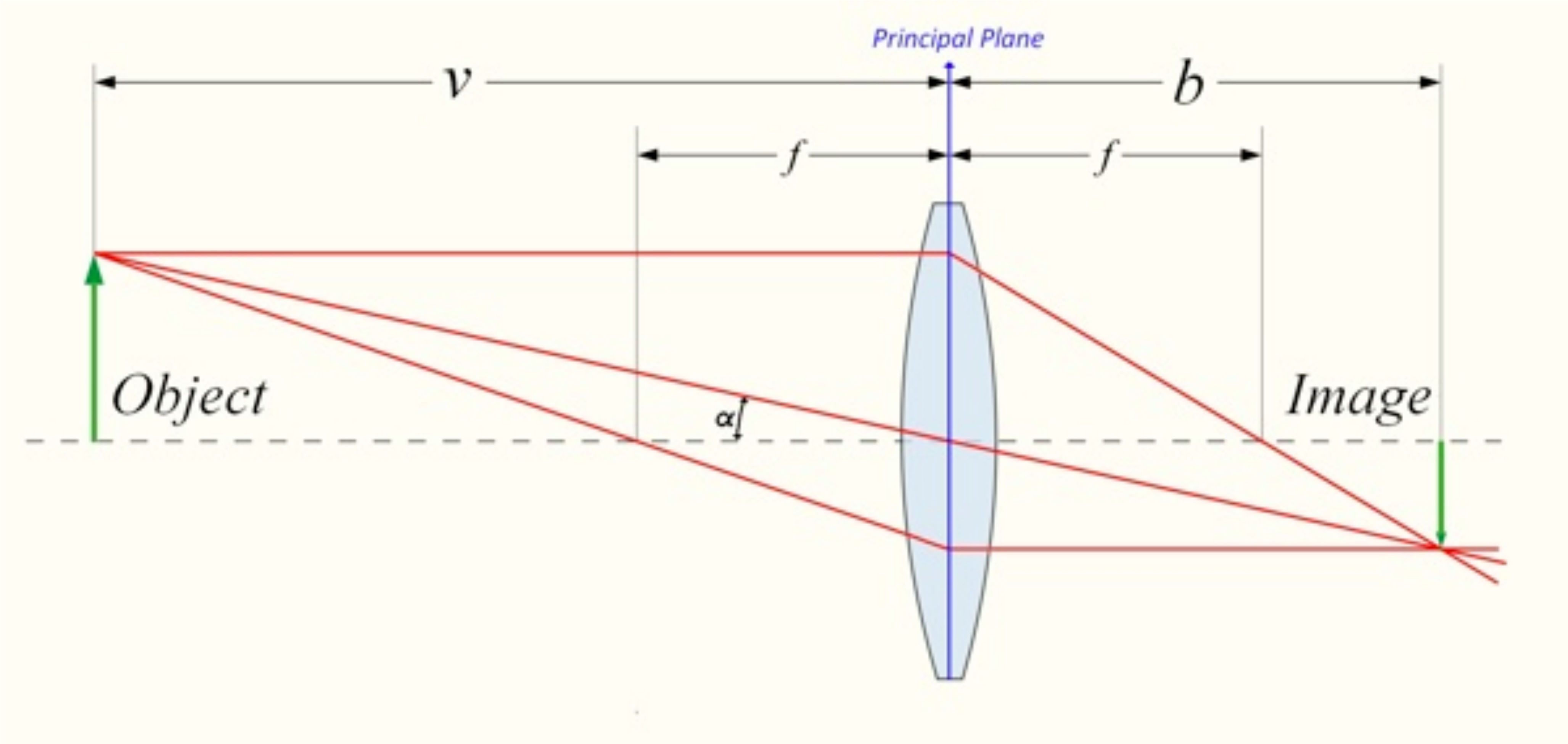
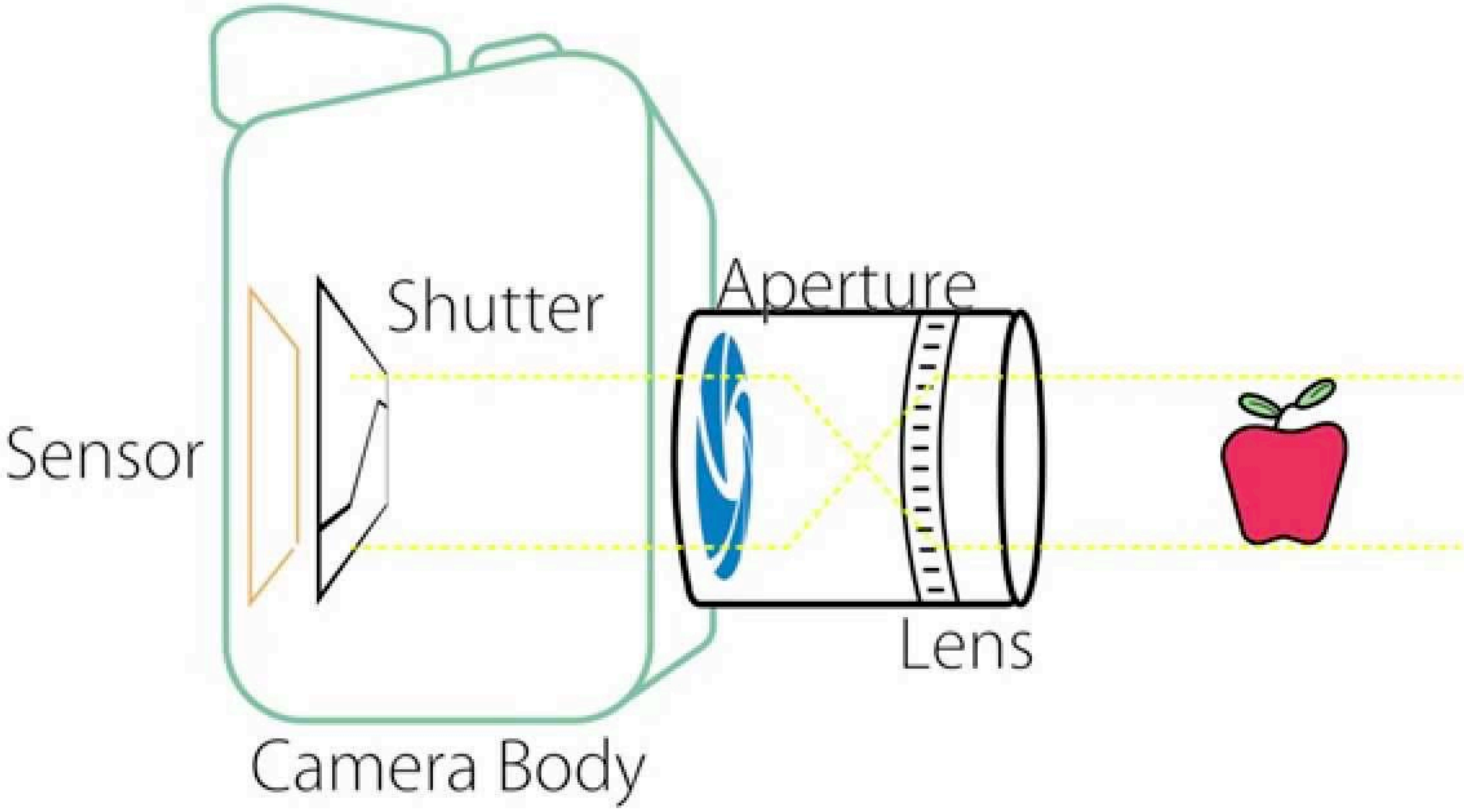
Robotica autonoma en entornos hostiles

Vision 3D

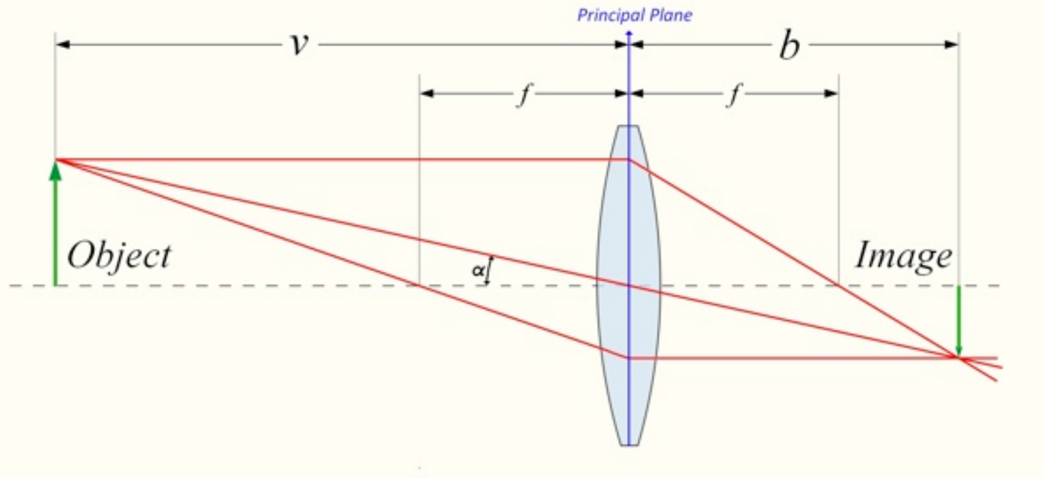
Di Martino, Abril 2022

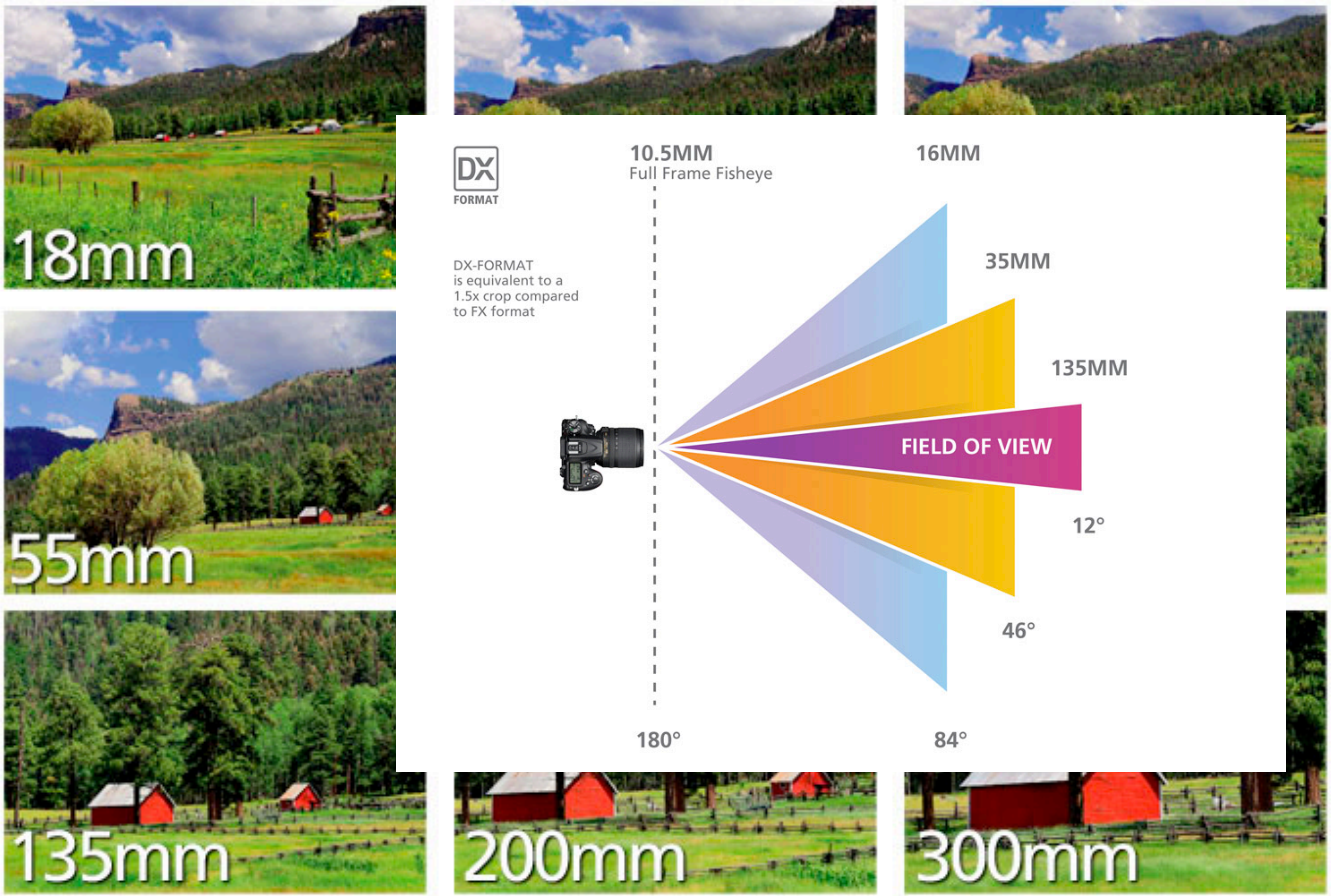
Imágenes Digitales

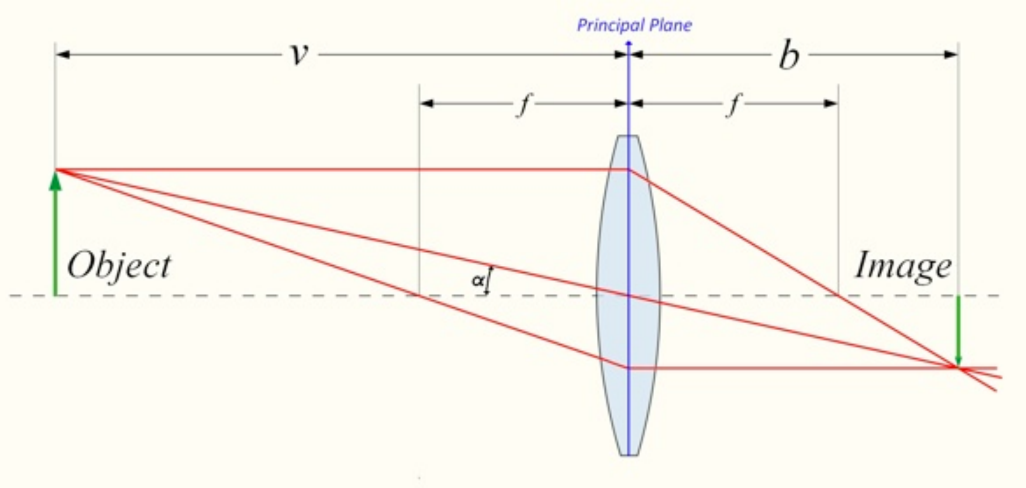

Principal Plane
v
b
f
f
Object
α
Image


Shutter
Aperture
Sensor
Lens
Camera Body


18mm
24mm
35mm
55mm
85mm
105mm
135mm
200mm
300mm


Principal Plane
v
b
f
f
Object
Image


18mm
55mm
135mm
200mm
300mm
DX
FORMAT
DX-FORMAT
is equivalent to a
1.5x crop compared
to FX format
10.5MM
Full Frame Fisheye
16MM
35MM
135MM
FIELD OF VIEW
12°
46°
180°
84°


Principal Plane
v
b
f
f
Object
Image


16mm
the
struggle
is reel
50mm
the
struggle
is reel
300mm
the
struggle
is reel

SHUTTER SPEED

2" | 1" | 1/2 | 1/4 | 1/8 | 1/15 | 1/30 | 1/60 | 1/125 | 1/250 | 1/500 | 1/1000

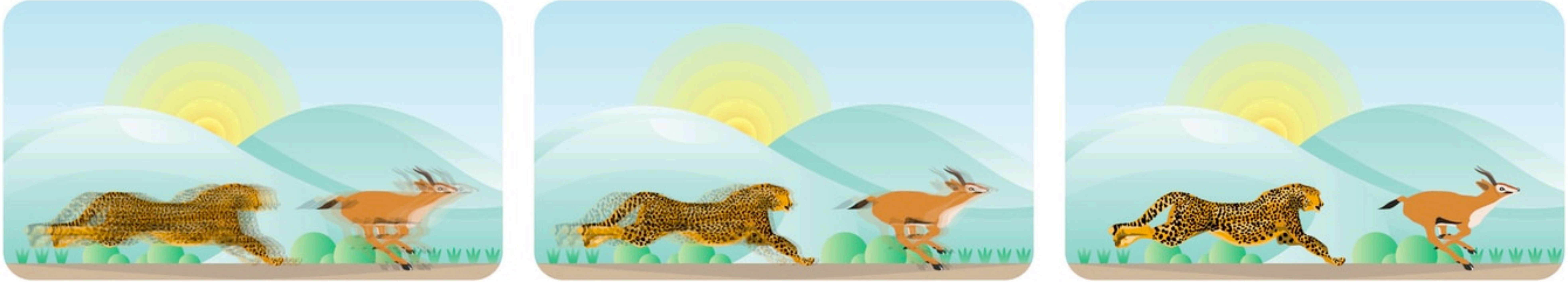
MOTION

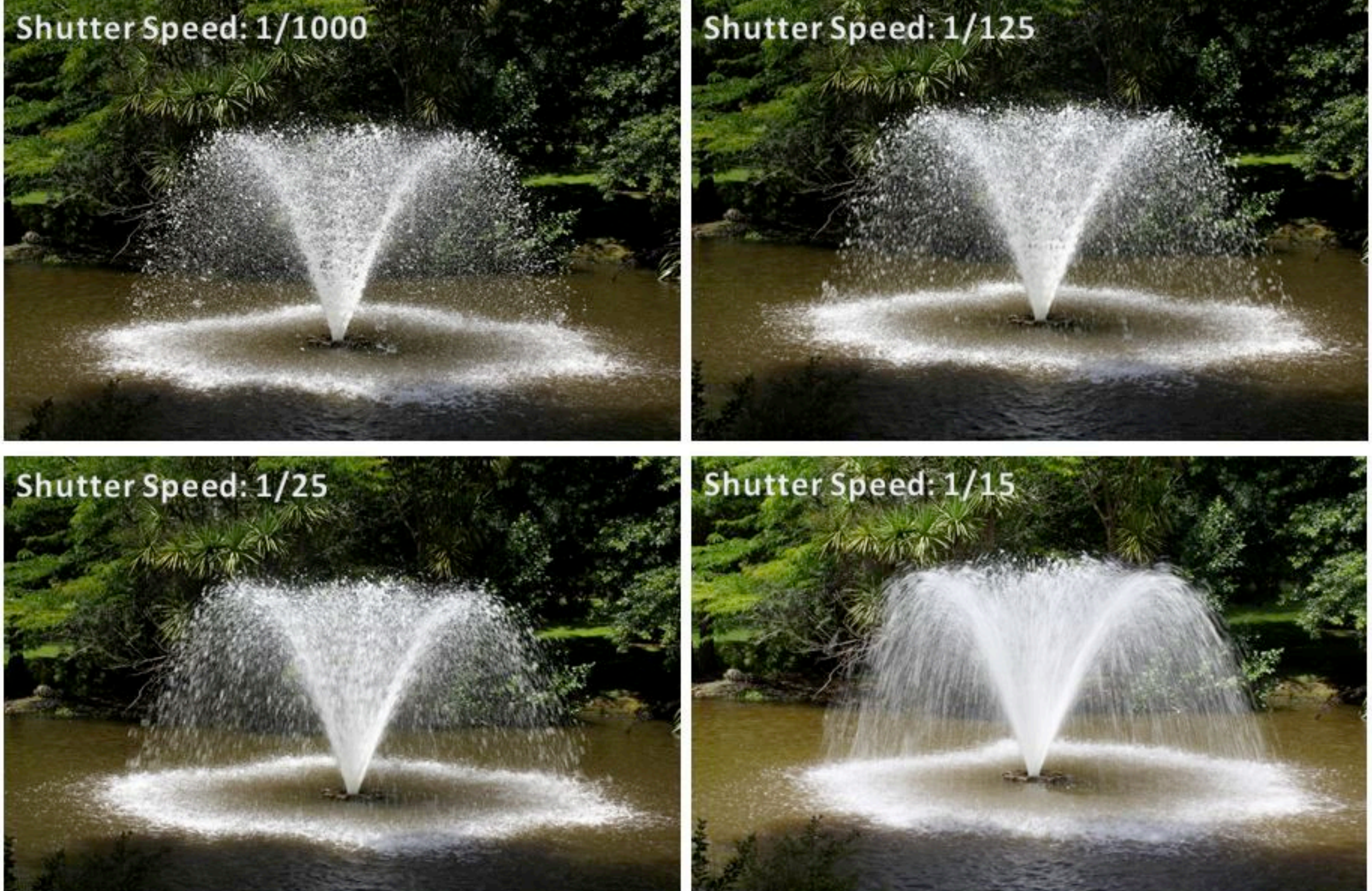
Shutter Speed and Motion

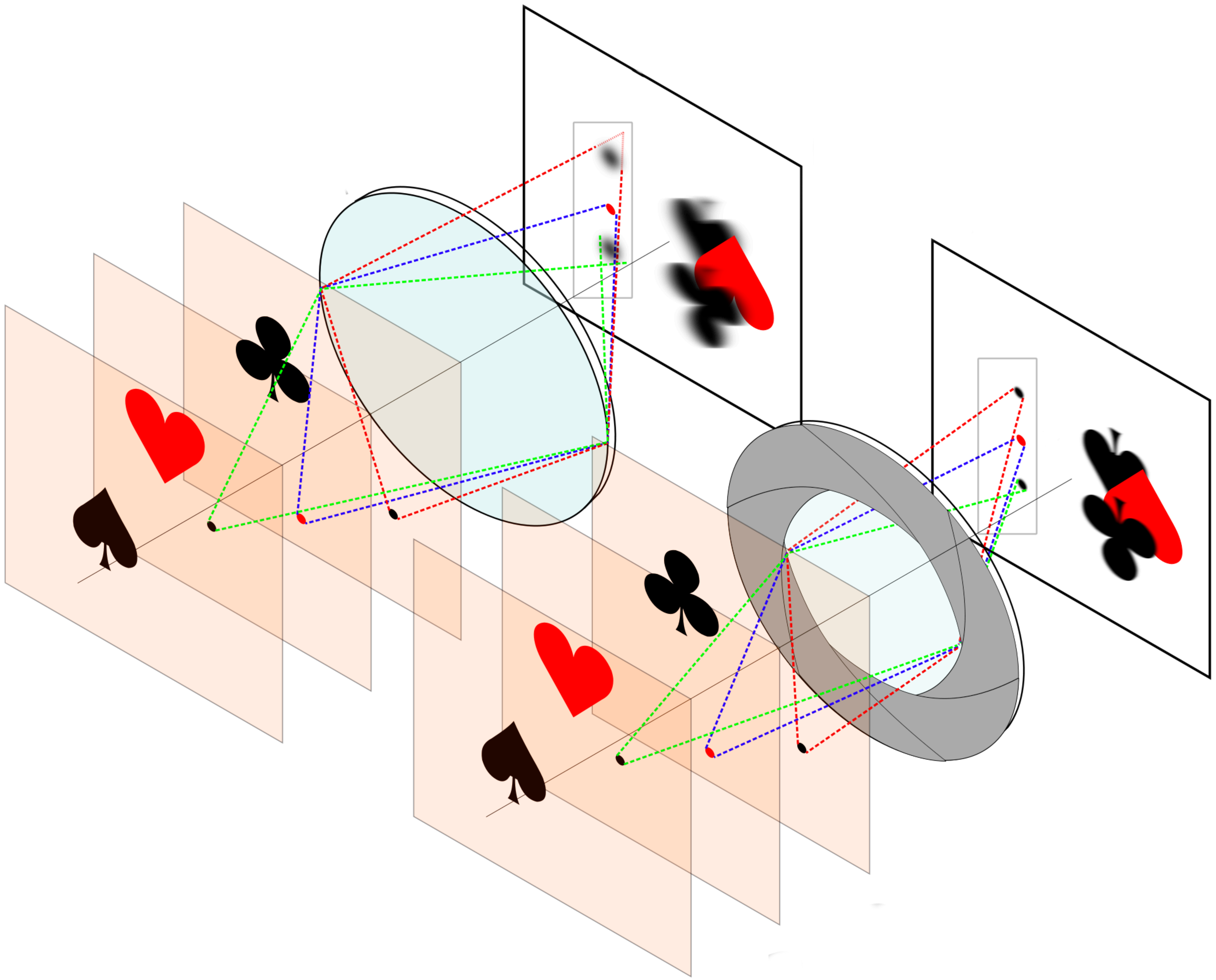
SLOWER ← → FASTER

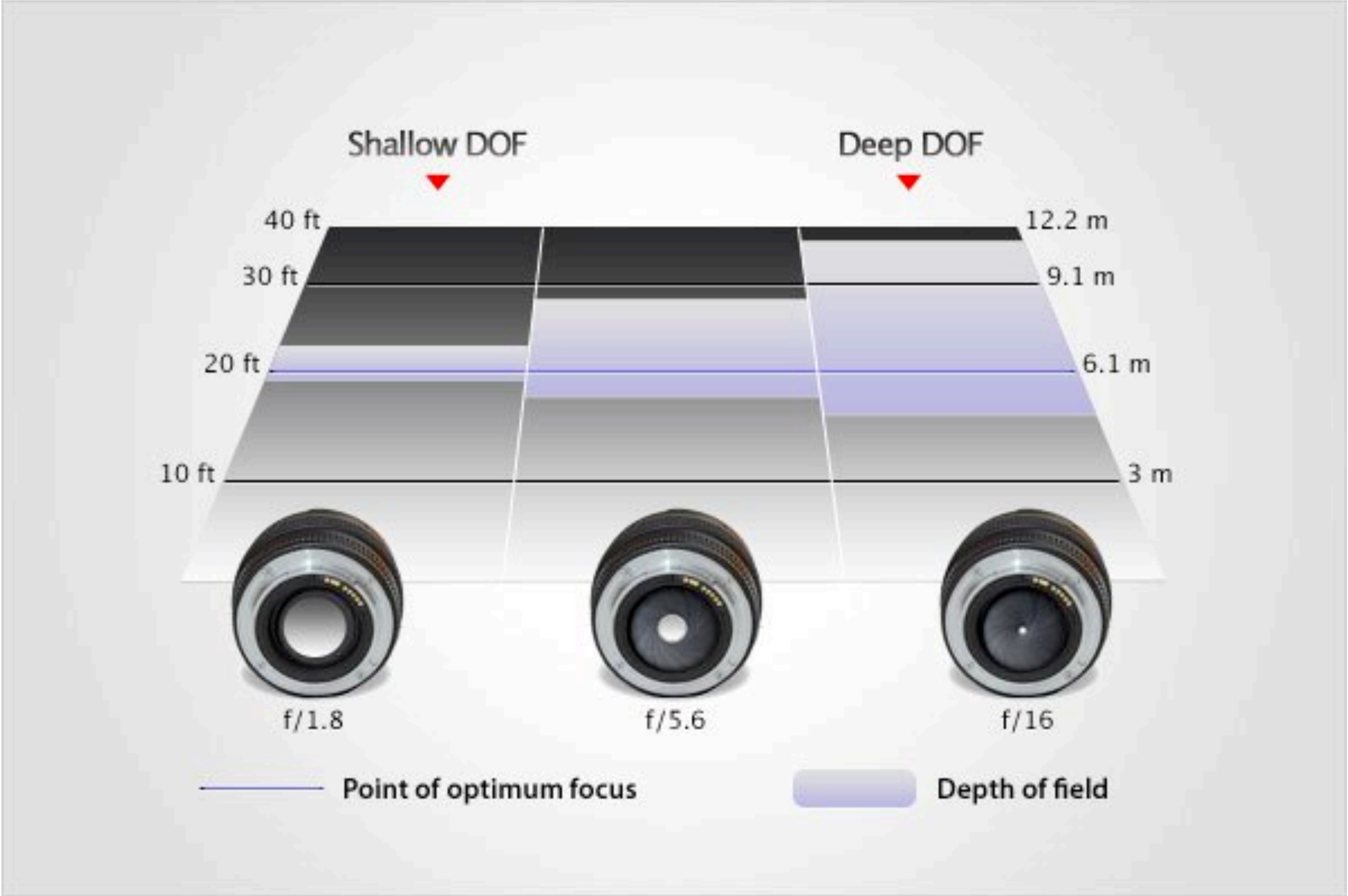
Blurry Motion ⟷ Freeze Motion

2" | 1" | 1/2 | 1/4 | 1/8 | 1/15 | 1/30 | 1/60 | 1/125 | 1/250 | 1/500 | 1/2000



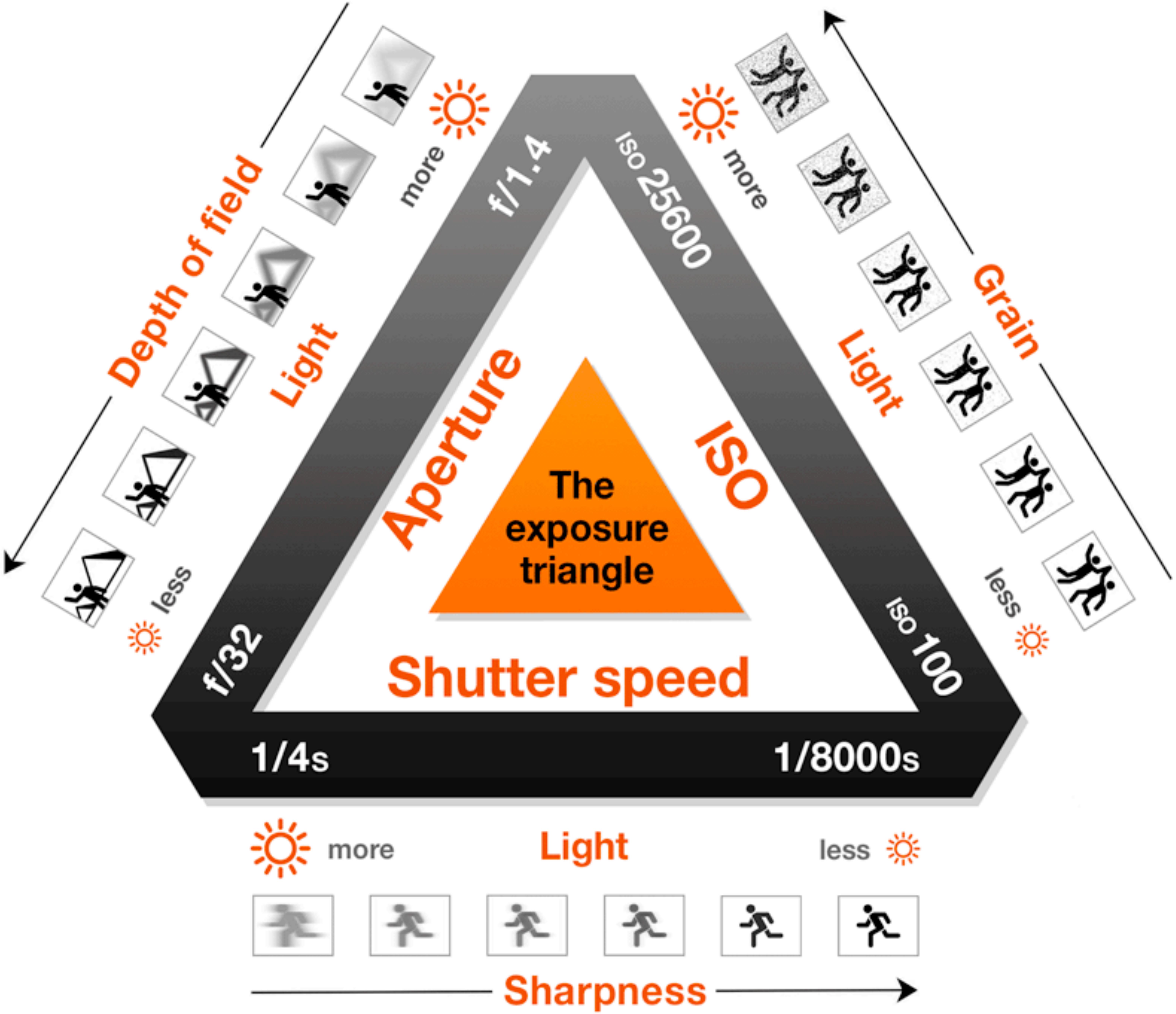

Shutter Speed: 1/1000
Shutter Speed: 1/125
Shutter Speed: 1/25
Shutter Speed: 1/15



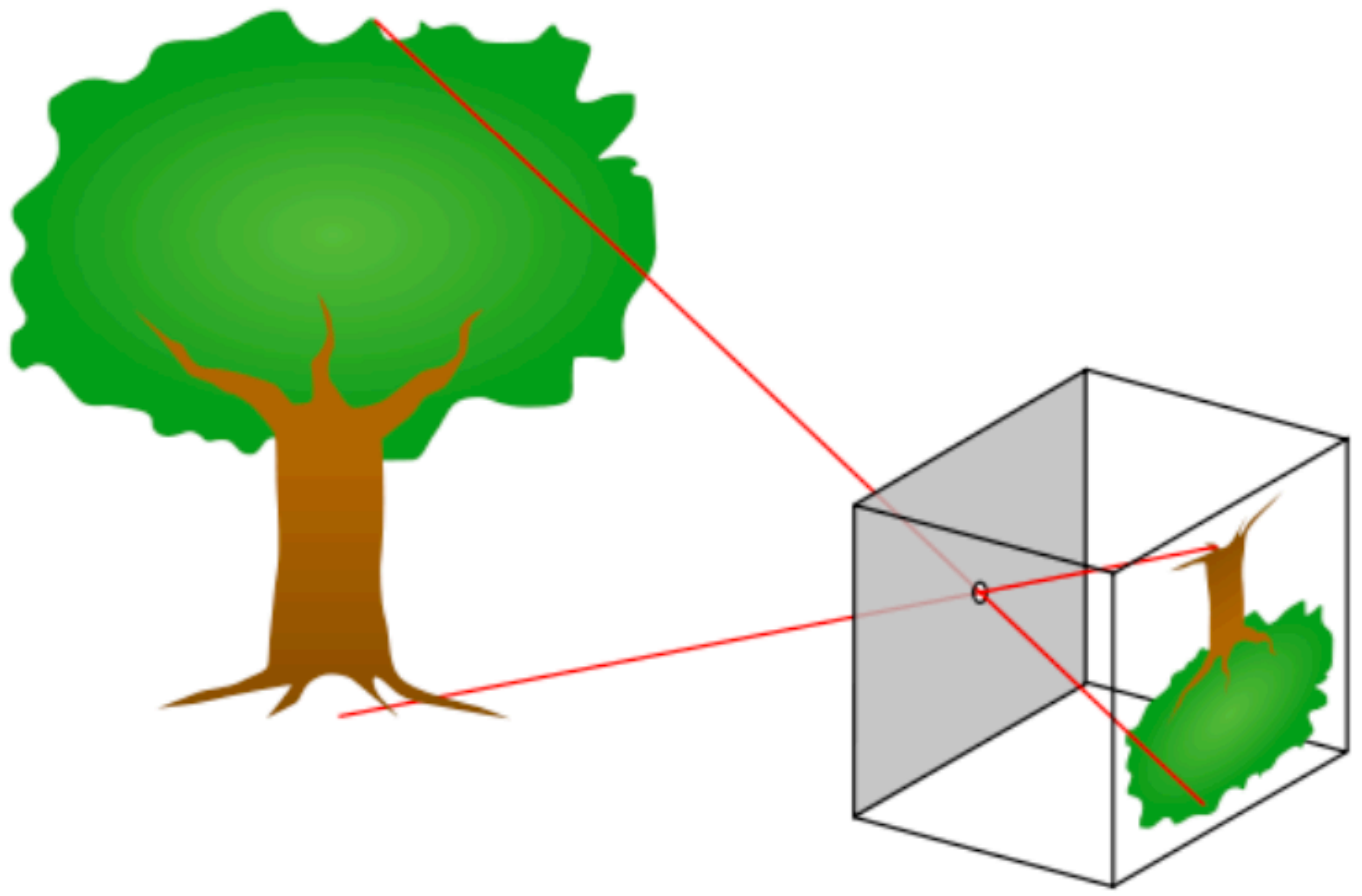

Shallow DOF
Deep DOF
40 ft
30 ft
20 ft
10 ft
12.2 m
9.1 m
6.1 m
3 m
f/1.8
f/5.6
f/16
Point of optimum focus
Depth of field

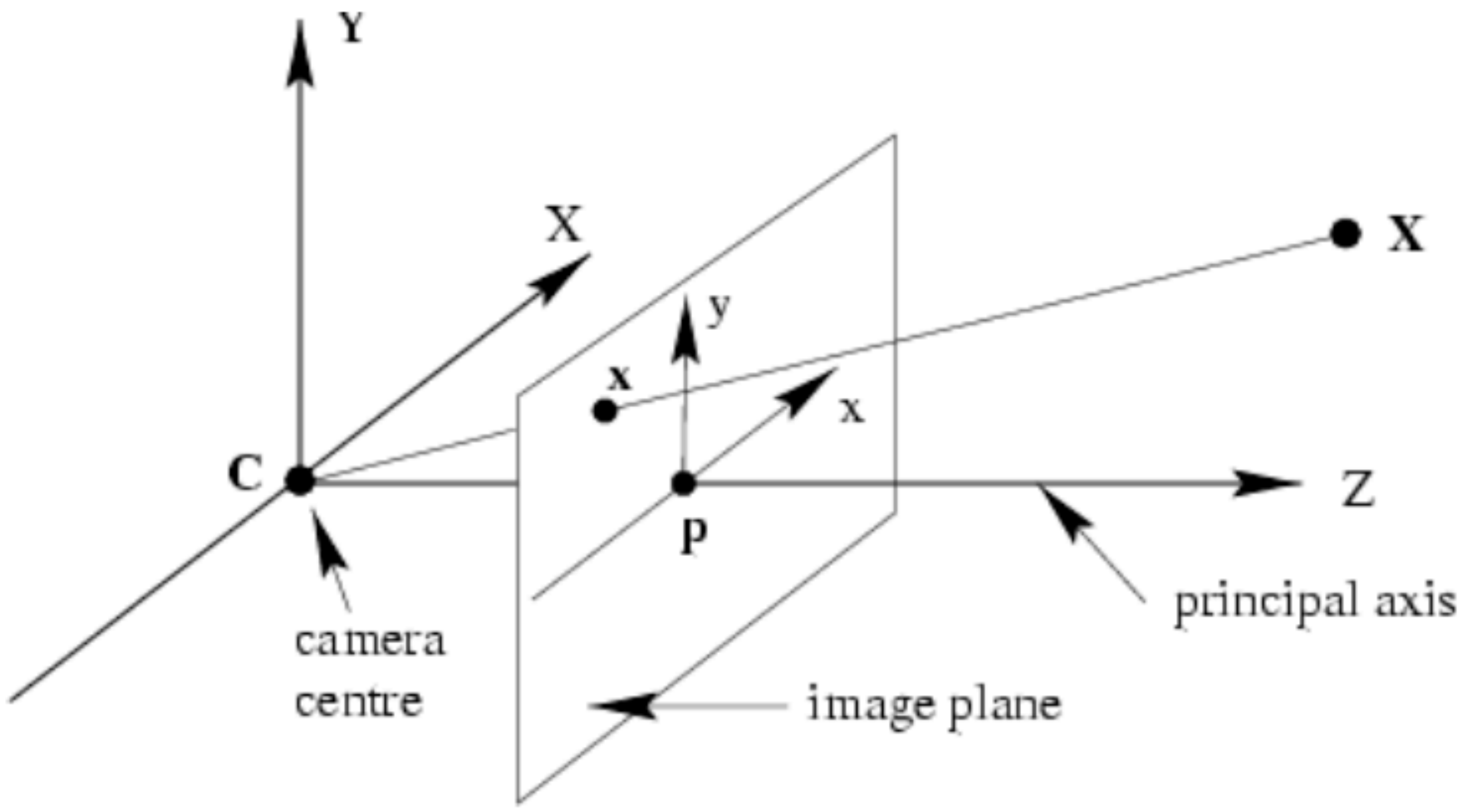

f/1.4
f/2
f/2.8
f/4
f/5.6
f/8
f/11
f/16


100% Crop


Depth of field
more
Light
less
f/1.4
f/32
Aperture
The exposure triangle
ISO
iso 25600
iso 100
more
Light
less
Grain
Shutter speed
1/4s
1/8000s
more
Light
less
Sharpness

Como modelamos una cámara?





Model

Projection (Source: Wikipedia)

The“pinhole” camera (French: sténopé):

- Ideal model with an aperture reduced to a single point.
- No account for blur of out of focus objects, nor for the lens geometric distortion.

Central projection in camera coordinate frame

- Rays from C are the same: $\vec{Cx} = \lambda \vec{CX}$
- In the camera coordinate frame $CXYZ$:

$$\begin{pmatrix} x \\ y \\ f \end{pmatrix} = \lambda \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

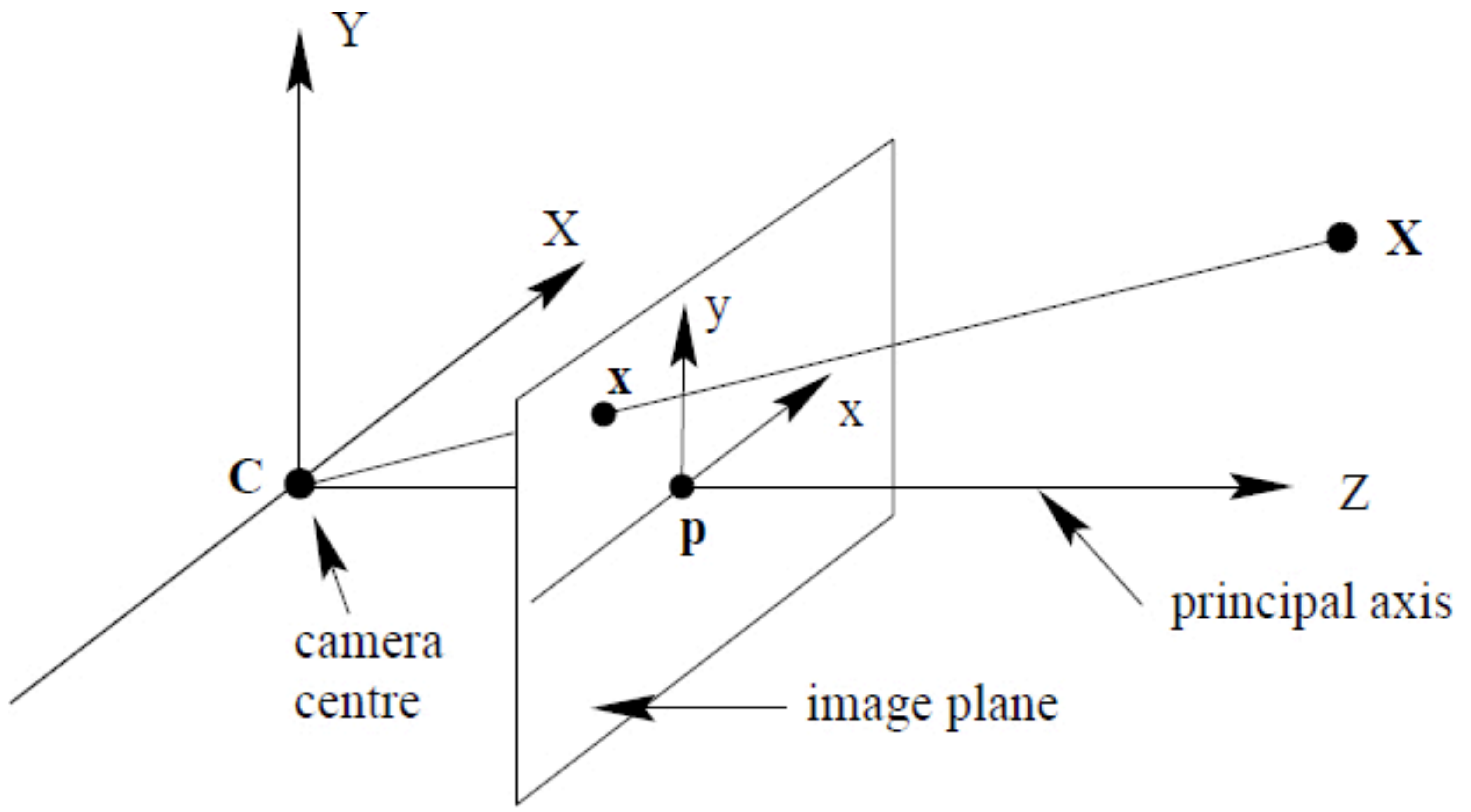
- Thus $\lambda = f/Z$ and

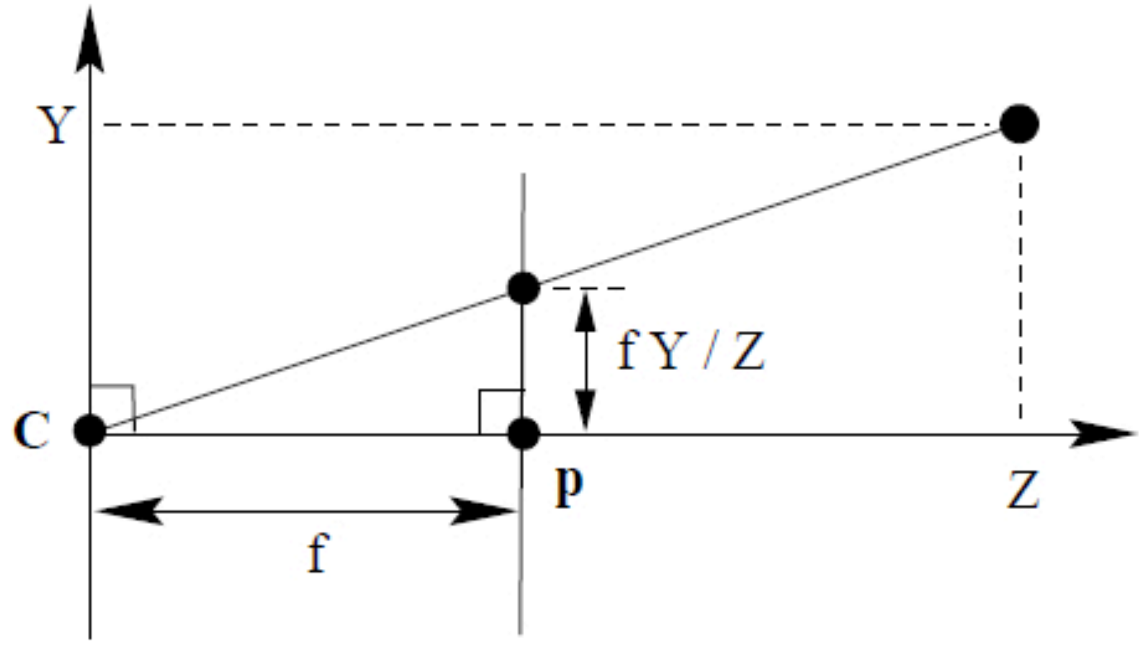
$$\begin{pmatrix} x \\ y \end{pmatrix} = f \begin{pmatrix} X/Z \\ Y/Z \end{pmatrix}$$

- In pixel coordinates:

$$\begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} \alpha x + c_x \\ \alpha y + c_y \end{pmatrix} = \begin{pmatrix} (\alpha f) X/Z + c_x \\ (\alpha f) Y/Z + c_y \end{pmatrix}$$

- αf: focal length *in pixels*, (c_x, c_y): position of principal point P in pixels.





Calibration matrix

- Let us get back to the projection equation:

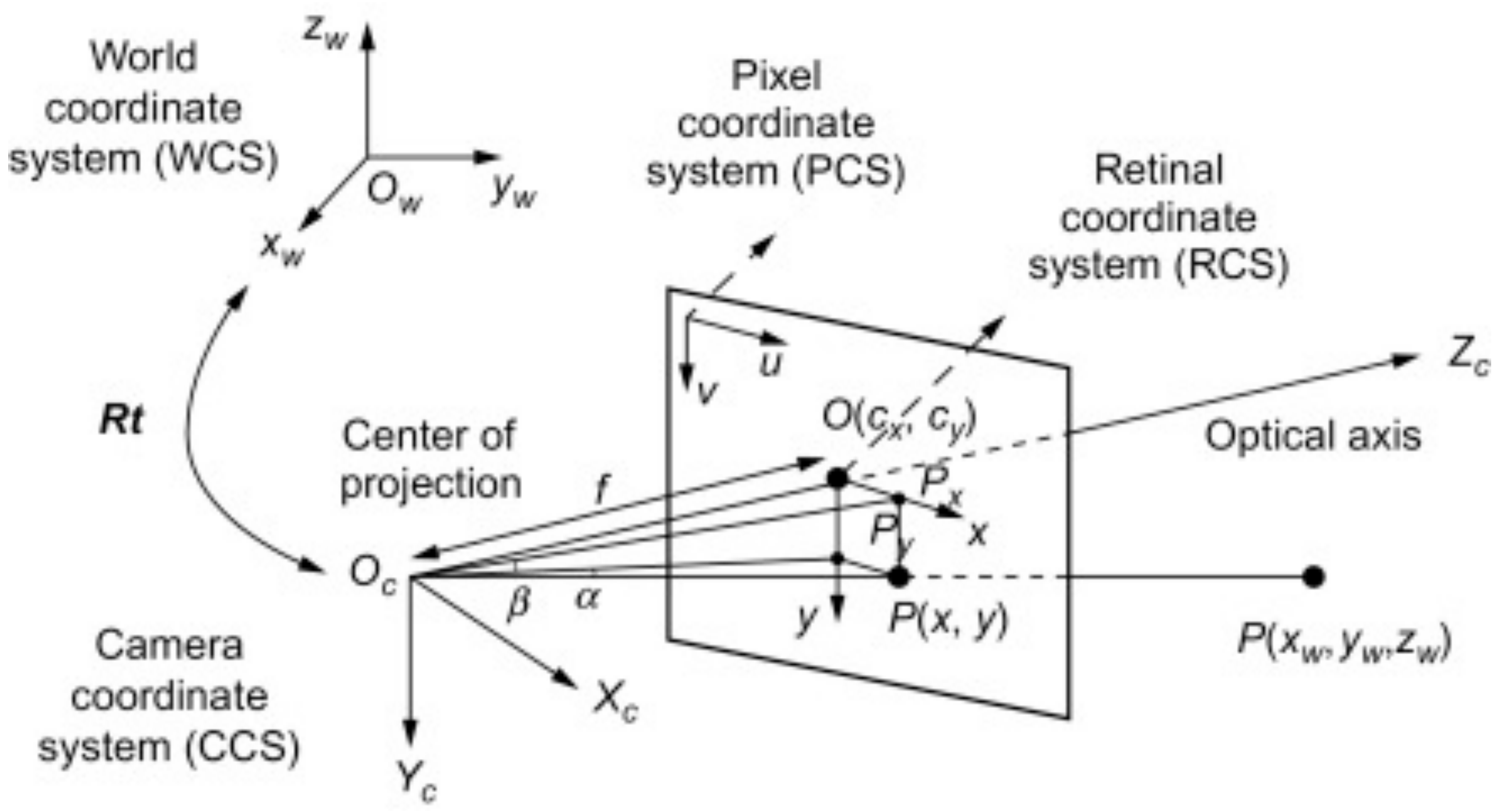
$$\begin{pmatrix} u \\ v \end{pmatrix} = \begin{pmatrix} fX/Z + c_x \\ fY/Z + c_y \end{pmatrix} = \frac{1}{Z}\begin{pmatrix} fX + c_x Z \\ fY + c_y Z \end{pmatrix}$$

  (replacing αf by f)
- We rewrite:

$$Z\begin{pmatrix} u \\ v \\ 1 \end{pmatrix} := x = \begin{pmatrix} f & & c_x \\ & f & c_y \\ & & 1 \end{pmatrix}\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

- The 3D point being expressed in another orthonormal coordinate frame:

$$x = \begin{pmatrix} f & & c_x \\ & f & c_y \\ & & 1 \end{pmatrix}\begin{pmatrix} R & T \end{pmatrix}\begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$



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$$x = \begin{pmatrix} f & & c_x \\ & f & c_y \\ & & 1 \end{pmatrix} \begin{pmatrix} R & T \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix}$$

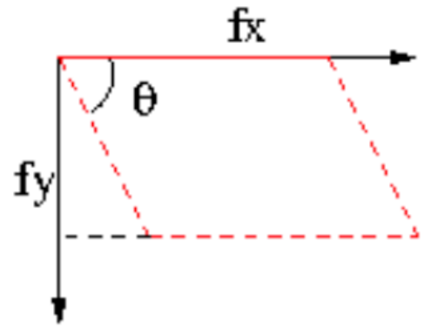
- The (internal) calibration matrix (3×3) is:

$$K = \begin{pmatrix} f & & c_x \\ & f & c_y \\ & & 1 \end{pmatrix}$$

- The projection matrix (3×4) is:

$$P = K \begin{pmatrix} R & T \end{pmatrix}$$

- If pixels are trapezoids, we can generalize K:



$$K = \begin{pmatrix} f_x & s & c_x \\ & f_y & c_y \\ & & 1 \end{pmatrix} \text{(with } s = -f_x \operatorname{cotan} \theta)$$

Function Documentation

◆ calibrateCamera() [1/2]

```
double cv::calibrateCamera ( InputArrayOfArrays    objectPoints,
                             InputArrayOfArrays    imagePoints,
                             Size                  imageSize,
                             InputOutputArray      cameraMatrix,
                             InputOutputArray      distCoeffs,
                             OutputArrayOfArrays   rvecs,
                             OutputArrayOfArrays   tvecs,
                             OutputArray           stdDeviationsIntrinsics,
                             OutputArray           stdDeviationsExtrinsics,
                             OutputArray           perViewErrors,
                             int                   flags = 0 ,
                             TermCriteria          criteria = TermCriteria(TermCriteria::COUNT+TermCriteria::EPS, 30, DBL_EPSILON)
                           )
```

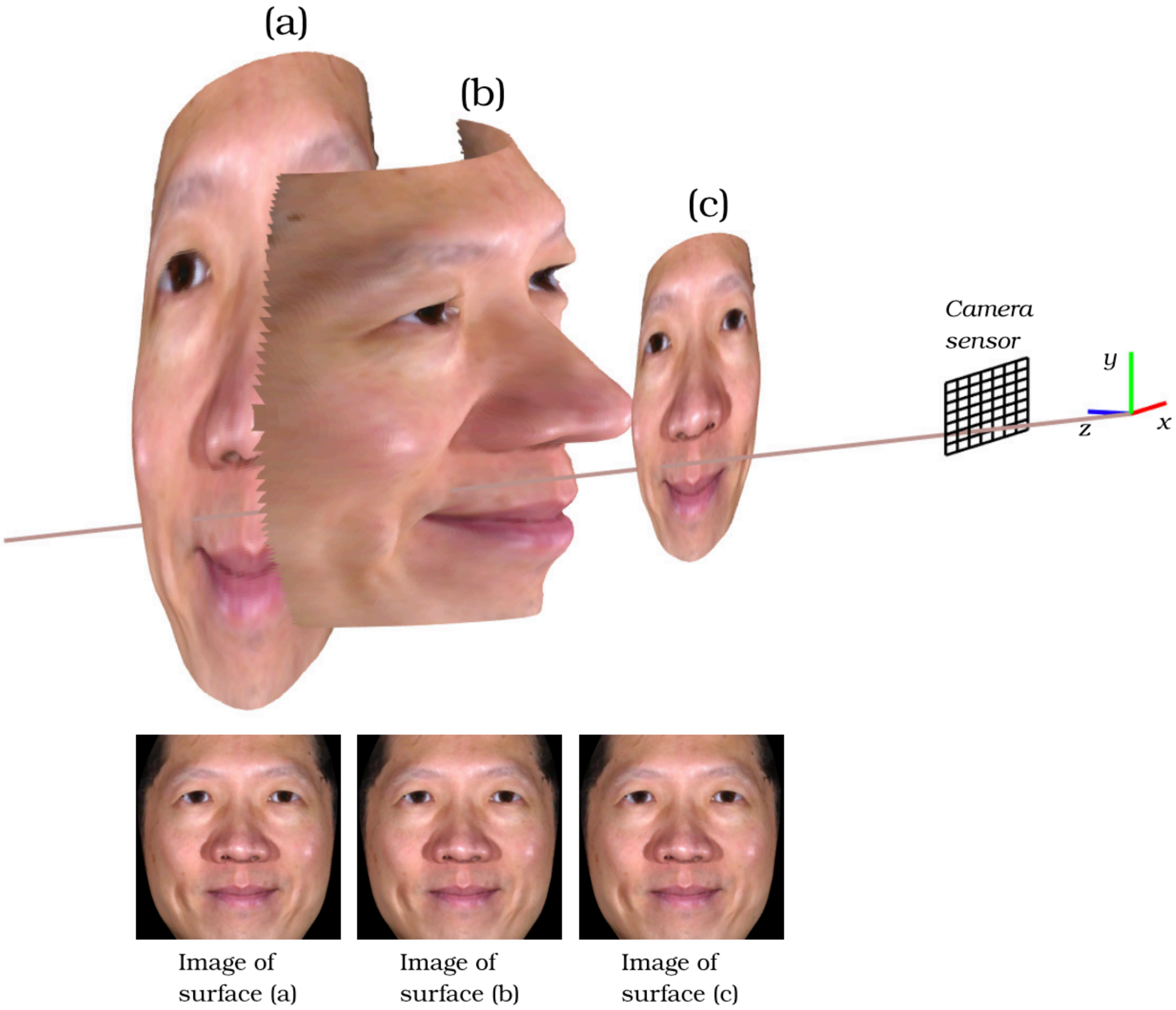
Python:

```
cv.calibrateCamera(    objectPoints, imagePoints, imageSize, cameraMatrix, distCoeffs[, rvecs[, tvecs[, flags[, criteria]]]]
```

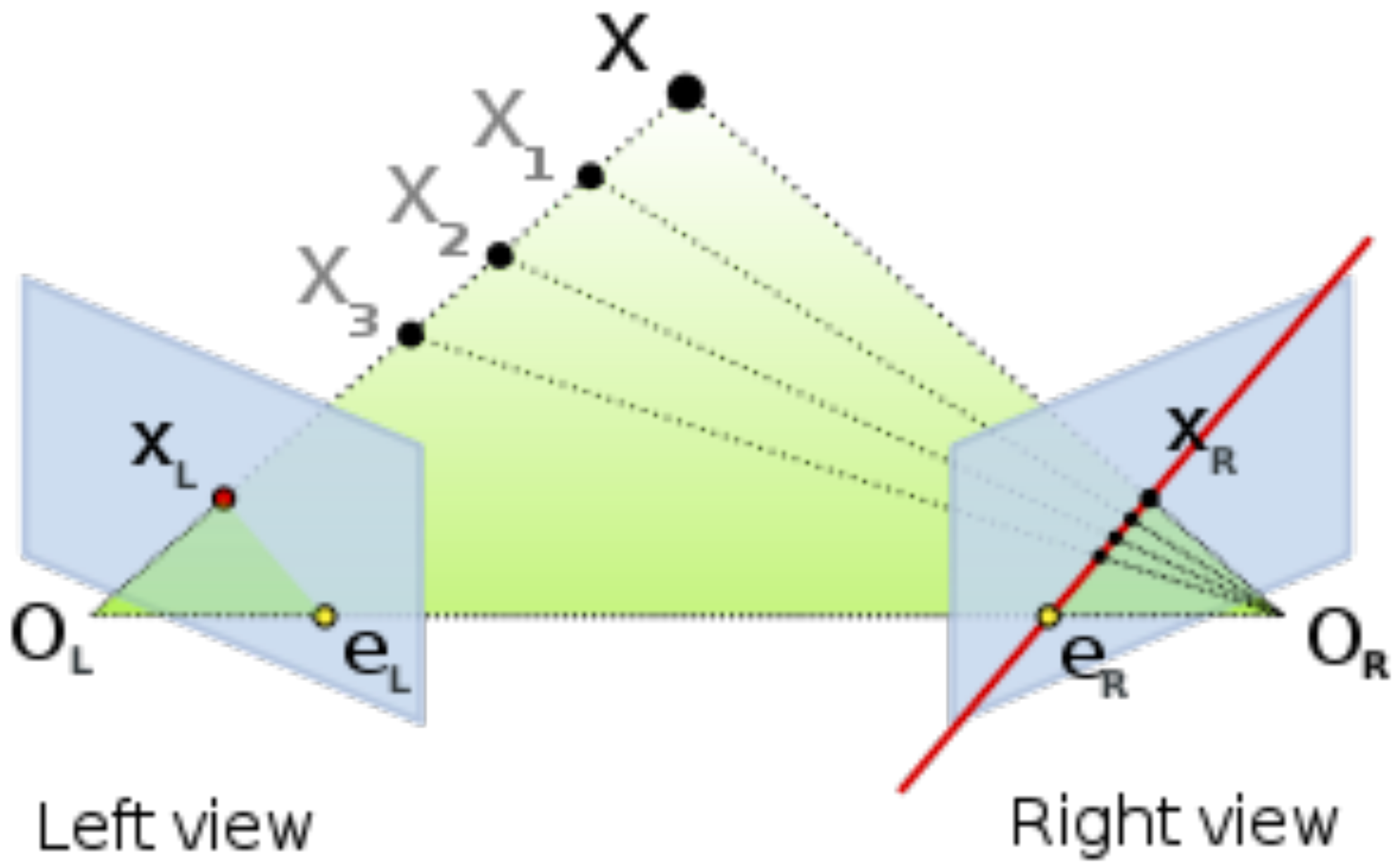
Parameters

objectPoints	In the new interface it is a vector of vectors of calibration pattern points in th many elements as the number of pattern views. If the same calibration patte partially occluded patterns or even different patterns in different views. Then plane (thus 0 in the Z-coordinate), if the used calibration pattern is a planar r
imagePoints	In the new interface it is a vector of vectors of the projections of calibration p imagePoints[i].size() and objectPoints[i].size() for each i, must be equal, res
imageSize	Size of the image used only to initialize the camera intrinsic matrix.
cameraMatrix	Input/output 3x3 floating-point camera intrinsic matrix $A = \begin{bmatrix} f_x & 0 & c_x \\ 0 & f_y & c_y \\ 0 & 0 & 1 \end{bmatrix}$.

Cómo podemos extraer información 3D usando cámaras?



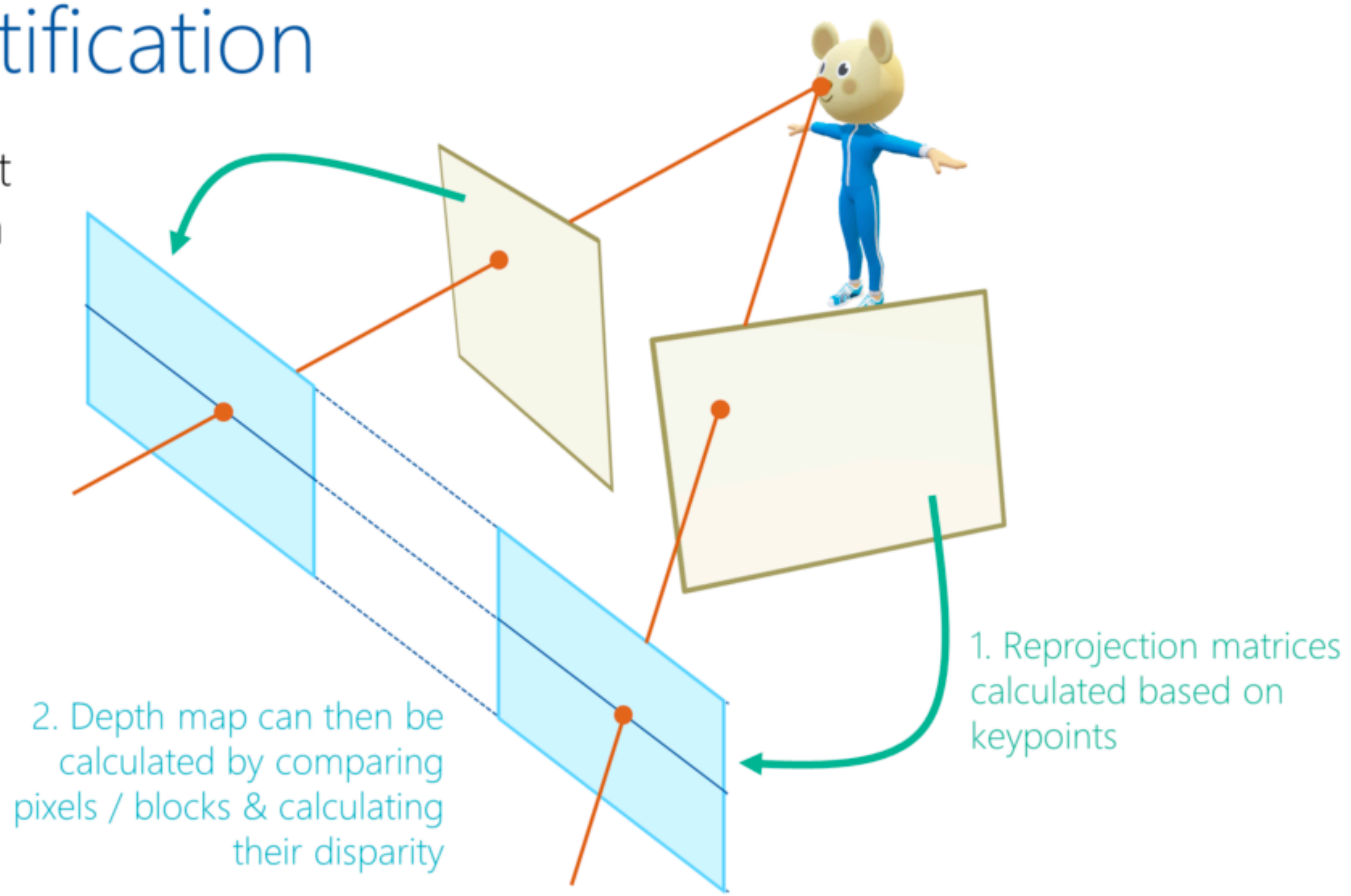
[1] Di Martino, J. Matias, Qiang Qiu, and Guillermo Sapiro. "Rethinking shape from shading for spoofing detection." *IEEE Transactions on Image Processing* 30 (2020): 1086-1099.



X
X1
X2
X3
xL
xR
OL
eL
eR
OR
Left view
Right view

Stereo Rectification

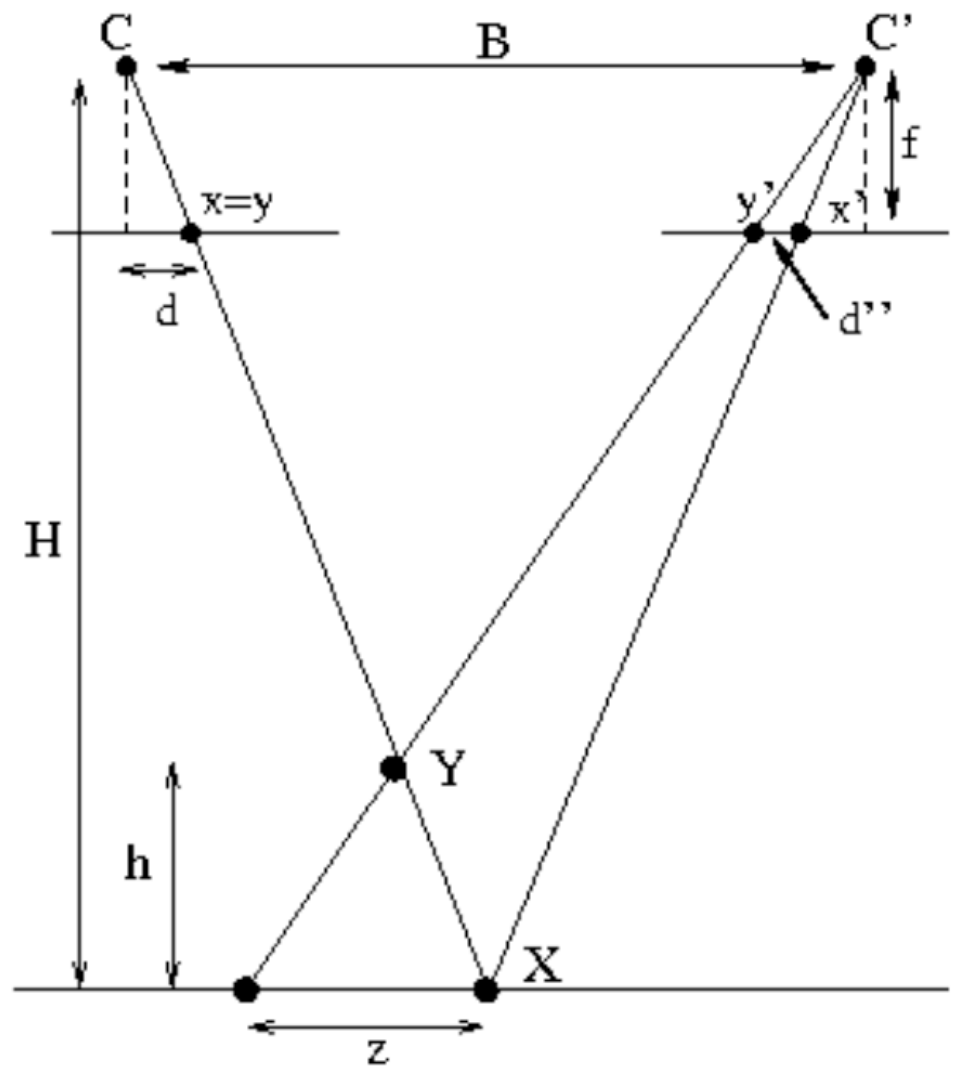
Reproject left & right image planes onto a common plane parallel to the line between camera centers



Based on Computer Vision / Epipolar Geometry, Kris Kitani, Carnegie Mellon University

Triangulation

Fundamental principle of stereo vision



$$h \backsimeq \frac{z}{B/H}, \quad z = d'' \frac{H}{f}.$$

f focal length.

H distance optical center-ground.

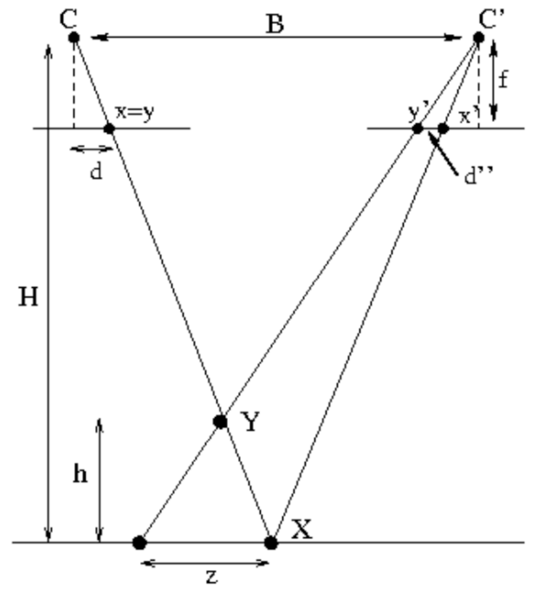
B distance between optical centers (baseline).

Goal

Given two rectified images, point correspondences and computation of their apparent shift (disparity) gives information about relative depth of the scene.

Triangulation

Fundamental principle of stereo vision



$$h \backsimeq \frac{z}{B/H}, \quad z = d'' \frac{H}{f}.$$

f focal length.
H distance optical center-ground.
B distance between optical centers (baseline).

Goal

Given two rectified images, point correspondences and computation of their apparent shift (disparity) gives information about relative depth of the scene.

- Let us write again the binocular formulae:

$$\lambda x = K(RX + T) \quad \lambda' x' = K' X$$

- Write $Y^T = \begin{pmatrix} X^T & \lambda & \lambda' \end{pmatrix}$:

$$\begin{pmatrix} KR & -x & 0_3 \\ K' & 0_3 & -x' \end{pmatrix} Y = \begin{pmatrix} KT \\ 0_3 \end{pmatrix}$$

(6 equations$\leftrightarrow$5 unknowns+1 epipolar constraint)

- We can then recover X.
- Special case: $R = Id$, $T = Be_1$
- We get:

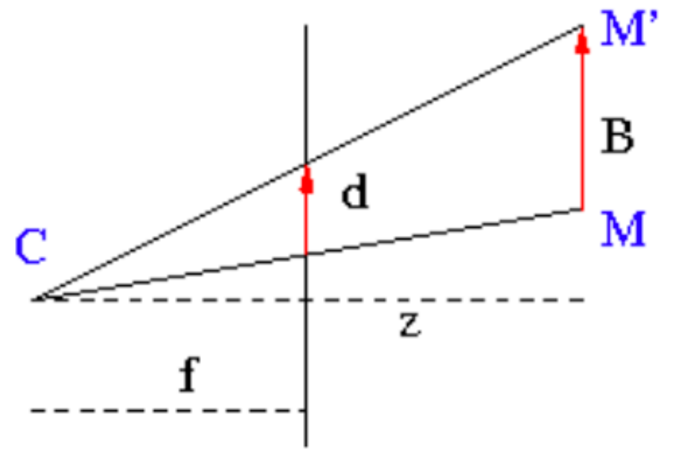
$$z(x - KK'^{-1}x') = \begin{pmatrix} Bf & 0 & 0 \end{pmatrix}^T$$

- If also $K = K'$,

$$z = fB/[(x - x') \cdot e_1] = fB/d$$

- d is the disparity

Disparity map



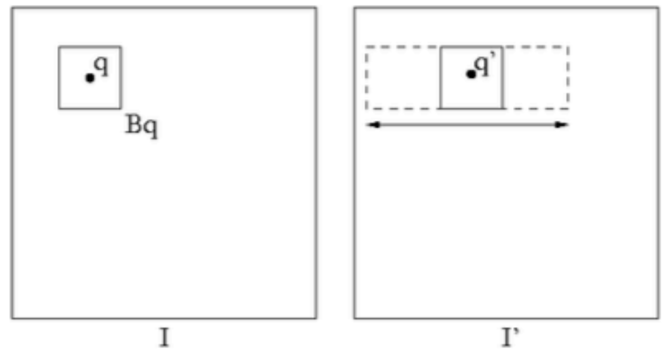
$$z = \frac{fB}{d}$$

Depth z is inversely proportional to disparity d (apparent motion, in pixels).

- Disparity map: At each pixel, its apparent motion between left and right images.
- We already know disparity at feature points, this gives an idea about min and max motion, which makes the search for matching points less ambiguous and faster.

Local search

- At each pixel, we consider a context window and we look for the motion of this window.



- Distance between windows:

$$d(q) = \arg\min_d \sum_{p \in F} (I(q+p) - I'(q+de_1+p))^2$$

- Variants to be more robust to illumination changes:
  1. Translate intensities by the mean over the window.

  $$I(q+p) \to I(q+p) - \sum_{r \in F} I(q+r)/\#F$$

  2. Normalize by mean and variance over window.

Right image

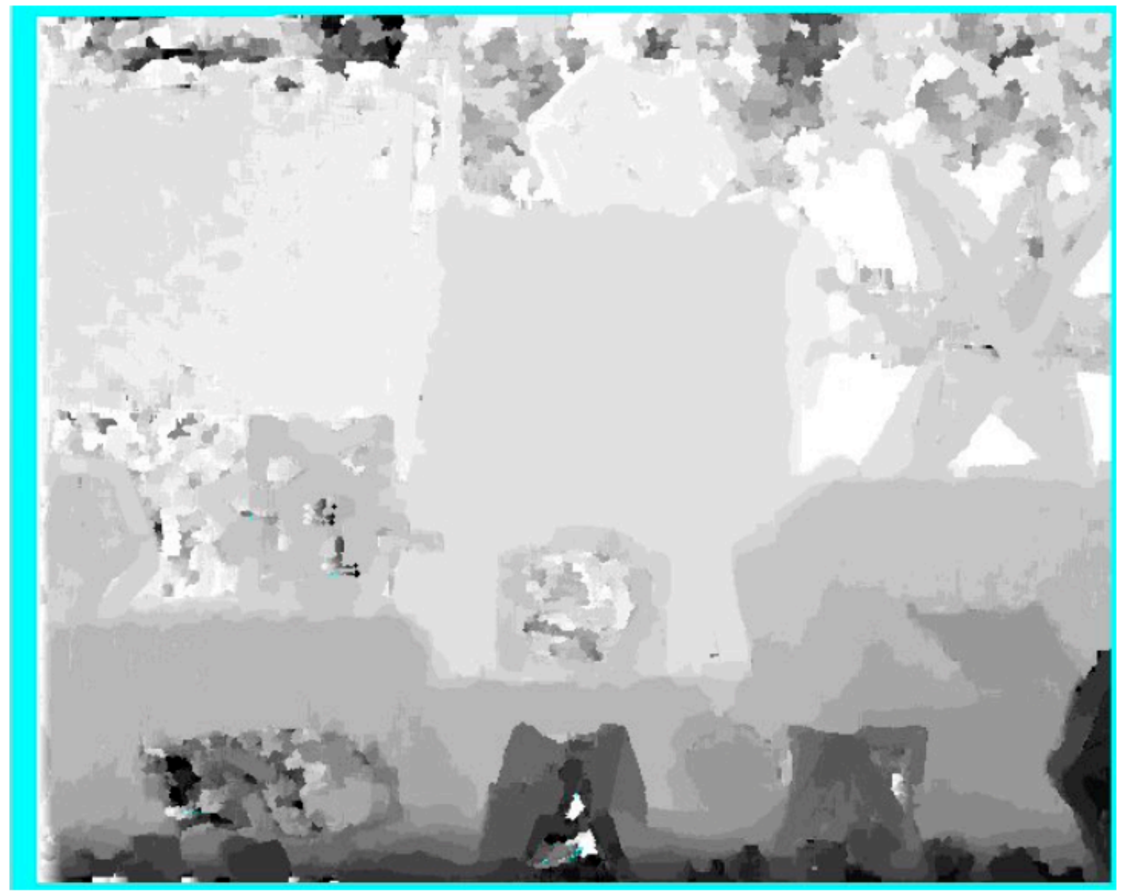
Left image

Right image

Left image


Right image

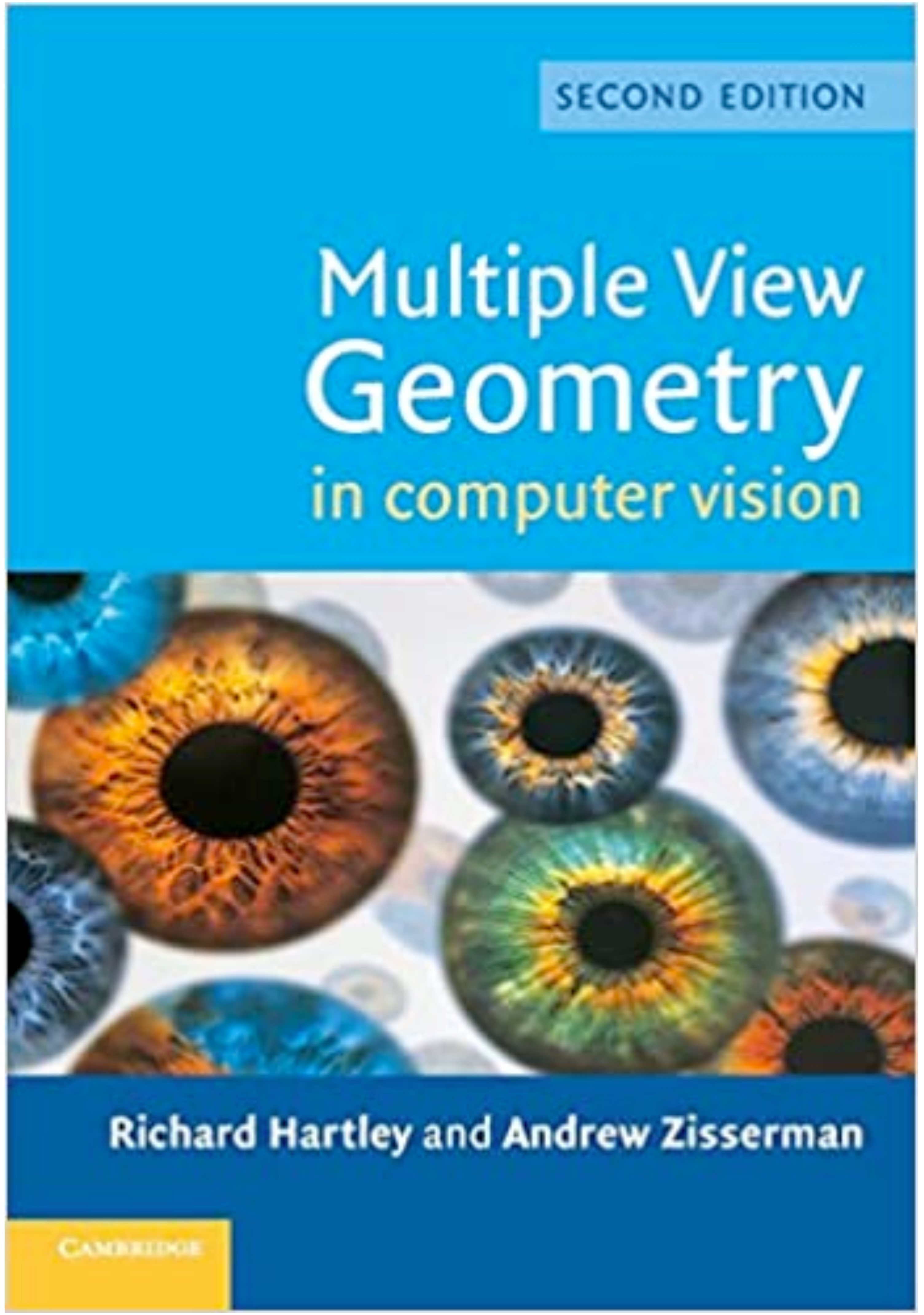

Left image



Resumiendo

- Modela una cámara y cuales son los parámetros más críticos.
- Pinhole model, matrix de proyección, parámetros intrínsecos y extrínsecos.
- Calibración de una cámara.
- Limites de vision monocular.
- Vision stereo puede usarse para obtener información 3D.
- Geometria epipolar.
- Disparidad entre imágenes epistolares contiene información de la profundidad.
- Desafíos asociados con la estimation de correspondencias (crucial para la calibración y para la estimación de correspondencias.

Material adicional



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Pascal Monasse

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BibTeX info

Communicated by Luis Álvarez
Demo edited by Agustín Salgado

Abstract

The standard setup in reconstructing the three-dimensional geometry of a scene from a pair of stereo images is to have them rectified, in which case the apparent motion of points is horizontal. With pinhole cameras, it is always possible to find two homographies that rectify the images. The method of Fusiello and Irsara assumes that both cameras are the same with principal point at the center, but keeps the focal length as an unknown. The virtual rotations of the two cameras are then evaluated to minimize the vertical motion of points.

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Quasi-Euclidean Epipolar Rectification

Pascal Monasse

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Depth Map from Stereo Images

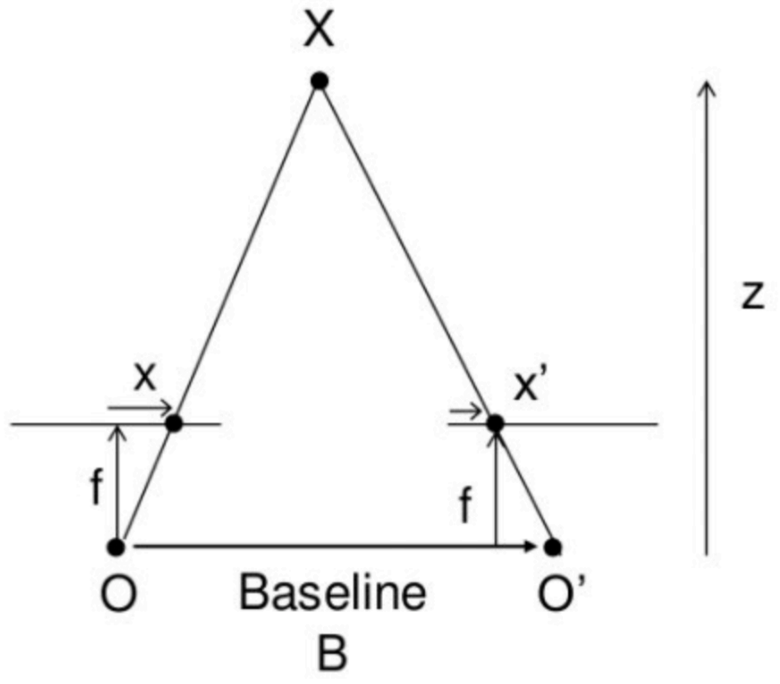
Goal

In this session,

- We will learn to create a depth map from stereo images.

Basics

In the last session, we saw basic concepts like epipolar constraints and other related terms. We also saw that if we have two images of same scene, we can get depth information from that in an intuitive way. Below is an image and some simple mathematical formulas which prove that intuition. (Image Courtesy :



image

The above diagram contains equivalent triangles. Writing their equivalent equations will yield us following result:

$$disparity = x - x' = \frac{Bf}{Z}$$

Omar Padierna
Jan 2, 2019 · 10 min read · Listen

Tutorial: Stereo 3D reconstruction with OpenCV using an iPhone camera. Part III.

Welcome to the third and final part of this 3 part tutorial on stereo reconstruction.

A quick recap:

During the first part we covered a brief mention on the steps required for stereo 3D reconstruction and the gist of how stereo reconstruction works.

Muchas gracias,
Preguntas?

Gracias a Pascal Monasse por dejarme usar su material!