CSE 185 Introduction to Computer Vision

Lecture 2: Camera Model

Slides credit: Yuri Boykov, Ming-Hsuan Yang, Boqing Gong, Richard Szeliski, Steve Seitz, Alyosha Efros, Fei-Fei Li, etc.

Why is the origin of the word camera?

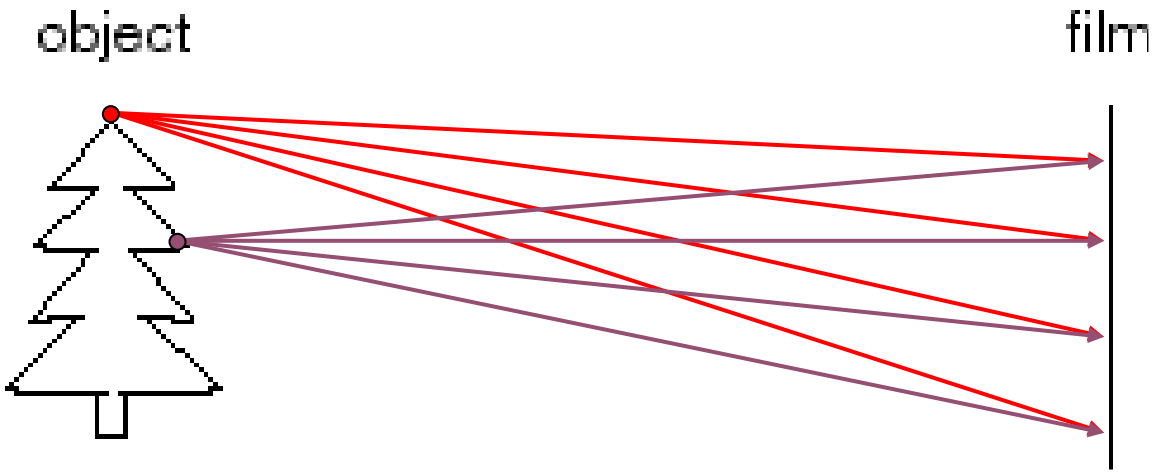
- In Latin *camera* meant room, and usually a room with a vaulted ceiling.
- How is camera related to a room?

Camera obscura (a.k.a dark room)

From James Ayscough's *A short account of the eye and nature of vision* (1755 fourth edition)

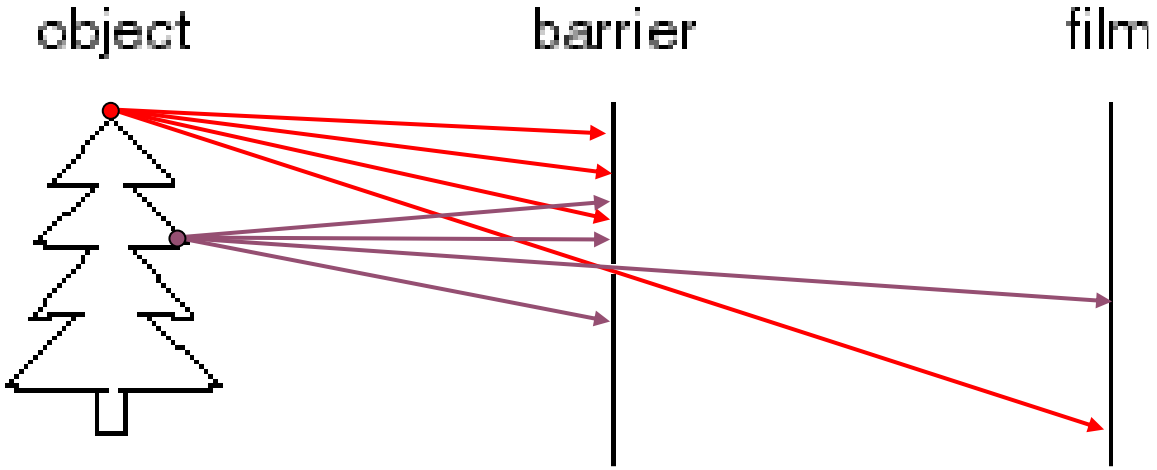
Let’s design a camera

- Put a piece of film in front of an object
- Do we get a reasonable image?

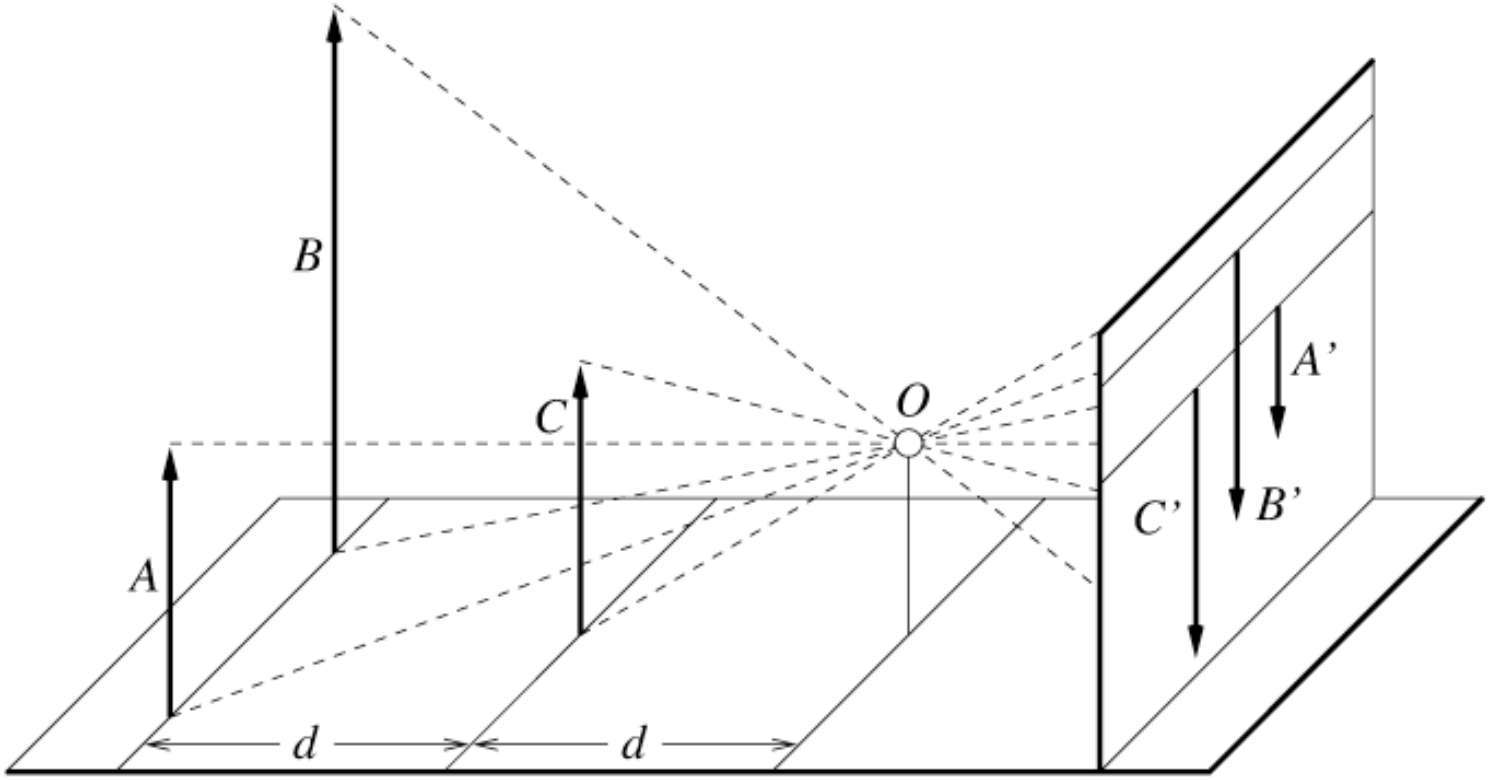


Pinhole camera

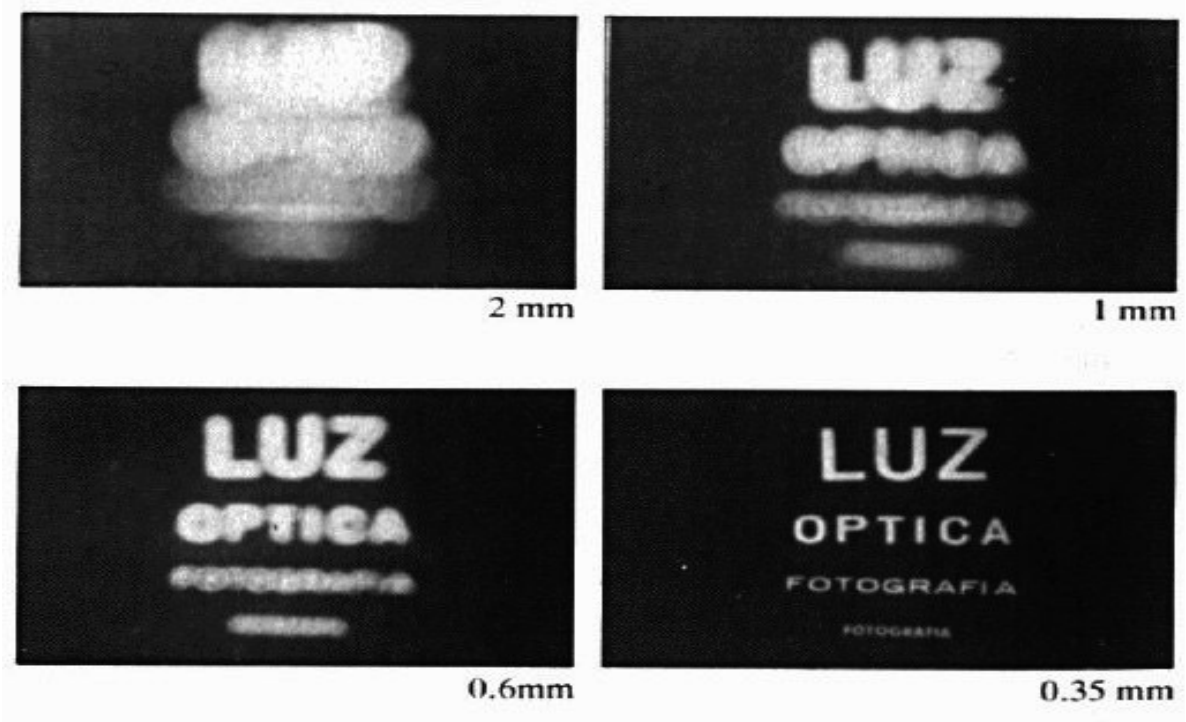
- Add a barrier to block off most of the rays
  - This reduce blurring
  - The opening known as the aperture
  - How does this transform the image?



Distant objects are smaller



Shrinking the aperture

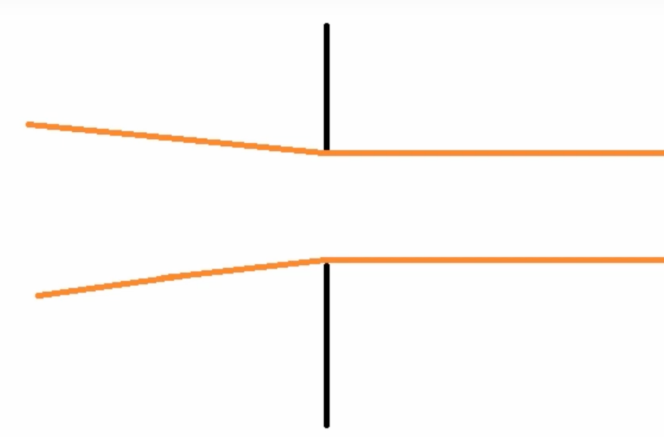


- Why not make the aperture as small as possible?
  - Less light gets through
  - Diffraction effect

Shrinking the aperture

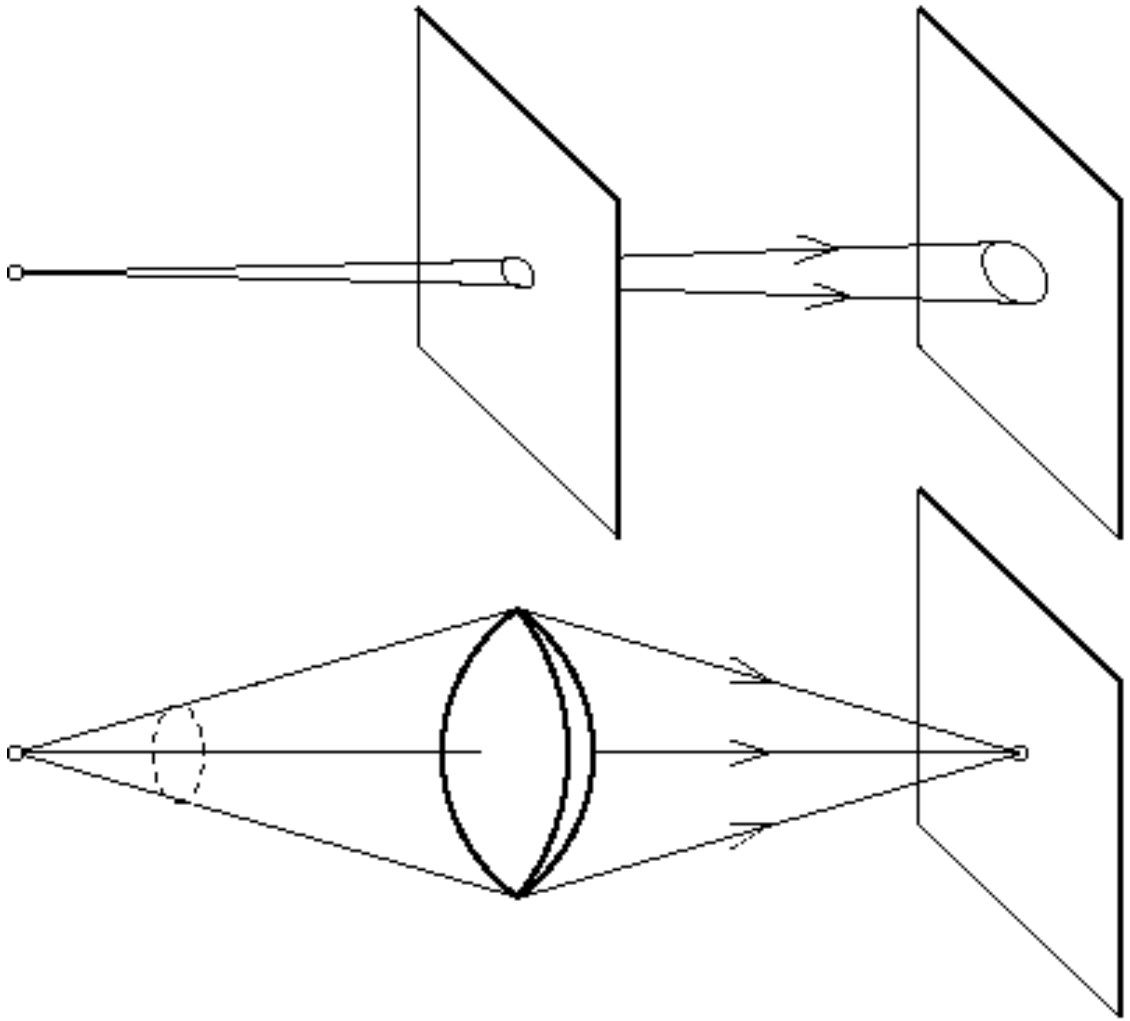
Light wave diffraction

- Diffraction is the bending of waves around the corners of an obstacle or through an aperture.

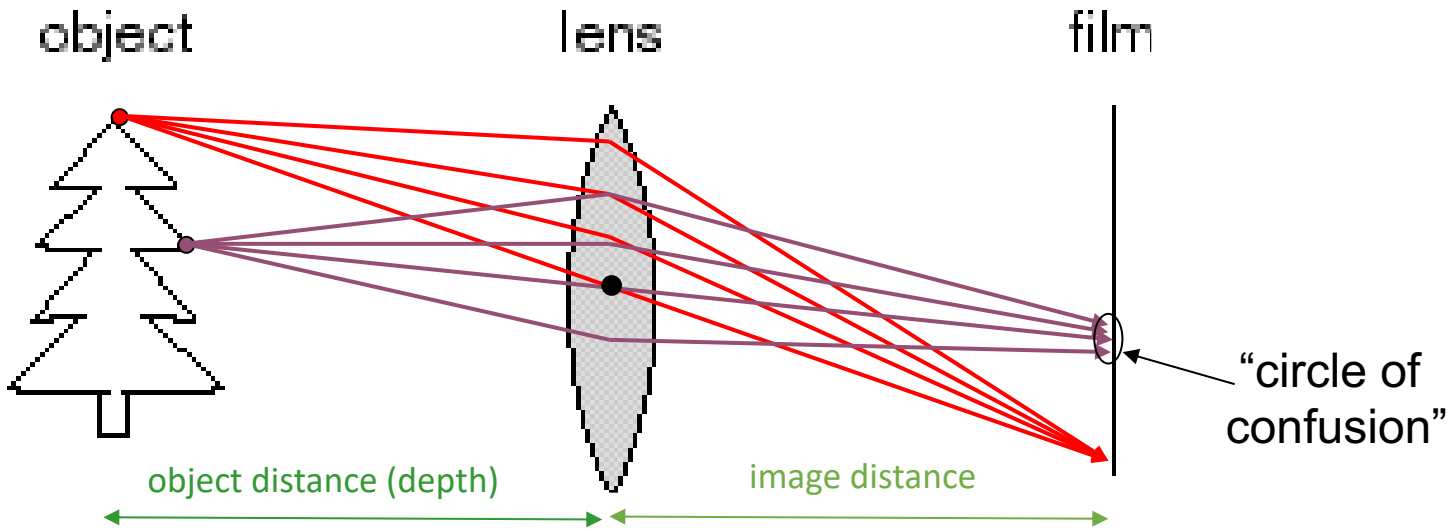


”silver lining” in clouds

The reason for lenses

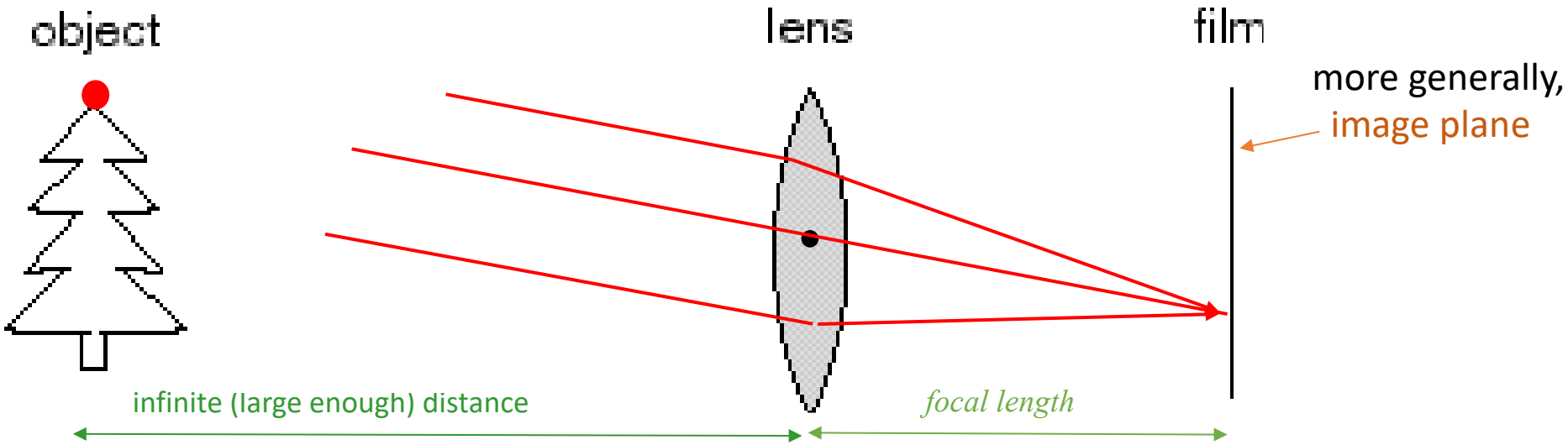


A lense focuses light onto a film



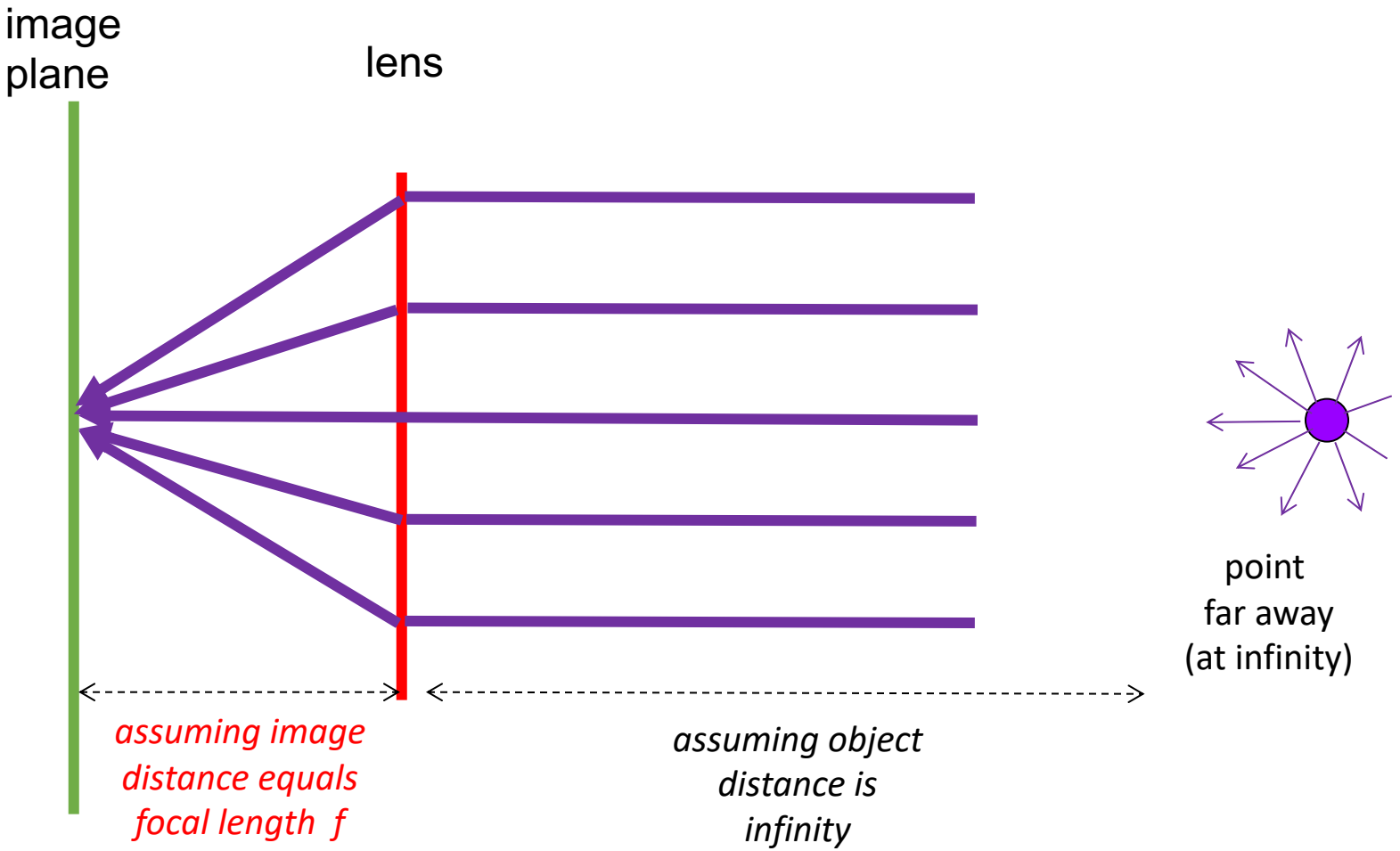
- There is a specific depth at which objects are "in focus"
  - Other points project to a "circle of confusion" in the image
- Changing image distance changes this depth

Focal length

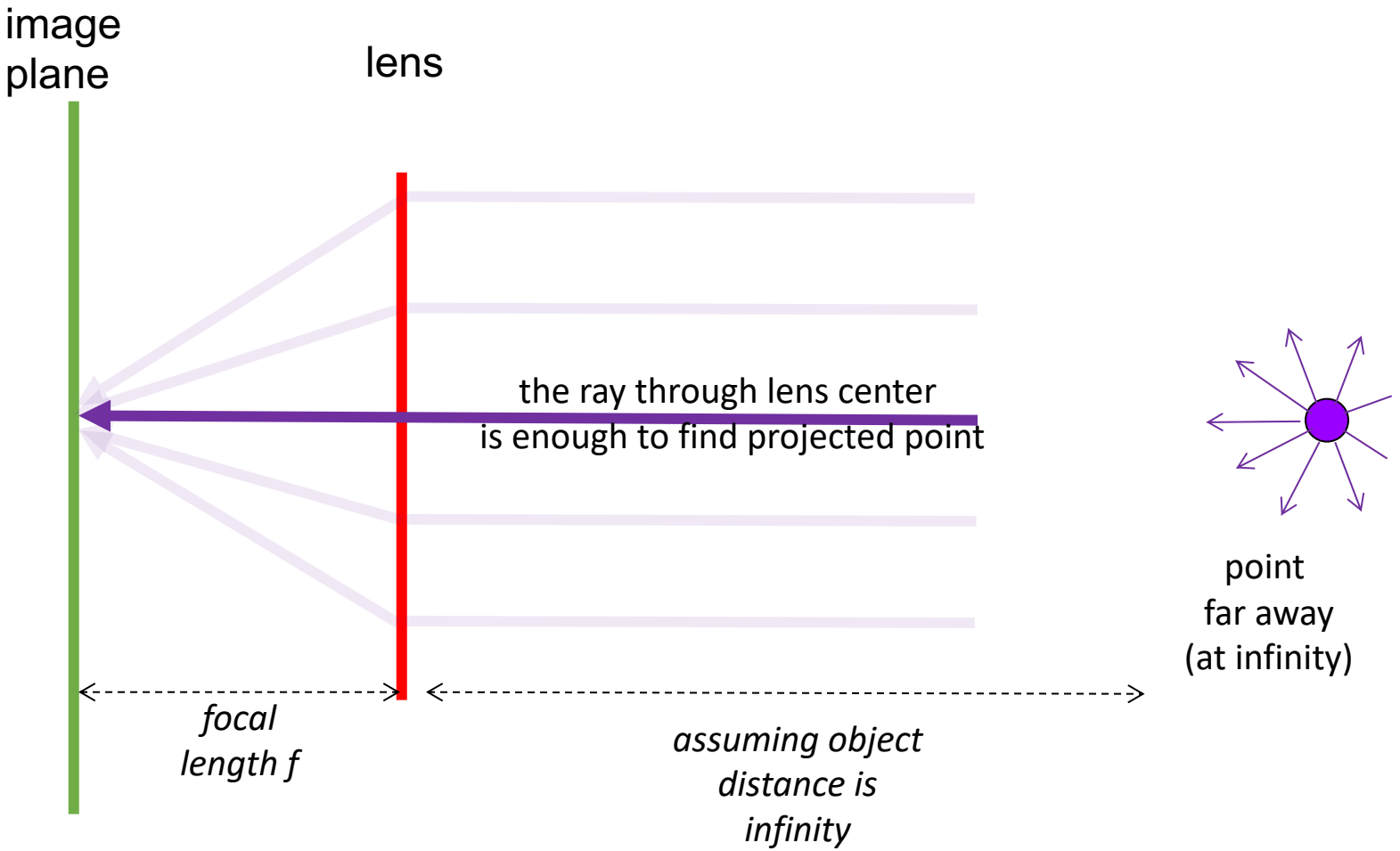


- Lens' **focal length** is image distance where objects at infinity appear in focus
- Focal length depends on lens' construction (e.g. surface radius). Some lenses may allow changing their focal length (typically, these are multi-lens constructions)

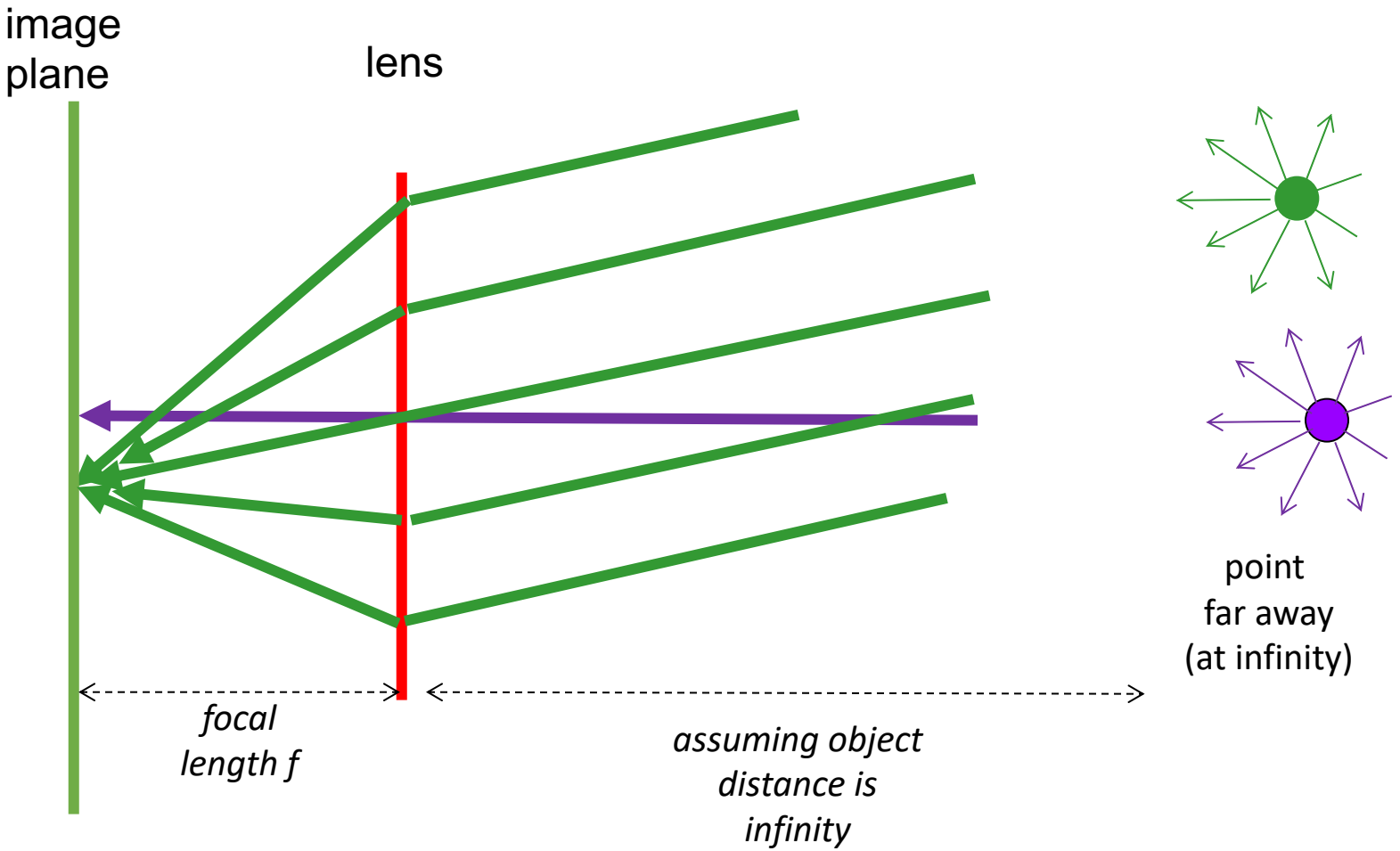
Basic lens camera



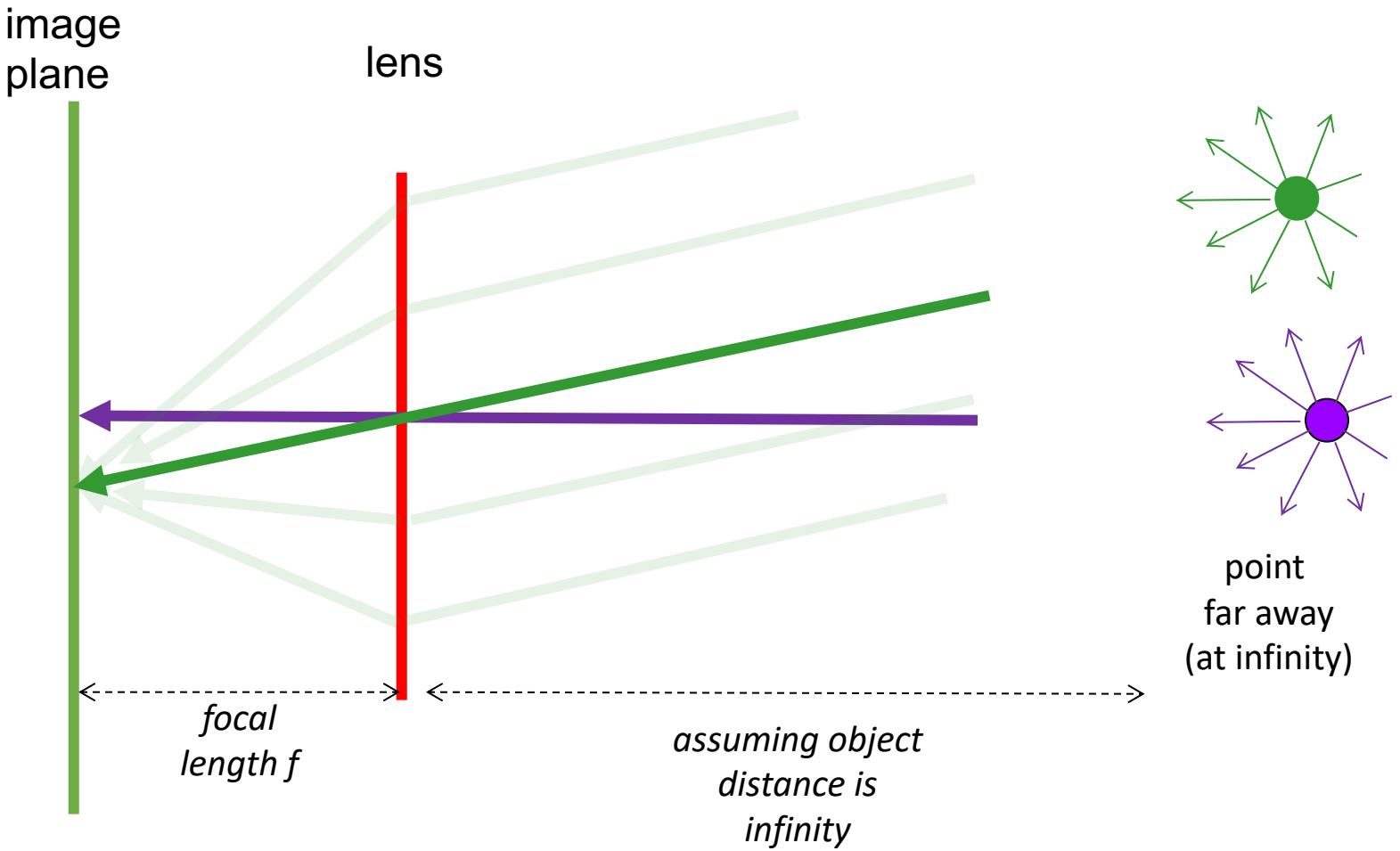
Basic lens camera



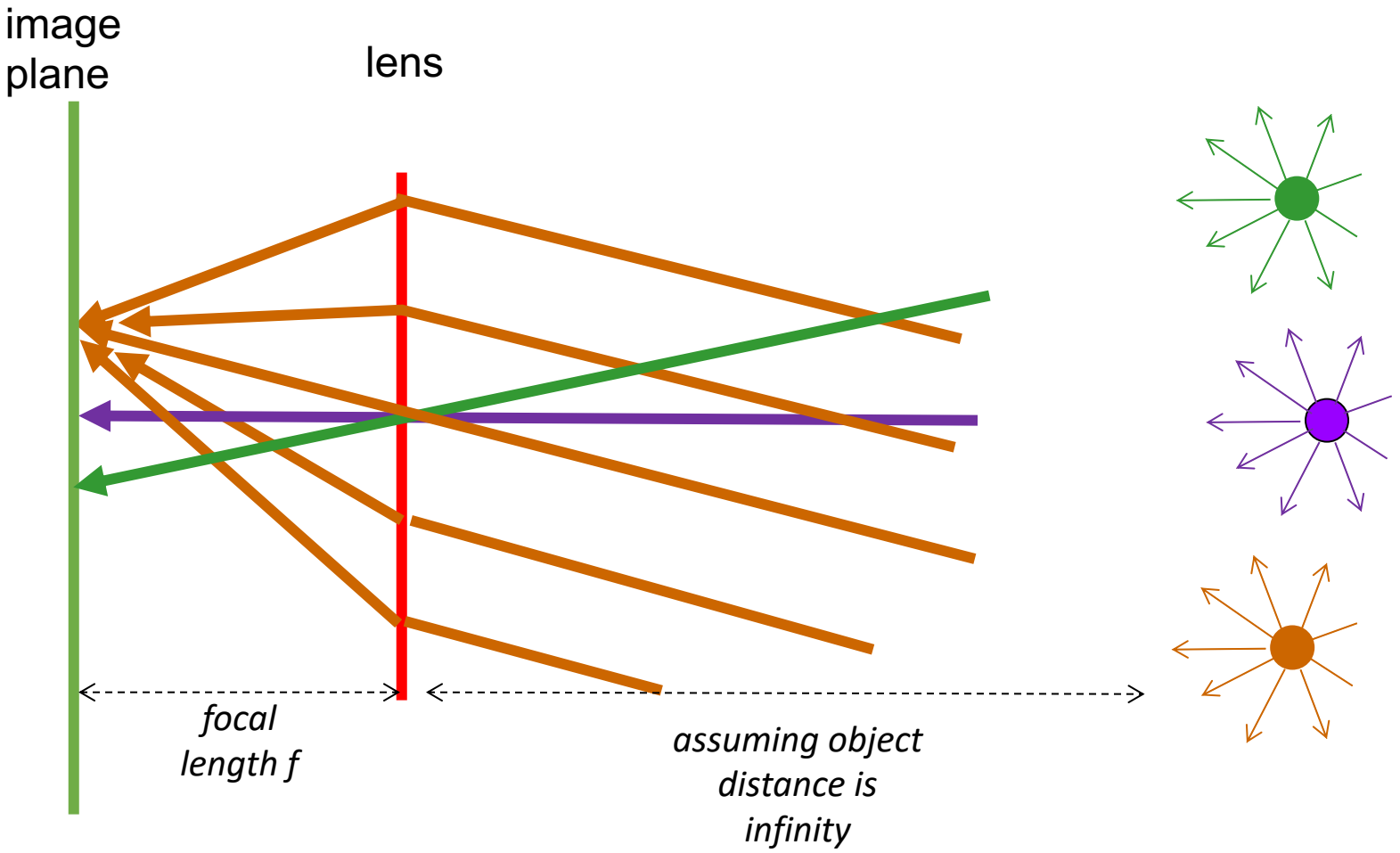
Basic lens camera



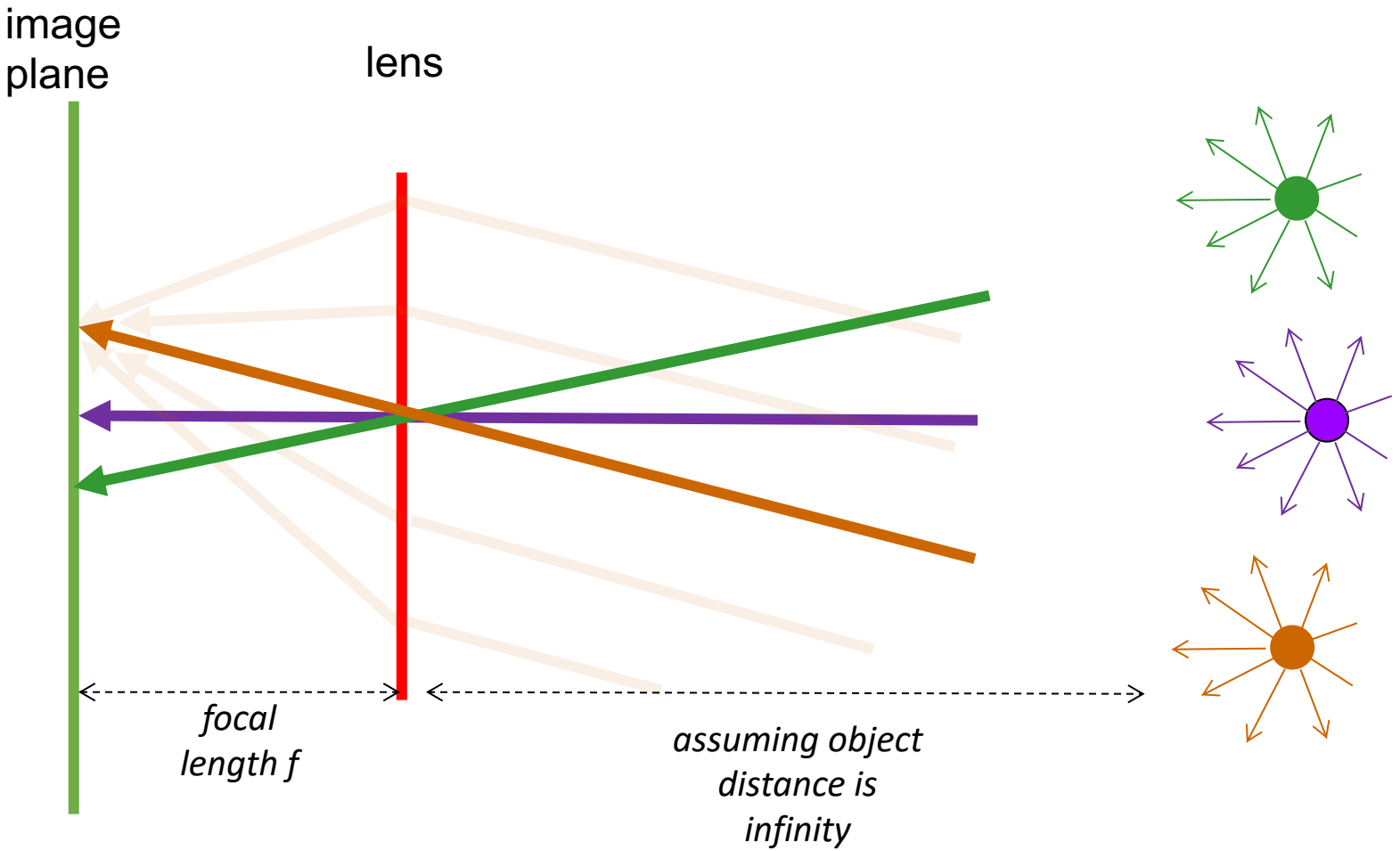
Basic lens camera



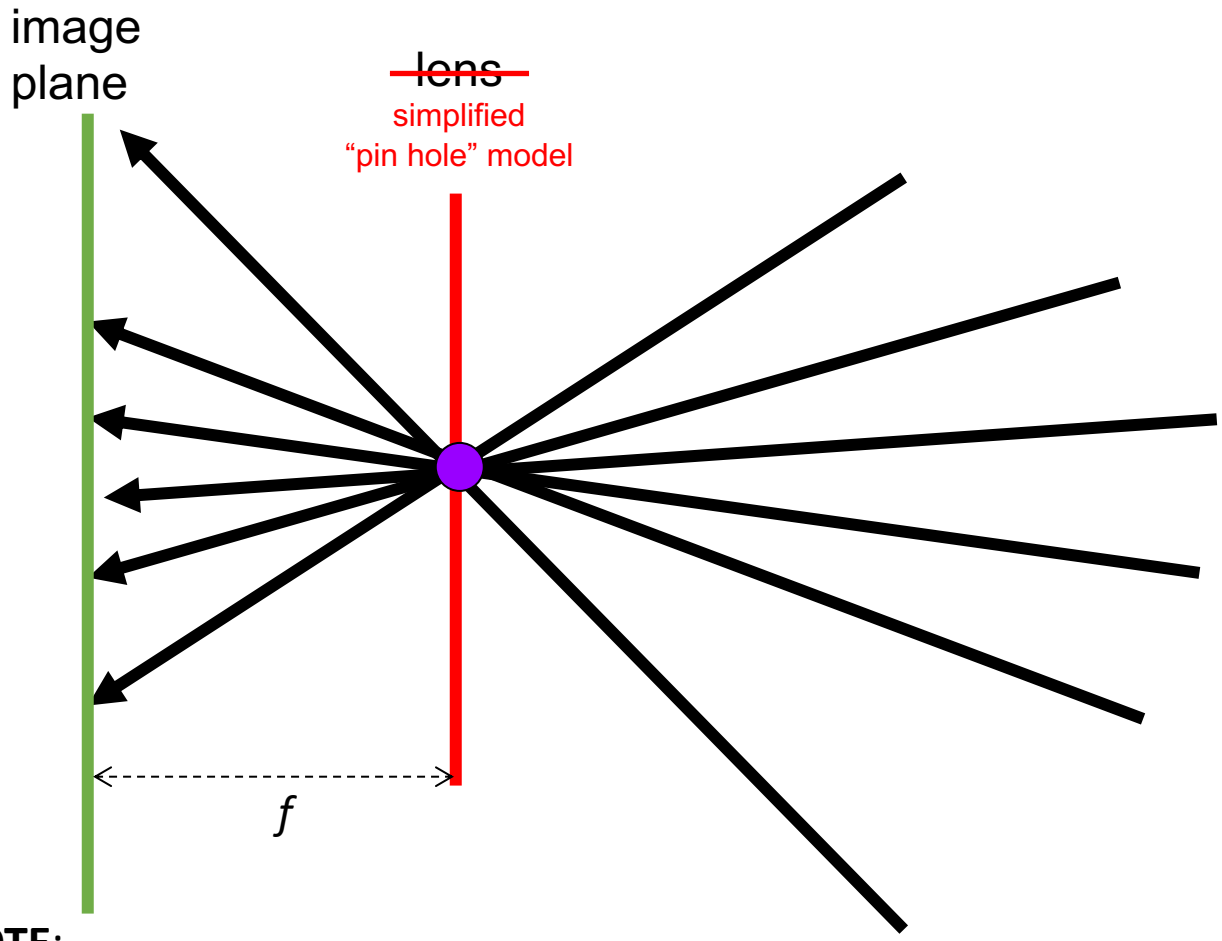
Basic lens camera



Basic lens camera



Basic camera model

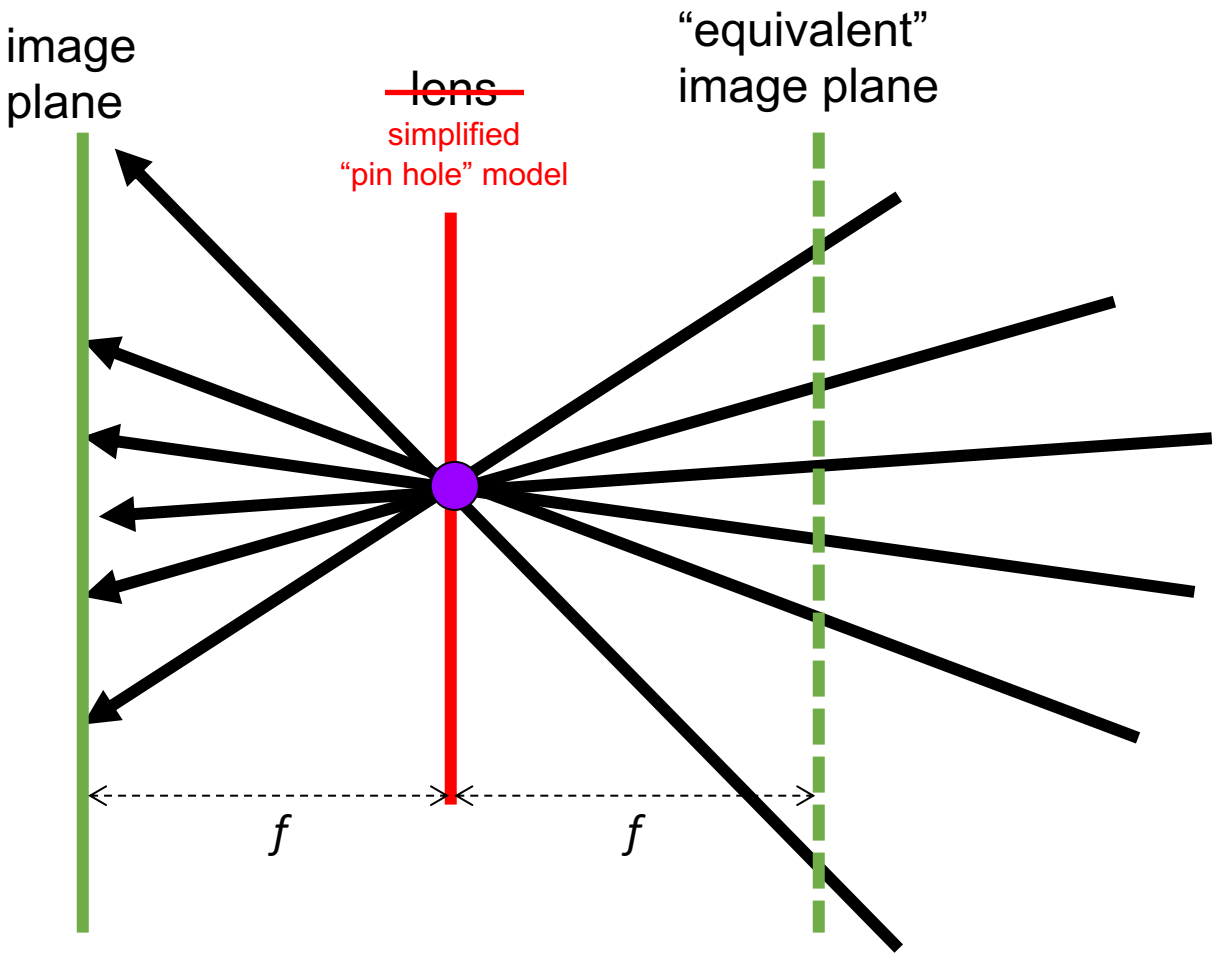


NOTE:

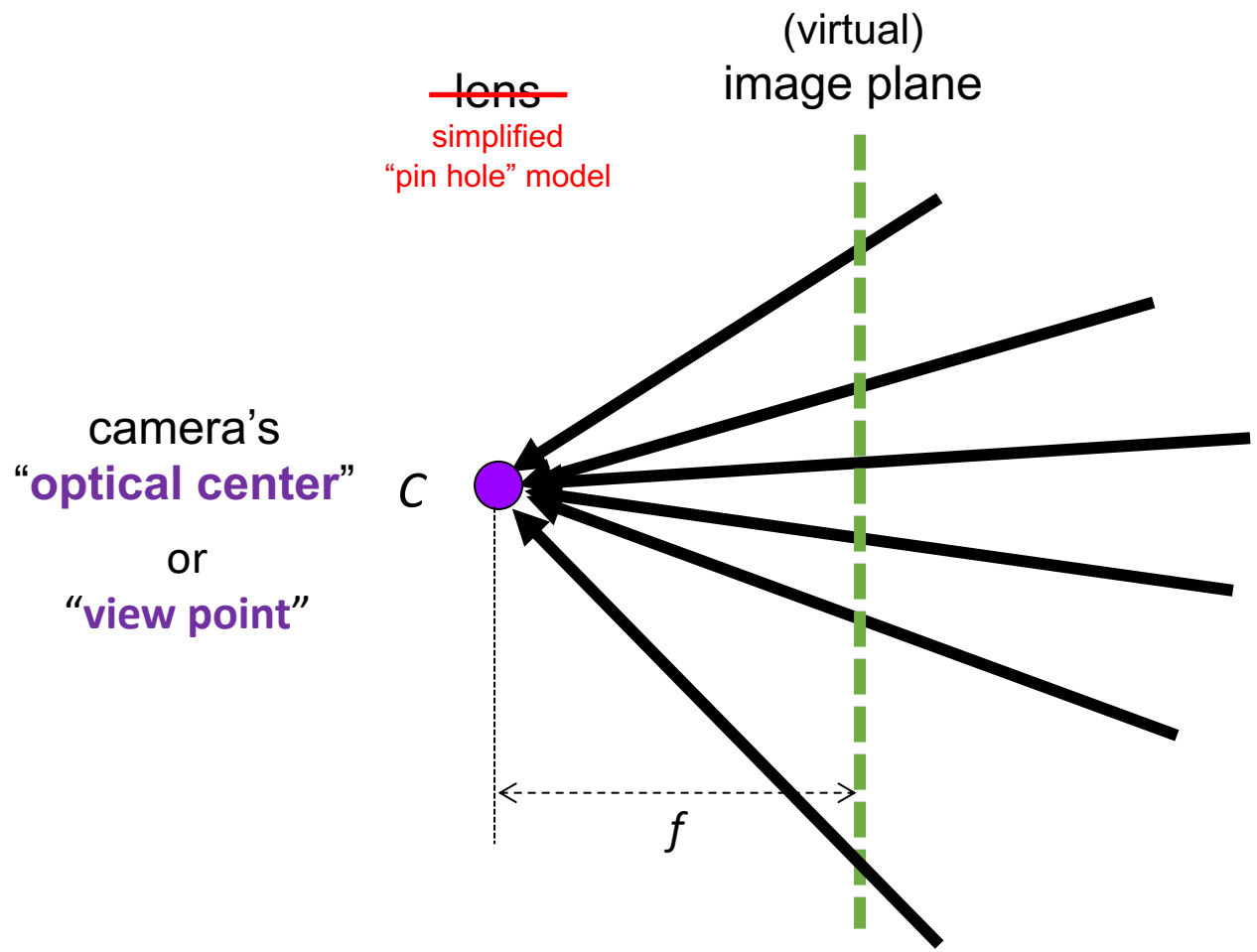
for pin hole camera model "focal length" (f) is defined as image distance (to the "hole").

As mentioned earlier, focal length of a lens does not have to be equal to the image distance (to the lens).

Basic camera model: “pin hole”



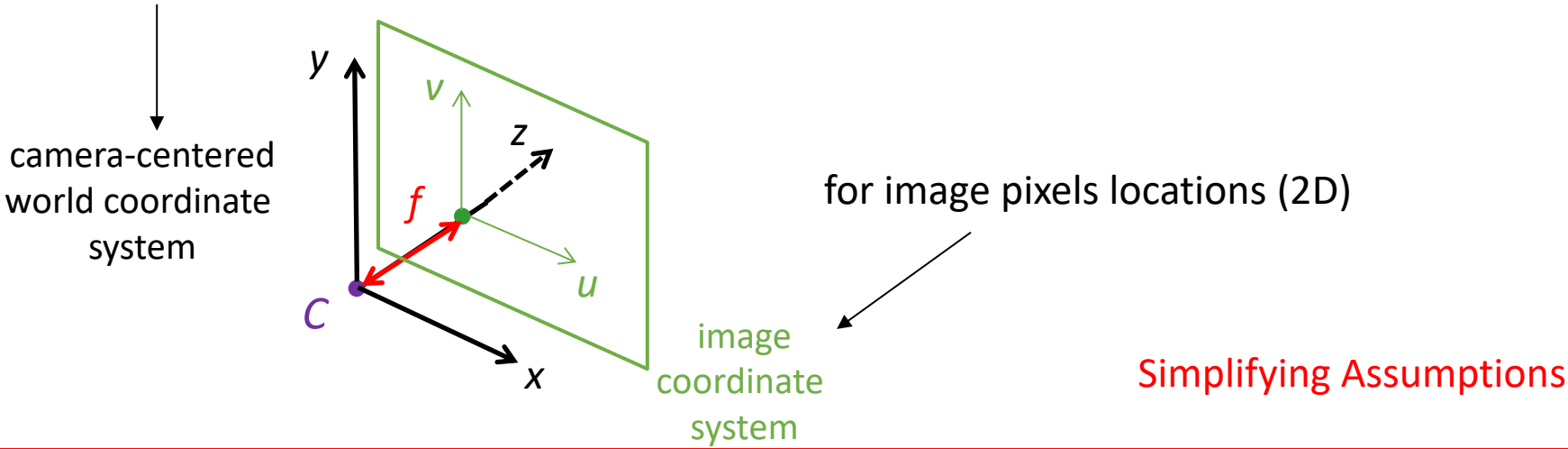
Basic camera model: “pin hole”



Simplified camera representation: image plane is drawn in front of the optical center.
We will use such “**pin hole” camera model** later in the course.

Projective Geometry (from 3D point to 2d Pixel)

Consider a simple example of so-called
camera-centered 3D world coordinate system (x,y,z):

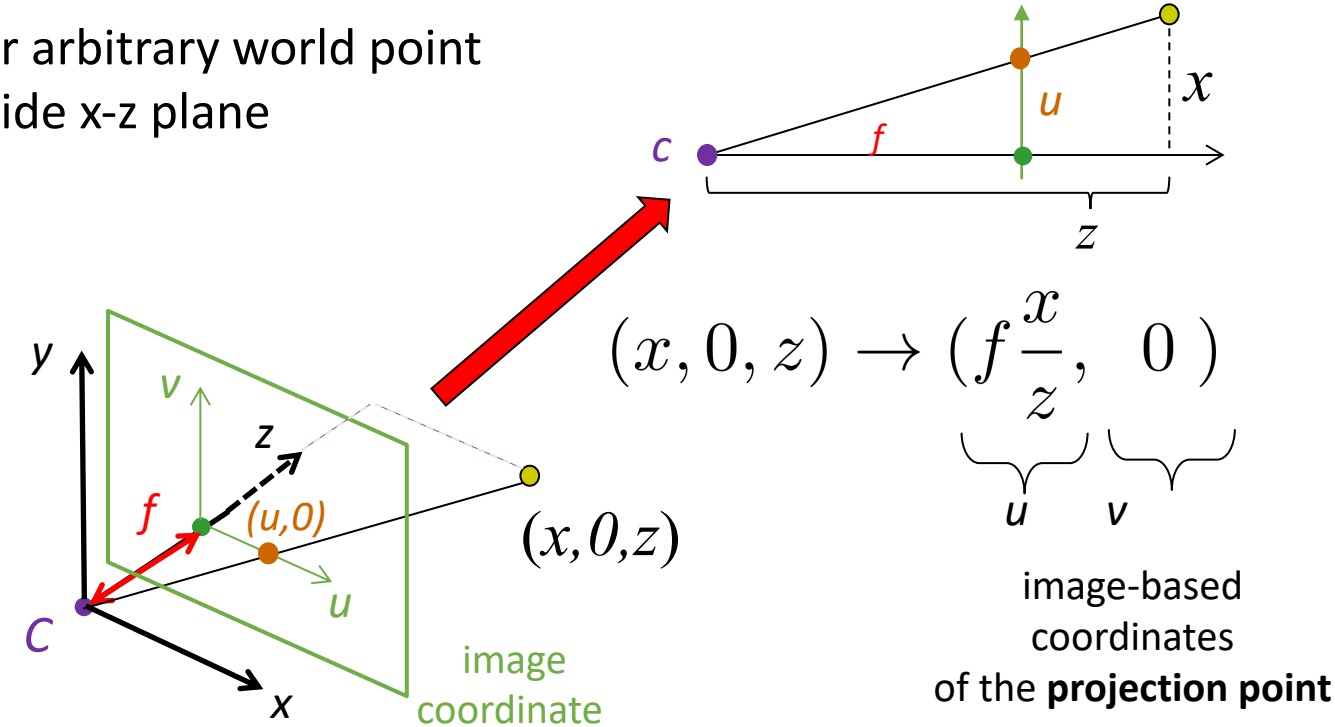


Simplifying Assumptions

- world coordinate system center (0,0,0) is at optical center *C*
- *x* -*y* plane is parallel to the image plane
- *x* and *y* axis parallel to *u* and *v* axis of the image coordinate system
- axis z (called ***optical axis***) intersects image at its coordinate center (0,0)

Projective Geometry (from 3D point to 2d Pixel)

First, consider arbitrary world point inside x-z plane



$$(x, 0, z) \rightarrow (f\frac{x}{z}, \quad 0\ )$$

u v

camera-centered world coordinate system

image coordinate system

image-based coordinates of the **projection point**

It projects onto some image point/pixel (*u*,0) on axis *u*

(by construction, intersection of x-z plane with the image plane is axis *u*)

Projective Geometry (from 3D point to 2d Pixel)

For a general point (x,y,z) in 3D

camera-centered world coordinate system

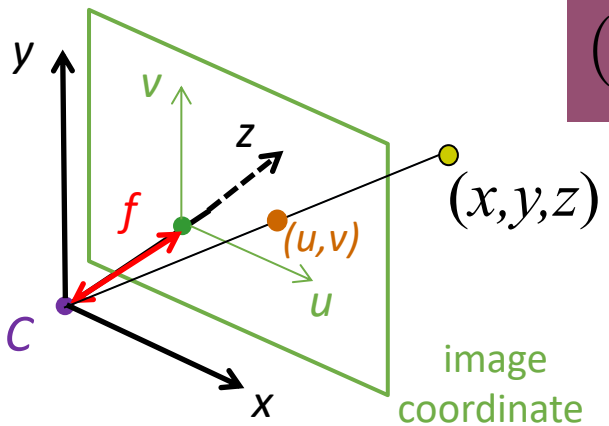


image coordinate system

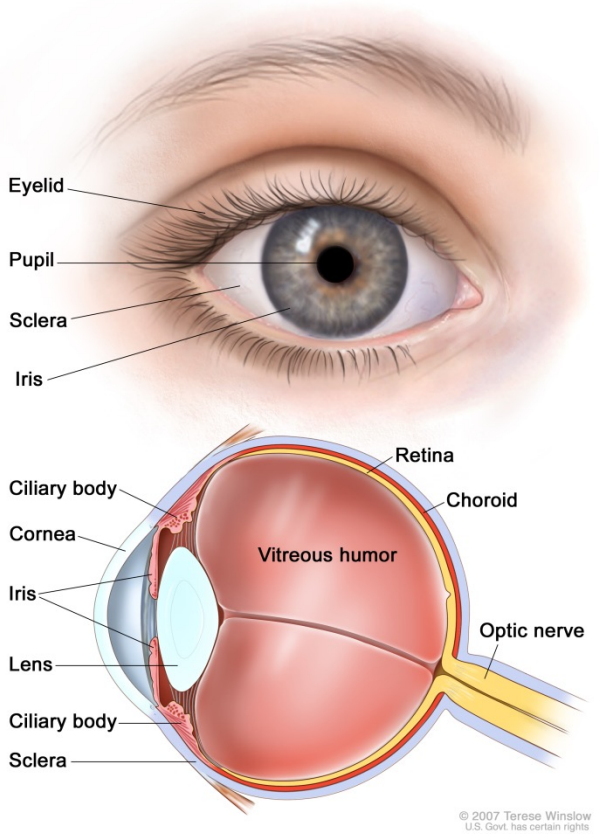
$$(x, y, z) \rightarrow (f\frac{x}{z}, f\frac{y}{z})$$

u v

image-based coordinates of the **projection point**

Simple observation: size of any 3D object image is inversely proportional to object's distance from the camera (z-coordinate value)

The eye

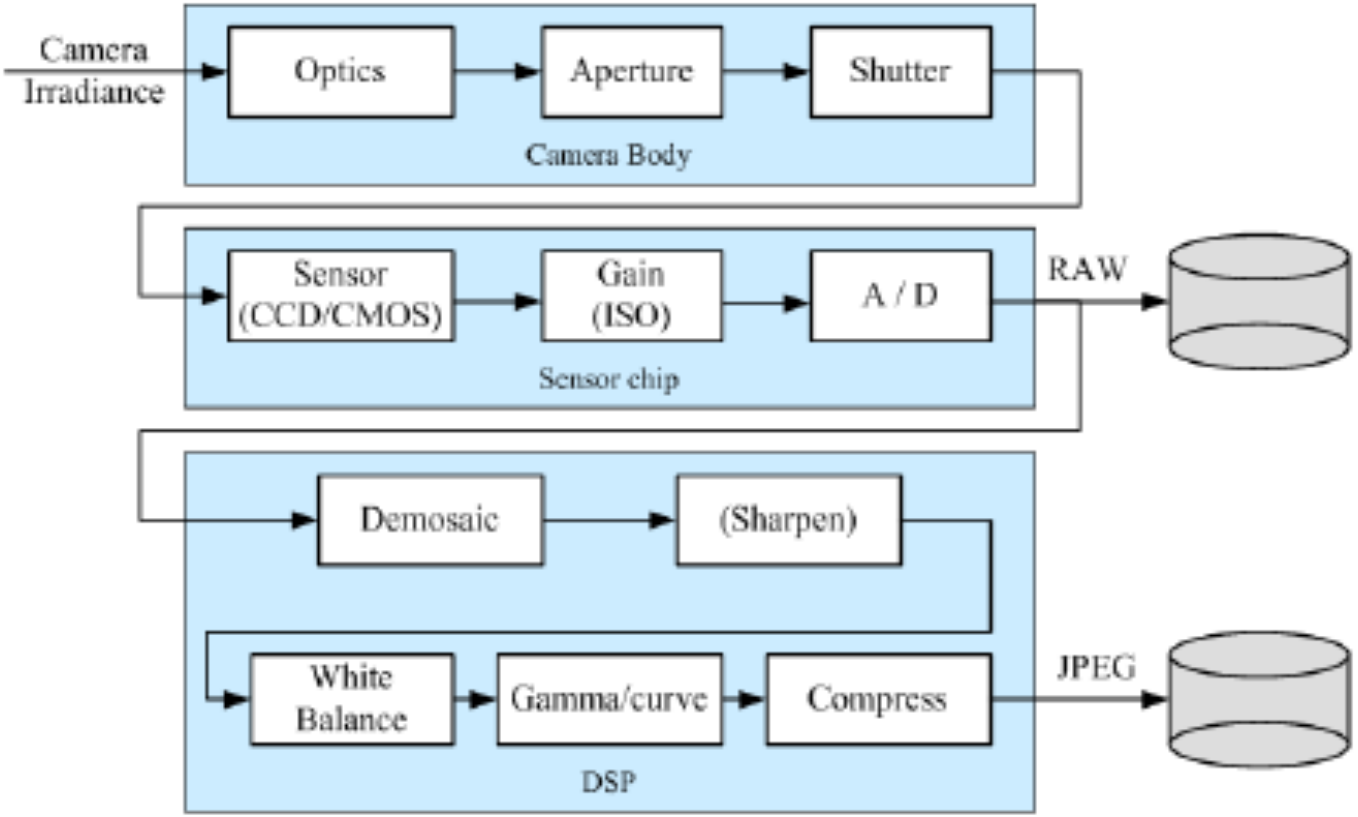


- The human eye is a camera
  - Iris - colored annulus with radial muscles
  - Pupil - the hole (aperture) whose size is controlled by iris
  - What's the film?

Digital camera

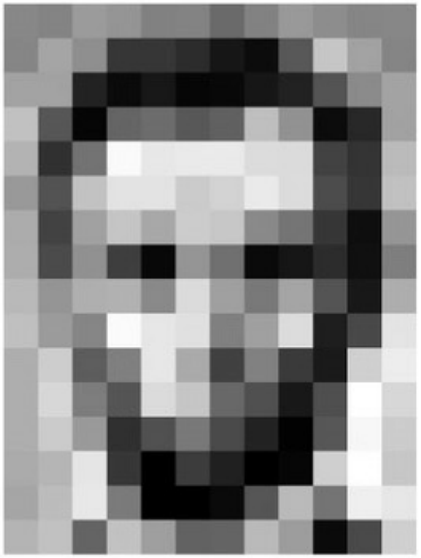
- A digital camera replaces film with a sensor array
  - Each cell in the array is a Charge Coupled Device (CCD)
  - light-sensitive diode that converts photons to electrons
  - Complementary Metal Oxide on Silicon (CMOS) sensor
  - CMOS is becoming more popular

Image sensing pipeline



A simple camera pipeline

Gray-scale image

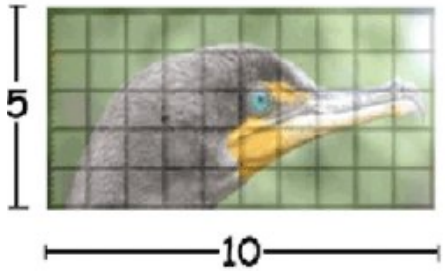


157	153	174	168	150	152	129	151	172	161	155	156
155	182	163	74	75	62	33	17	110	210	180	154
180	180	50	14	34	6	10	33	48	106	159	181
206	109	5	124	131	111	120	204	166	15	56	180
194	68	137	251	237	239	239	228	227	87	71	201
172	105	207	233	233	214	220	239	228	98	74	206
188	88	179	209	185	215	211	158	139	75	20	169
189	97	165	84	10	168	134	11	31	62	22	148
199	168	191	193	158	227	178	143	182	106	36	190
205	174	155	252	236	231	149	178	228	43	95	234
190	216	116	149	236	187	86	150	79	38	218	241
190	224	147	108	227	210	127	102	36	101	255	224
190	214	173	66	103	143	96	50	2	109	249	215
187	196	235	75	1	81	47	0	6	217	255	211
183	202	237	145	0	0	12	108	200	138	243	236
195	206	123	207	177	121	123	200	175	13	96	218

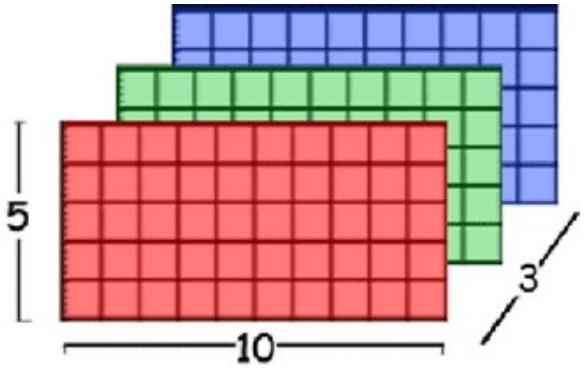
157	153	174	168	150	152	129	151	172	161	155	156
155	182	163	74	75	62	33	17	110	210	180	154
180	180	50	14	34	6	10	33	48	106	159	181
206	109	5	124	131	111	120	204	166	15	56	180
194	68	137	251	237	239	239	228	227	87	71	201
172	105	207	233	233	214	220	239	228	98	74	206
188	88	179	209	185	215	211	158	139	75	20	169
189	97	165	84	10	168	134	11	31	62	22	148
199	168	191	193	158	227	178	143	182	106	36	190
205	174	155	252	236	231	149	178	228	43	95	234
190	216	116	149	236	187	86	150	79	38	218	241
190	224	147	108	227	210	127	102	36	101	255	224
190	214	173	66	103	143	96	50	2	109	249	215
187	196	235	75	1	81	47	0	6	217	255	211
183	202	237	145	0	0	12	108	200	138	243	236
195	206	123	207	177	121	123	200	175	13	96	218

- Gray scale: 0-255
- Usually normalized between 0 and 1 (dividing by 255) and convert it into a vector for processing

Color image



Original Color Image



Matlab RGB Matrix

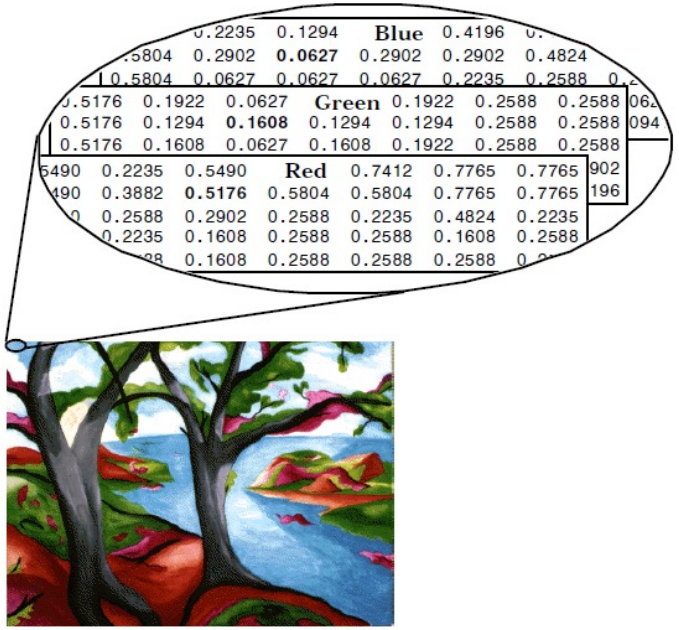


Image as functions

$$f(x, y) : \mathcal{R}^2 \rightarrow \mathcal{R}$$