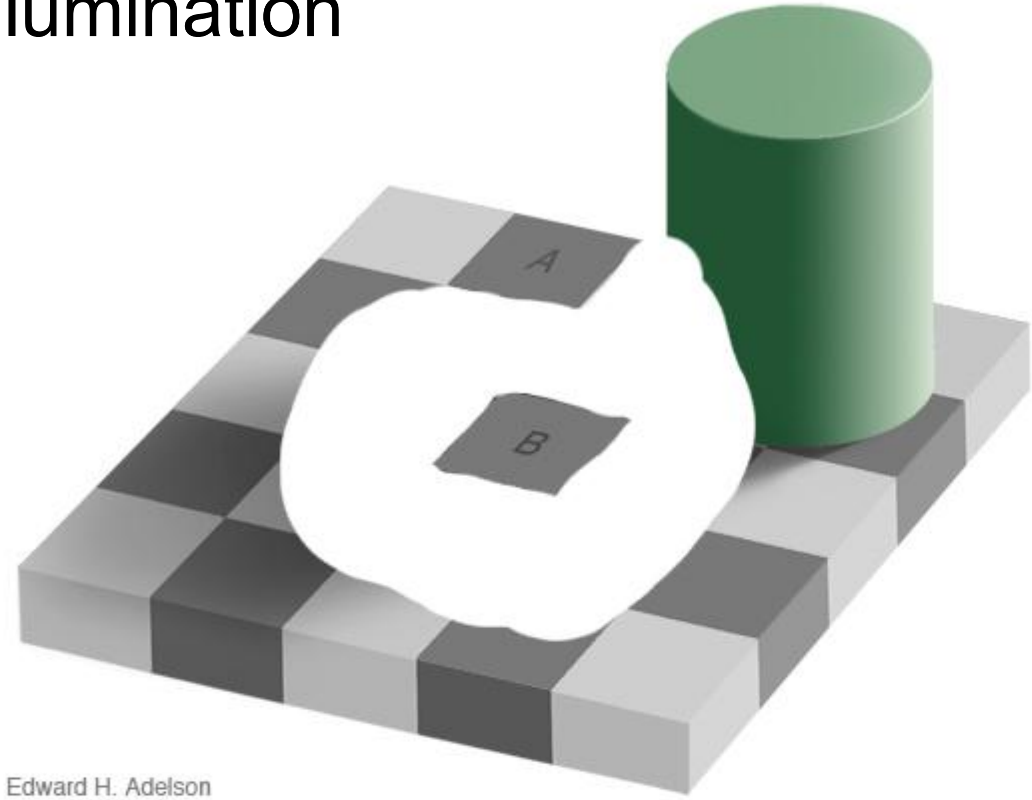
In general, it is **impossible to compute all of these factors** based only on the recording from the sensor, without additional information about the scene!

Color vs. Illumination

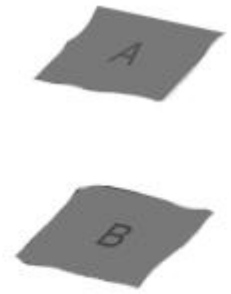


Edward H. Adelson

Color vs. Illumination



Color vs. Illumination



Recap

- "Color" (number) of a pixel depends on:
    - light source: spectral distribution
    - object(s) light bounces of:
        - geometry
        - shininess
        - color
    - camera parameters:
        - position relative to scene
        - projection matrix
        - focus
- Generally impossible to disambiguate!

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- Does this image contain a coffee mug?
- Draw a bounding box (as tight as possible) around the mug in the image
- Which pixels in the image belong to mug?

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What type of learning problems are these?

Object Detection / Segmentation

- Does this image contain a coffee mug?
- Draw a bounding box (as tight as possible) around the mug in the image
- Which pixels in the image belong to mug?

- Types of detection/segmentation problems:
  - Instance level (one specific mug)
  - Class level (any mug)

What can change for each of these?

Regression and Classification on Images

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Regressor / Classifier

Image class

Bounding box location

Per pixel class

Regression and Classification on Images

1,000 x 1,000 Pixels

1M pixel / channel

3M pixel / image

$\mathbf{x}_i \subset \Re^{3,000,000}$

$N = ?$

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