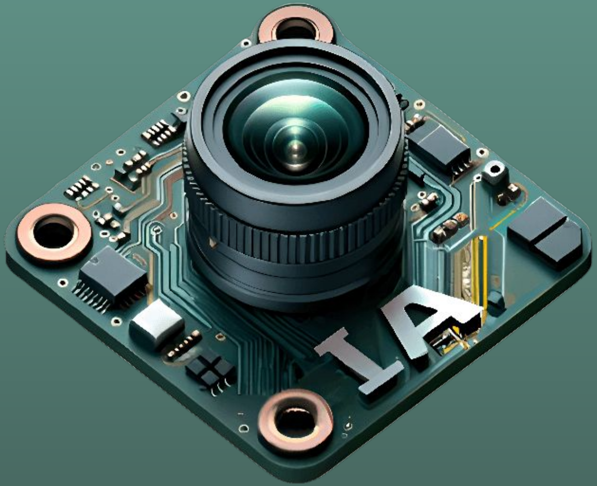
Universidad Industrial de Santander



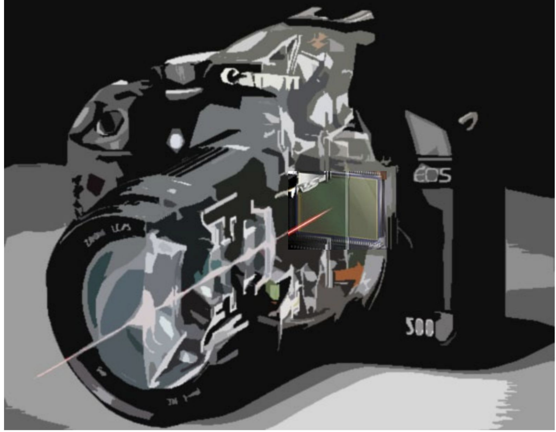
Semillero de Investigación

“Hands - on”

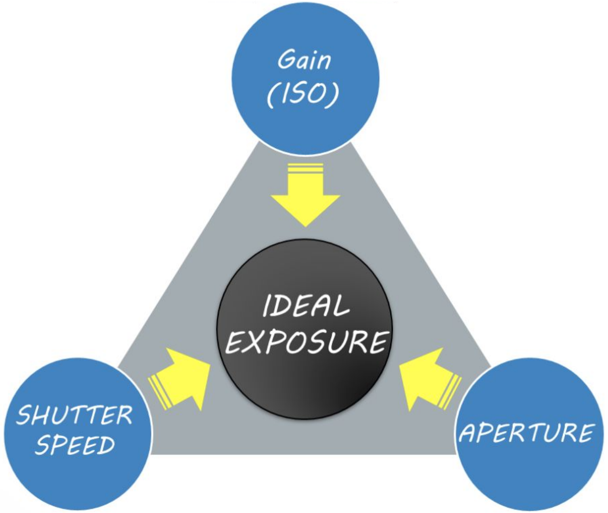
Computer Vision


SONY
SESIÓN 2:
DE FOTONES A
PIXELES

Contenidos



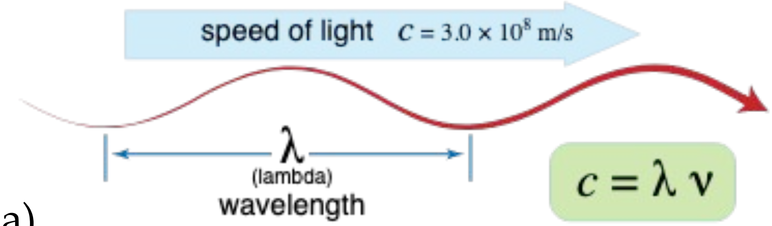
1. La cámara oscura (pinhole camera)
2. Formación de imágenes (FOV, AOV, DoF)
3. Triángulo de la exposición
4. Pipeline de procesamiento de imágenes
5. Transformaciones de imágenes

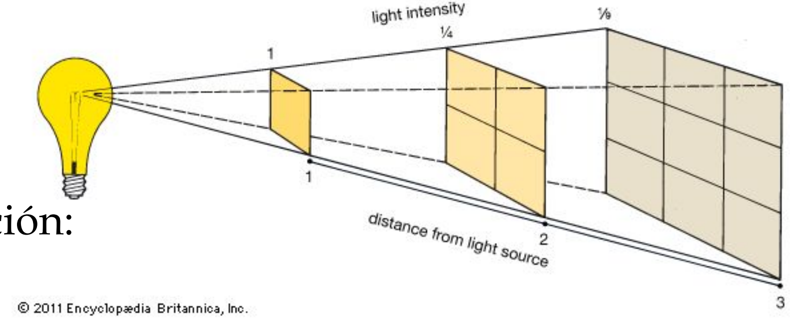


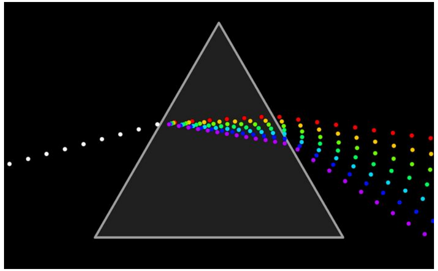
1. Cámara oscura

La luz

1. La luz viaja muy rápido (c = 300.000 km/s)
2. La luz tiene una doble naturaleza (onda y/o partícula)
3. Viaja en línea recta (menor distancia, parsimonia)
4. Varía en intensidad (inverse square law)
5. Interactúa con la materia (cambia velocidad y dirección: reflexión, refracción, absorción, difracción, etc.)
6. Tiene muchos colores (dispersión)
7. Contiene energía e información (radio, celulares, fibra óptica, etc.)

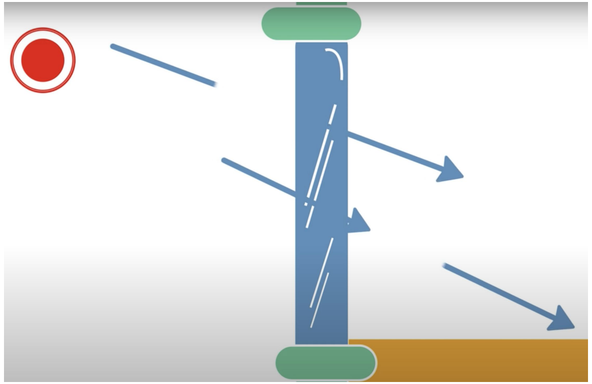




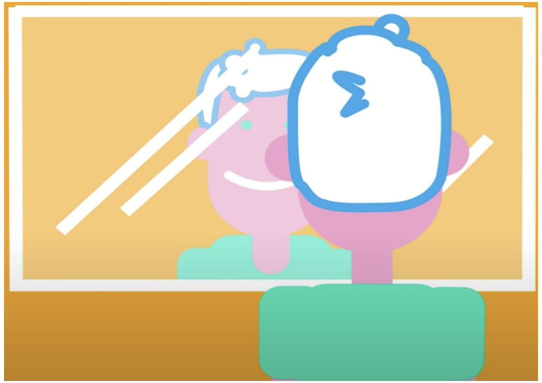


Propagación de la luz

Transmisión



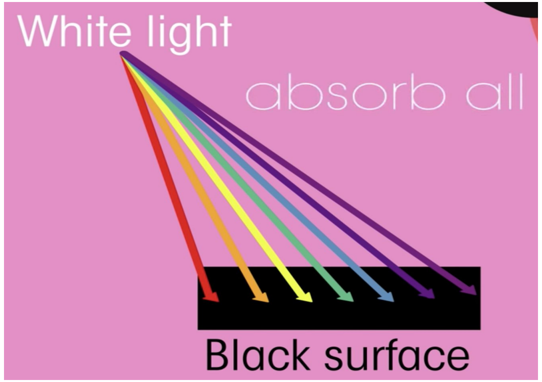
Reflexión



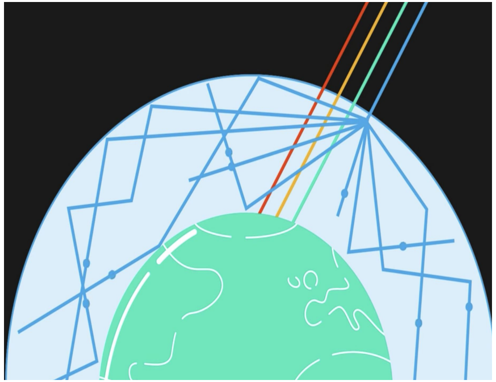
Refracción

Difracción

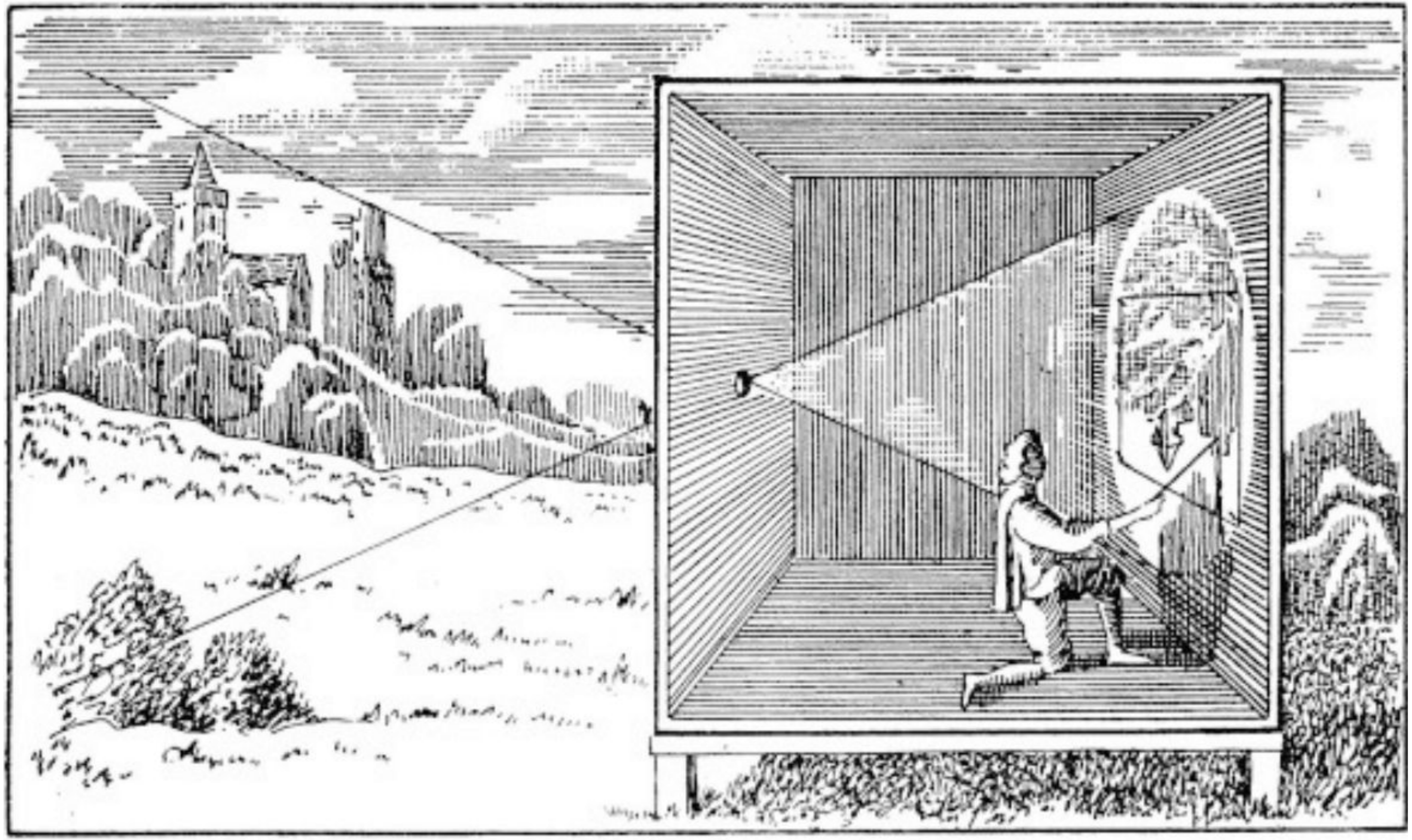
Absorción



Scattering



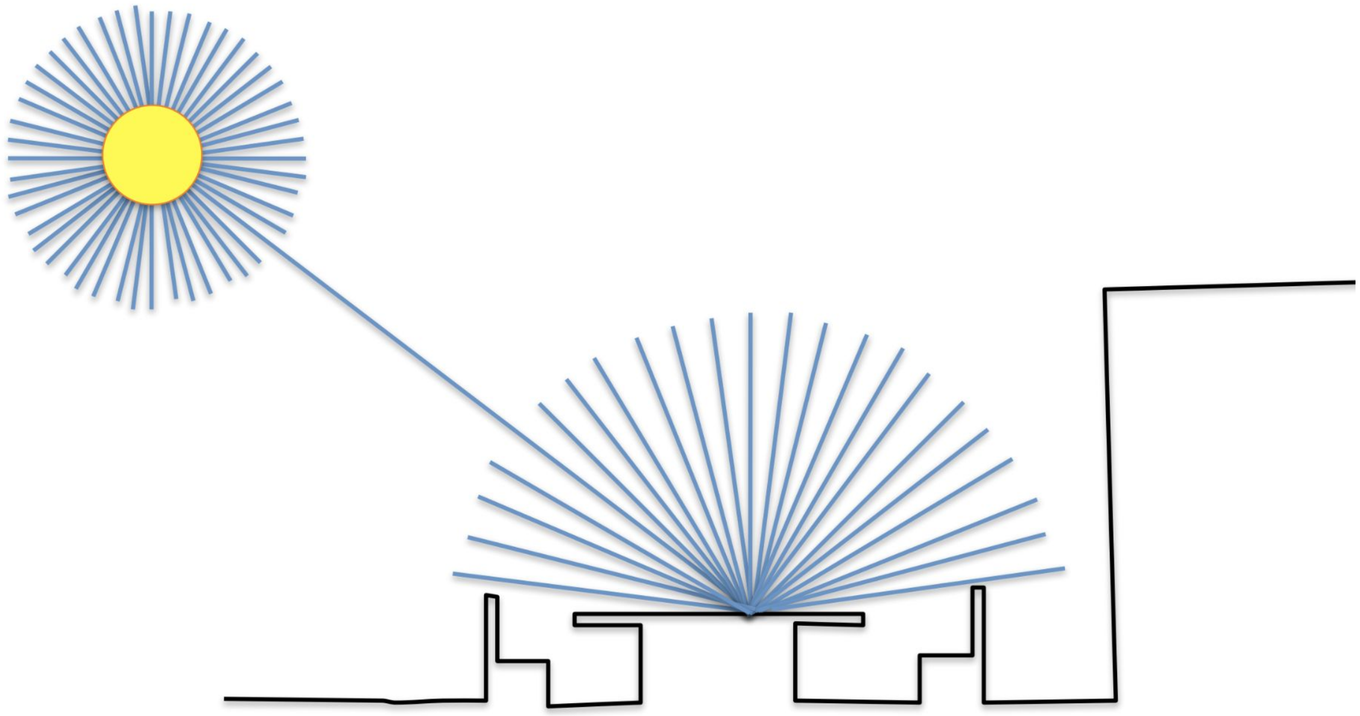
Pinhole Camera / Camera Obscura



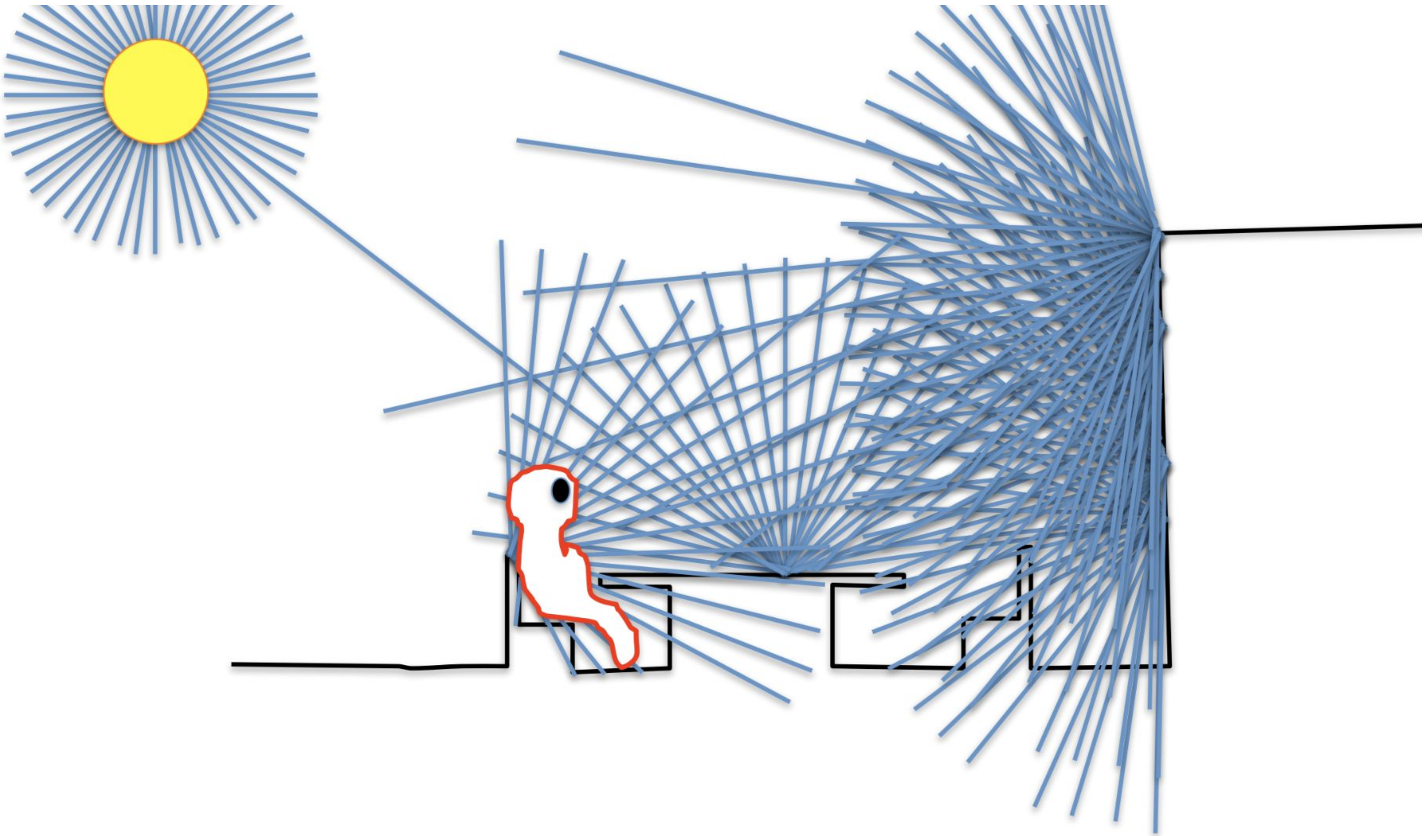
Mo-Ti (Chinese Philosopher) 470-390 BC

Demo:
Camera obscura

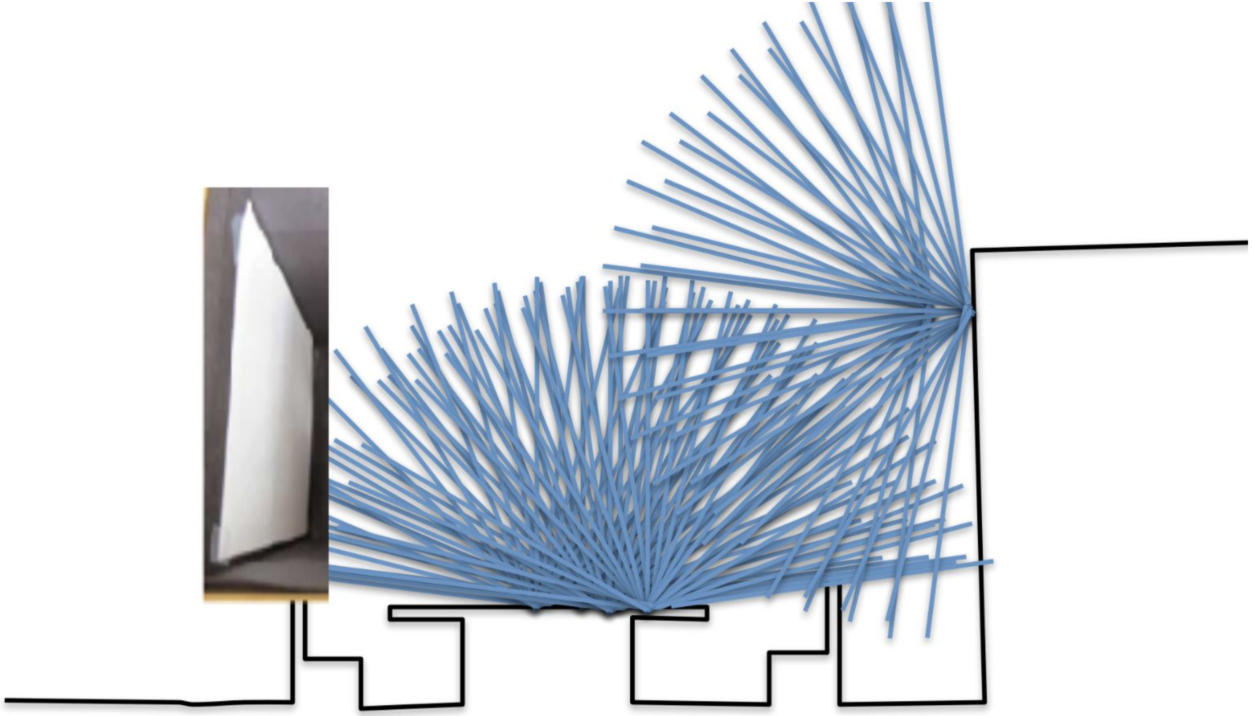
Propagación de la luz



Propagación de la luz



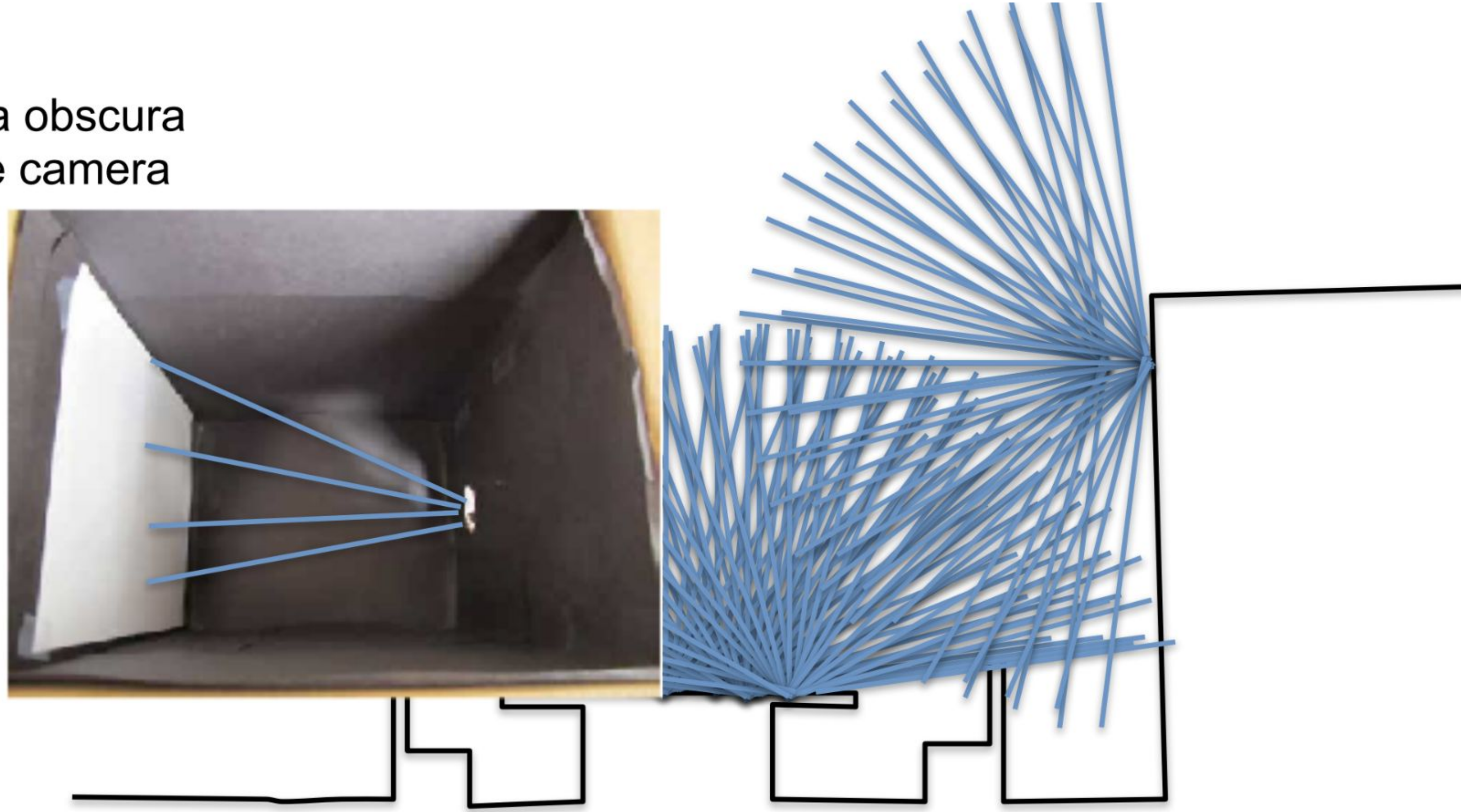
Propagación de la luz



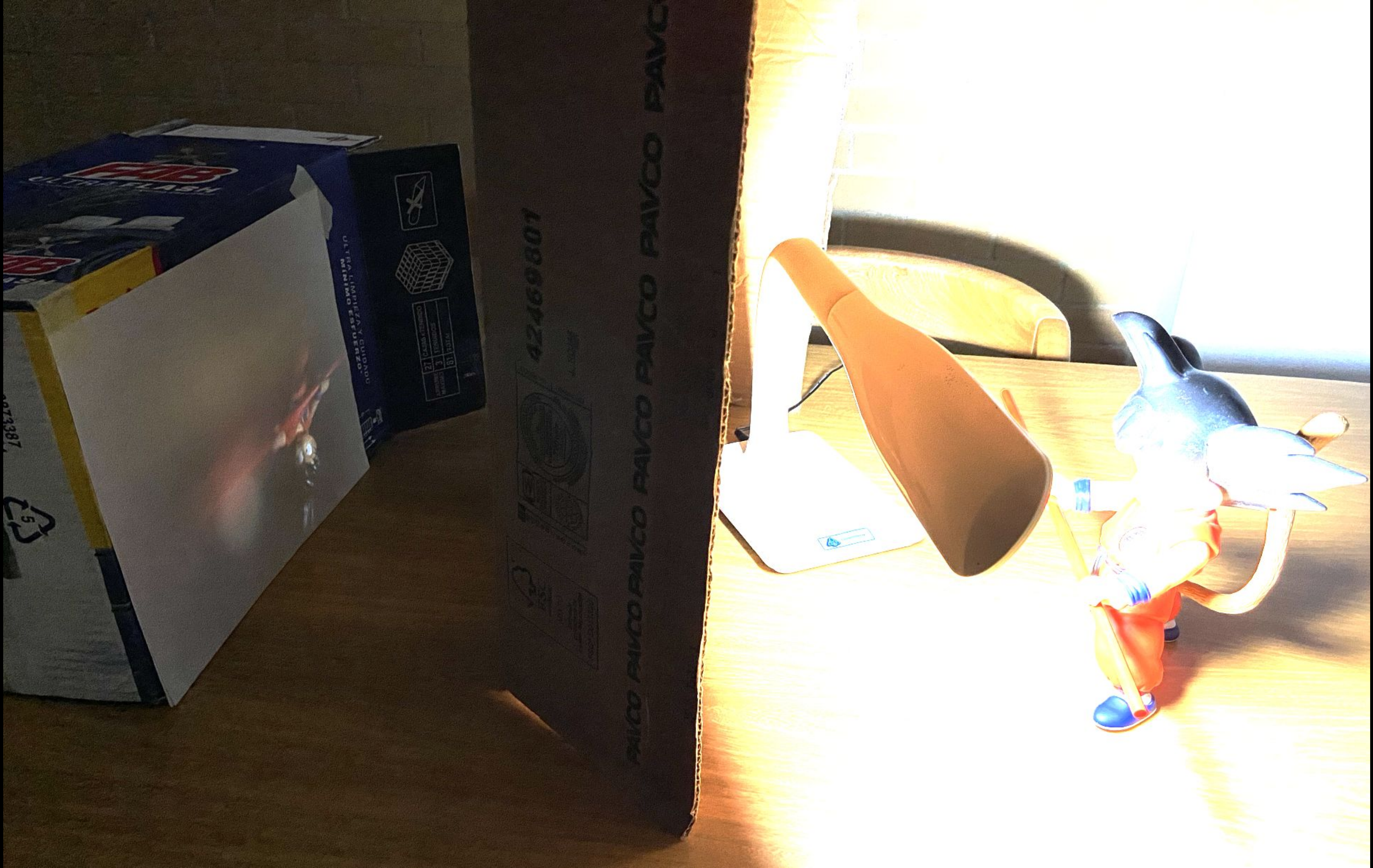
Why is there no picture appearing on the paper?

Propagación de la luz

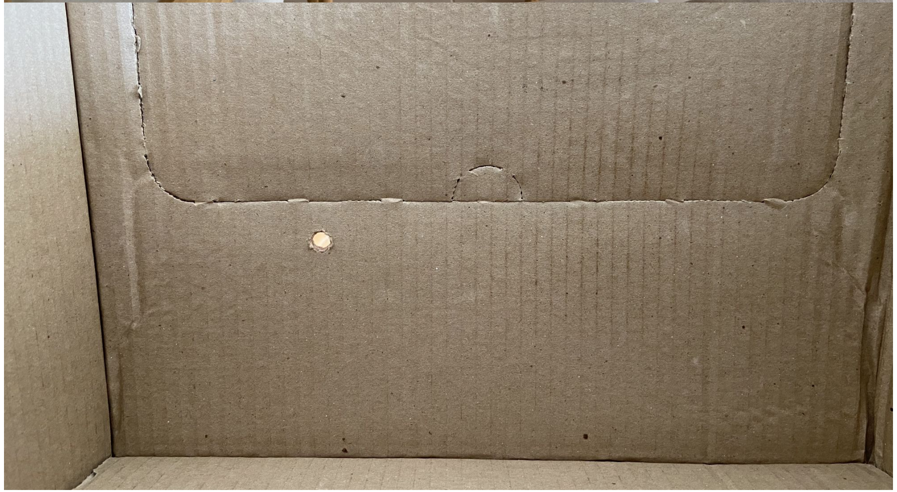
The camera obscura
The pinhole camera




FAB
ULTRA FLASH
ULTRA LIMPIEZA Y CUIDADO
MÍNIMO ESFUERZO
27 CAJAS x TENDIDO
3 TENDIDOS
81 TOTAL
ARRUME MÁXIMO


ULTRA FLASH
424698801
PAVCO PAVCO PAVCO PAVCO PAVCO

Construyendo la Camera Obscura



2. Formación de imágenes

Fotografía analógica

Óptica para enfocar
la luz en un plano
de imagen

Película para capturar
luz enfocada
(proceso químico)

Cuarto oscuro para
posprocesamiento limitado
(proceso químico)

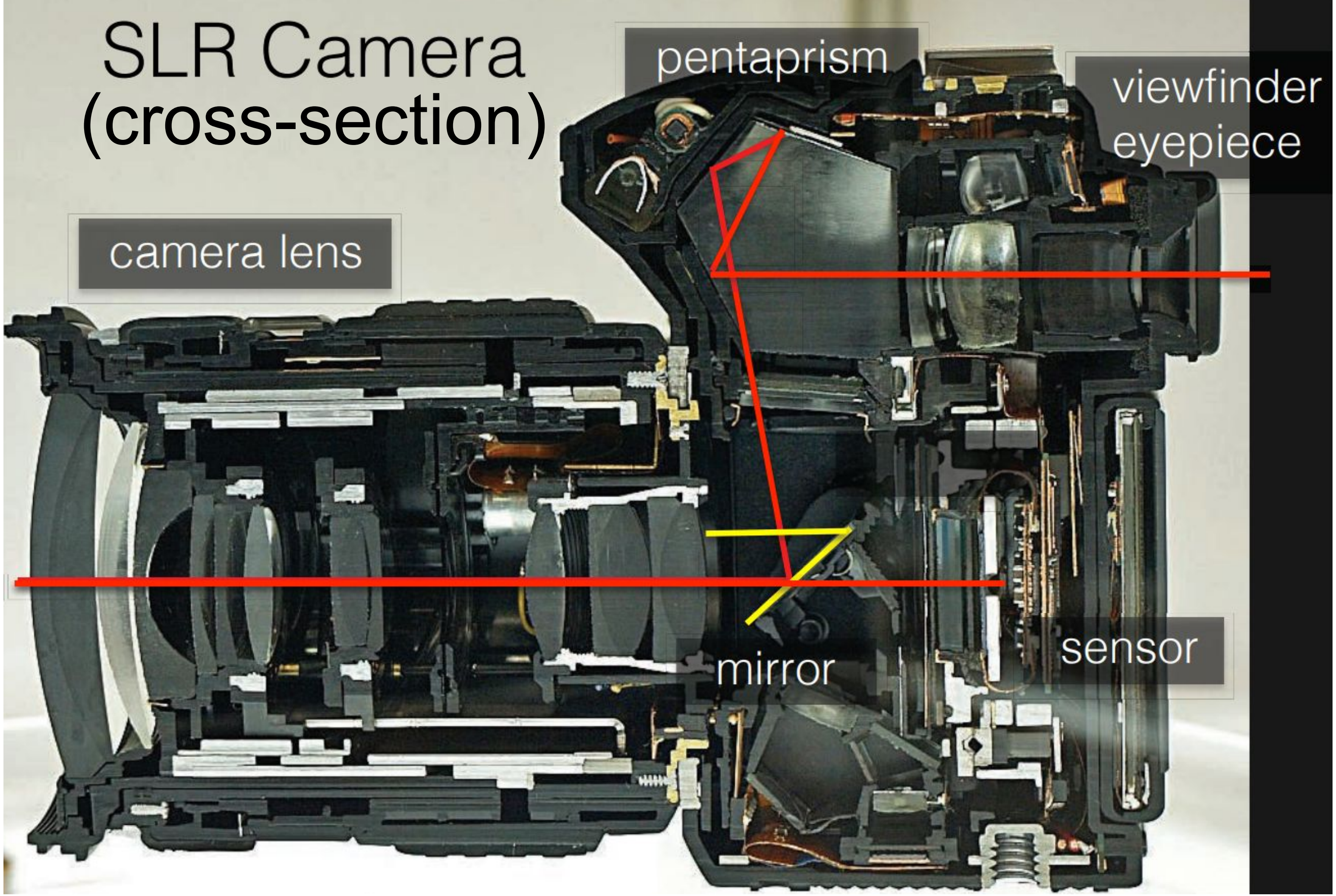
Fotografía digital

Óptica para enfocar la luz en un plano de imagen

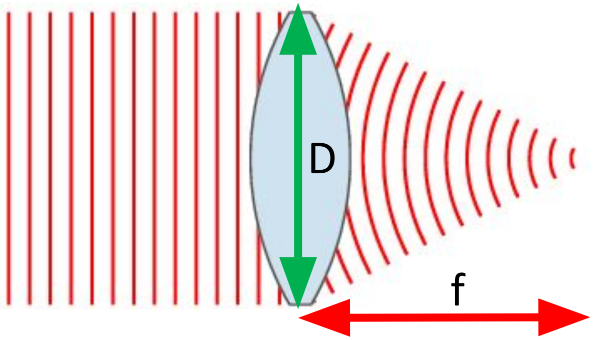
Sensor digital para capturar luz enfocada (proceso eléctrico)

Procesador integrado para posprocesamiento (proceso digital)

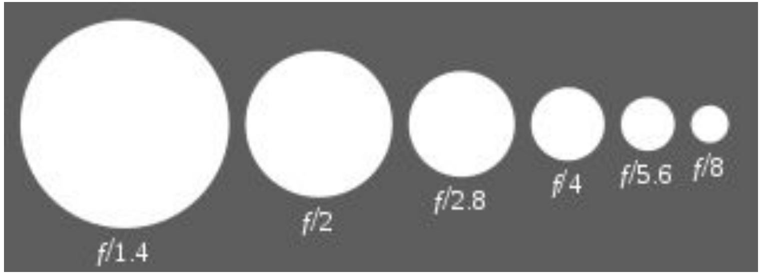
SLR Camera (cross-section)



Conceptos básicos de lentes



1. Propiedades de los lentes (F/#, power)
   - Distancia focal
   - Apertura (D)
   - F-number (f/#): f/D
   - Power (dioptría) = 1/f



2. Trazado de rayos básico (3 rayos son suficientes)

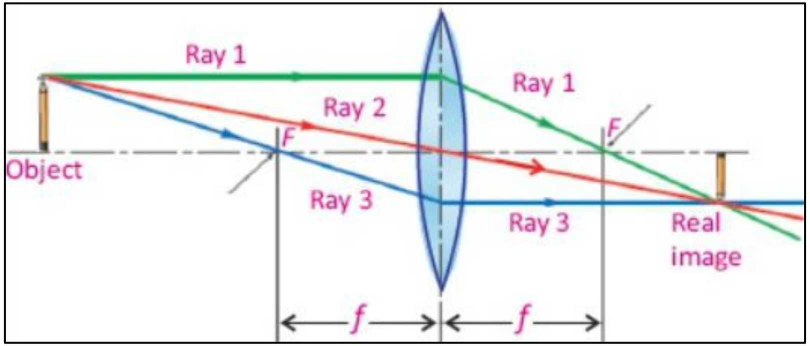
   https://ophysics.com/l12.html

3. Trazado de rayos (Lens' Maker formula)

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

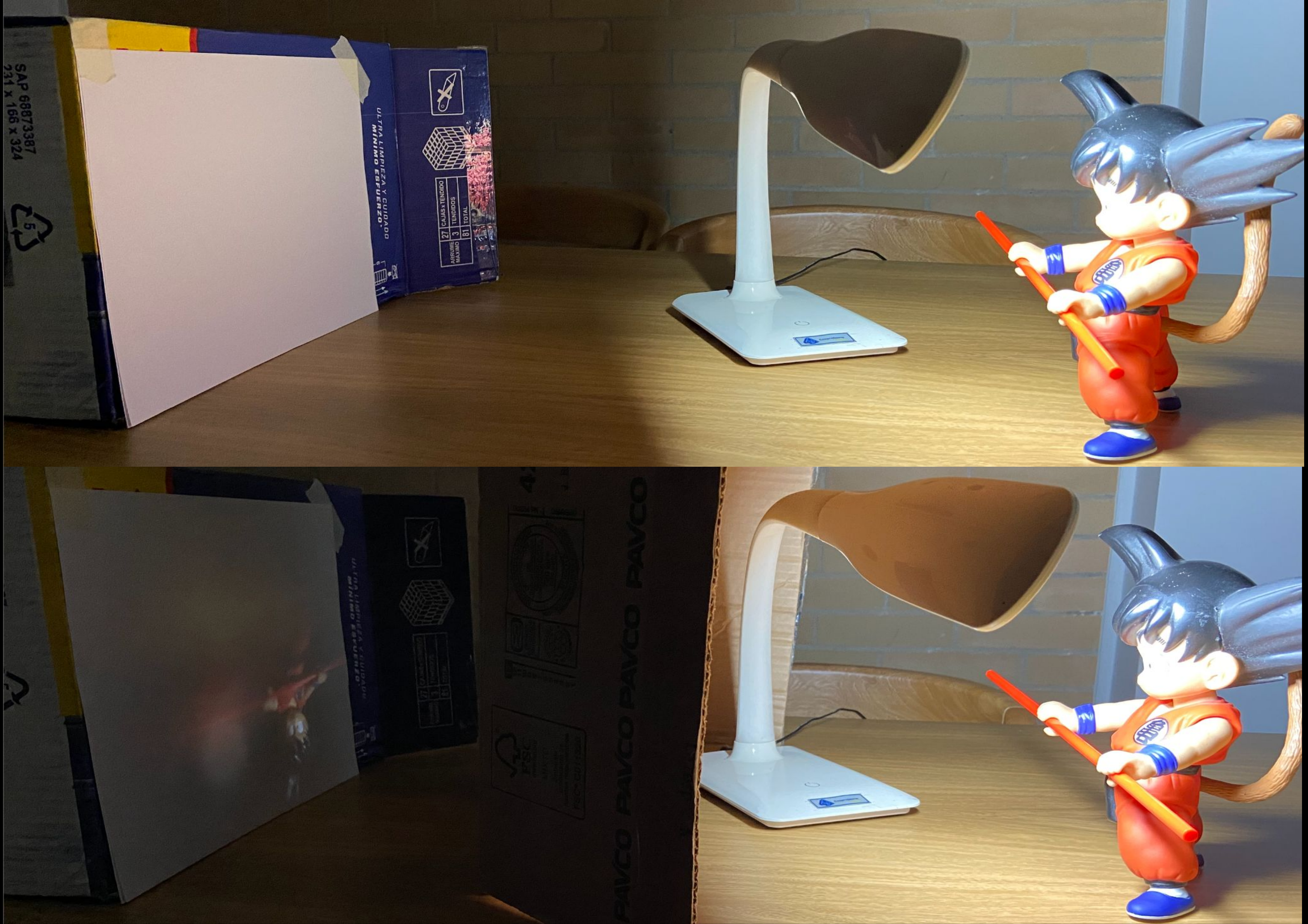
$$y_i = \frac{d_i * y_o}{d_o}$$

$$M = \frac{d_i}{d_o} = \frac{y_i}{y_o}$$



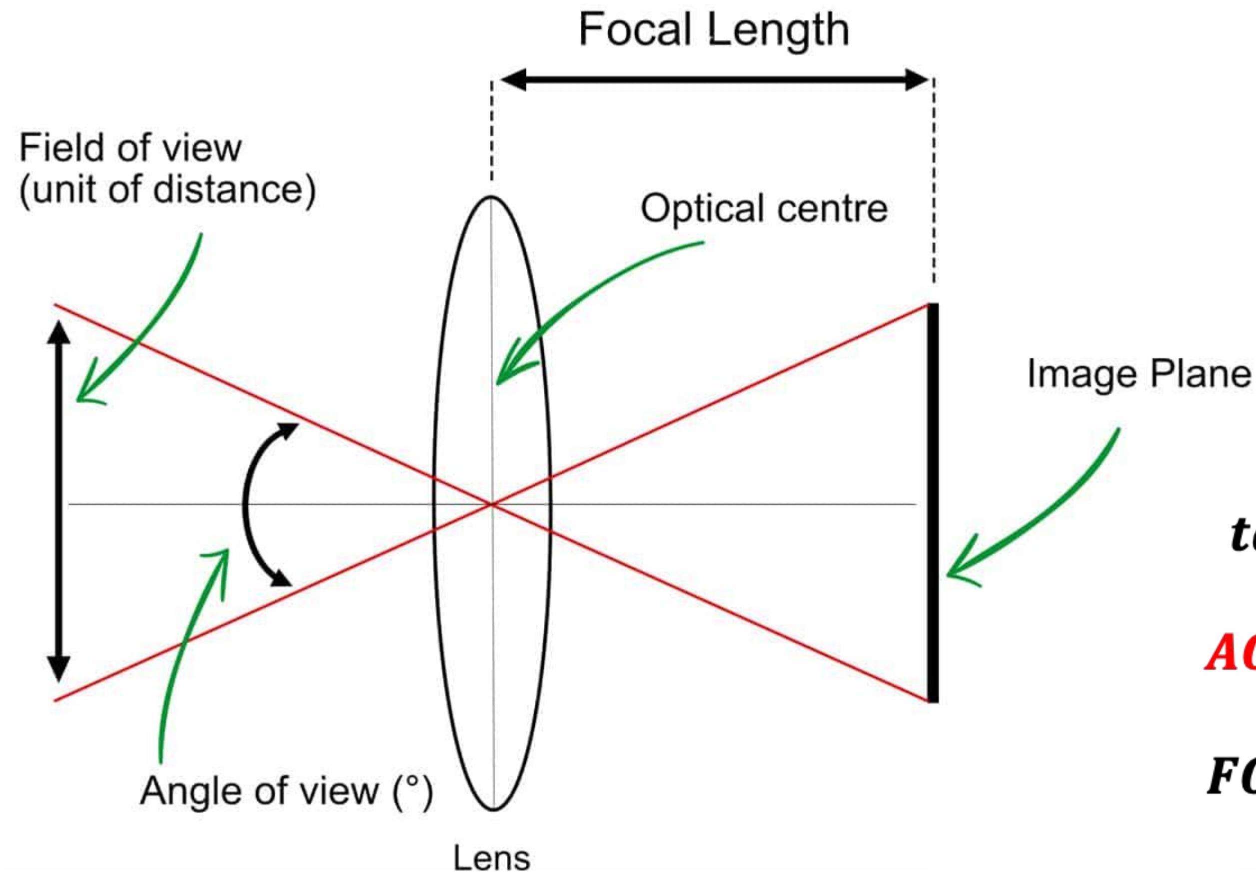
Demo:
Pinhole vs Lente


ESTE LADO ARRIBA
MANTENER EN LUGAR
FRESCO Y SECO
ULTRA LIMPIEZA Y CUIDADO
MÍNIMO ESFUERZO
FAB
ULTRA FLASH
EL LAVADO IDEAL DE SU ROPA ES MUY SIMPLE CON LOS SIGUIENTES PASOS:
MODO DE USO
RECOMENDACIONES DE USO
FAB DT LIQ FLORAL BOTELLA 1X2X3L



SAP 68873387
231 x 166 x 324
ULTRA LIMPIEZA Y CUIDADO
MÍNIMO ESFUERZO
PAVCO

Angle of view (AOV) vs. Field of View (FOV)



$$tan\left(\frac{\alpha}{2}\right) = \frac{h/2}{f}$$

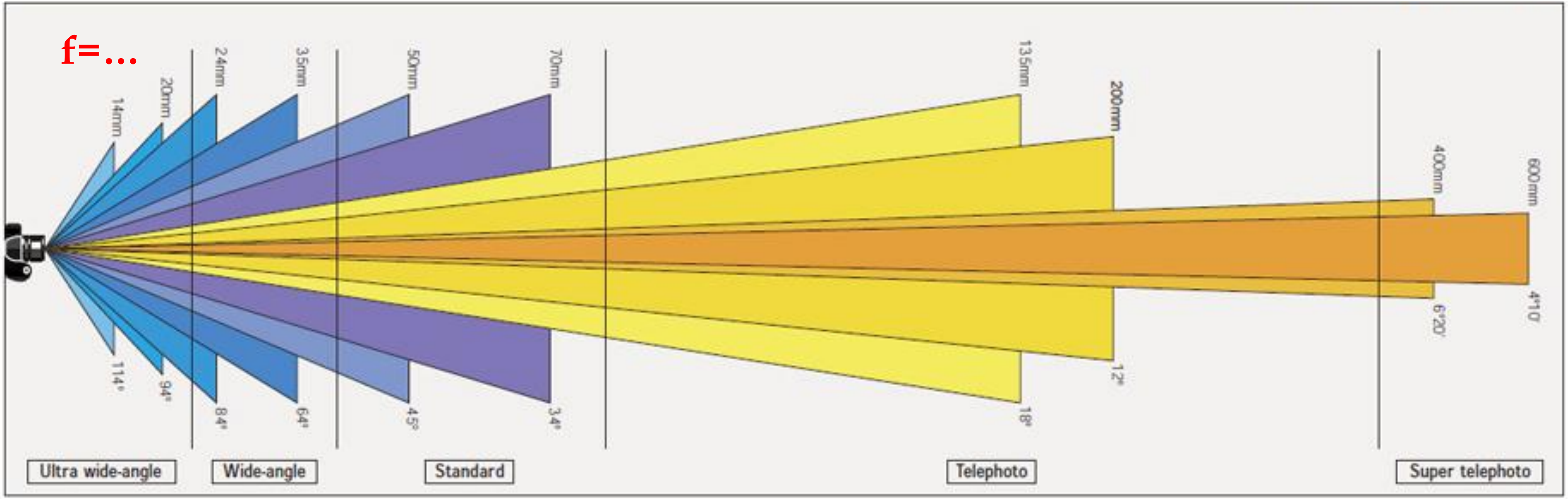
$$AOV = \alpha = 2\arctan\left(\frac{h}{2f}\right)$$

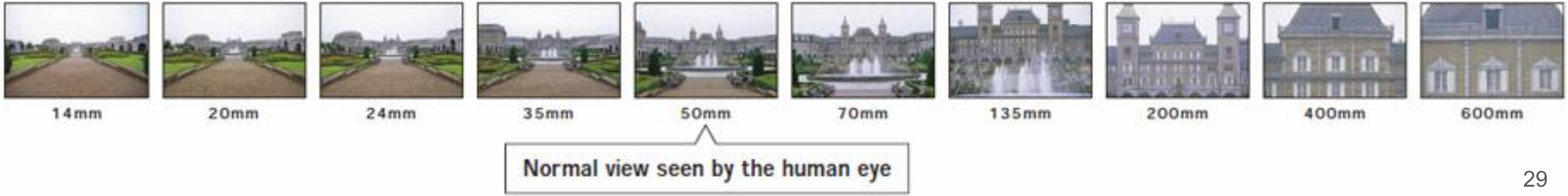
$$FOV = 2\tan\left(\frac{AOV}{2} * d_o\right)$$

Ejemplos de diferentes FOV

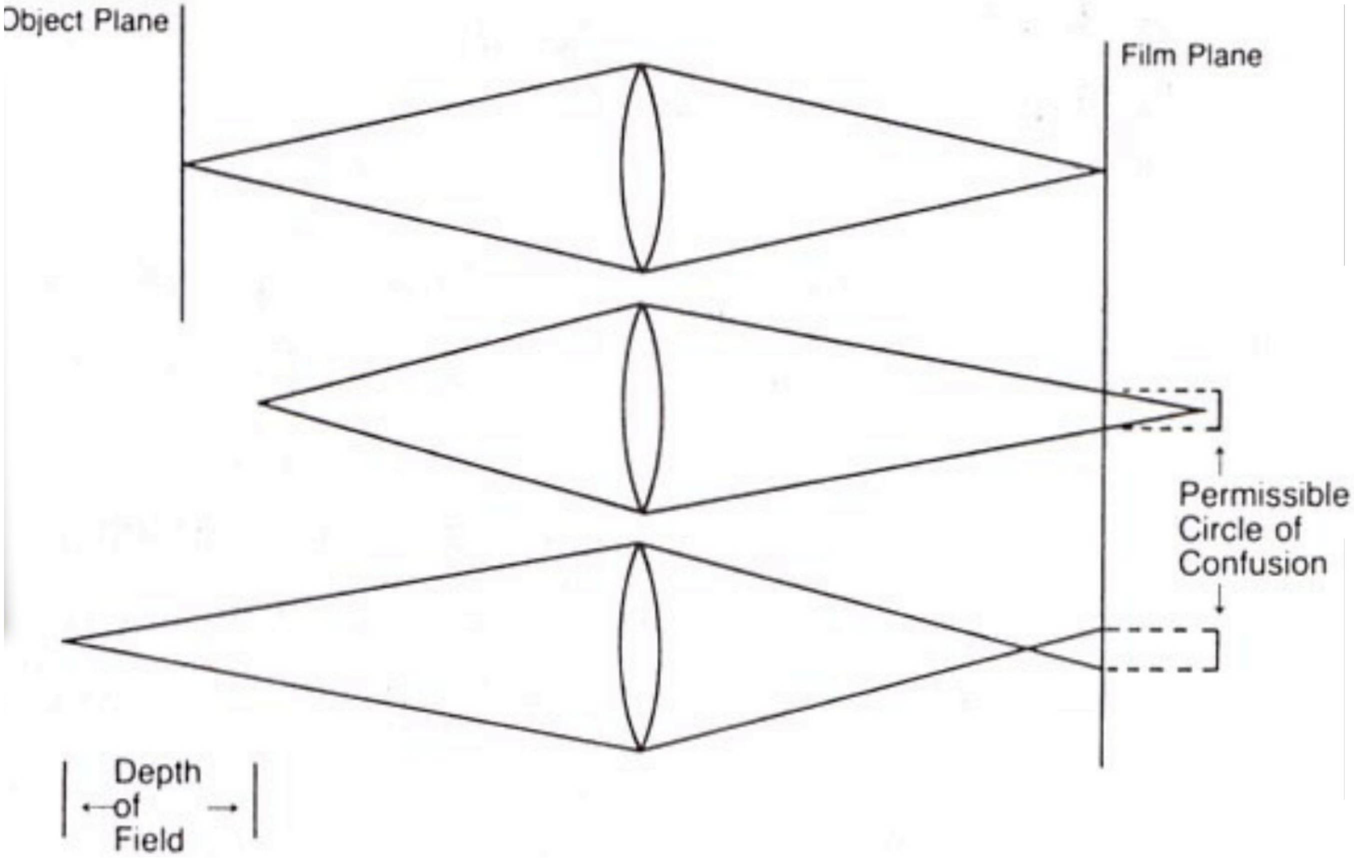
DIY w. h = 43 mm

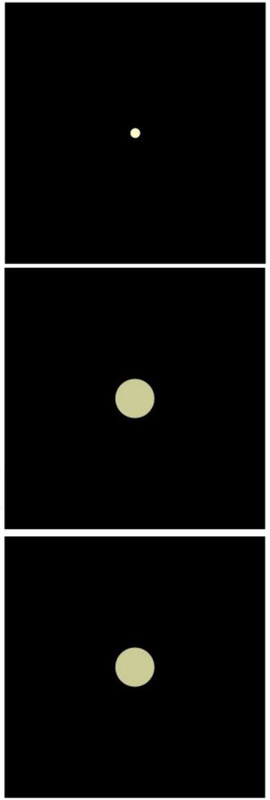
f=…





Profundidad de campo (Círculo de confusión)





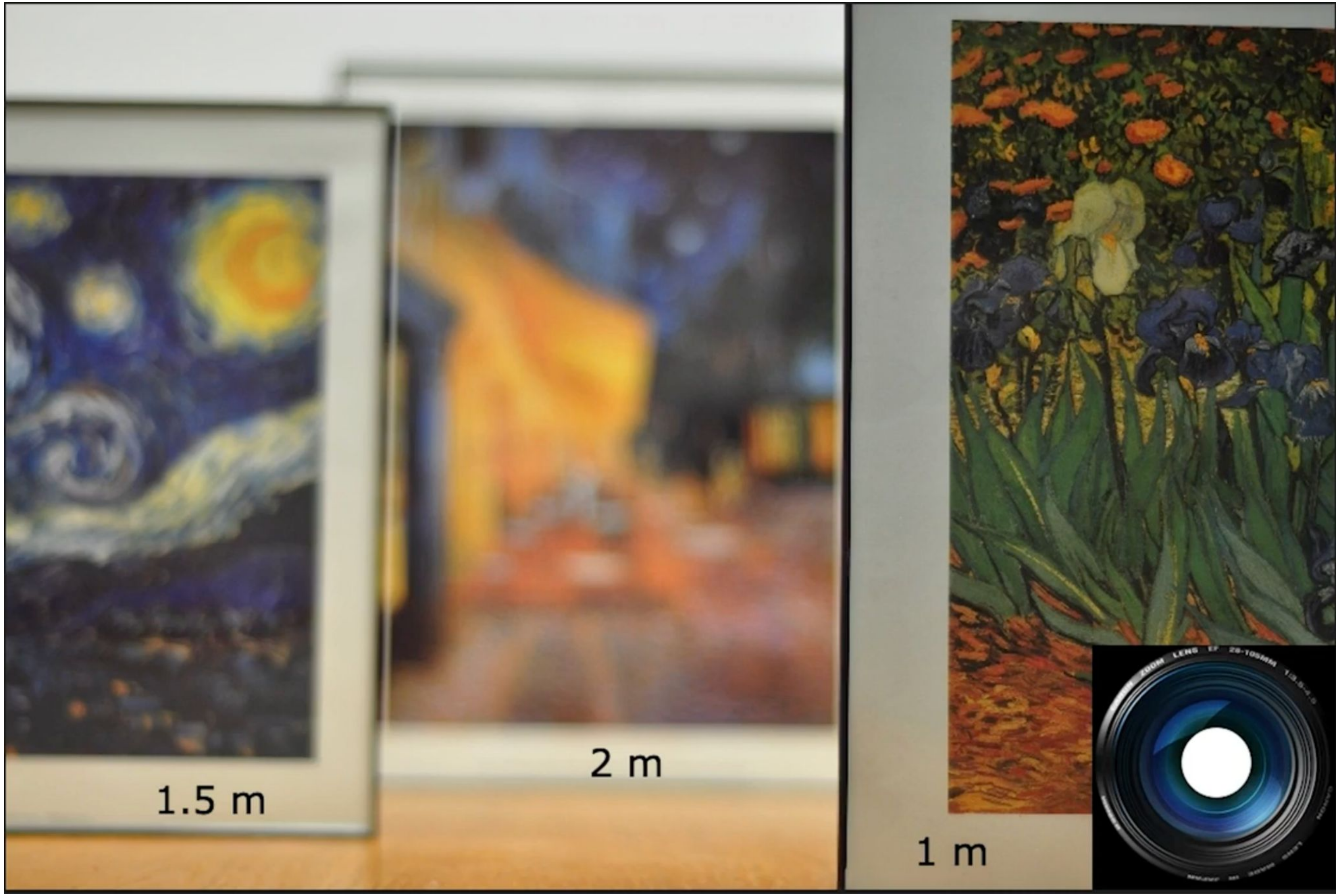
Foco perfecto

Fuera de foco

Fuera de foco

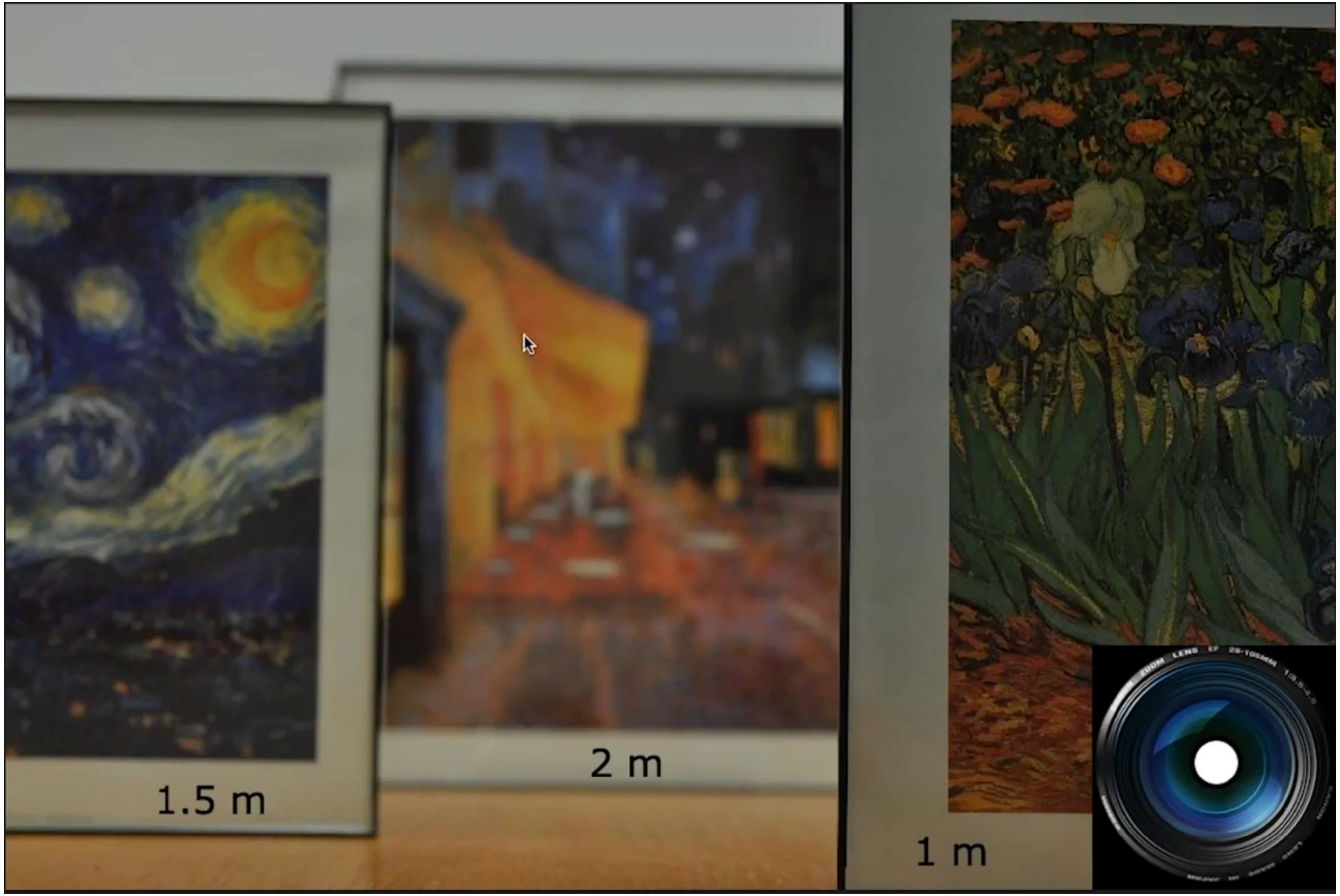
Profundidad de campo (Depth of field, DoF)

Example (Reducing aperture)



f/2

Example (Reducing aperture)



f/4

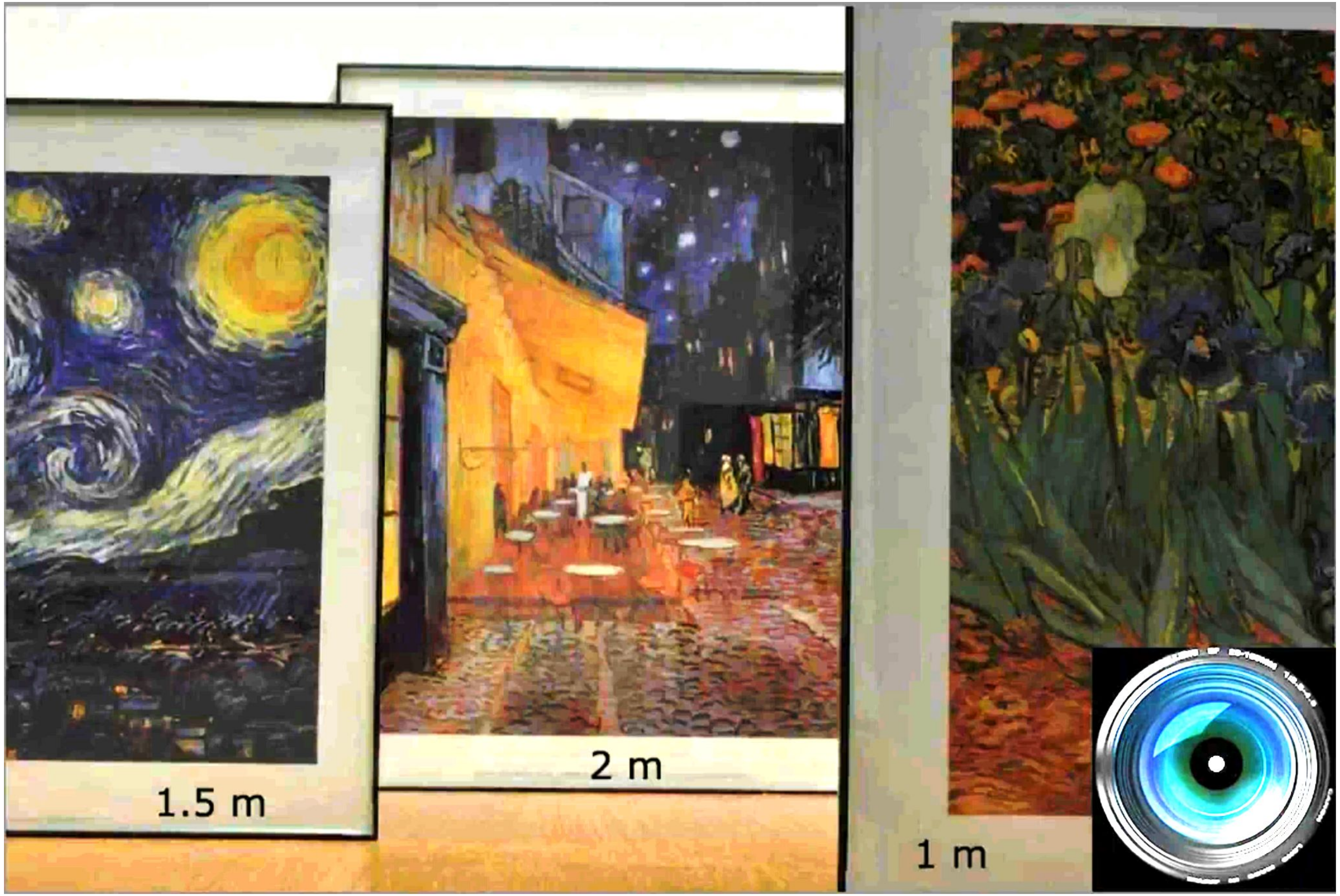
Example (Reducing aperture)

f/8

Example (Reducing aperture)

f/16

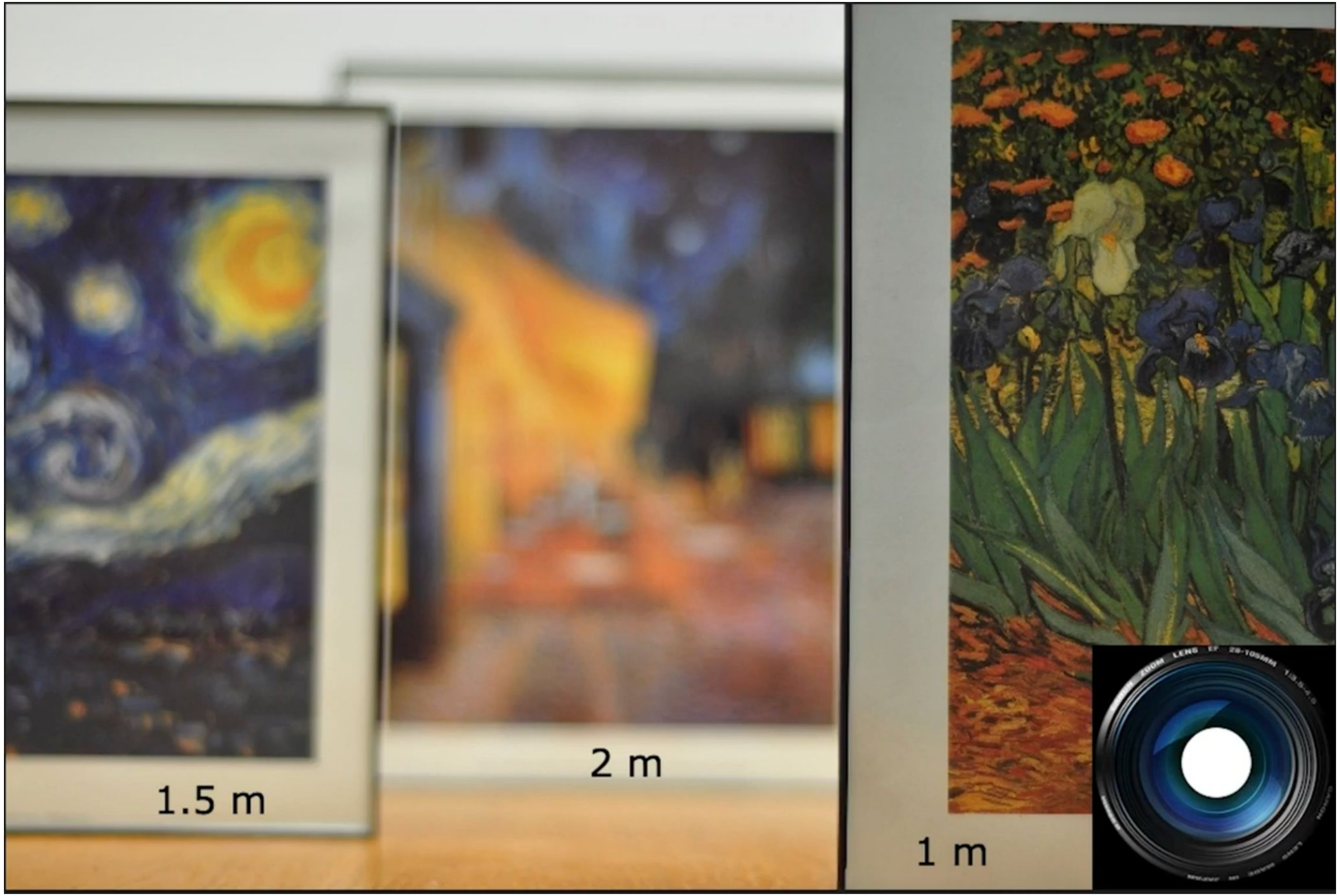
Example (Reducing aperture)



f/16

Ajustando intensidad digitalmente

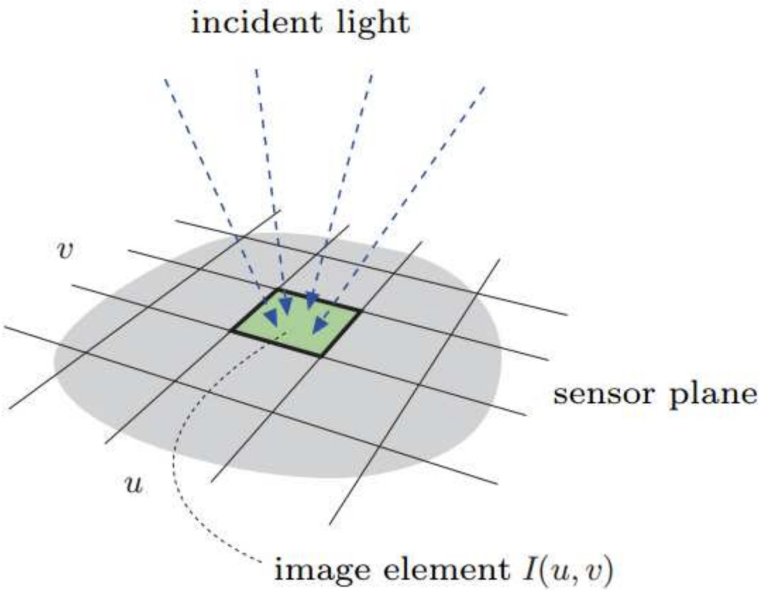
Example (Reducing aperture)



f/2

Imagen digital

¿Qué es una imagen digital?



La proyección en el plano imagen de una cámara es una distribución continua de energía luminosa bidimensional, dependiente del tiempo.

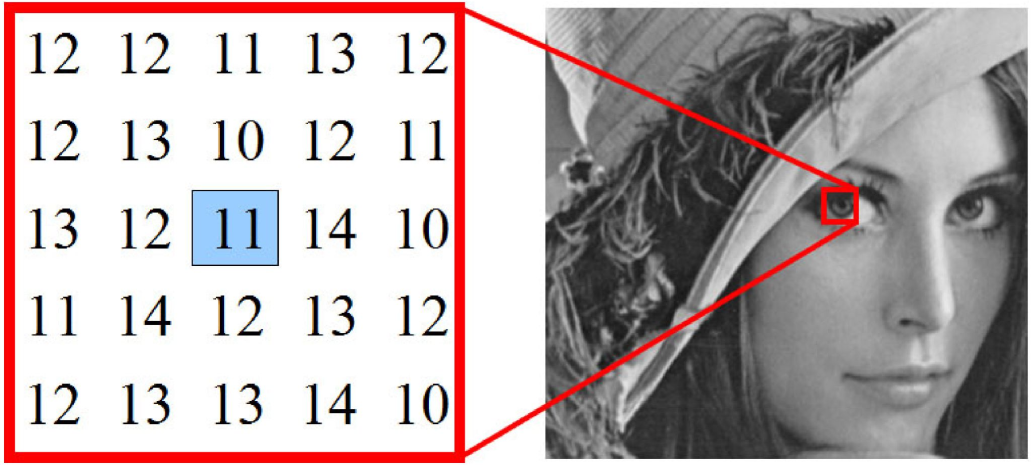
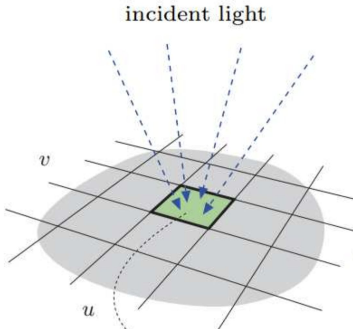


Imagen = Matriz de números (cada número es un pixel)

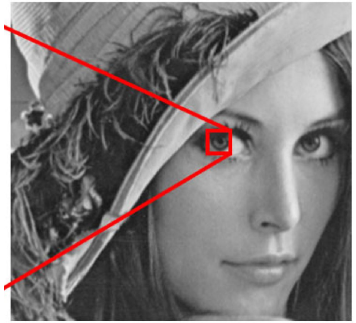
Del dominio continuo al dominio digital



Muestreo espacial

Muestreo temporal

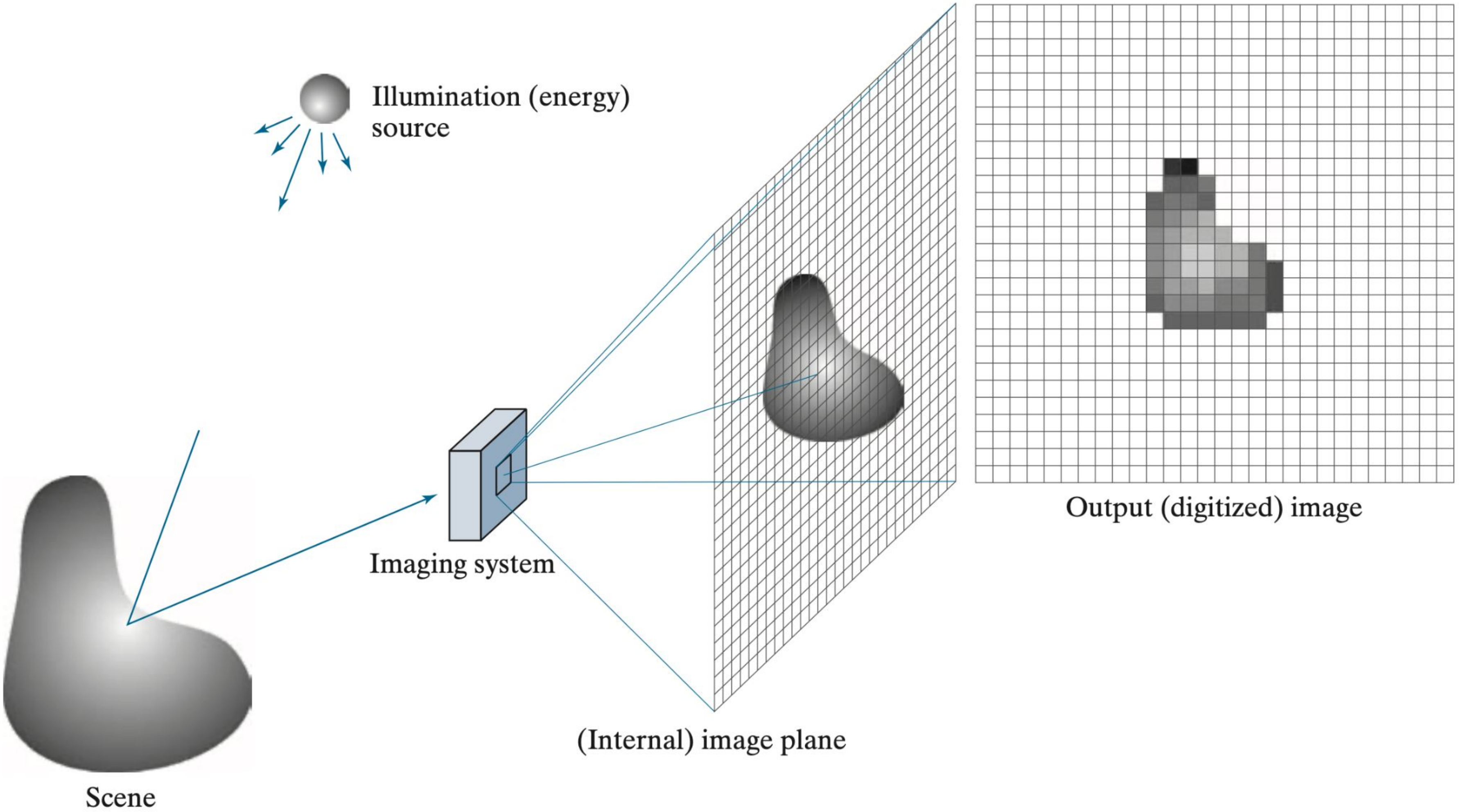
Cuantización



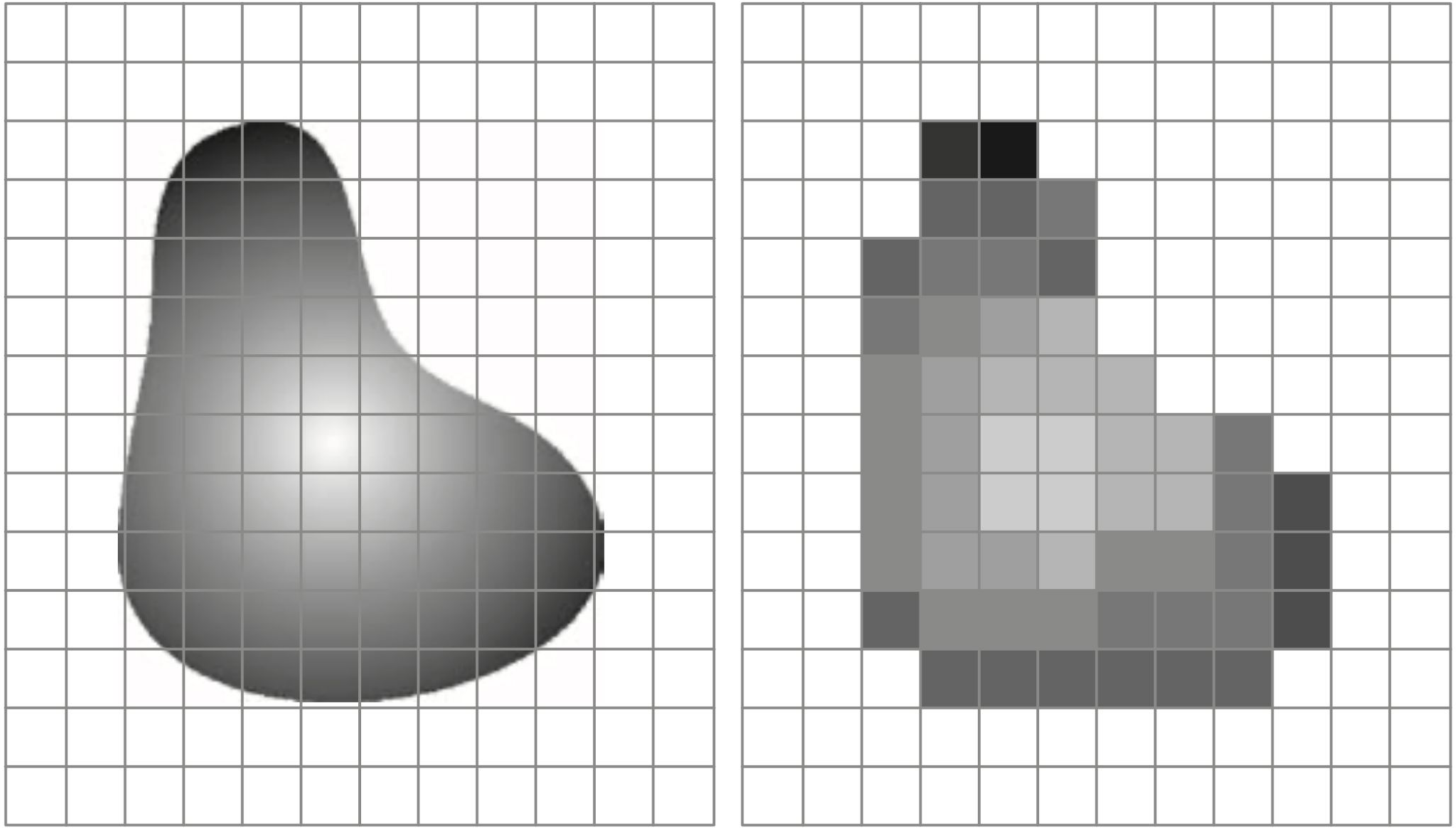
Conversión de la señal continua a su representación discreta

Integra la cantidad de luz que incide en cada pixel a intervalos regulares

Los valores de la imagen se convierten a una escala de números enteros


Illumination (energy)
source
Imaging system
(Internal) image plane
Output (digitized) image
Scene

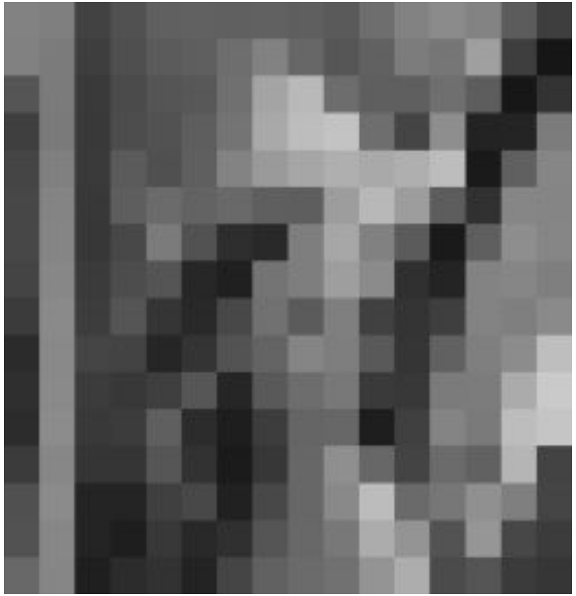
Del dominio continuo al dominio digital



Efecto del número de píxeles en el muestreo

256x256

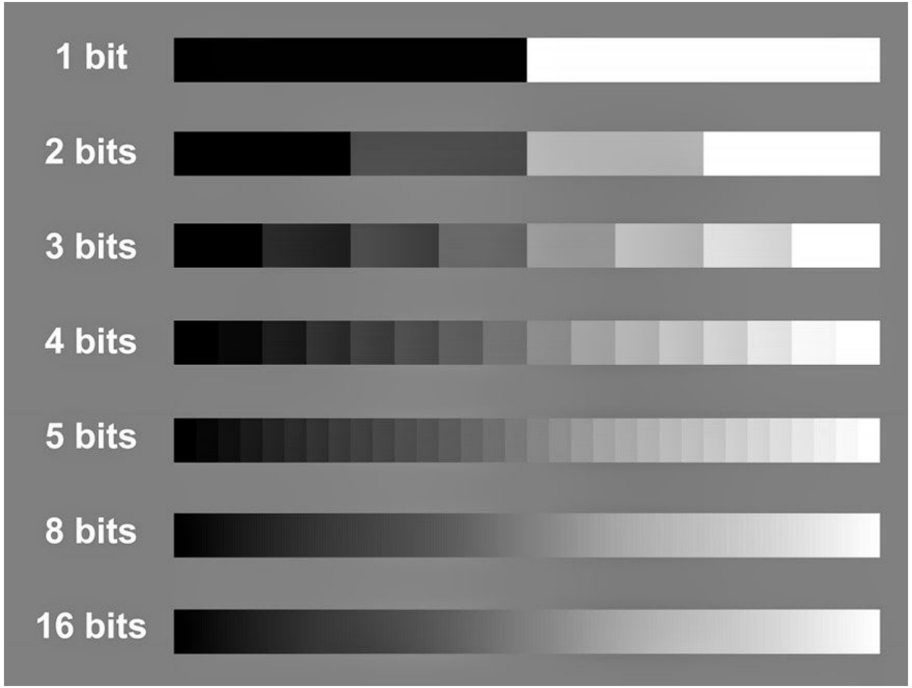
64x64



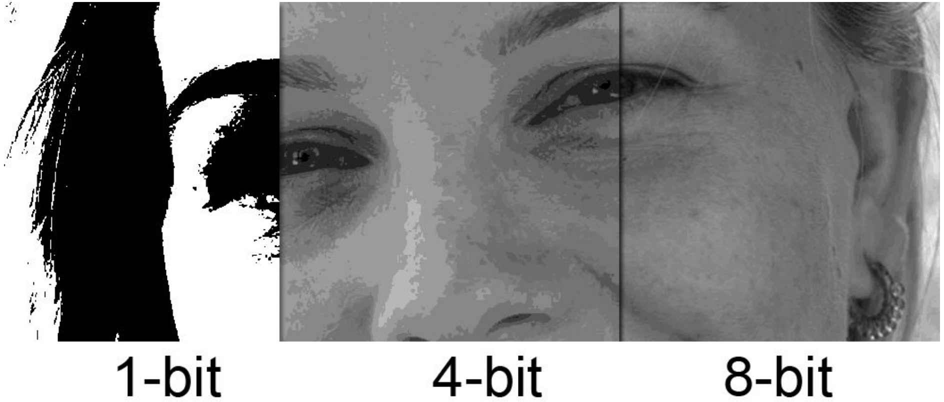
16x16

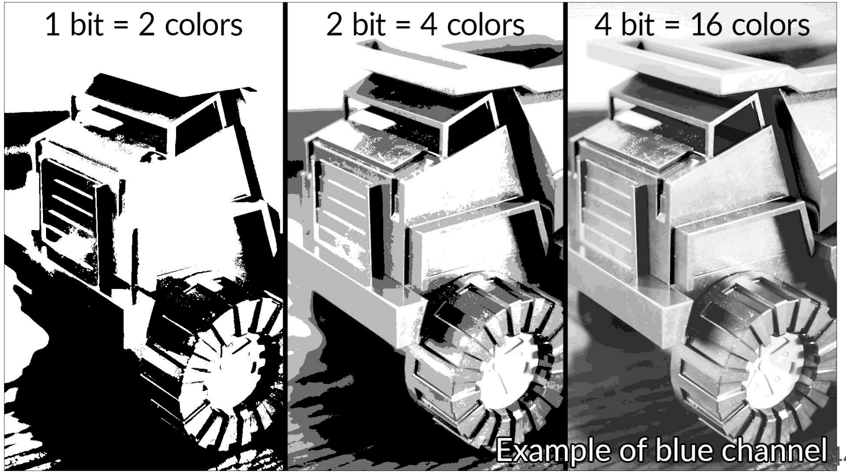
https://www.microscopyu.com/tutorials/spatial-resolution-in-digital-imaging

Profundidad de bits = Tonos de gris



X bit depth = 2^X levels





Tipos de imágenes = Proyecciones de la función plenóptica

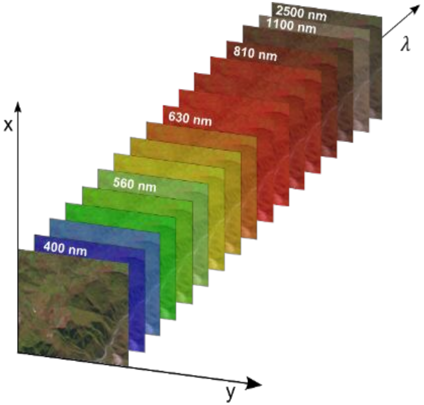
Binaria

Escala de grises

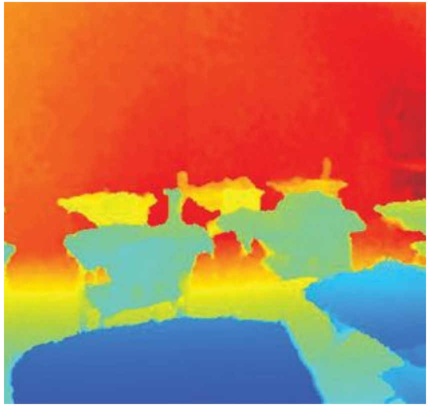
Color

Video

Espectral

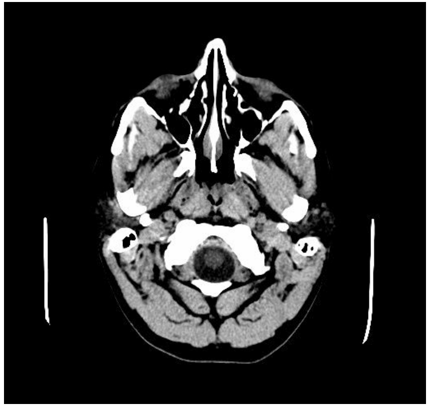


De profundidad

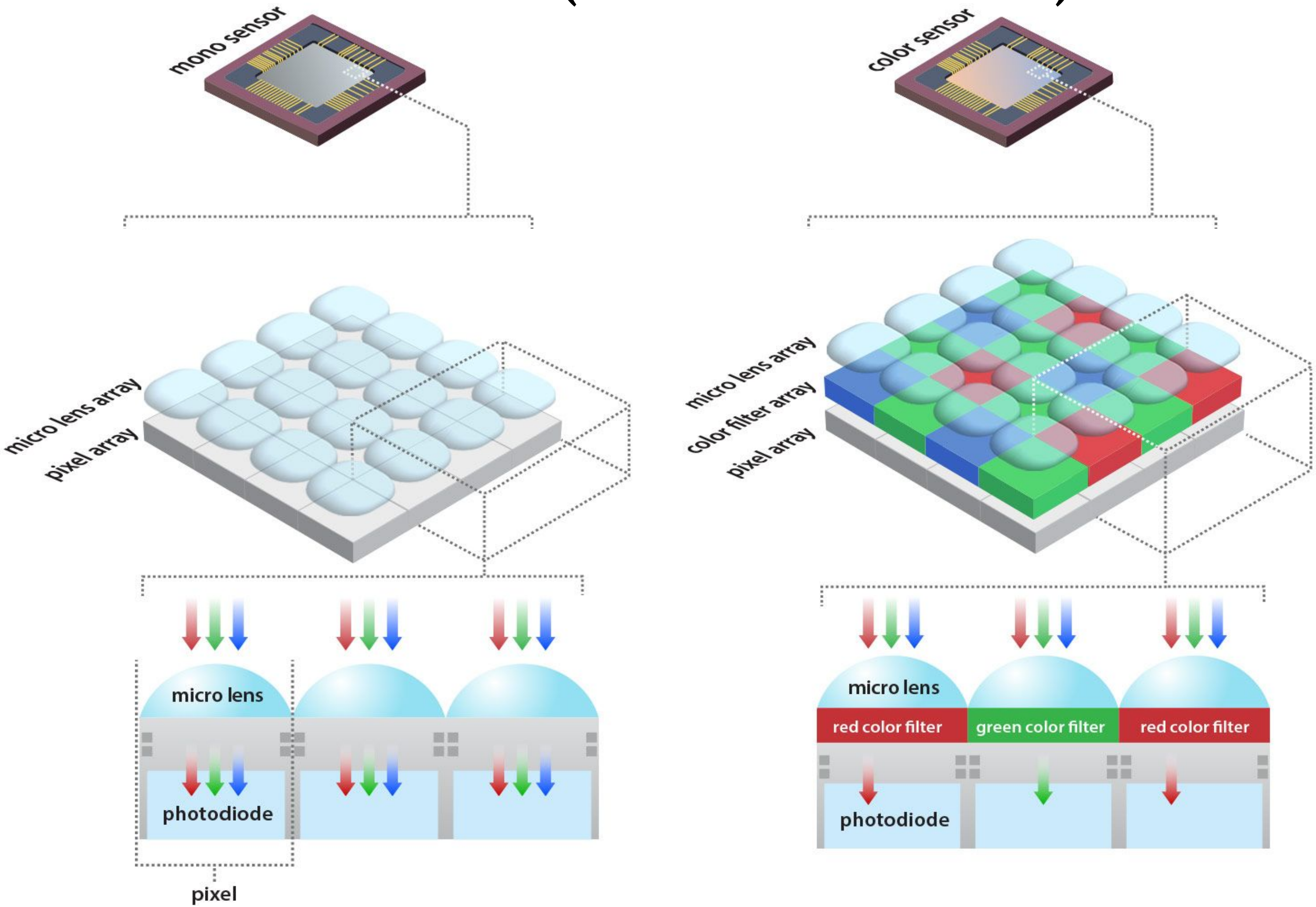


Térmica

Tomografía



Anatomía de un sensor (Mono vs Color)



Anatomía de un sensor

A – Colour filter array: Mosaic Bayer Filter.

B – Low-pass filter/Anti-aliasing filter: Prevent aliasing.

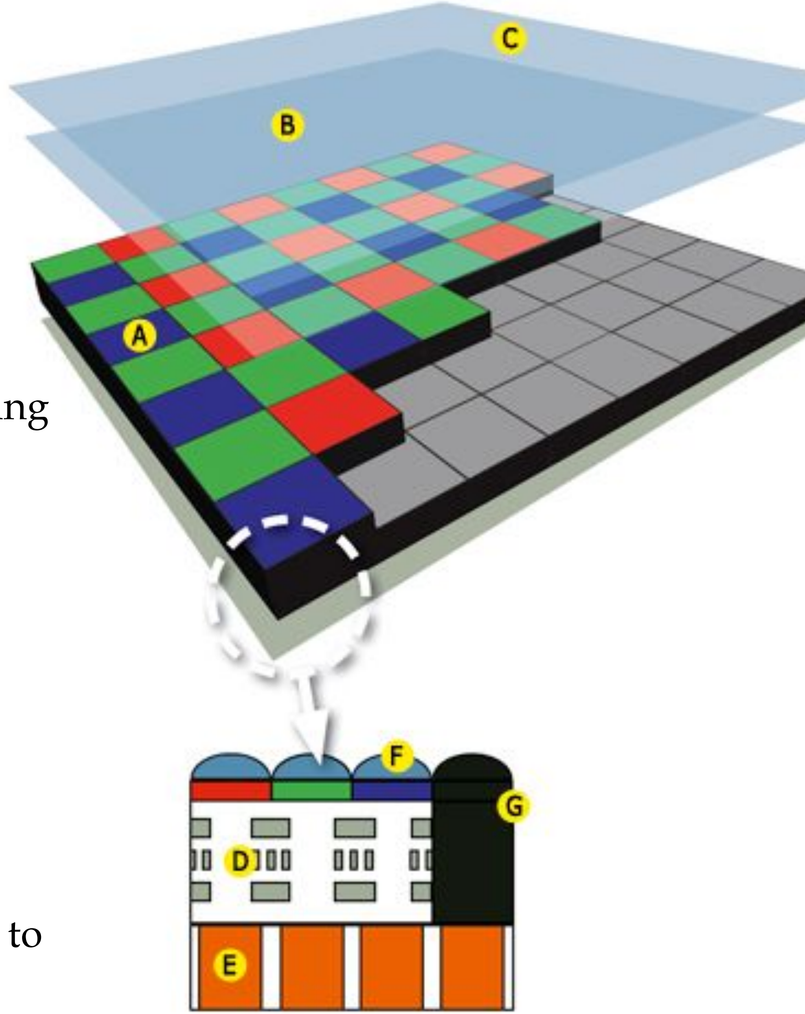
C – Infrared filter (hot mirror): Prevents IR light from reaching the sensor, and helps minimise any colour casts or artefacts

D – Circuitry: CCD vs CMOS.

E – Pixel: Contains a light sensitive photodetector, which measures the amount of light (photons) falling onto it.

F – Microlenses: Help funnel light into each pixel, thereby increasing the sensitivity of the sensor.

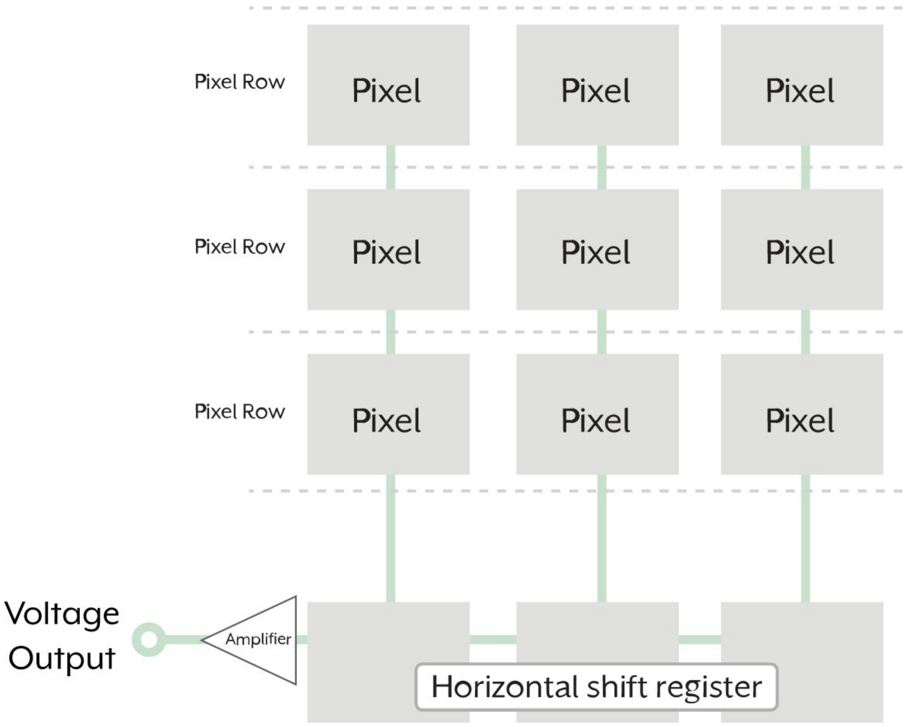
G – Black pixels: Around the peripheries, allows the camera to see how much dark current builds up during an exposure.



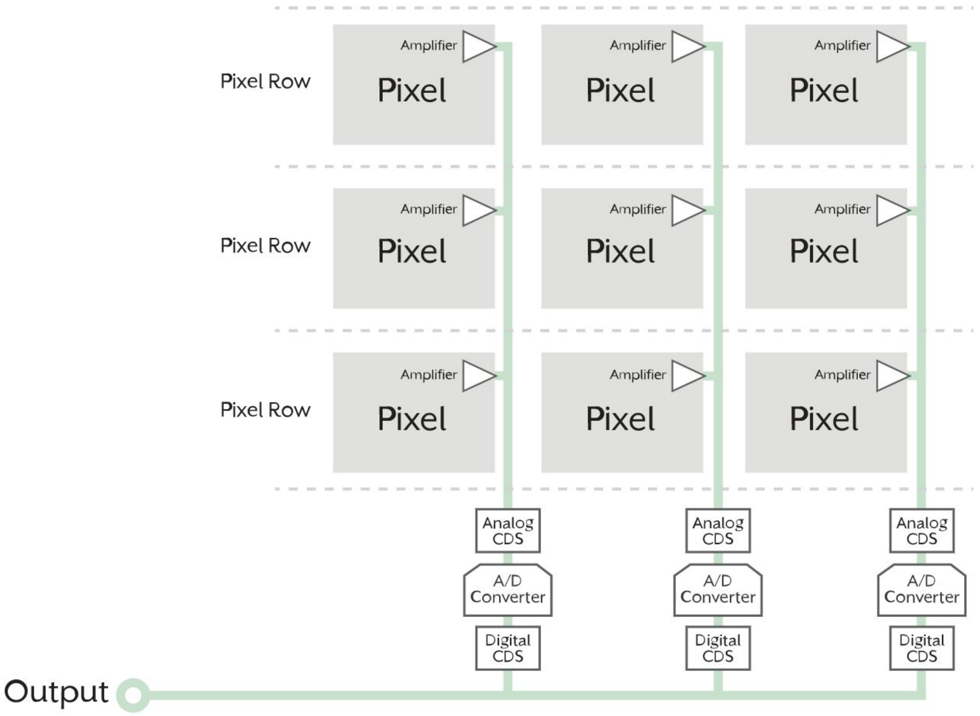
De fotones a pixeles: CCD vs CMOS

Diferencia principal: Electrónica por pixel o global

CCD: Charged Coupled Device



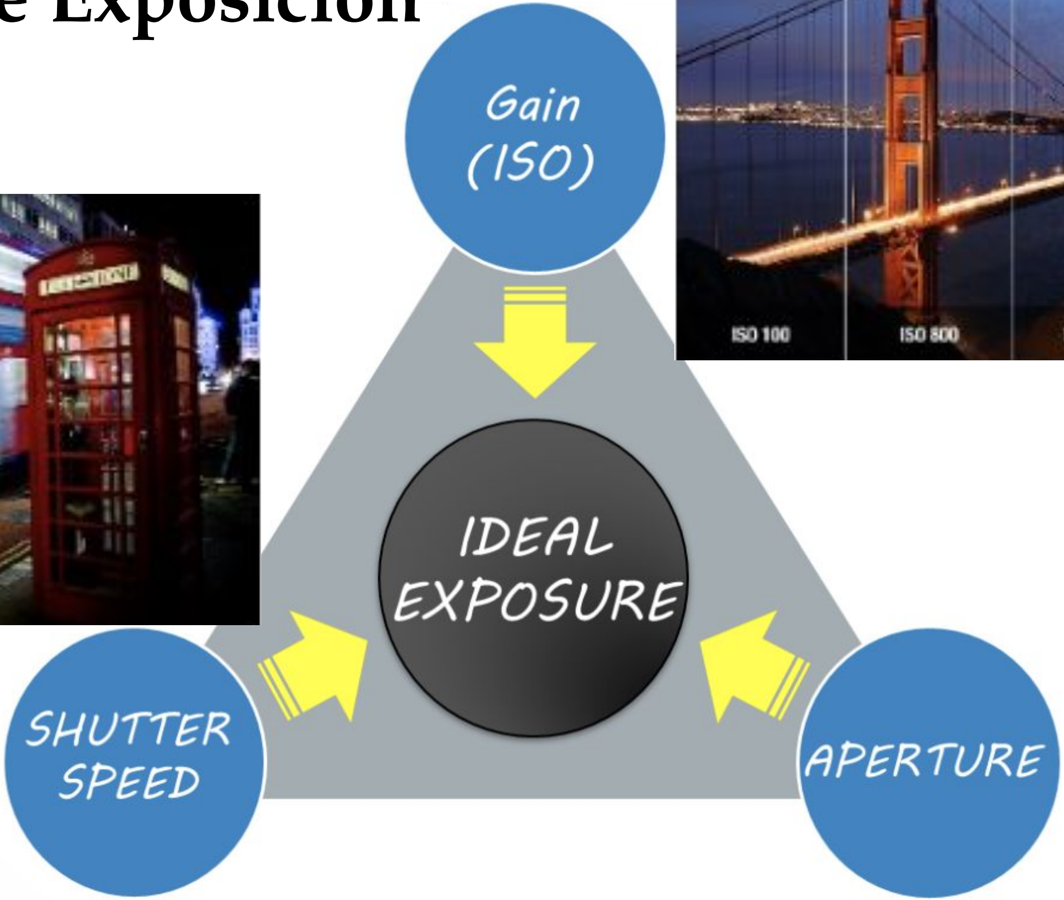
CMOS: Complementary Metal-Oxide Semiconductor

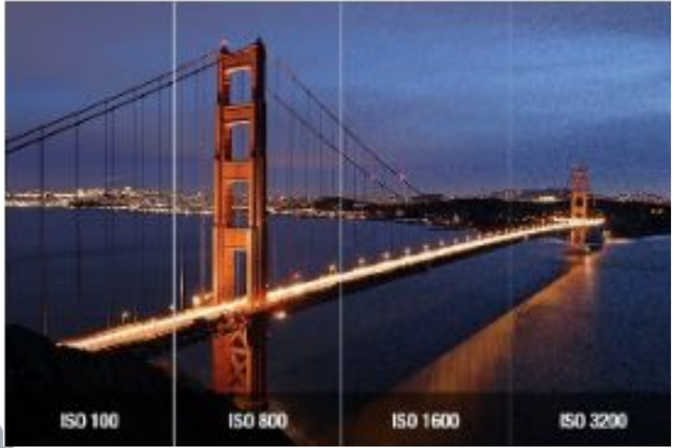


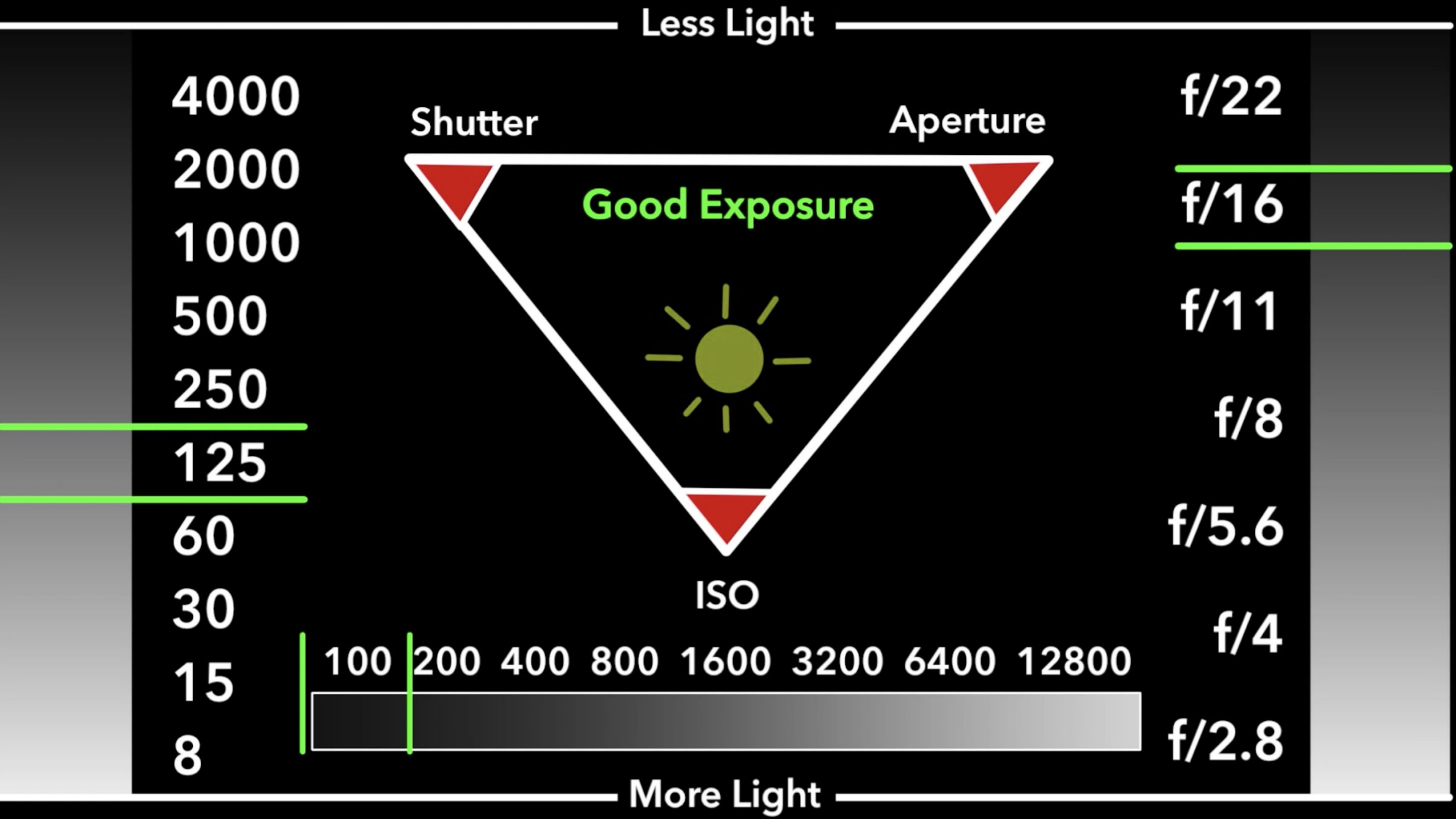
3. El triángulo de la exposición

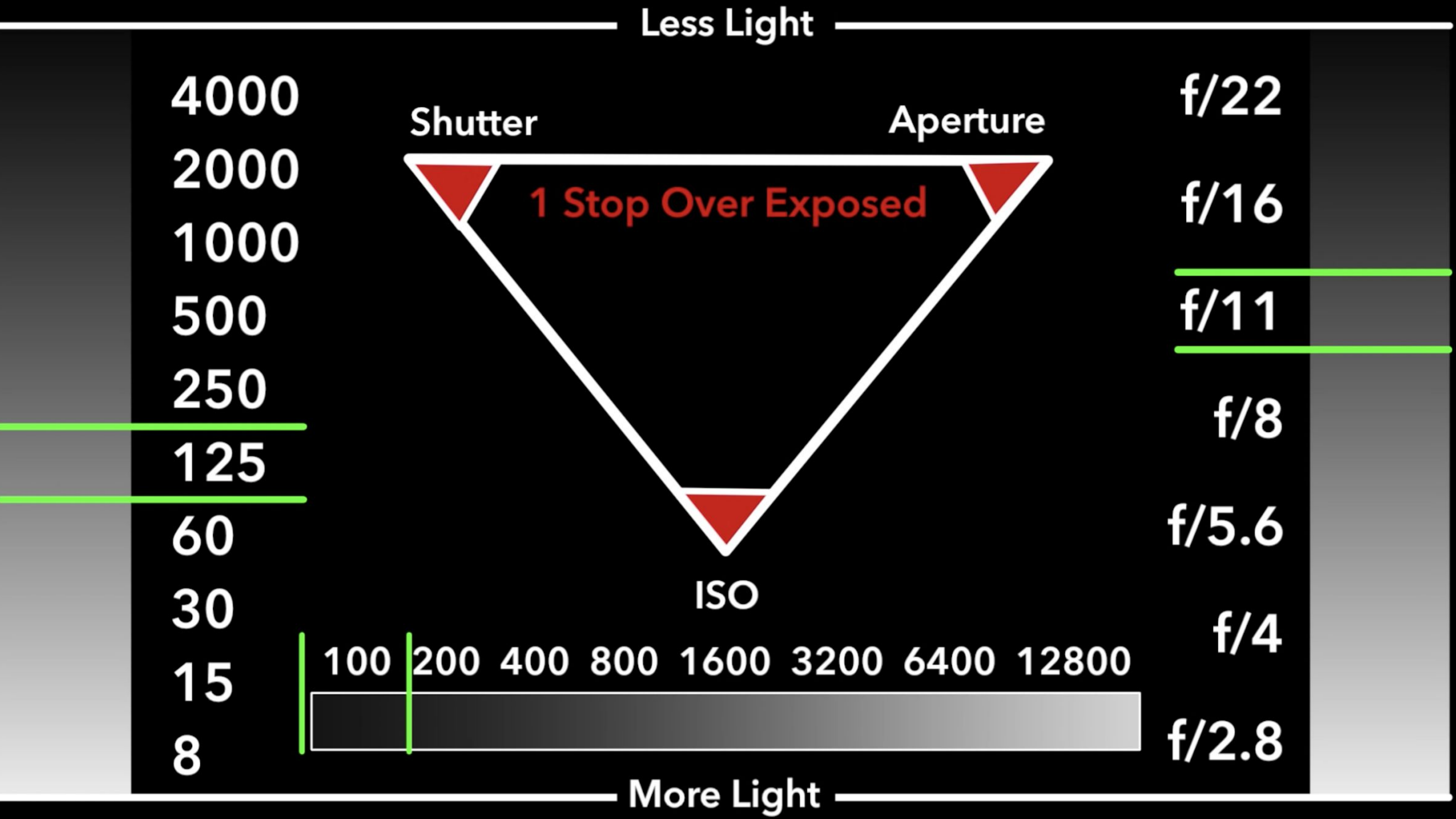

-2 Ev
0 Ev
+2 Ev

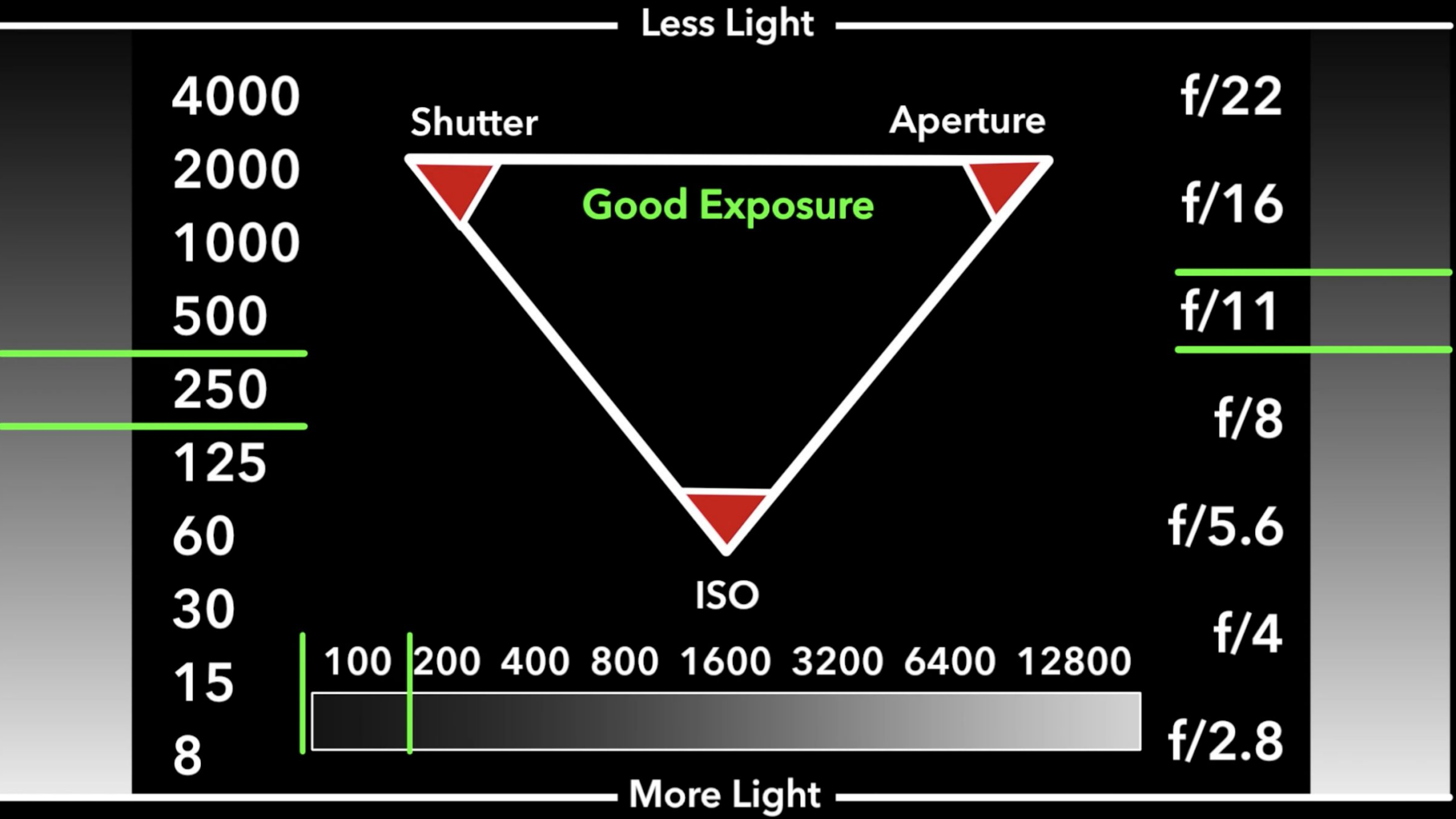
Triángulo de Exposición

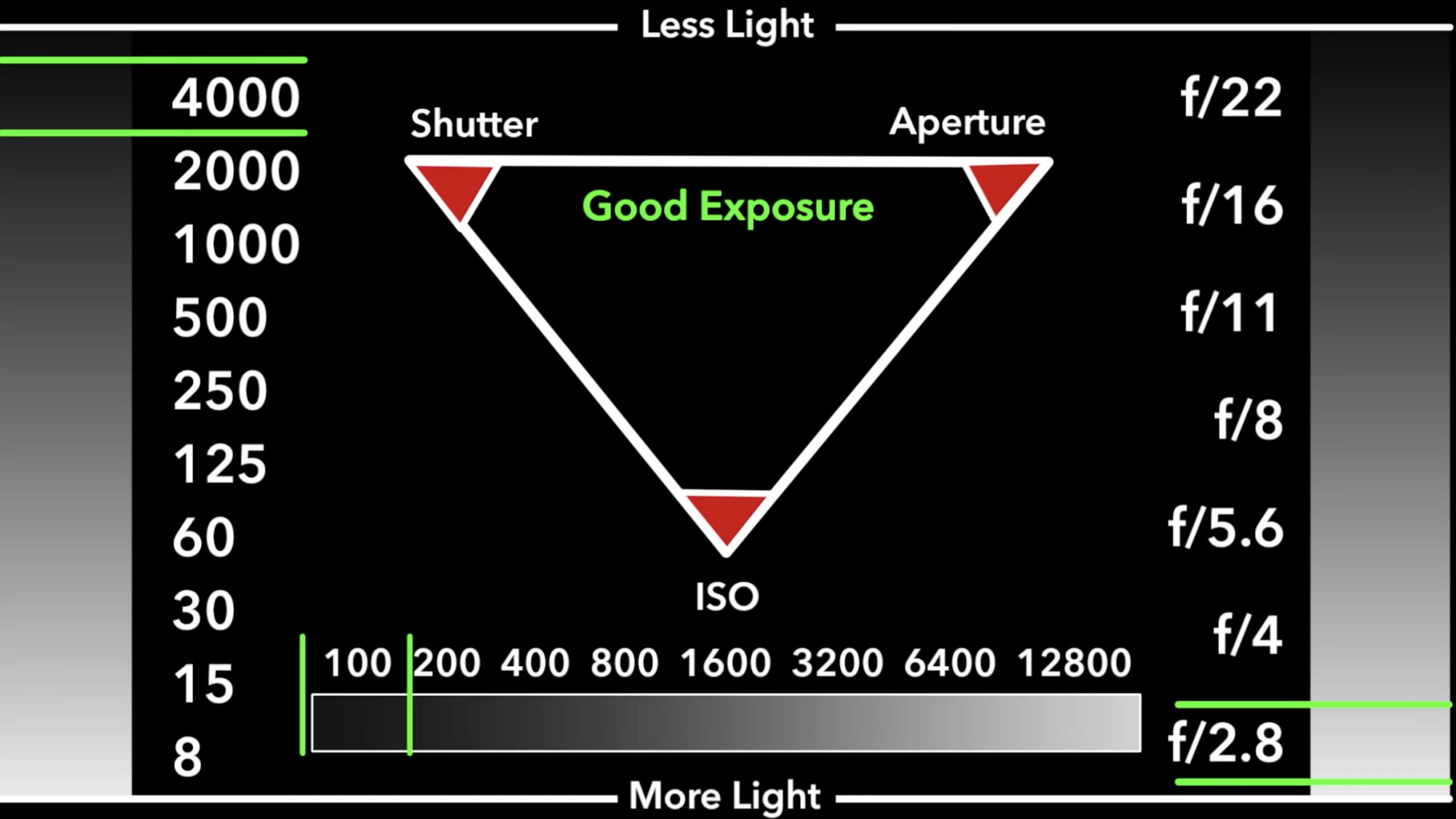


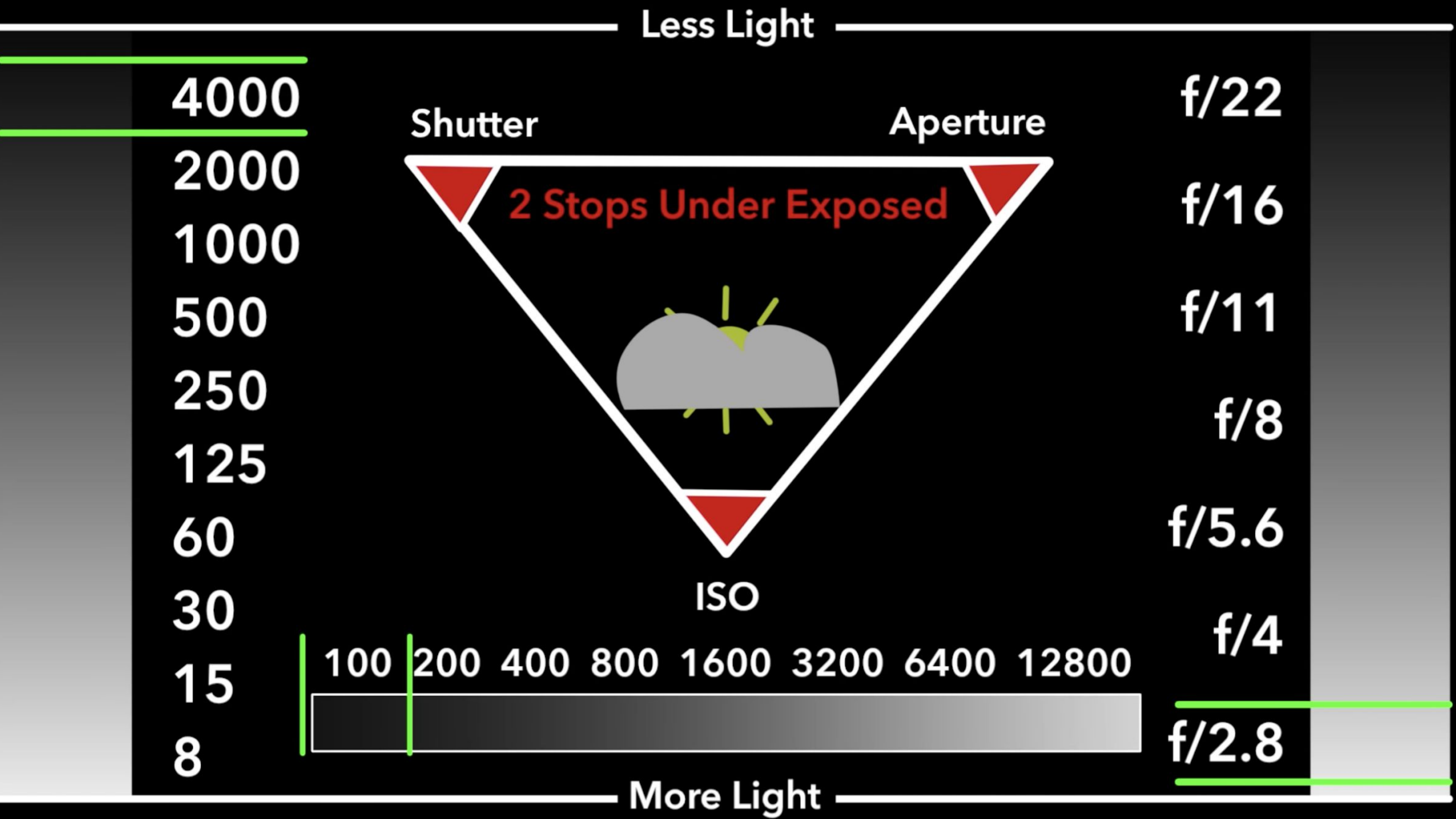


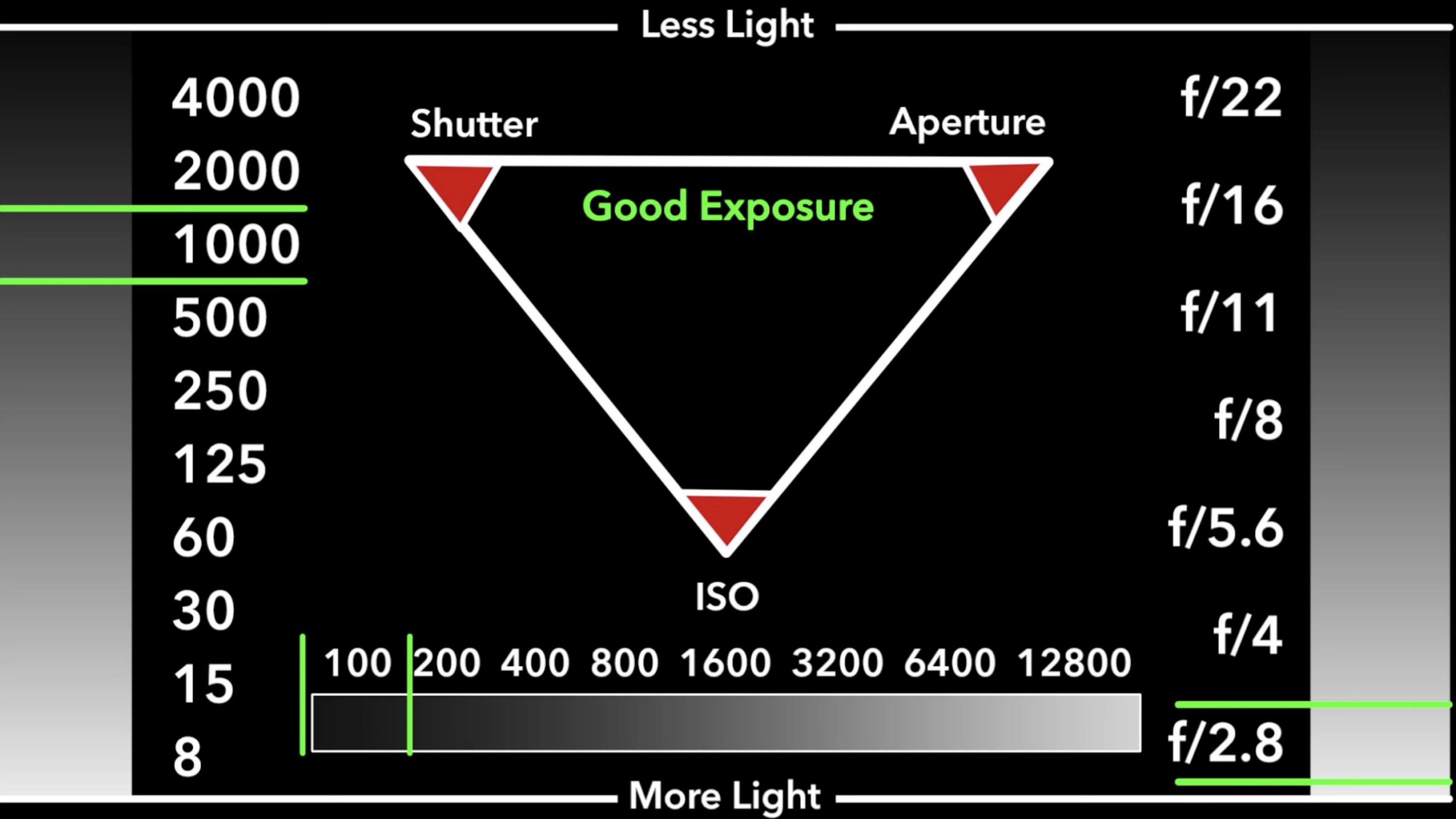

Less Light
4000
2000
1000
500
250
125
60
30
15
8
Shutter
Aperture
Good Exposure
ISO
100 200 400 800 1600 3200 6400 12800
f/22
f/16
f/11
f/8
f/5.6
f/4
f/2.8
More Light


Less Light
4000
2000
1000
500
250
125
60
30
15
8
Shutter
Aperture
1 Stop Over Exposed
ISO
100 200 400 800 1600 3200 6400 12800
f/22
f/16
f/11
f/8
f/5.6
f/4
f/2.8
More Light


Less Light
4000
2000
1000
500
250
125
60
30
15
8
Shutter
Aperture
Good Exposure
ISO
100 200 400 800 1600 3200 6400 12800
f/22
f/16
f/11
f/8
f/5.6
f/4
f/2.8
More Light


Less Light
4000
2000
1000
500
250
125
60
30
15
8
Shutter
Aperture
Good Exposure
ISO
100 200 400 800 1600 3200 6400 12800
f/22
f/16
f/11
f/8
f/5.6
f/4
f/2.8
More Light


Less Light
4000
2000
1000
500
250
125
60
30
15
8
Shutter
Aperture
2 Stops Under Exposed
ISO
100 200 400 800 1600 3200 6400 12800
f/22
f/16
f/11
f/8
f/5.6
f/4
f/2.8
More Light



Less Light
4000
2000
1000
500
250
125
60
30
15
8
Shutter
Aperture
Good Exposure
ISO
100
200
400
800
1600
3200
6400
12800
f/22
f/16
f/11
f/8
f/5.6
f/4
f/2.8
More Light

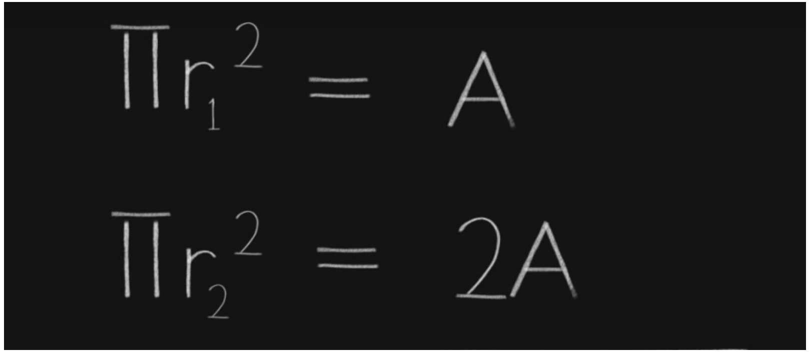
Shutter Speed

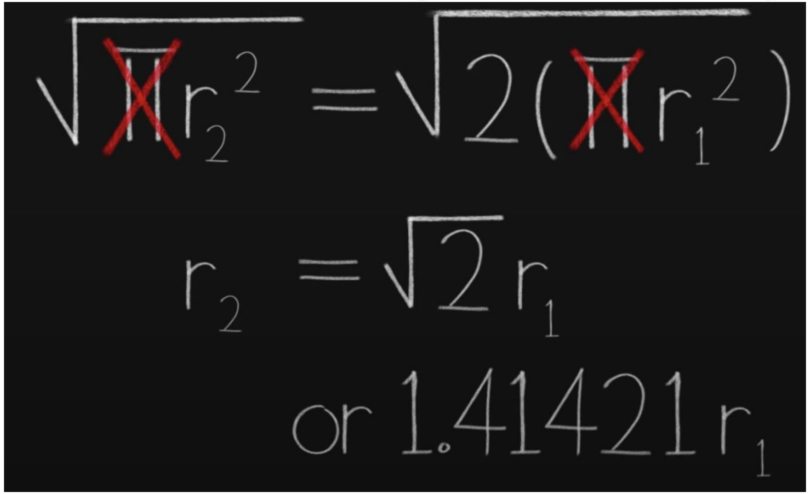

1 sec
1/4 sec
1/15 sec
1/60 sec
1/160 sec


1/750 of a second
1/125 of a second
1/10 of a second
0.7 of a second

Apertura

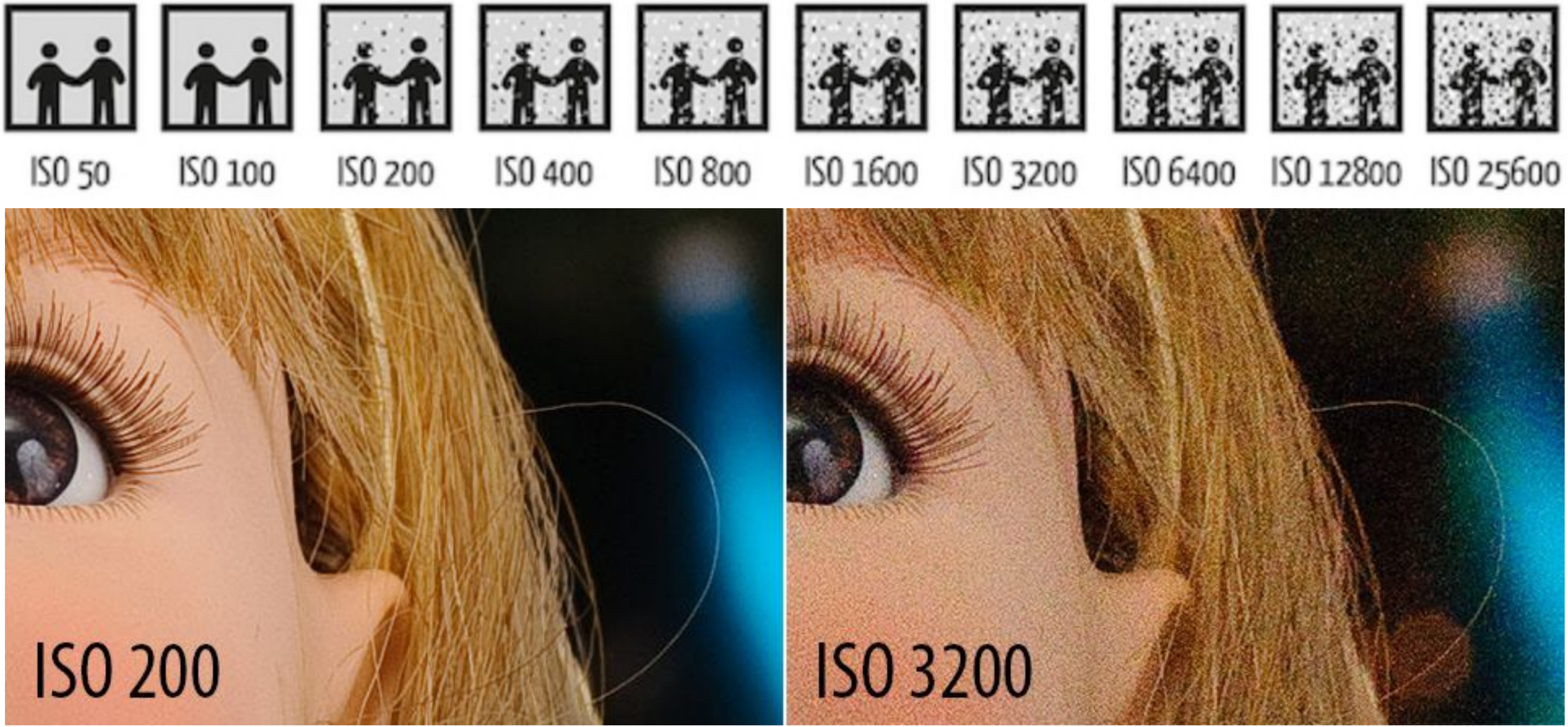

F32
F22
F16
F11
F8
F5,6
F4
F2,8
F2
F1,4


$\pi r_1^2 = A$
$\pi r_2^2 = 2A$


$\sqrt{\pi r_2^2} = \sqrt{2(\pi r_1^2)}$
$r_2 = \sqrt{2} r_1$
or $1.41421 r_1$


Large f/#
Small f/#

Gain (ISO)


ISO 50
ISO 100
ISO 200
ISO 400
ISO 800
ISO 1600
ISO 3200
ISO 6400
ISO 12800
ISO 25600
ISO 200
ISO 3200

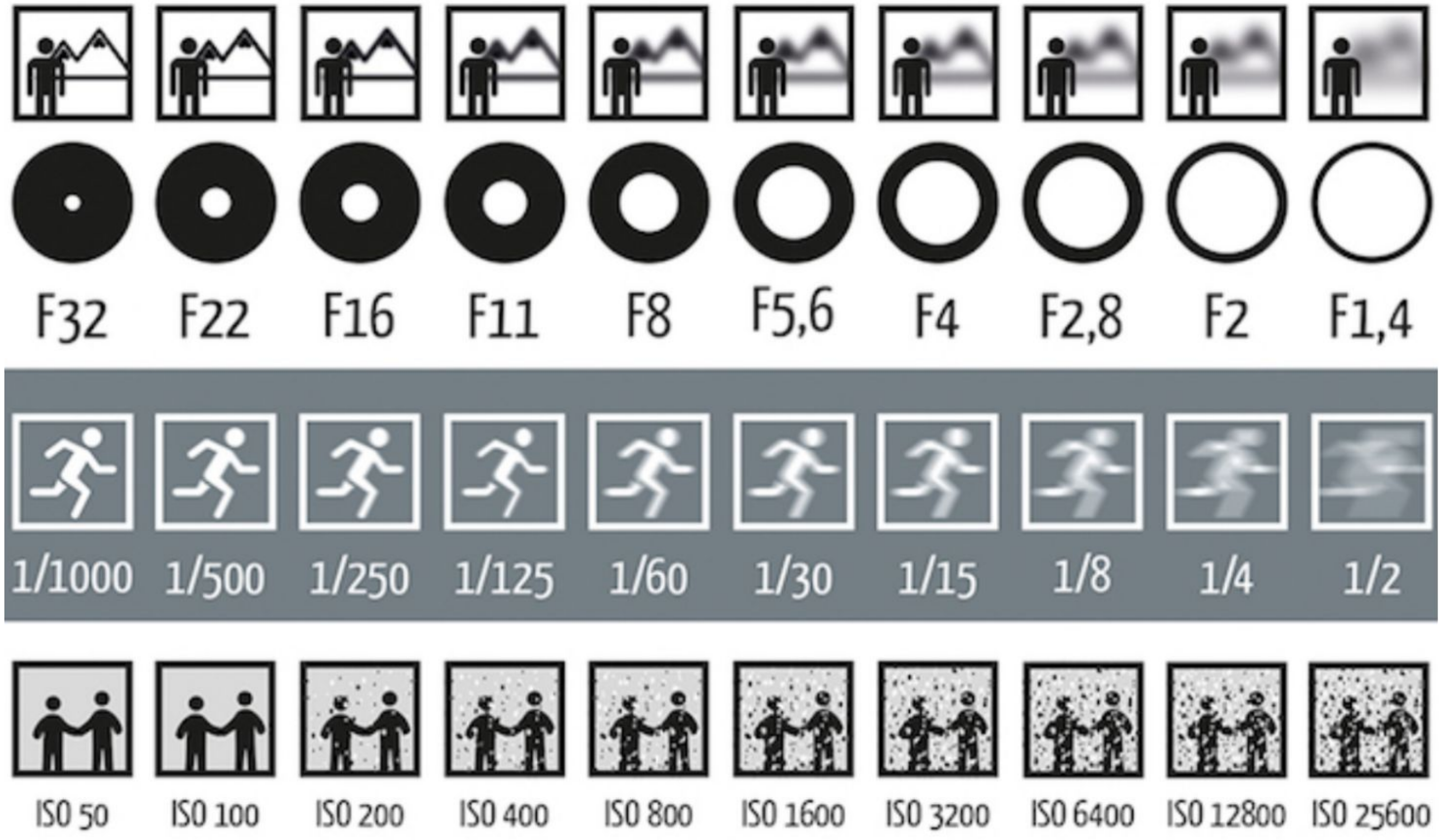

ISO 100
ISO 3200
CLEAN IMAGE
NOISY IMAGE

Triángulo de la exposición = Trade-off

Apertura

Shutter Speed

ISO

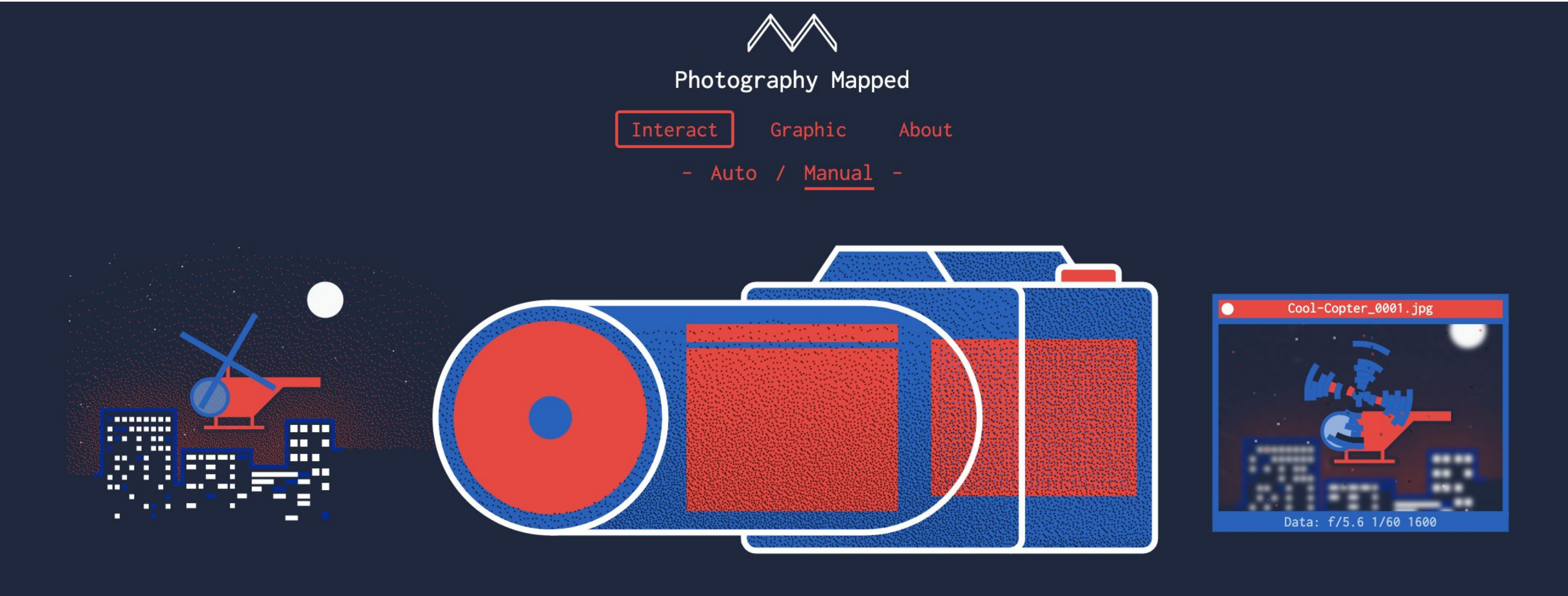


Try it yourself

https://camerasim.com/original-camerasim/

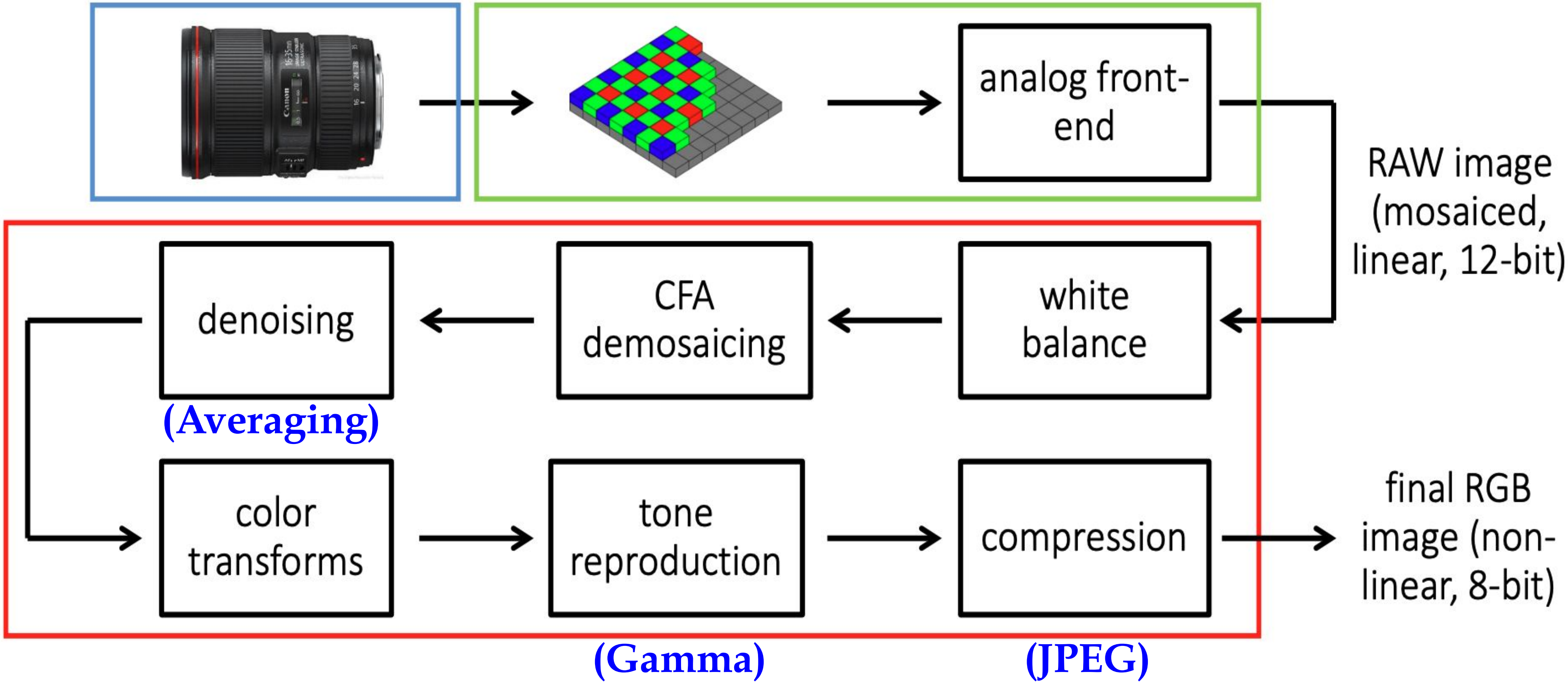
Try it yourself

http://photography-mapped.com/interact.html



4. Pipeline de procesamiento de imágenes digitales (en cámara)

The (in-camera) image processing pipeline



Balance de Blancos

Human visual system has *chromatic adaptation*:

- We can perceive white (and other colors) correctly under different light sources.

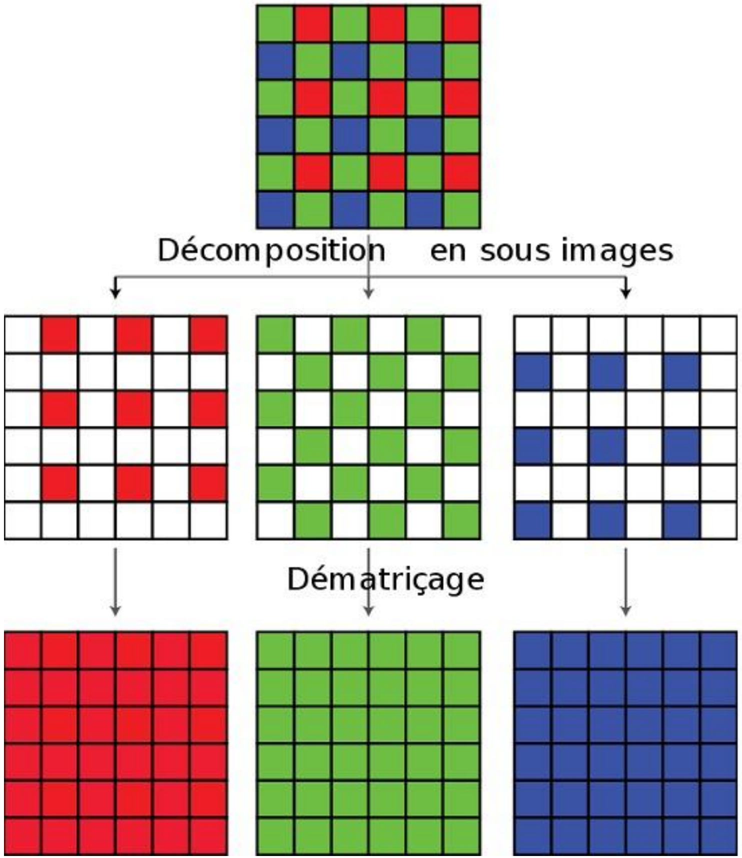
Retinal vs perceived color.

[Slide credit: Todd Zickler]

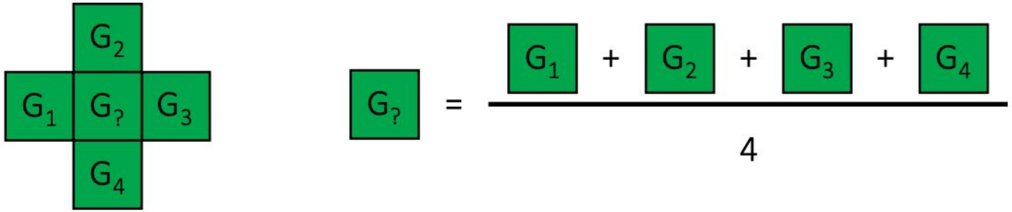
Fun fact


ORIGINAL
(Blue and Gold)
+0% brightness, +0% contrast
BRIGHTER
(White and Gold)
+40% brightness, +40% contrast
DARKER
(Blue and Black)
-30% brightness, +40% contrast

Demosaicking

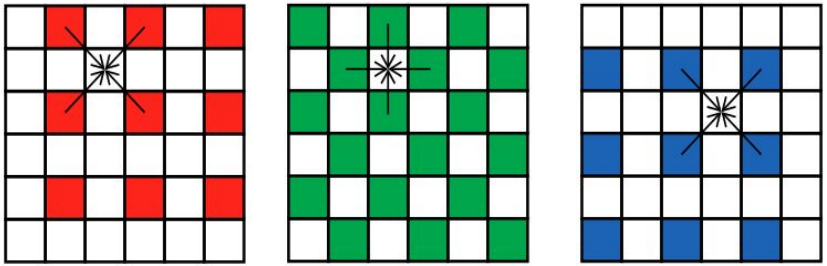


- Interpolación bilineal (método simple)

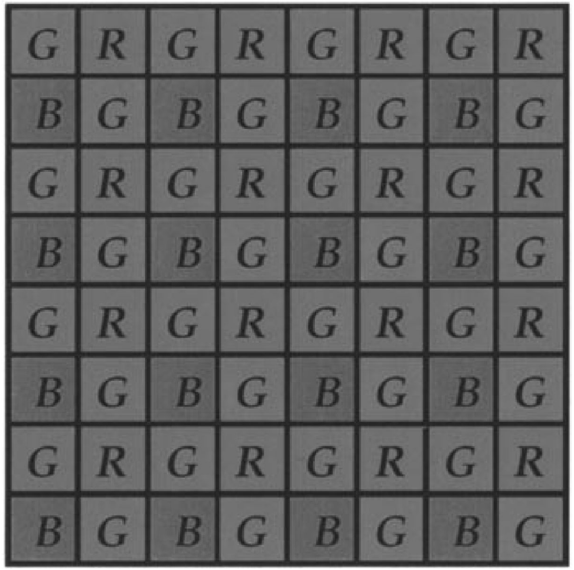


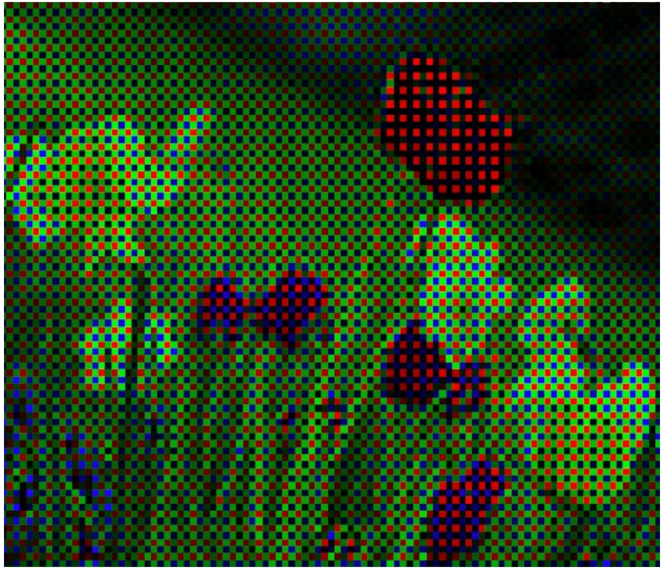
- Se usan métodos más avanzados
  - Menon
  - Malvar
  - Freeman, Etc.

- ⅔ partes de los datos son “inventados”

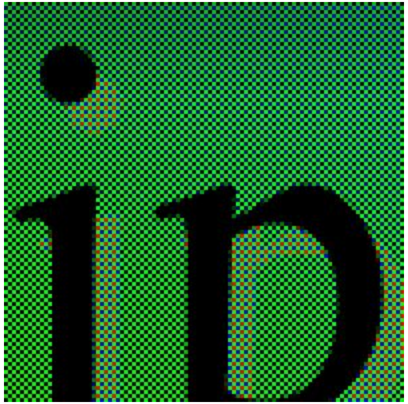


Demosaicking (Raw Data)



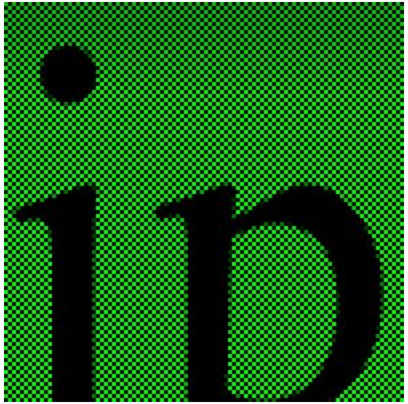


Demosaicking (Interpolation Example)



Raw image

Red channel



Green channel

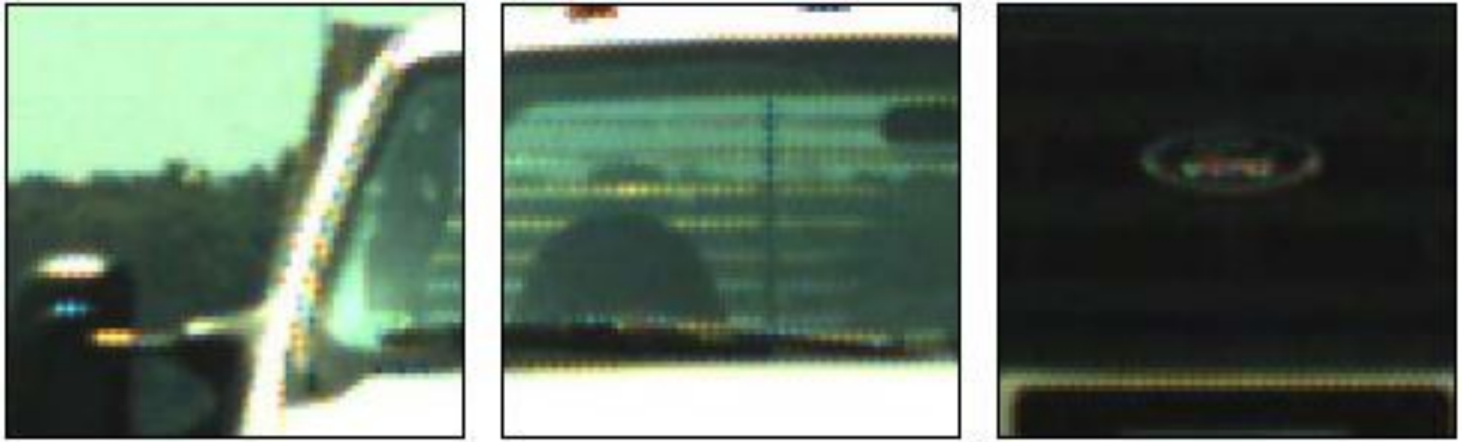
Blue channel

Ground truth

Demosaicked

Problemas

Artefactos de color falso



Artefacto de cremallera

Denoising (Tipos de ruido)

1) **Ruido de disparo** (fotónico):

Las tasas de llegada de fotones son un proceso aleatorio (Poisson)

2) **Ruido oscuro:**

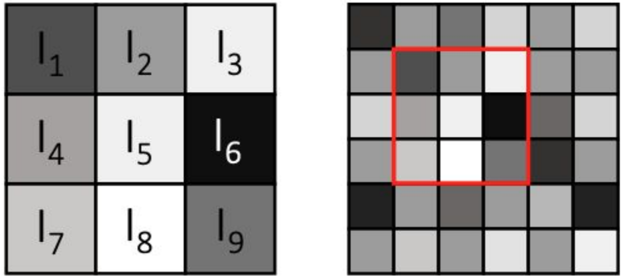
Electrones debido a la actividad térmica (empeora cuando el sensor se calienta)

3) **Ruido de lectura:**

Causado por la lectura y la electrónica AFE (por ejemplo, ganancia, conversor A/D)

Denoising (Eliminación de ruido)

Look at the neighborhood around you.



- Mean filtering (take average):

$$I'_5 = \frac{I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7 + I_8 + I_9}{9}$$

- Median filtering (take median):

$$I'_5 = \text{median}(I_1, I_2, I_3, I_4, I_5, I_6, I_7, I_8, I_9)$$

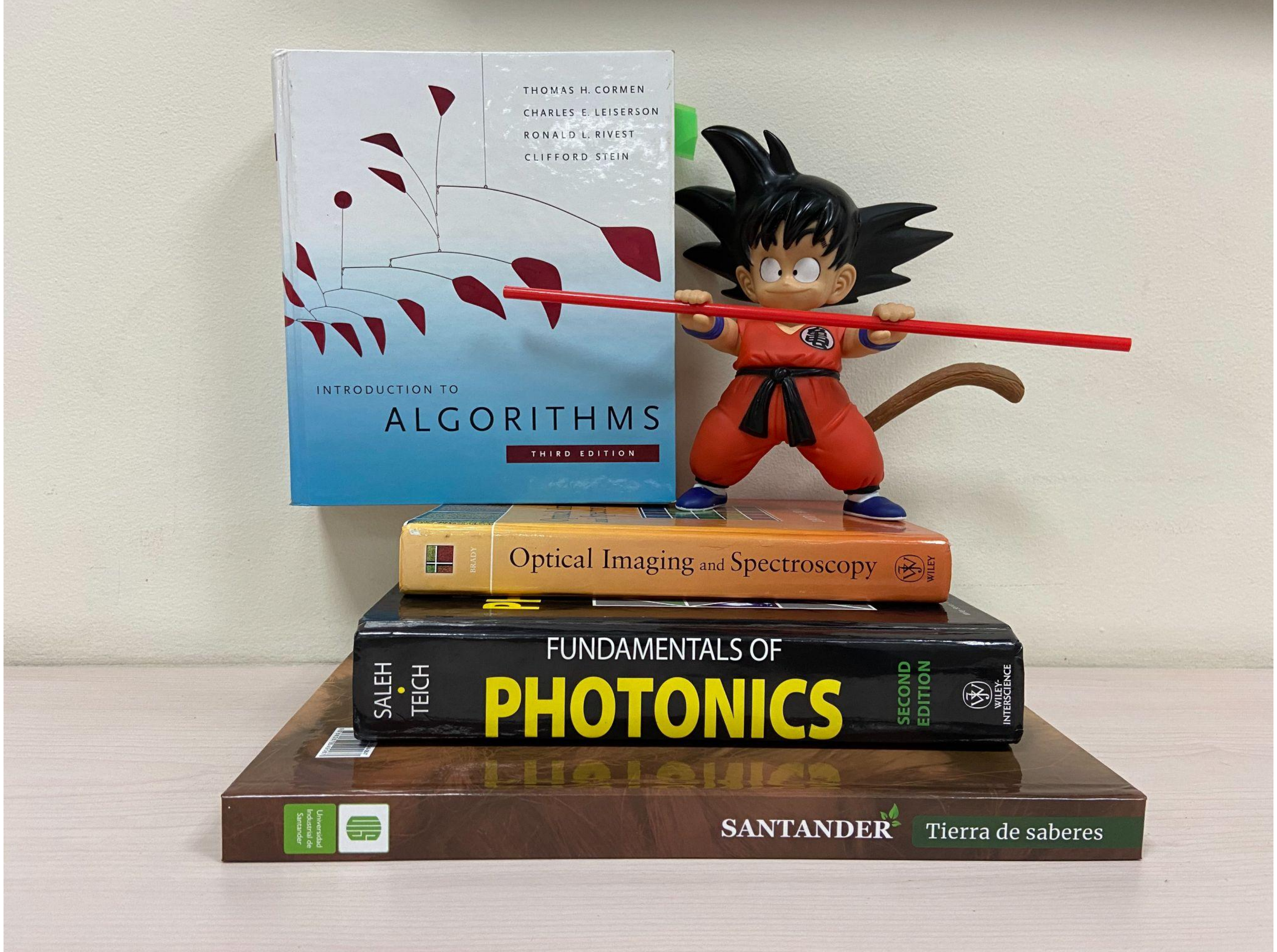
Large area of research. We will see some more about filtering in a later lecture.

Diferentes cámaras generan diferentes imágenes

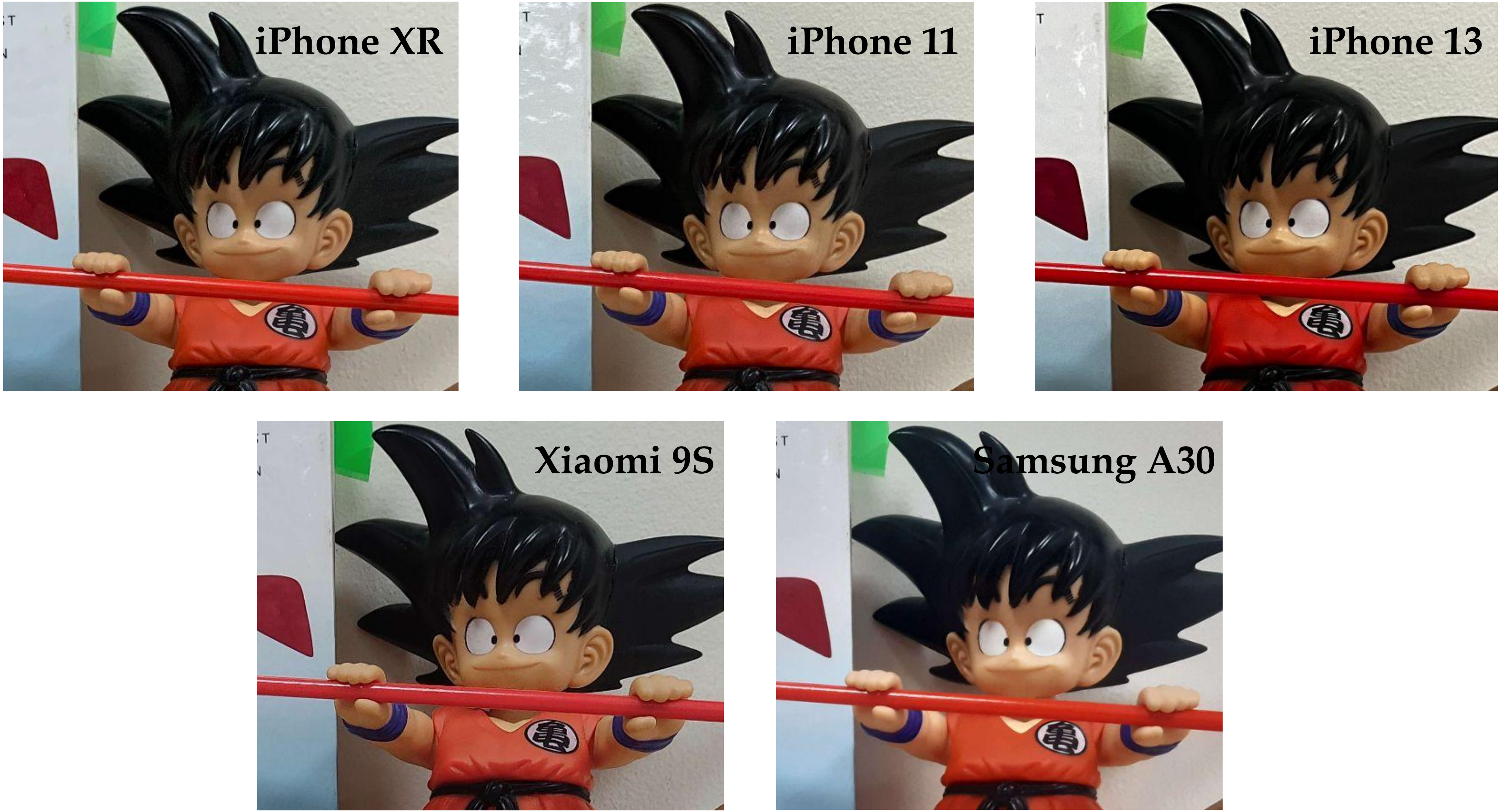

Xiaomi 9S

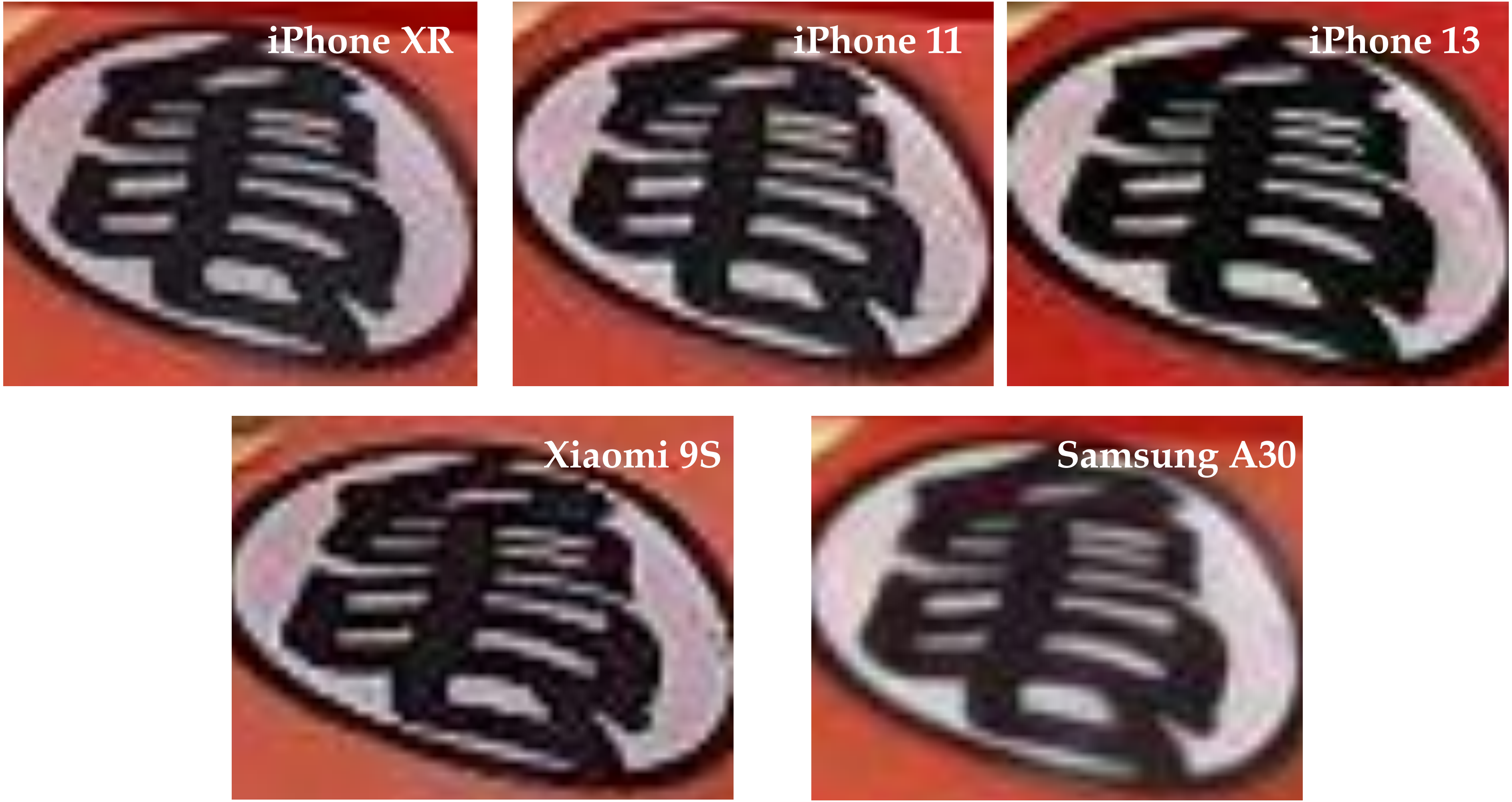
Samsung A30

Ejemplo



THOMAS H. CORMEN
CHARLES E. LEISERSON
RONALD L. RIVEST
CLIFFORD STEIN
INTRODUCTION TO
ALGORITHMS
THIRD EDITION
BRADY
Optical Imaging and Spectroscopy
WILEY
FUNDAMENTALS OF
PHOTONICS
SALEH
TEICH
SECOND EDITION
WILEY-INTERSCIENCE
SANTANDER
Tierra de saberes


iPhone XR
iPhone 11
iPhone 13
Xiaomi 9S
Samsung A30


iPhone XR
iPhone 11
iPhone 13
Xiaomi 9S
Samsung A30

iPhone XR

iPhone 11

iPhone 13

Xiaomi 9S

Samsung A30

5. Transformaciones de imágenes

¿Qué es una transformación geométrica?

- Usadas para modificar la disposición espacial de los píxeles de una imagen.
- Las T.G. constan de dos operaciones básicas:
  a. Transformación espacial de coordenadas.
  b. Interpolación de intensidad, que asigna valores de intensidad a los píxeles transformados espacialmente.

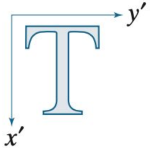
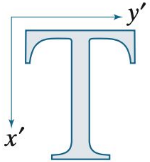
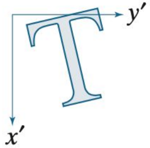
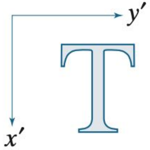
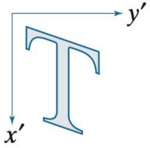
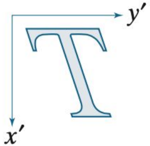
Transformación de coordenadas

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \mathbf{T} \begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} t_{11} & t_{12} \\ t_{21} & t_{22} \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

Transformación afín de coordenadas

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \mathbf{A} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

Puede escalar, rotar, mover o estirar una imagen.

Transformation Name	Affine Matrix, A	Coordinate Equations	Example
Identity	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x' = x$ $y' = y$	
Scaling/Reflection (For reflection, set one scaling factor to –1 and the other to 0)	$\begin{bmatrix} c_x & 0 & 0 \\ 0 & c_y & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x' = c_x x$ $y' = c_y y$	
Rotation (about the origin)	$\begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x' = x\cos\theta - y\sin\theta$ $y' = x\sin\theta + y\cos\theta$	
Translation	$\begin{bmatrix} 1 & 0 & t_x \\ 0 & 1 & t_y \\ 0 & 0 & 1 \end{bmatrix}$	$x' = x + t_x$ $y' = y + t_y$	
Shear (vertical)	$\begin{bmatrix} 1 & s_v & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x' = x + s_v y$ $y' = y$	
Shear (horizontal)	$\begin{bmatrix} 1 & 0 & 0 \\ s_h & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$	$x' = x$ $y' = s_h x + y$	

Histograma

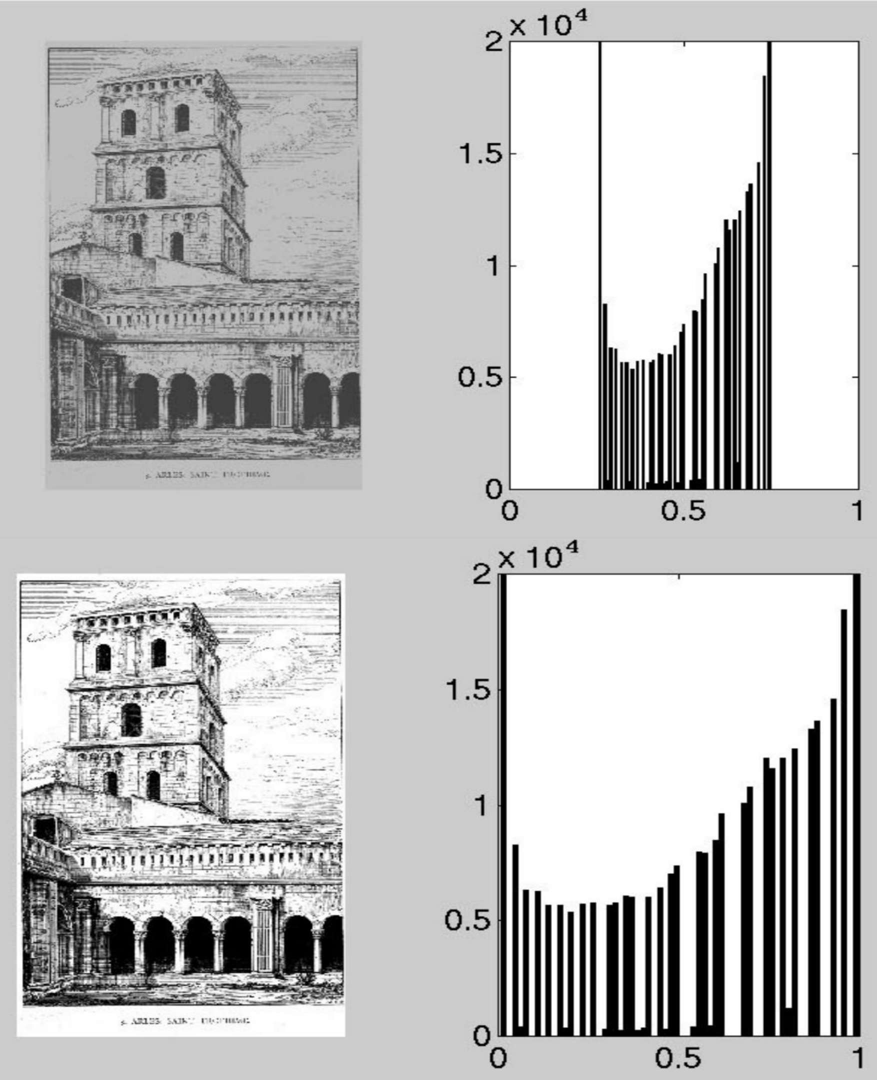
Cada entrada del histograma se define como el "Número de píxeles con el valor de intensidad i"

$$h(i) = \mathsf{card}\left\{(u,v)\,|\,I\,(u,v) = i\right\}$$

$$0 \leq i < K$$

K = niveles de intensidad (depende de #bits)

- h(0) es el número de píxeles con el valor 0
- h(1) el número de píxeles con el valor 1
- y así sucesivamente



Transformaciones espaciales de intensidad

Pixel-a-pixel

$$s = T(r)$$

r = valor del píxel de entrada
s = valor del píxel de salida
T = operador sobre una **vecindad de 1x1**

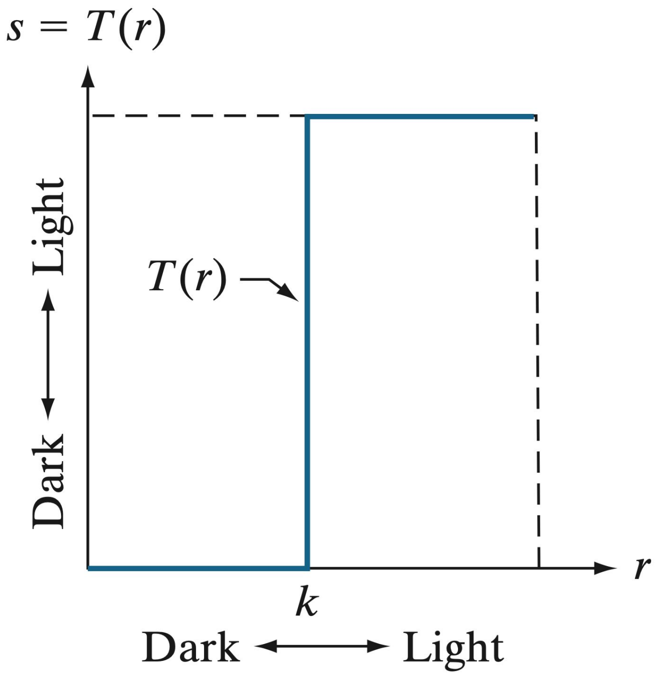
La transformación es independiente de la ubicación; depende solo de la intensidad del pixel

De vecindario

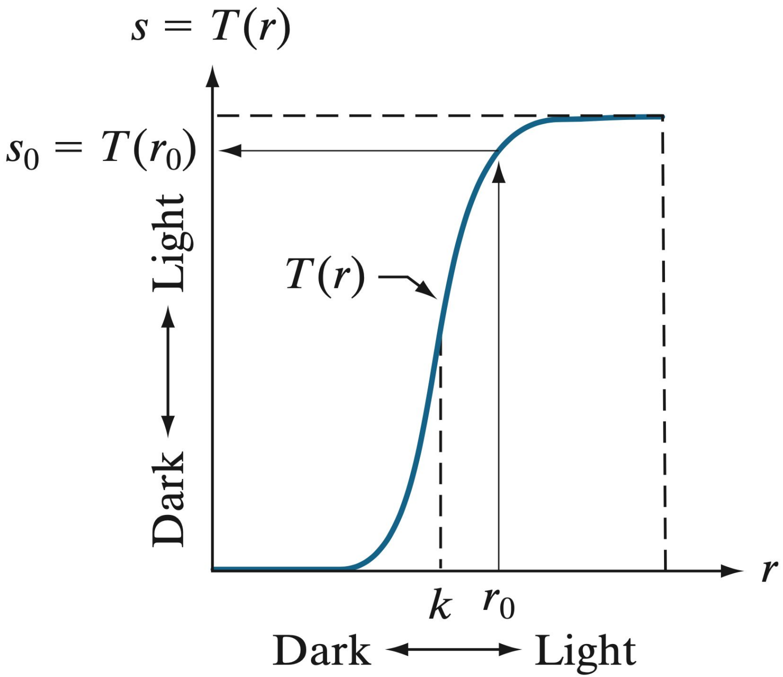
$$g(x,y) = T\left[f(x,y)\right]$$

f (x, y) = imagen de entrada
g(x, y) = imagen de salida
T = operador en f definido sobre una **vecindad** del punto (x, y)

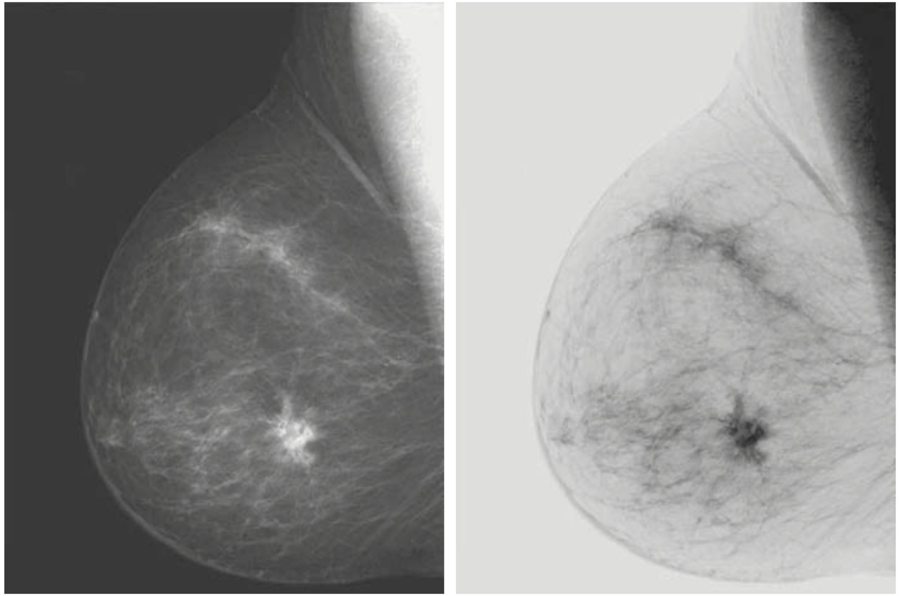
1. Umbralización



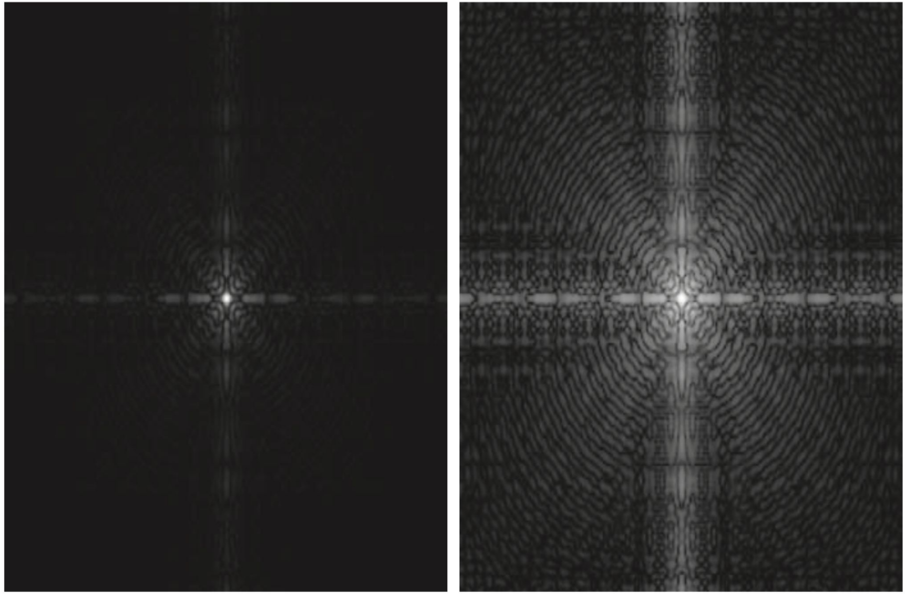
2. Mejoramiento de contraste



- Las T.I. son técnicas simples de procesamiento de imágenes
- Implementadas normalmente a través de Look-Up-Tables (LUT)



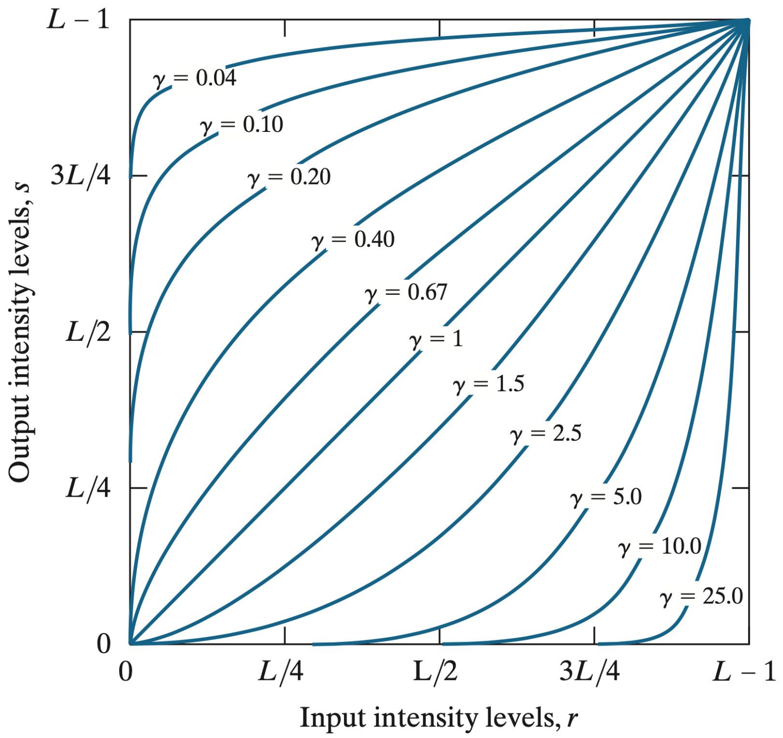
Negativa

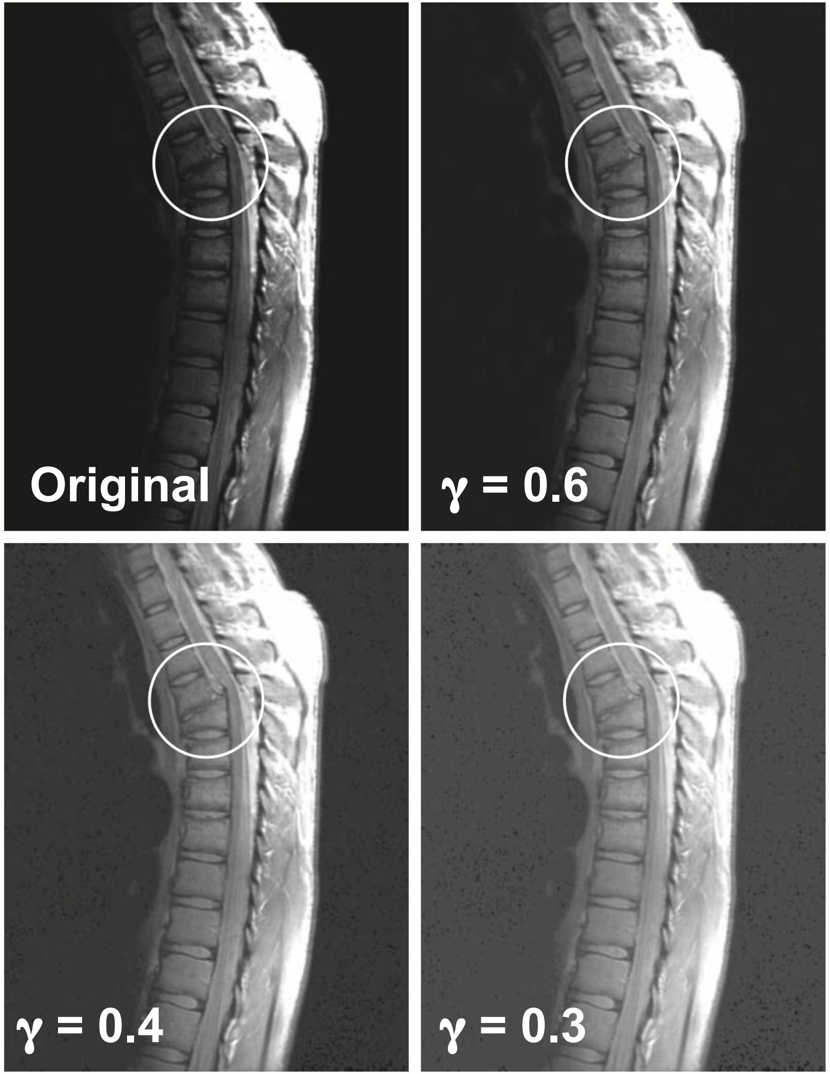


Logarítmica (c=1)

Corrección Gamma $s = cr^{\gamma}$

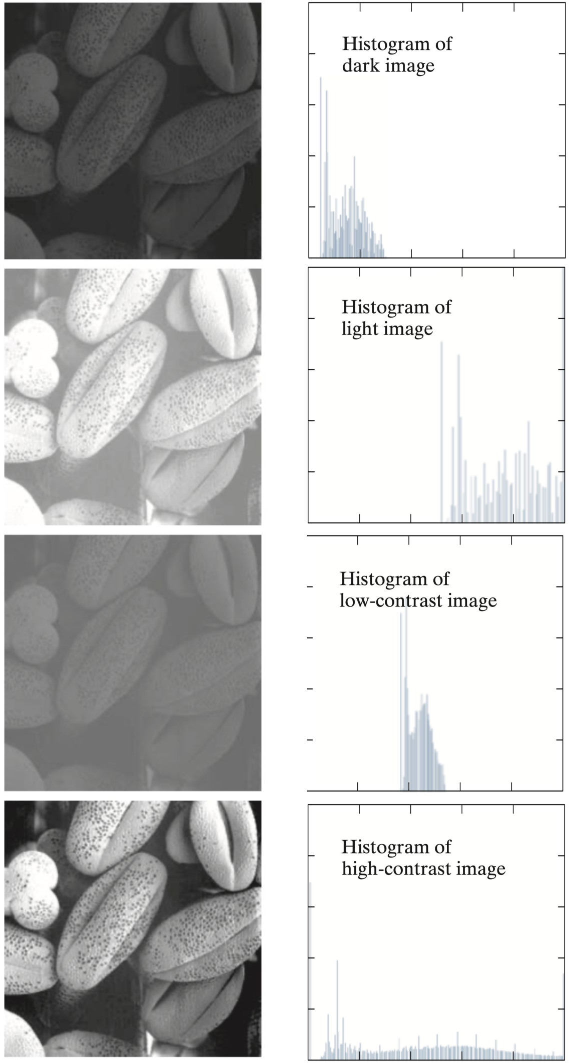
$\gamma < 1$: Mejora áreas oscuras
$\gamma > 1$: Mejora áreas brillantes

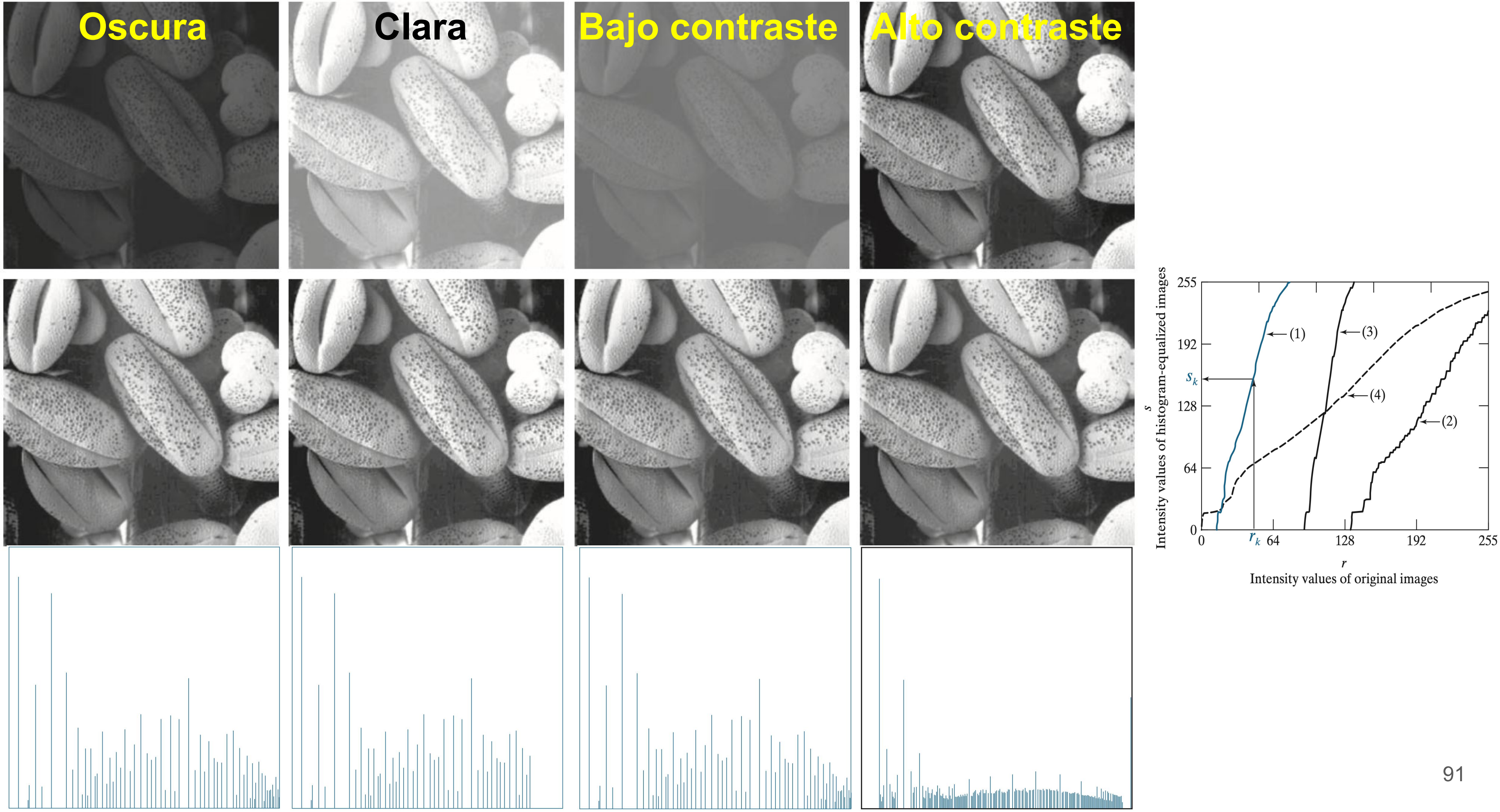




Ecualización del histograma

- Imágenes claras, oscuras y de bajo contraste tienen **histogramas concentrados.**
- Imágenes con histogramas uniformes
  - Contienen toda la gama de valores de gris
  - Tienen alto contraste
  - Mejor apariencia visual general

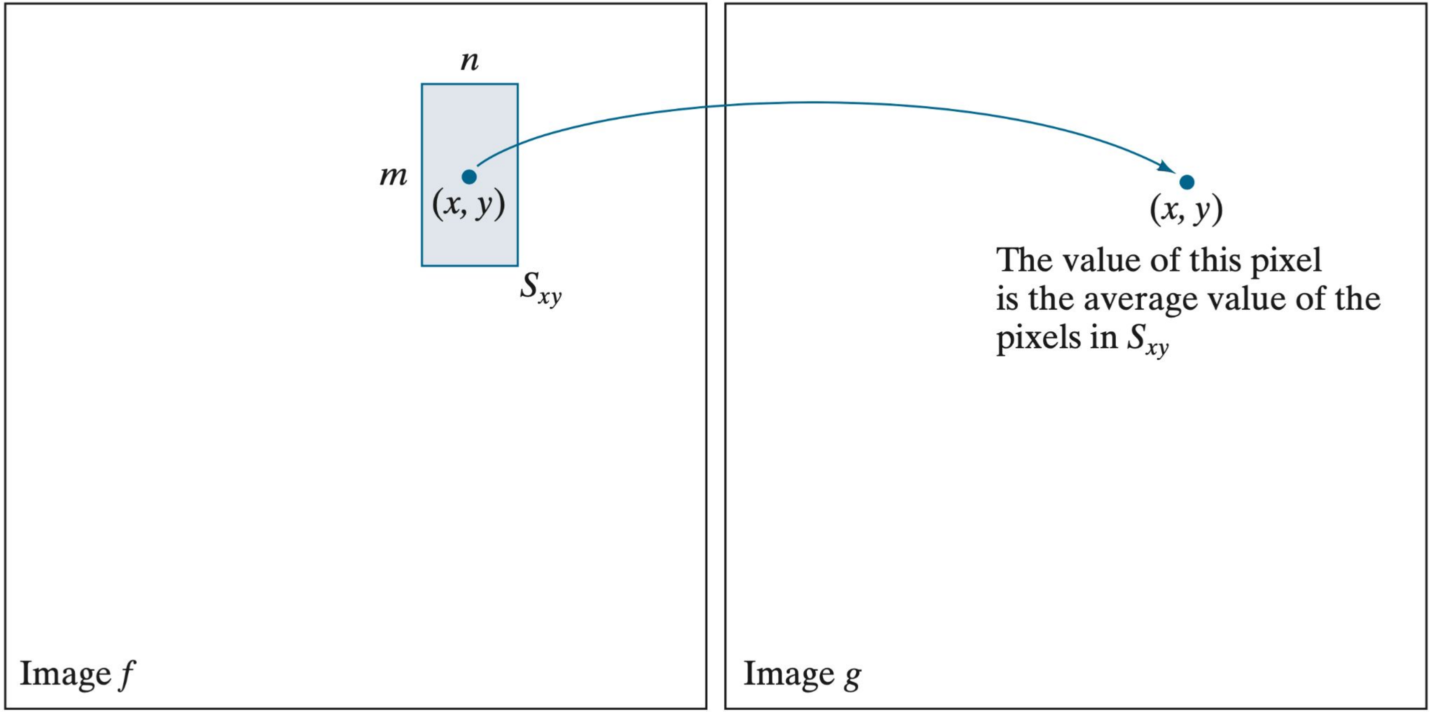




Oscura
Clara
Bajo contraste
Alto contraste
255
192
s_k
128
64
0
Intensity values of histogram-equalized images
s
0
r_k
64
128
192
255
r
Intensity values of original images
(1)
(2)
(3)
(4)

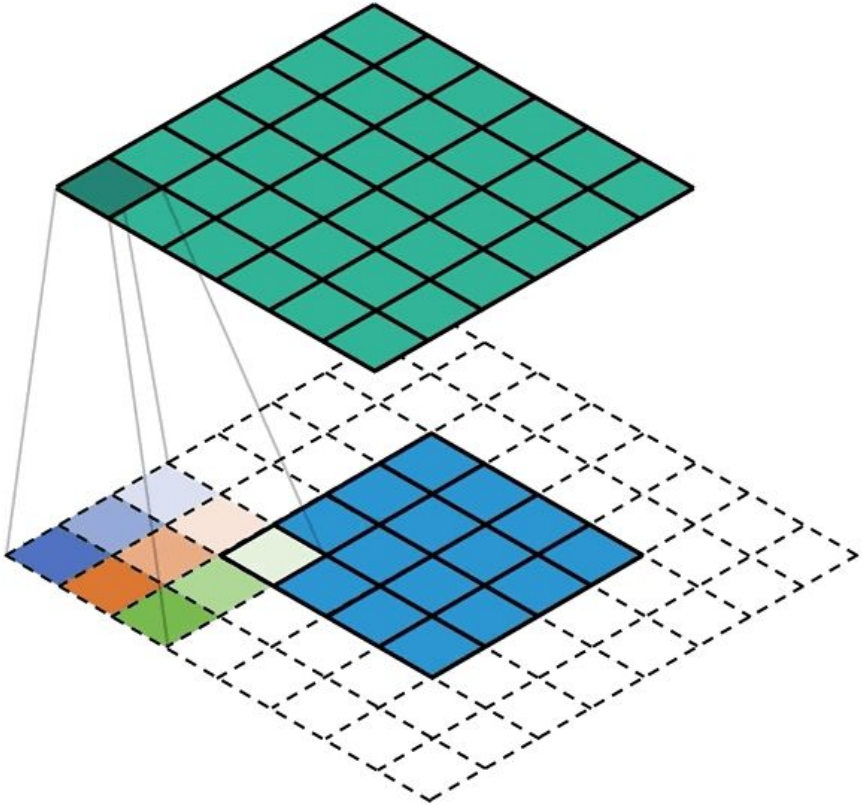
Transformaciones de vecindario (Convolución)

Transformaciones de vecindario



$$g(x,y) = \frac{1}{mn} \sum_{(r,c)\in S_{xy}} f(r,c)$$

Convolución 2D $g(x,y) = h(x,y) \circledast f(x,y)$

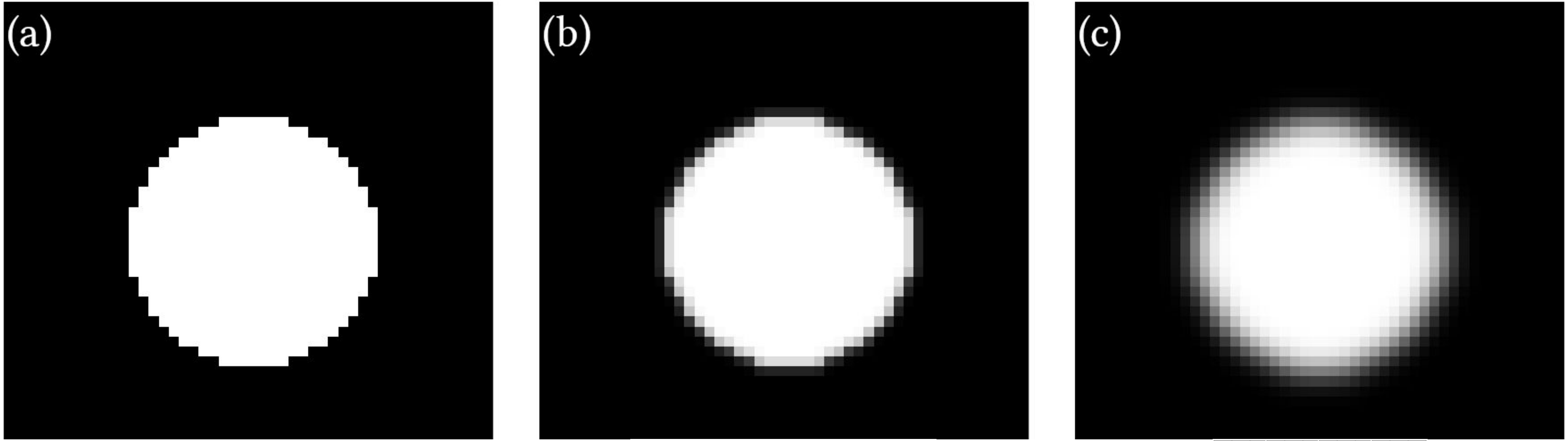


3_0	3_1	2_2	1	0
0_2	0_2	1_0	3	1
3_0	1_1	2_2	2	3
2	0	0	2	2
2	0	0	0	1

12.0	12.0	17.0
10.0	17.0	19.0
9.0	6.0	14.0

https://www.algorithm-archive.org/contents/convolutions/2d/2d.html

Filtrado lineal (Desenfoque = Bajas frecuencias)



$\frac{1}{9}$

1	1	1
1	1	1
1	1	1

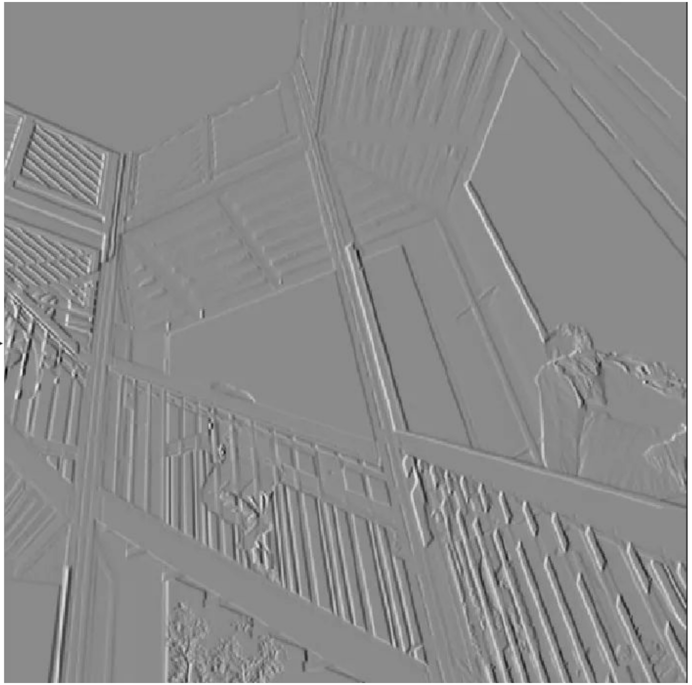
$\frac{1}{20}$

1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1

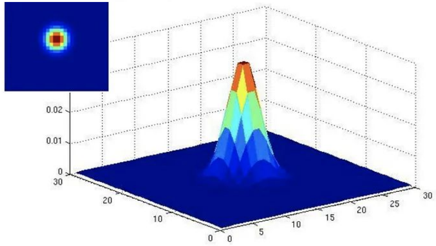
Filtrado lineal (Bordes = Altas frecuencias)

$$\begin{bmatrix} +1 & 0 & -1 \\ +2 & 0 & -2 \\ +1 & 0 & -1 \end{bmatrix}$$

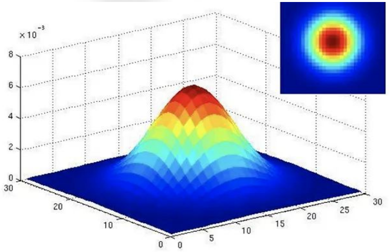
Horizontal Sobel kernel



Filtro que representa un Lente = Gaussian Kernel



$\sigma = 2$ with 30×30
kernel



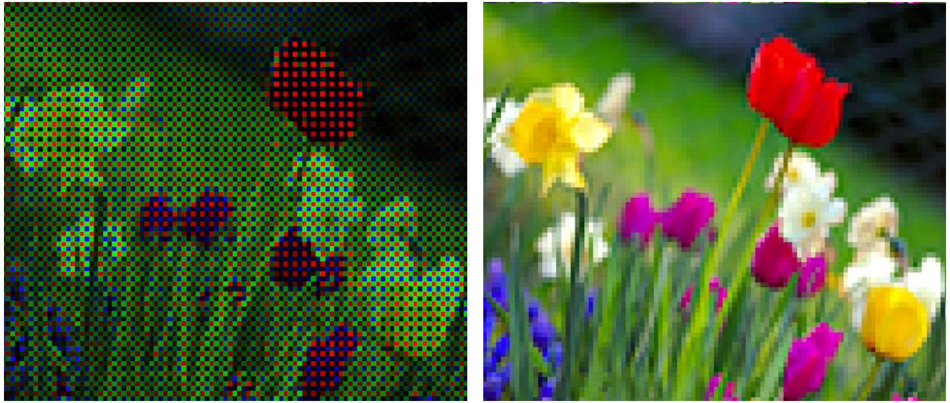
$\sigma = 5$ with 30×30
kernel

Problemas a Resolver

1. Demosaicking
2. Deconvolution/Deblurring
3. Denoising

Deconvolution

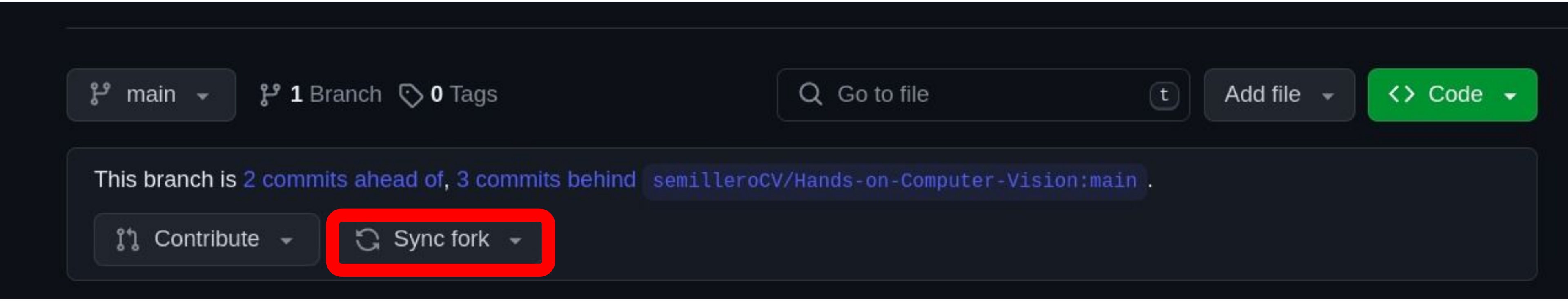
Demosaicking



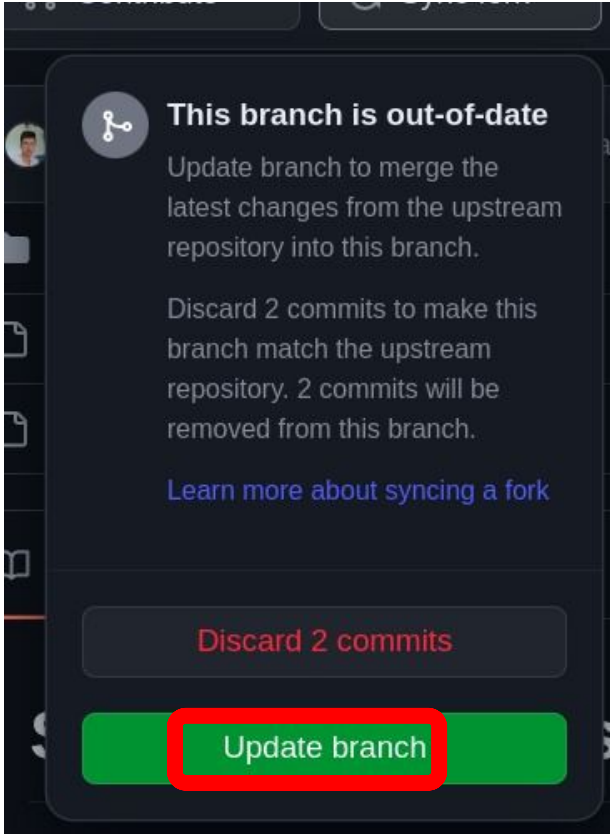
Denoising

Hands-on: Transformaciones y Demosaicing

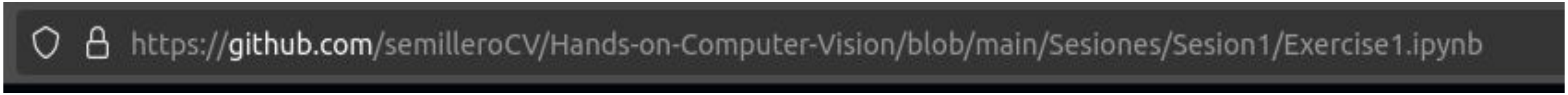
Actualicemos el repositorio!



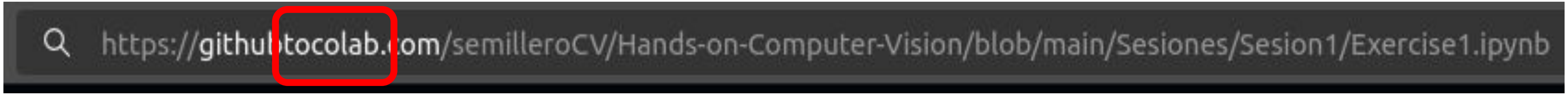
Actualicemos el repositorio!



Abrelo en colab usando “**githubtocolab**”



Agrega la palabra “tocolab” y da ENTER



Next Week