

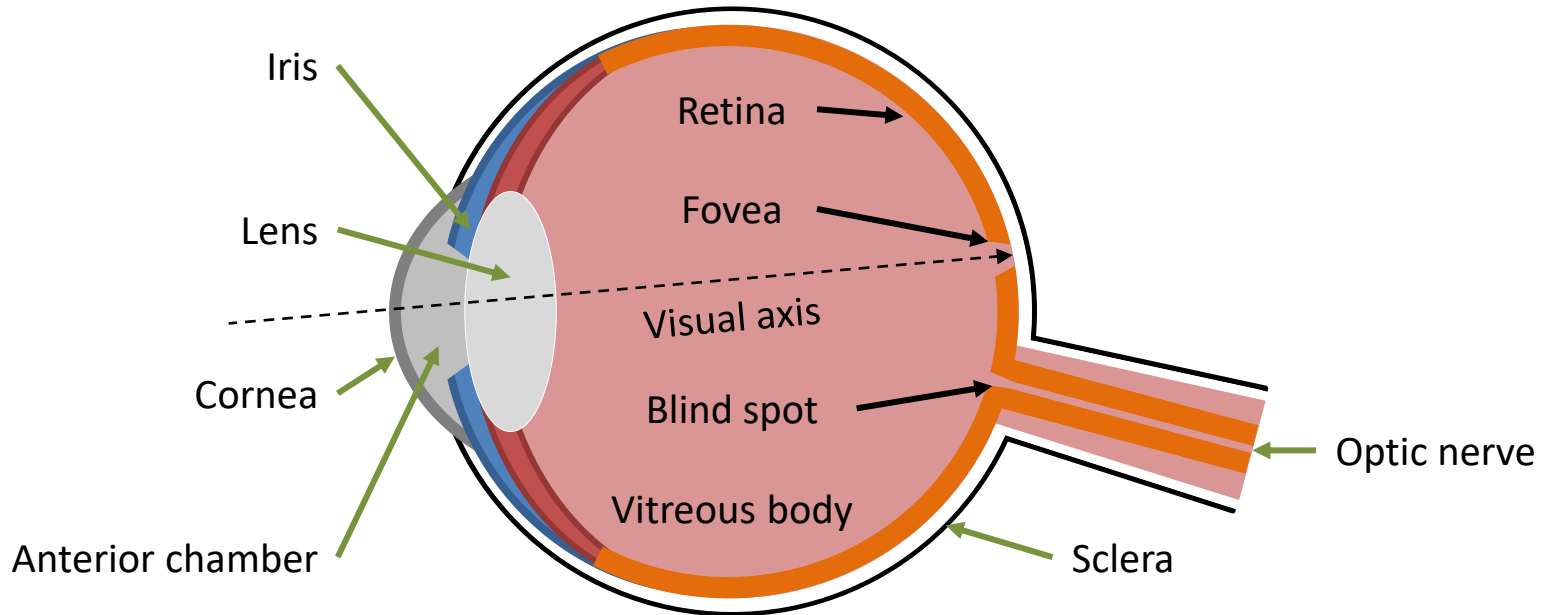
Lecture 02 – Fundamentals of digital imaging I

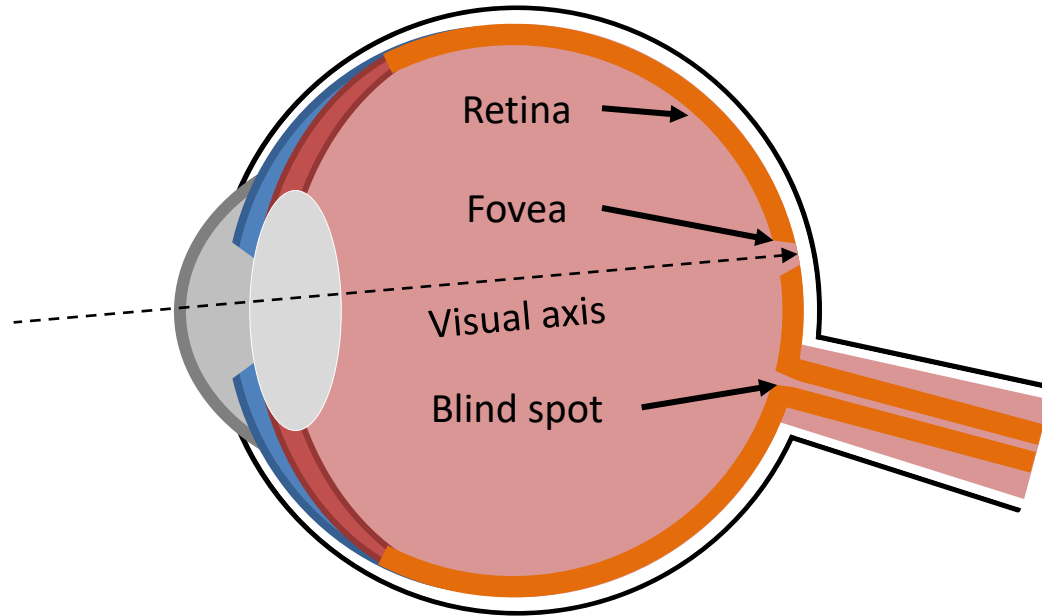
Prof. João Fernando Mari

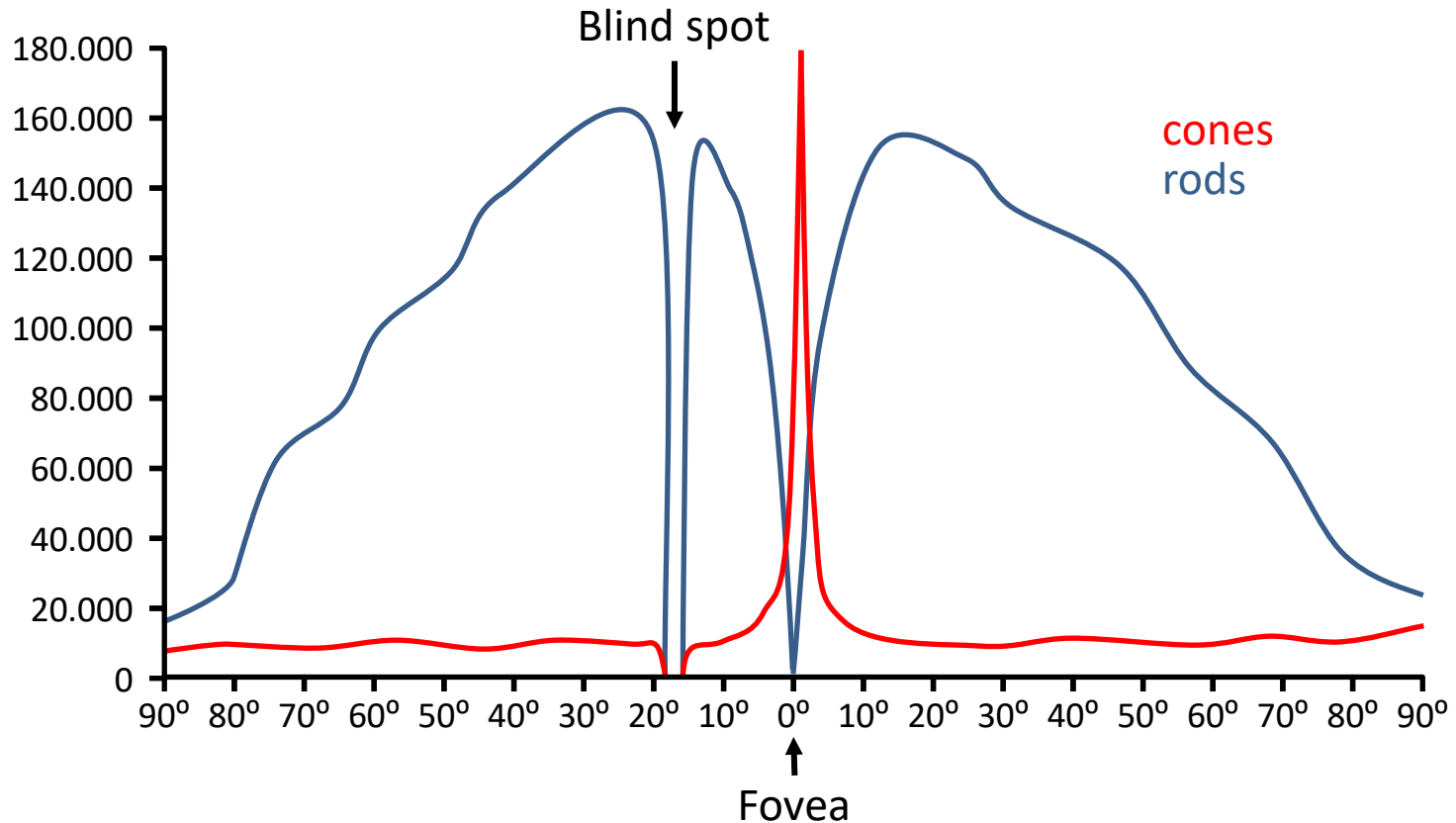
joaofmari.github.io

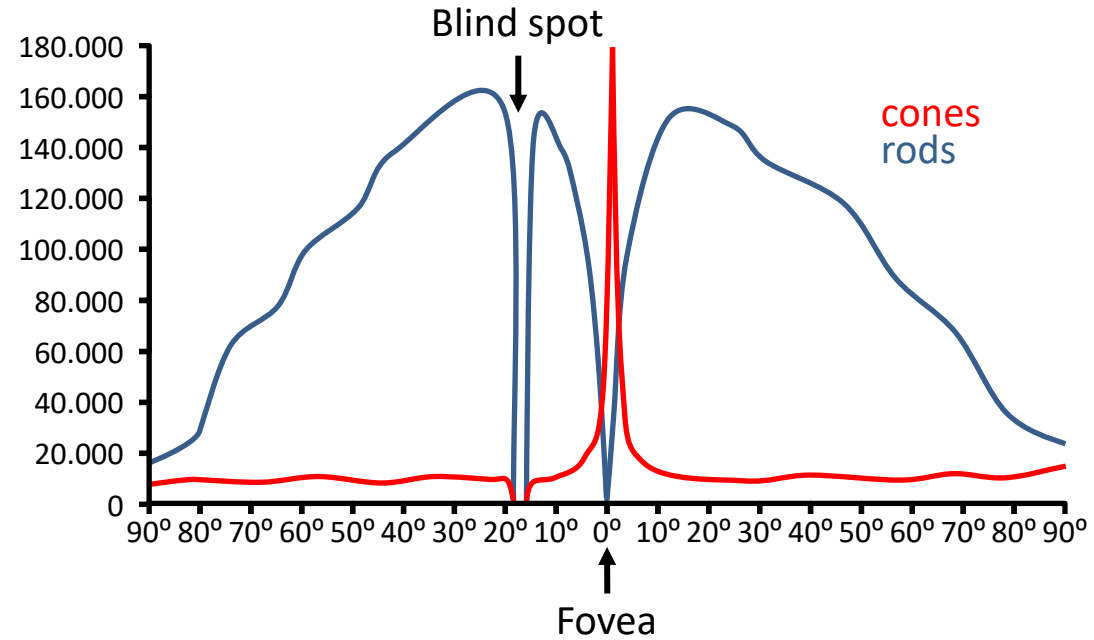
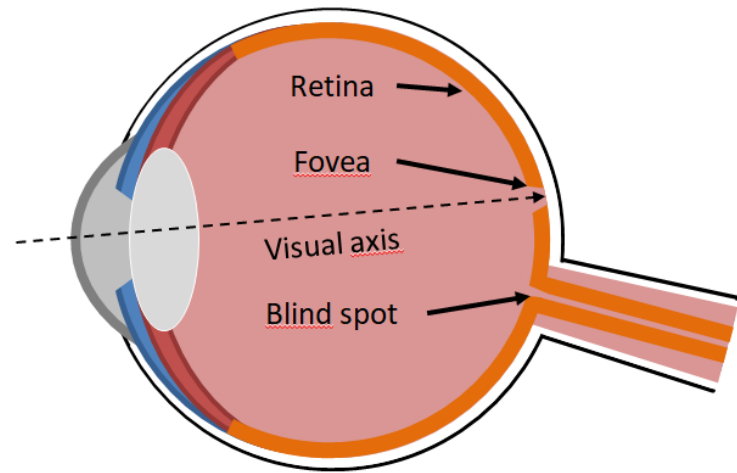
joaof.mari@ufv.br

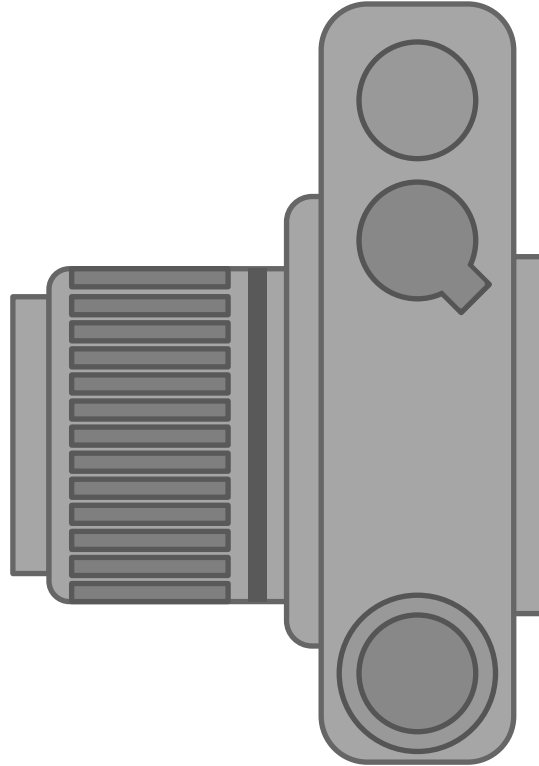
- The human eye
- Photographic camera
- The digital image
- Colored images– RGB
- The RGB color space
- Image acquisition
- CCD sensor and Bayer pattern
- Sampling
- Effects of spatial resolution
- Intensity resolution
- Effects of intensity resolution

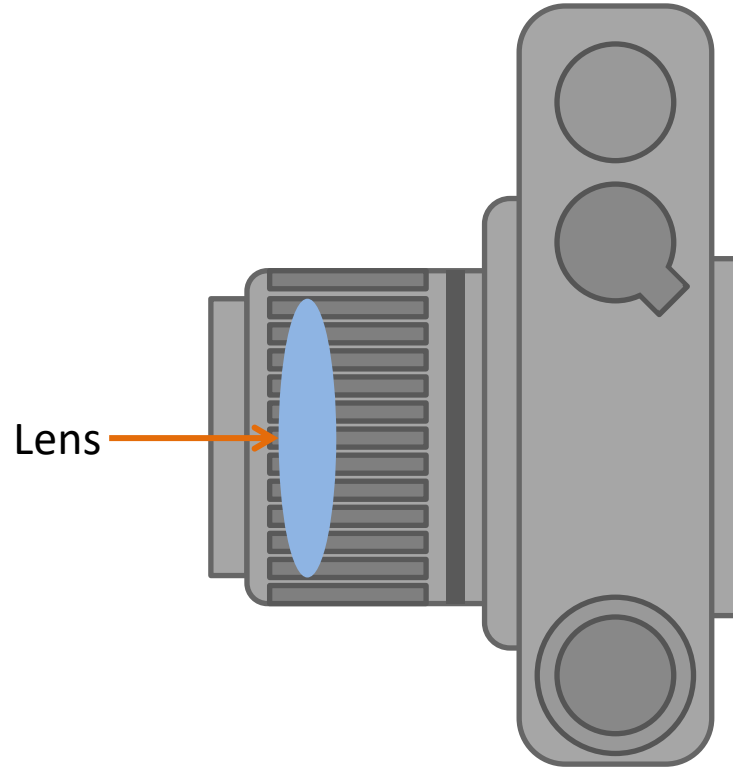


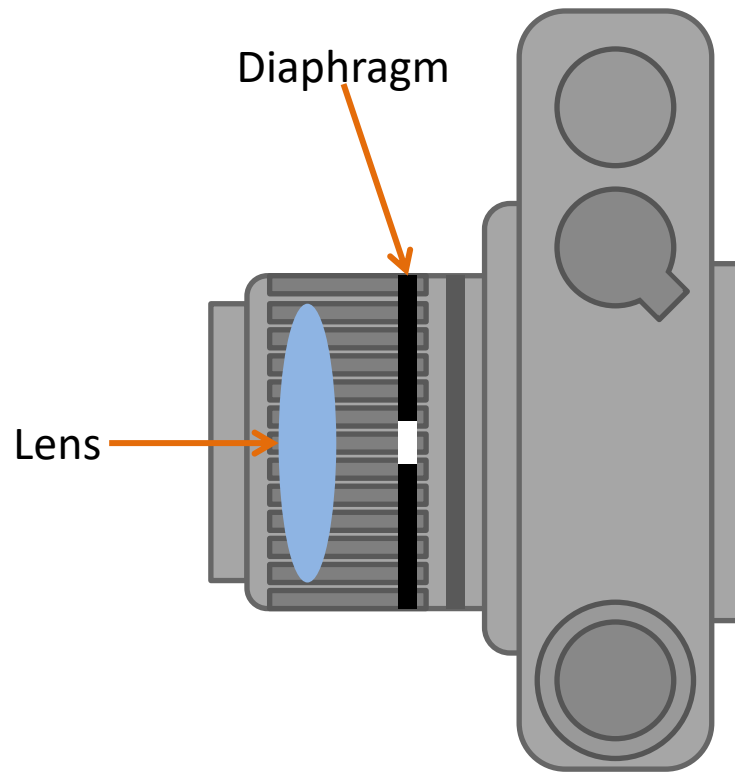


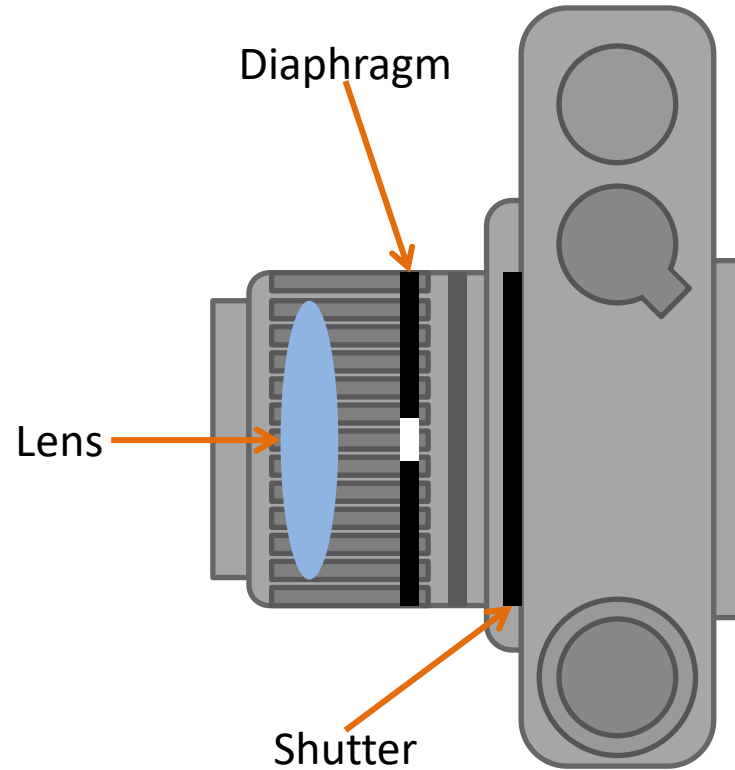


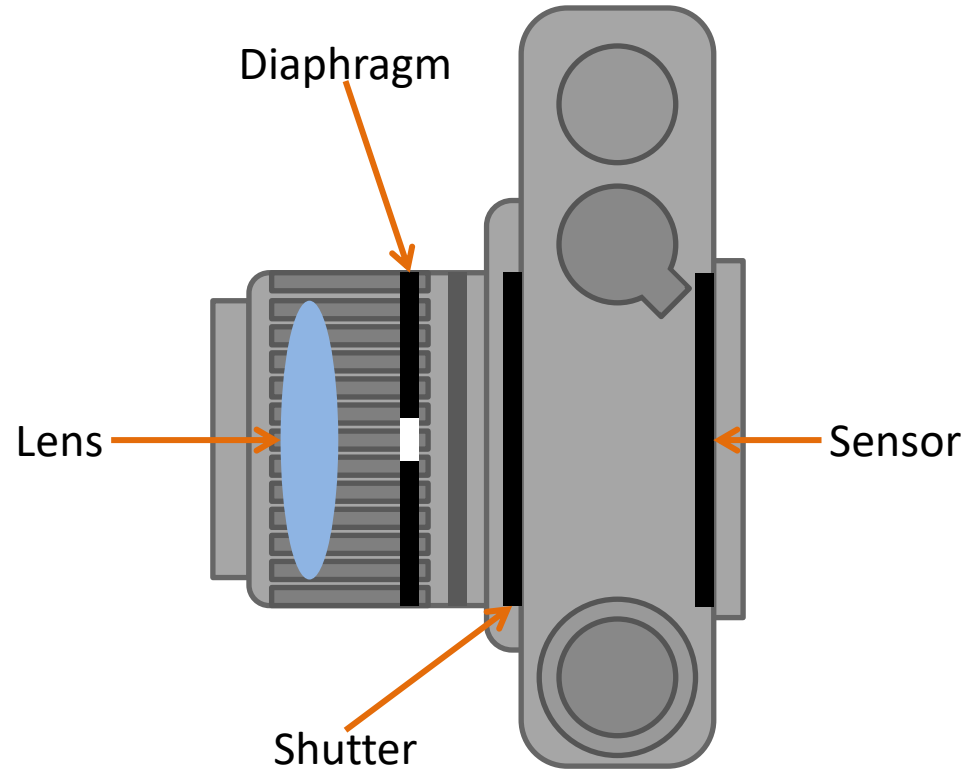


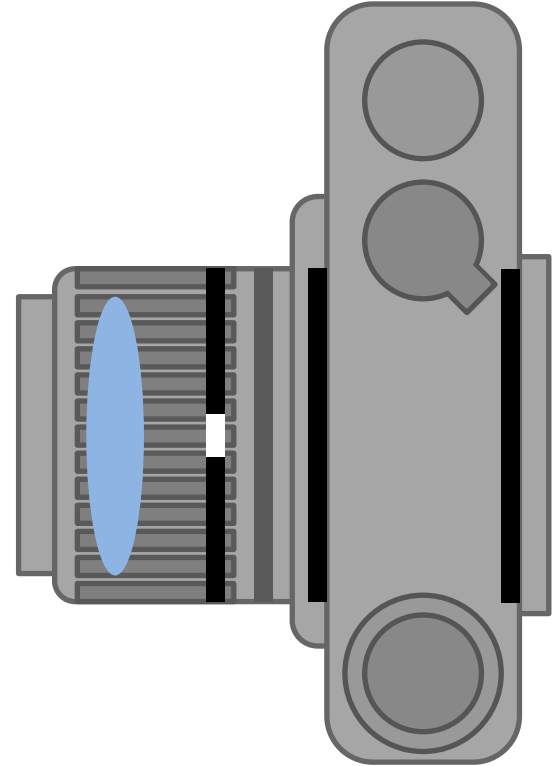


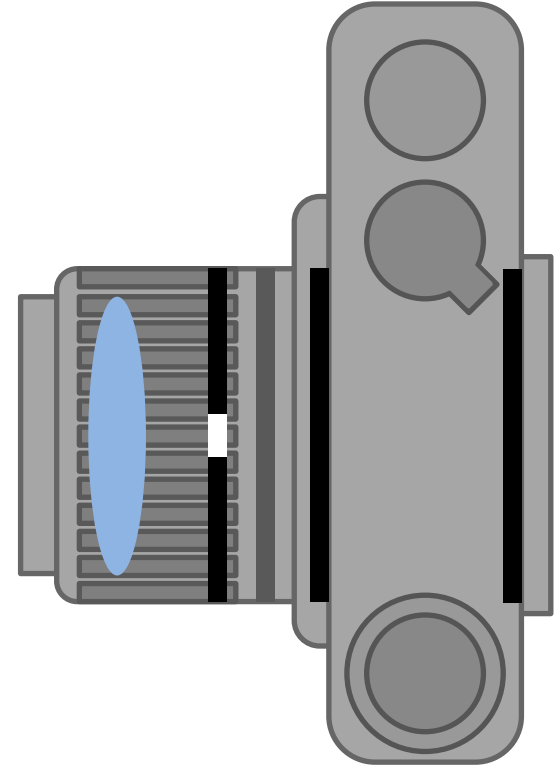
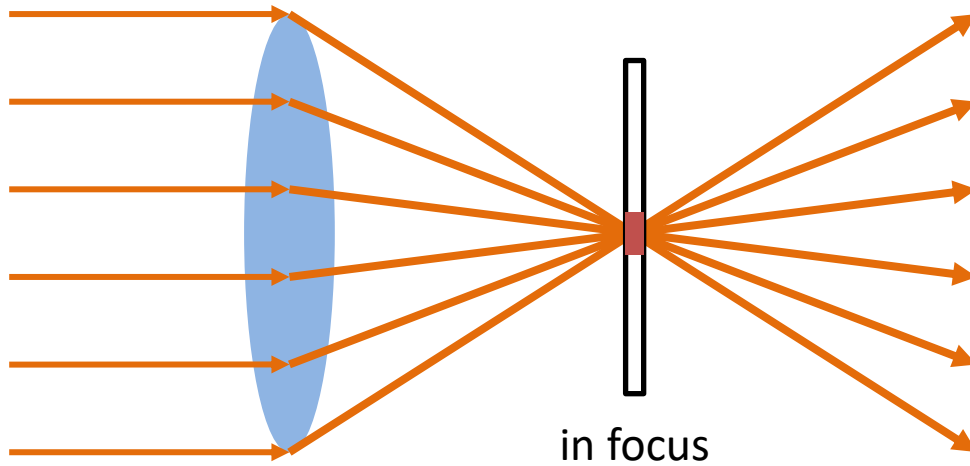


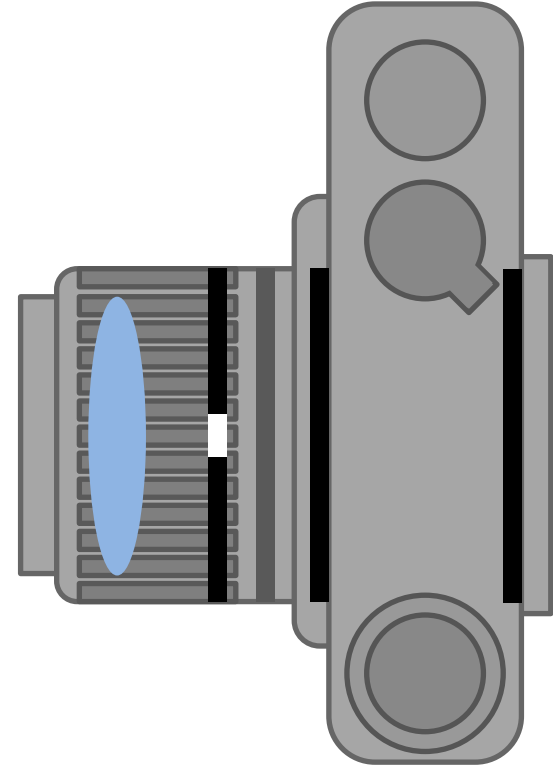
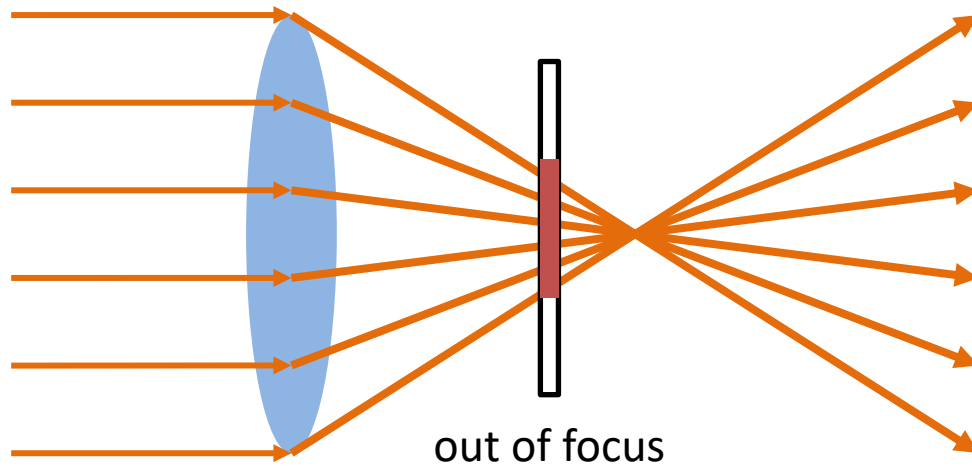


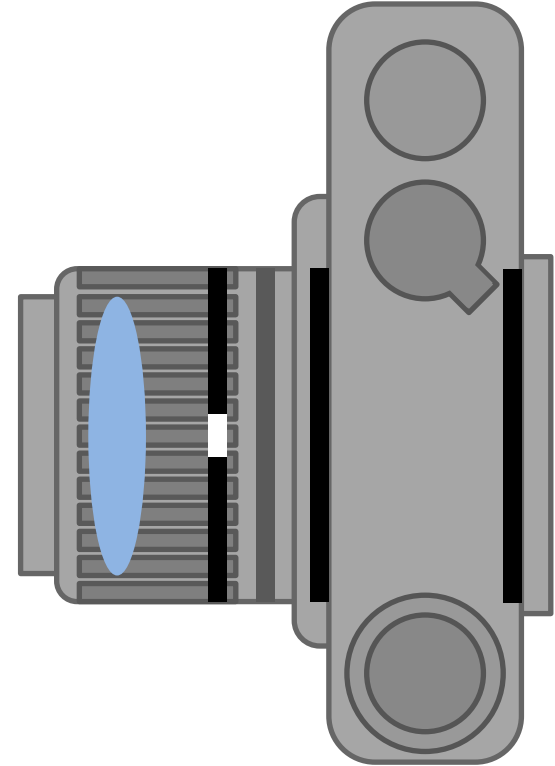
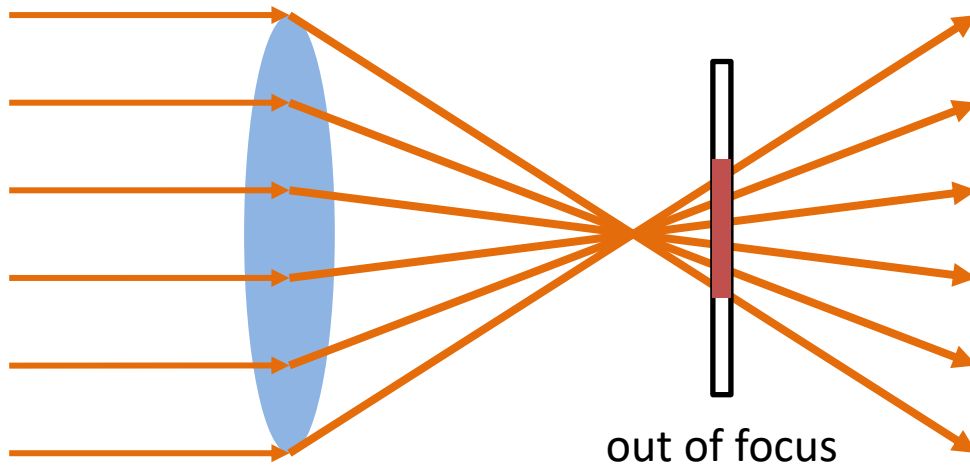


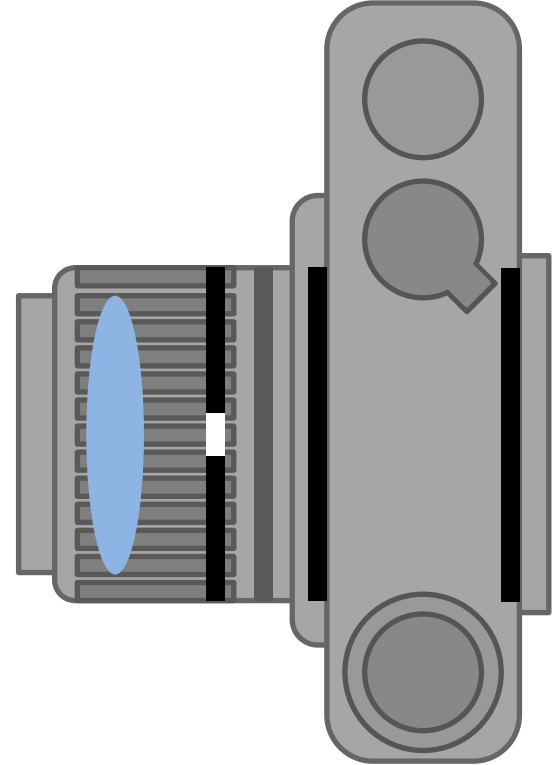
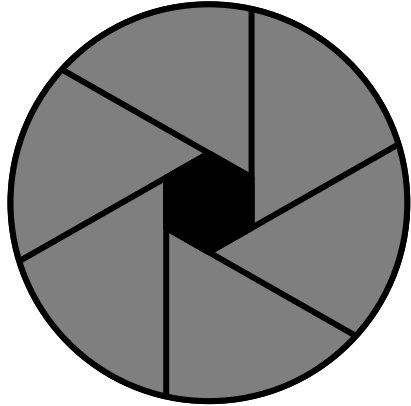


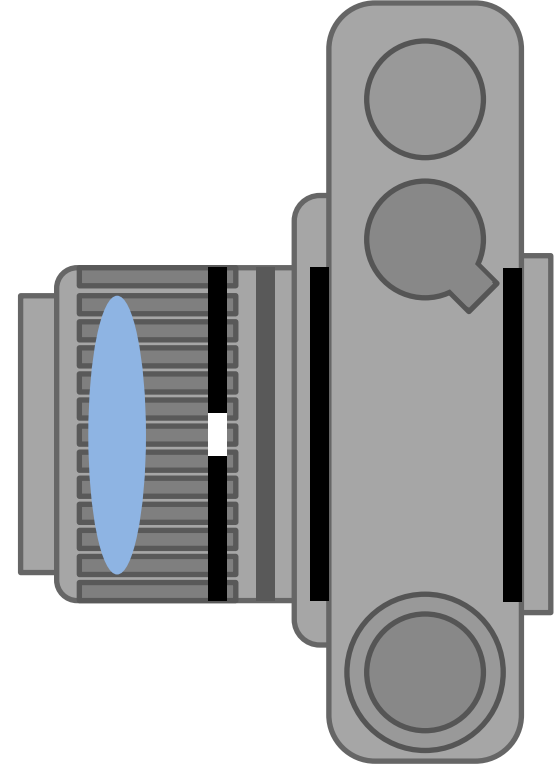
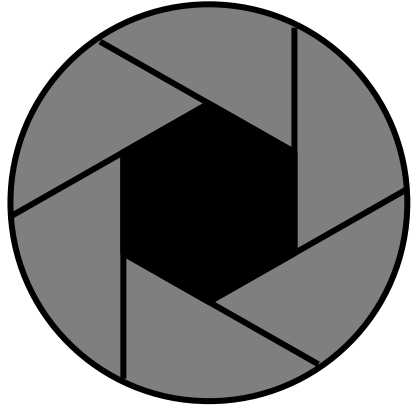


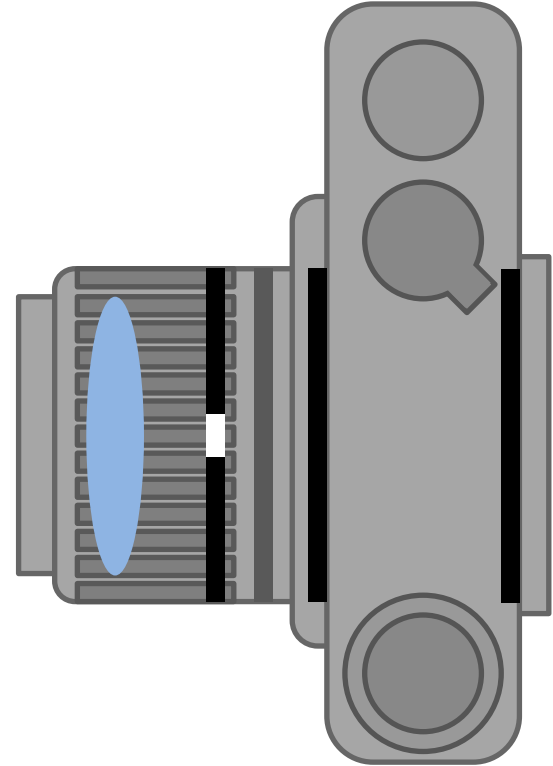
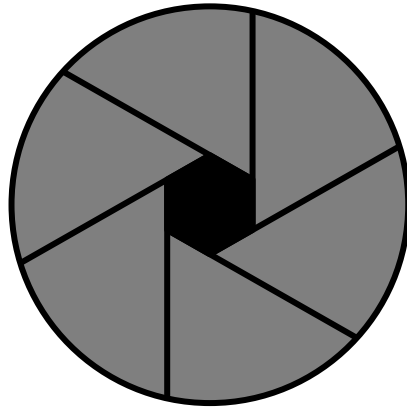
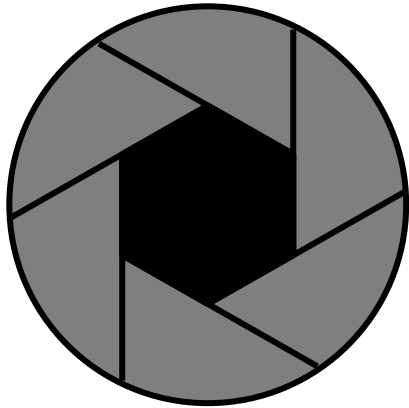


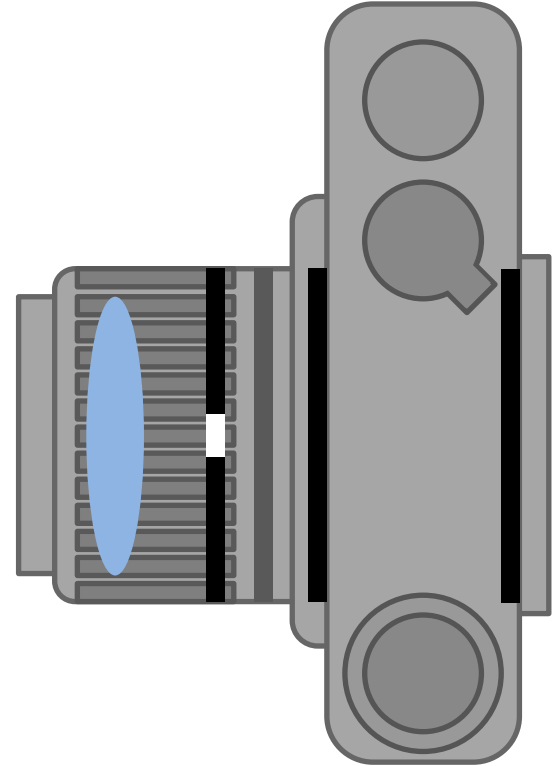
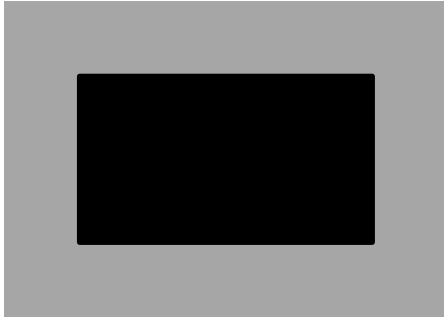


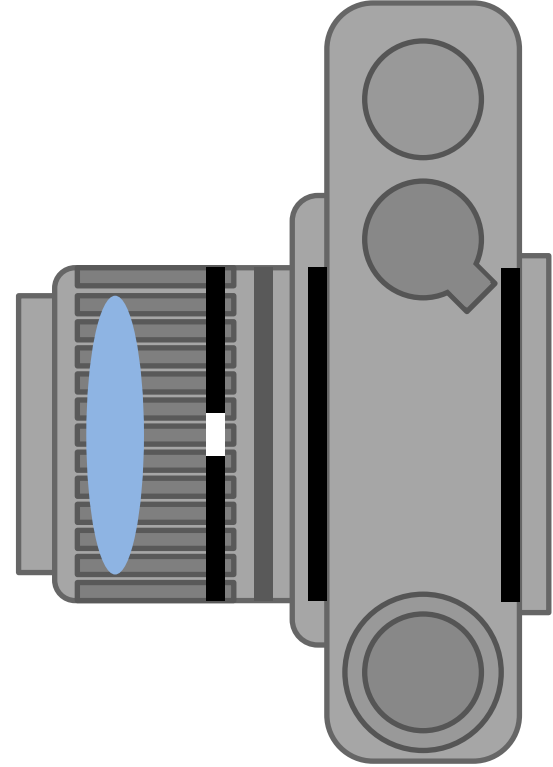
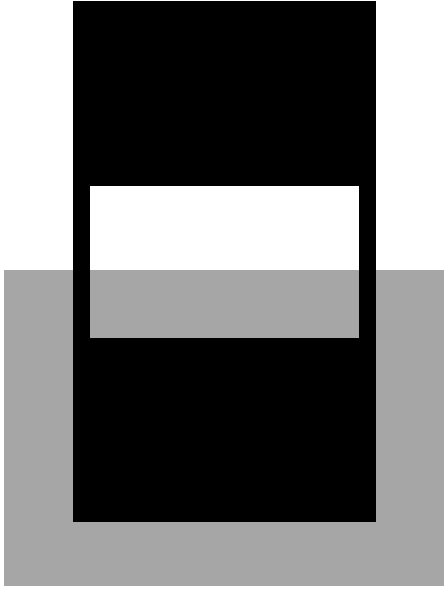


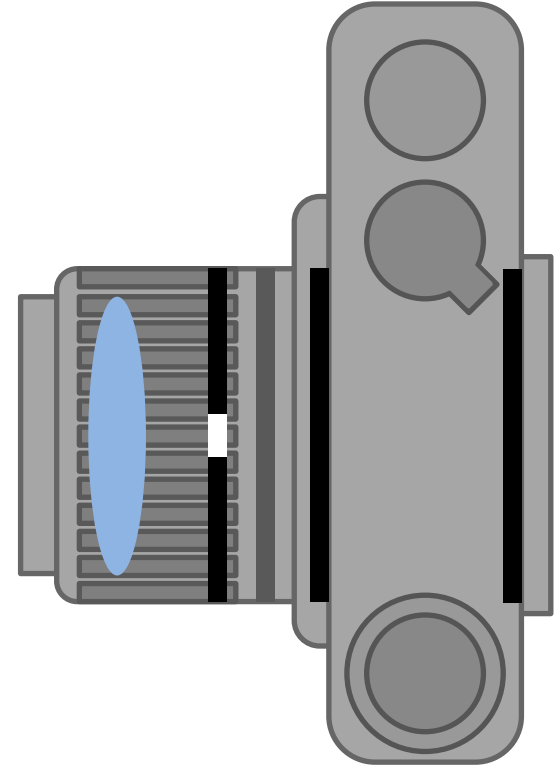
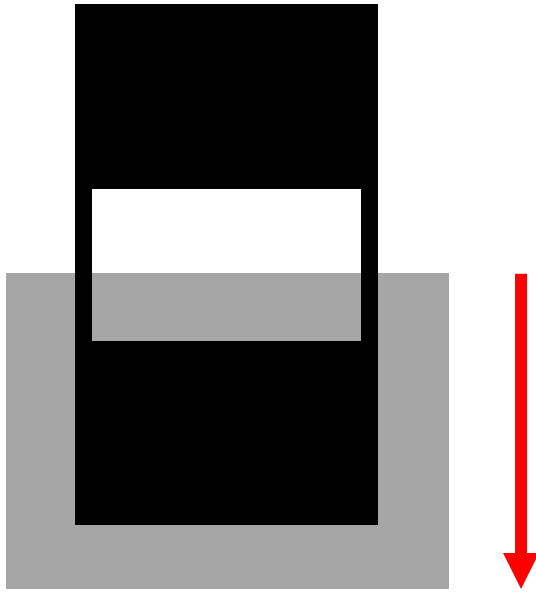


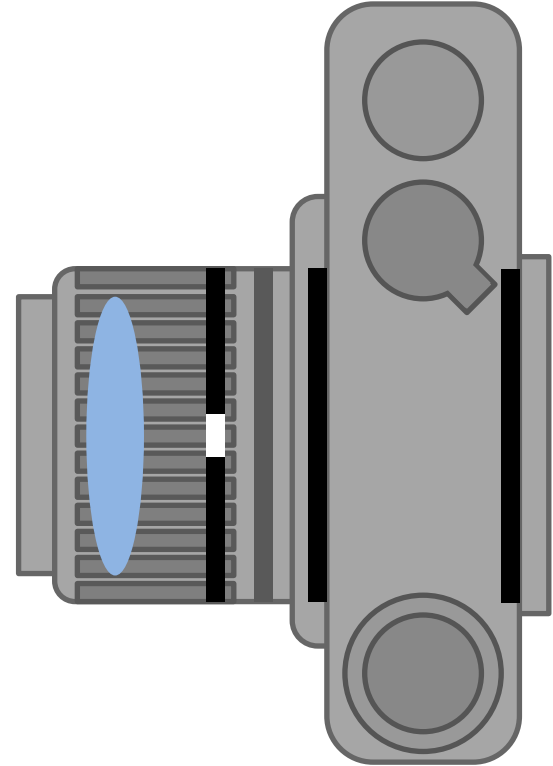
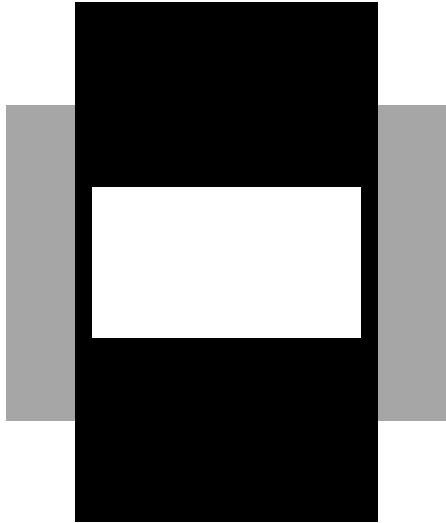


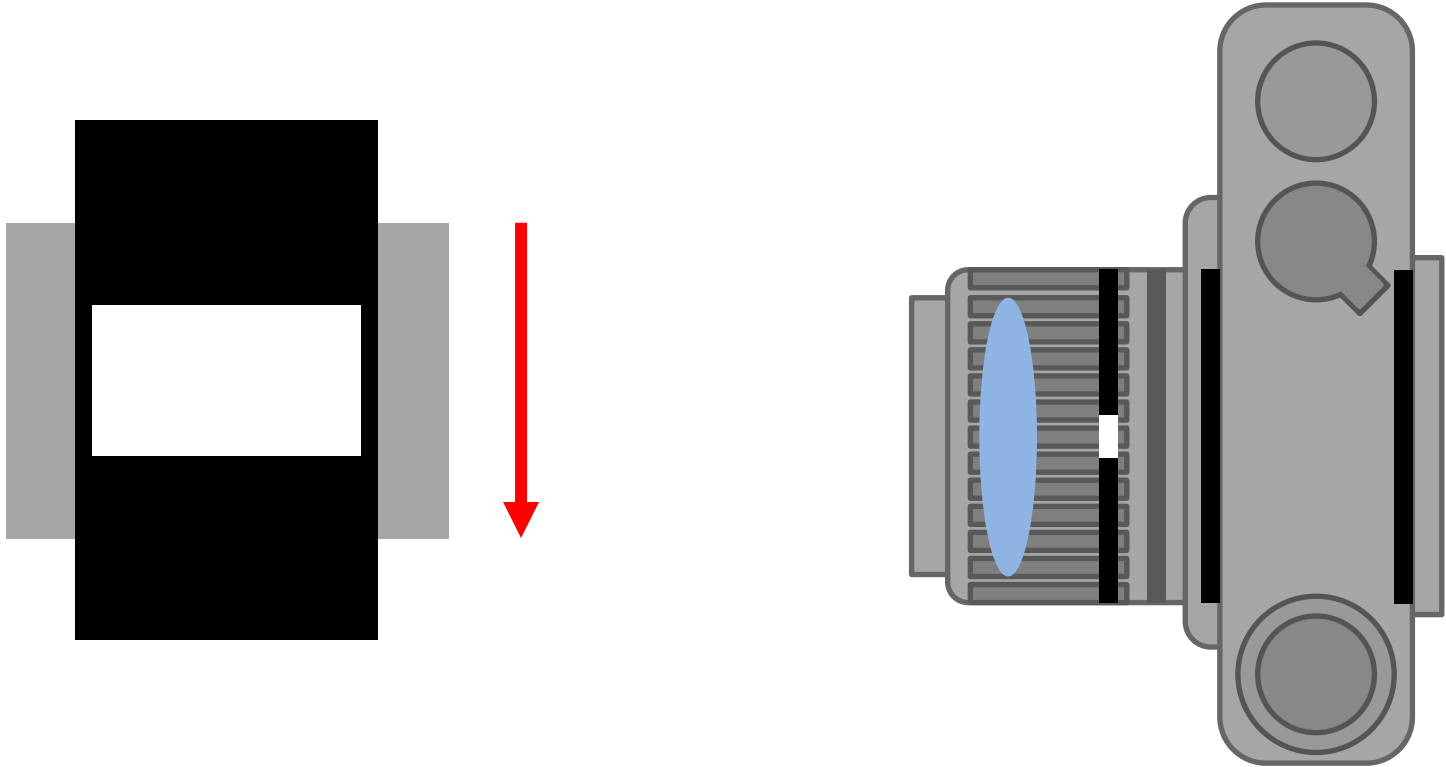


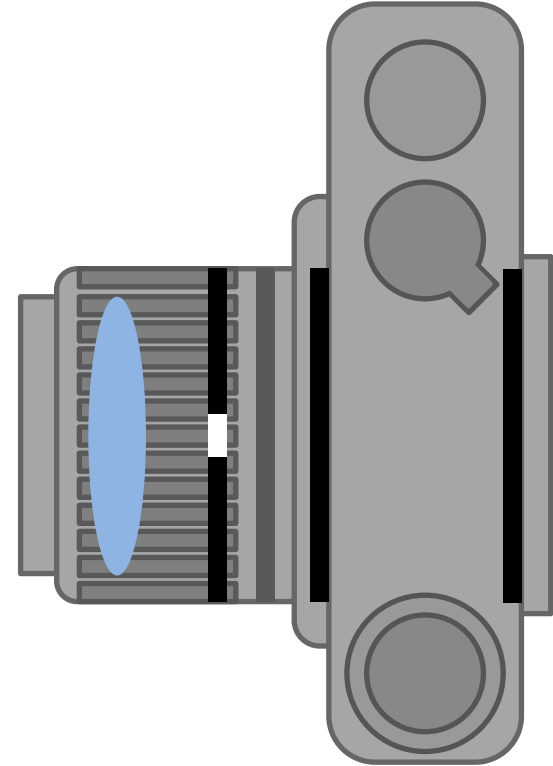
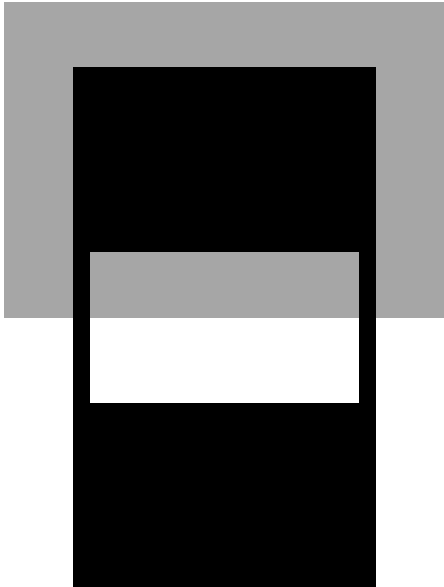


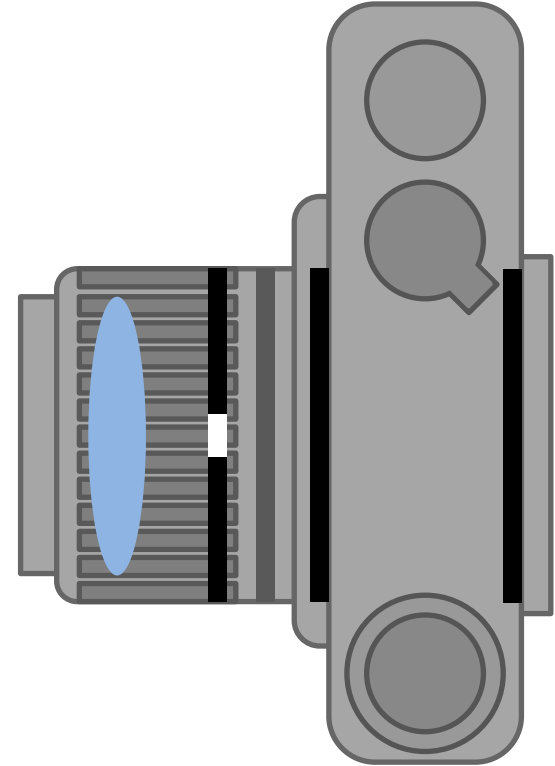
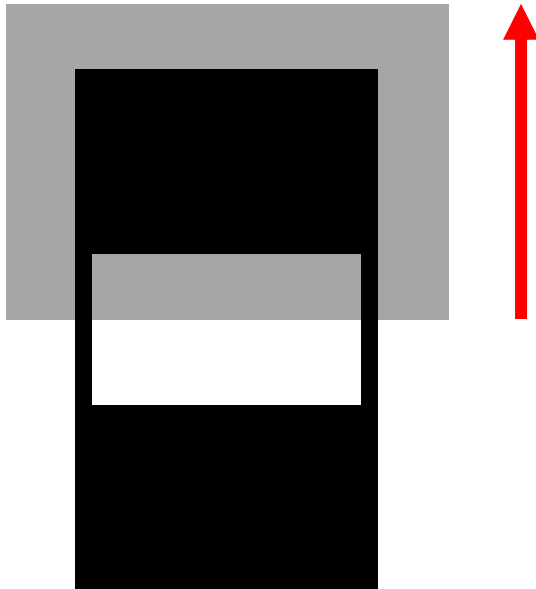


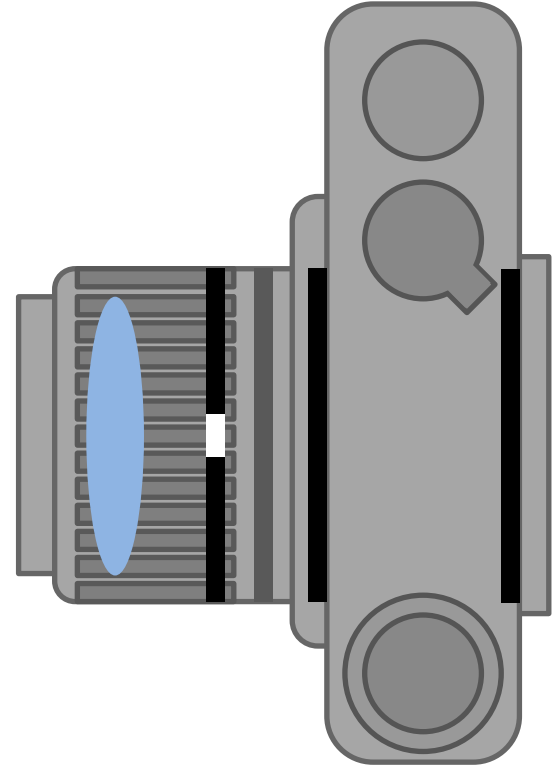


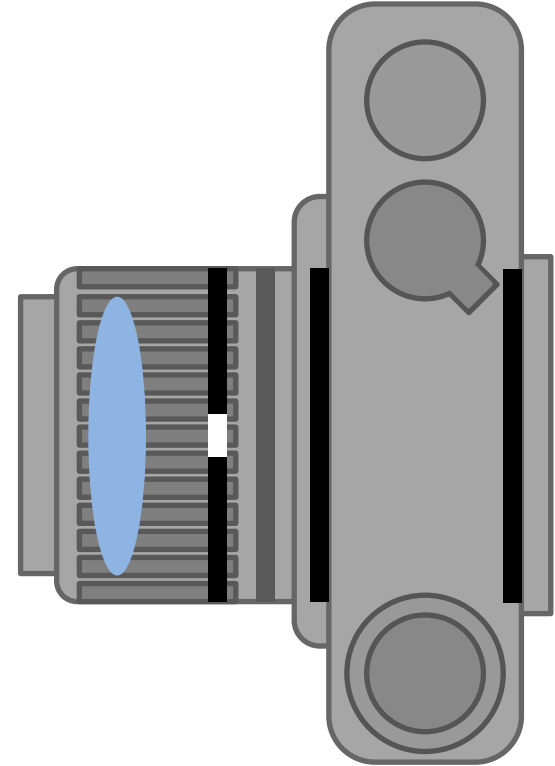
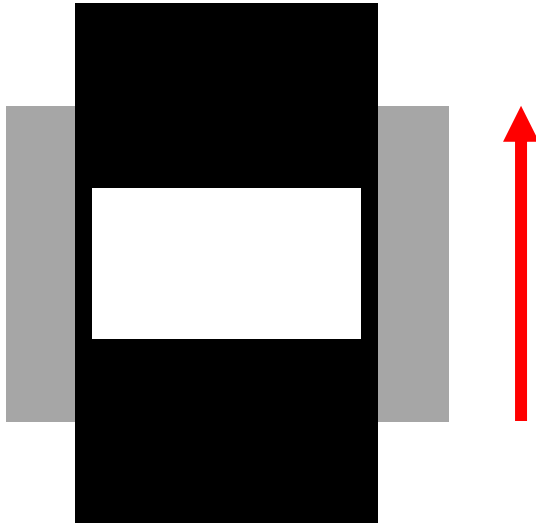


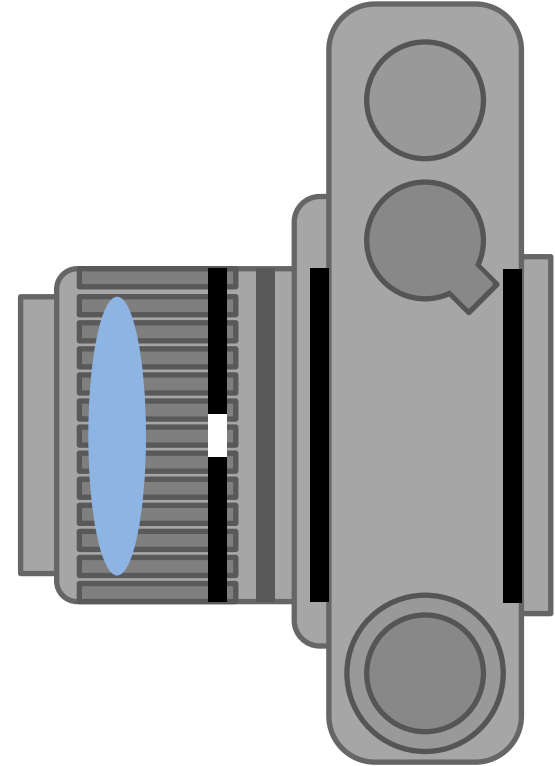
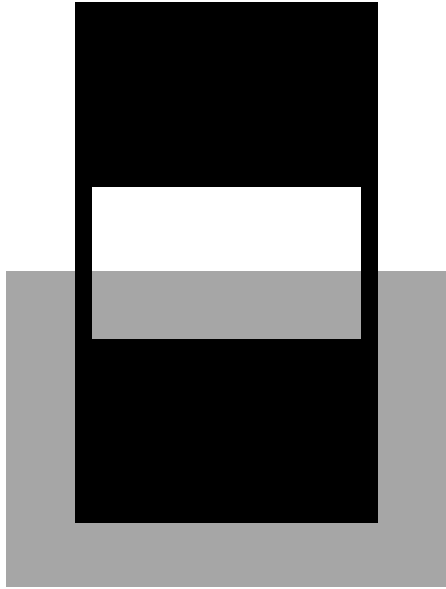












Intensity image (gray levels):



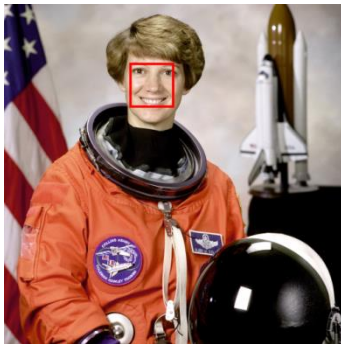
Colored image (RGB):



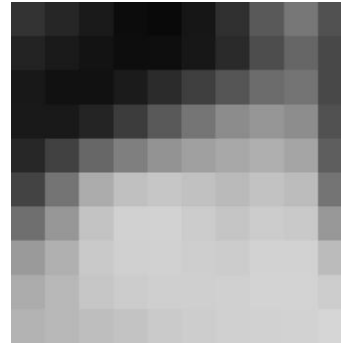
Intensity image (gray levels):



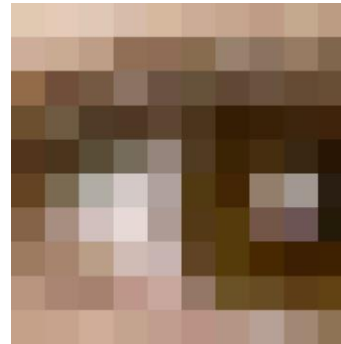
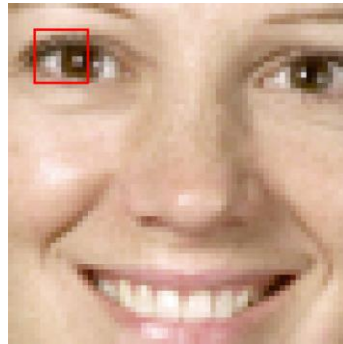
Colored image (RGB):



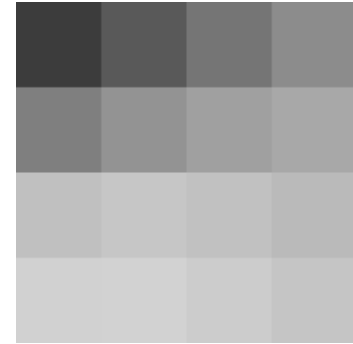
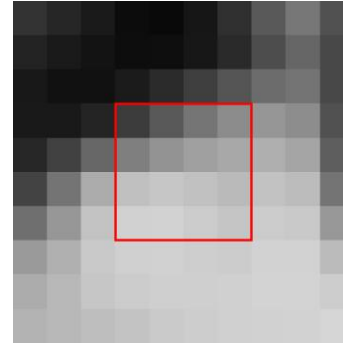
Intensity image (gray levels):



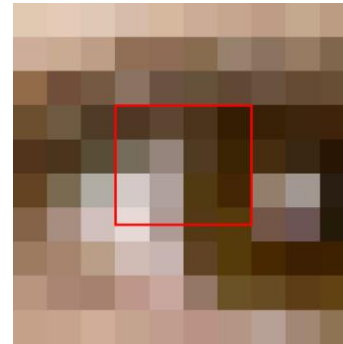
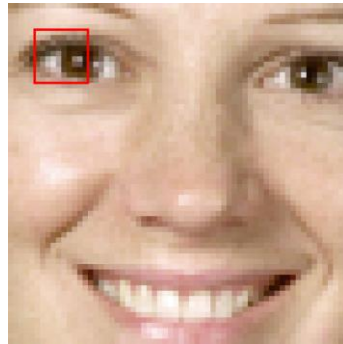
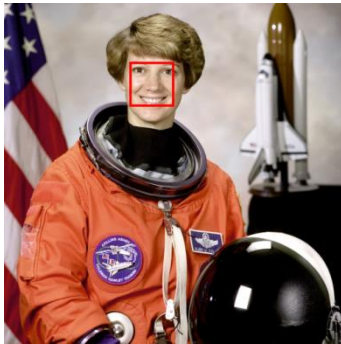
Colored image (RGB):



Intensity image (gray levels):

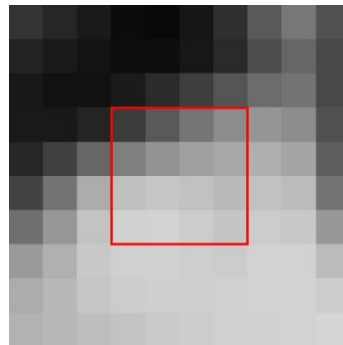


Colored image (RGB):



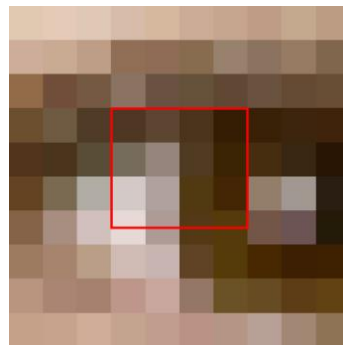
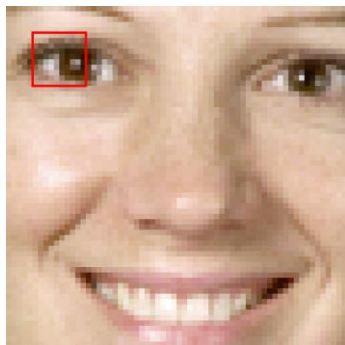
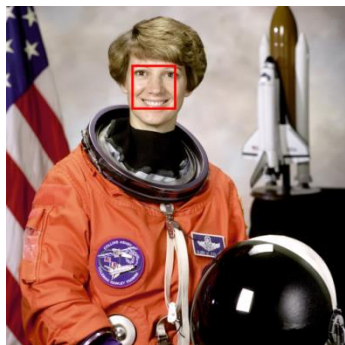
The digital image

Intensity image (gray levels):



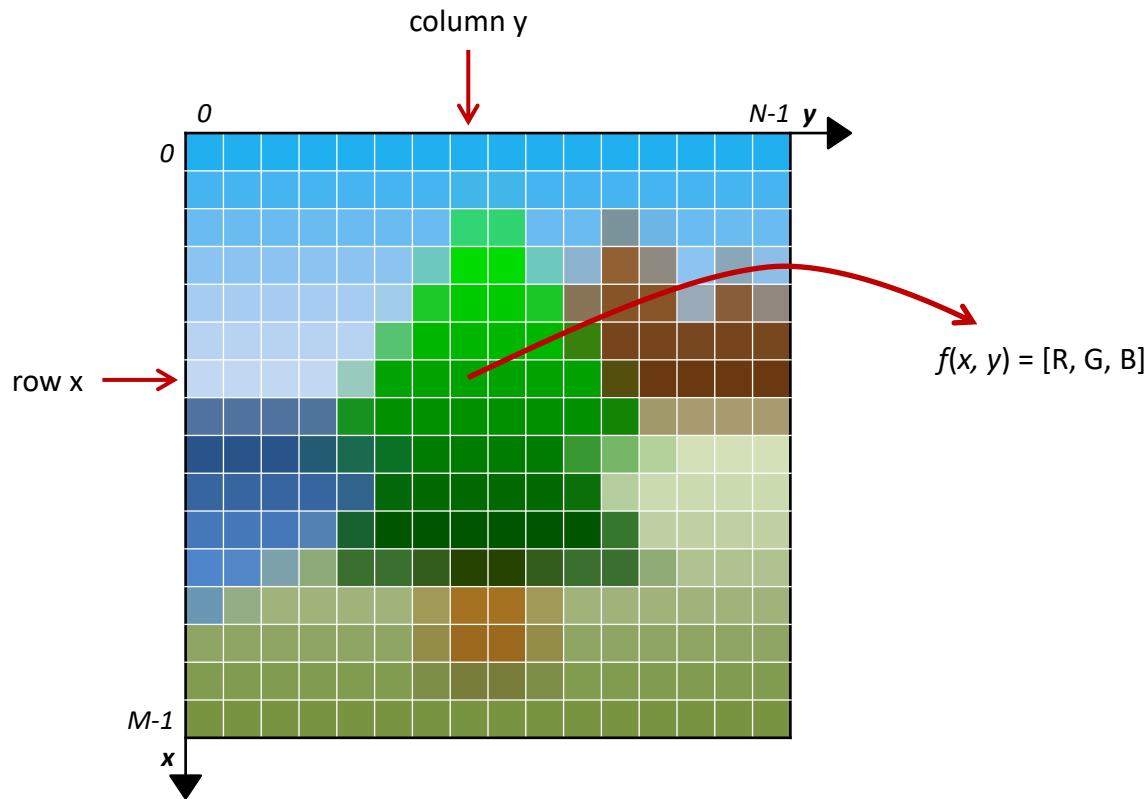
60	89	117	140
127	147	160	168
192	198	193	186
209	210	204	197

Colored image (RGB):



78	92	75	51
56	70	52	30
36	49	28	3
118	149	80	59
108	133	58	36
91	124	33	3
211	176	81	69
202	161	57	38
200	158	17	4
231	174	83	85
218	155	57	58
214	150	21	11

The digital image



M rows
N columns
 $M \times N$ pixels





R (red)





R (red)



G (green)





R (red)



G (green)



B (blue)





R (red)



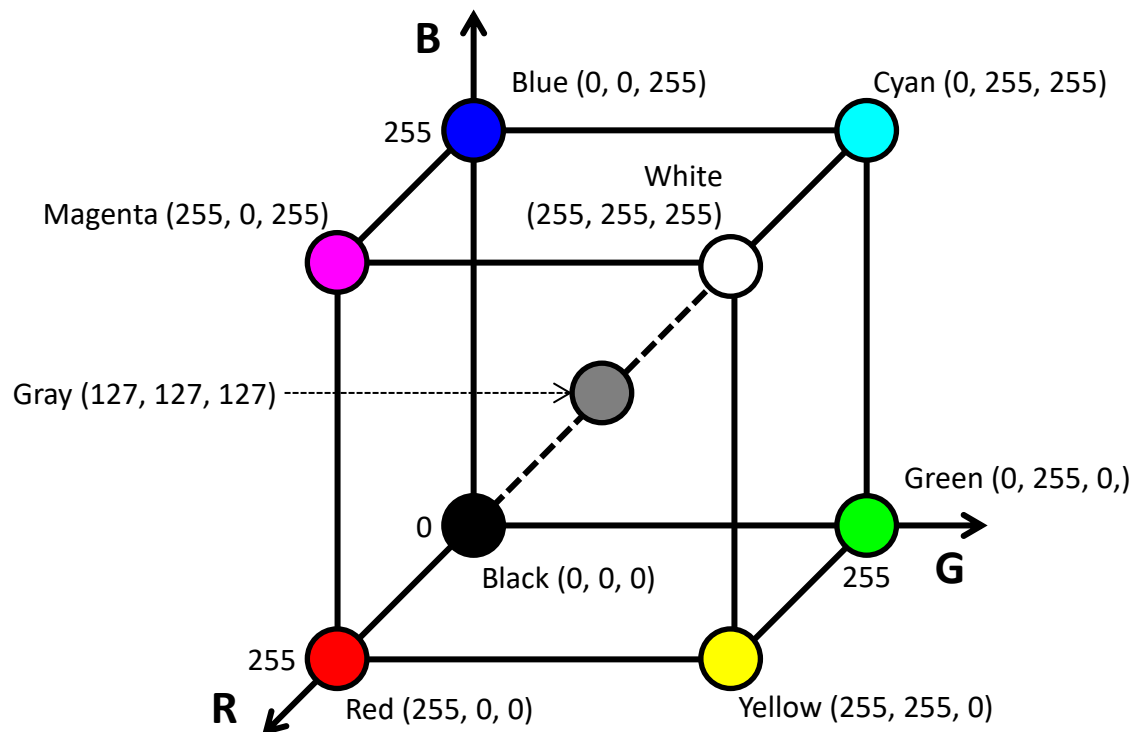
G (green)



B (blue)

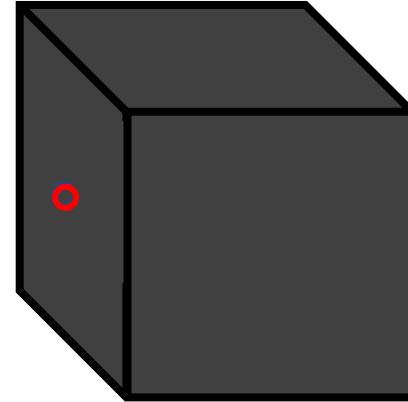


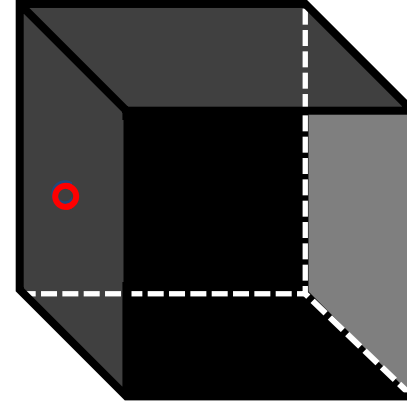
The RGB color space

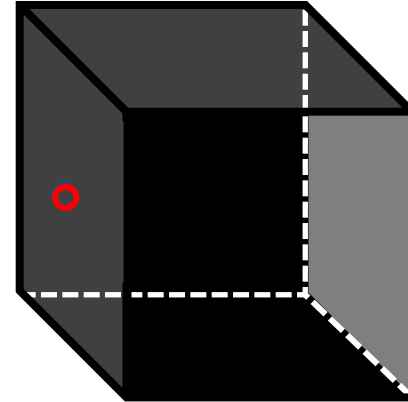
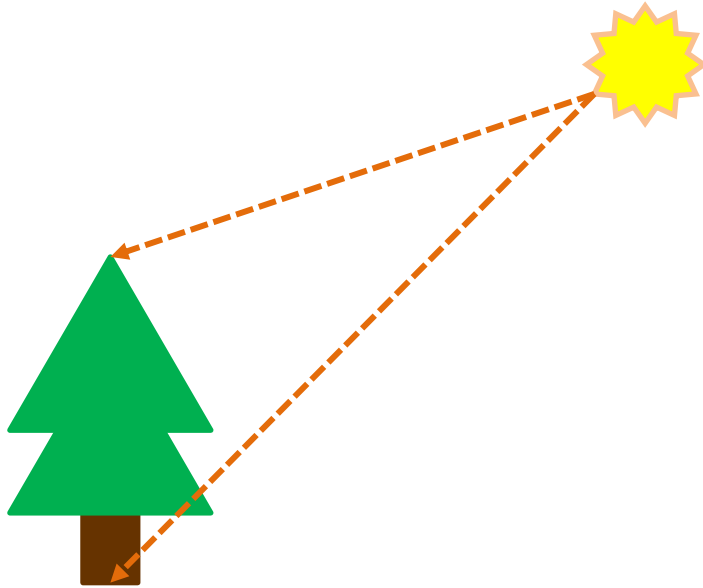


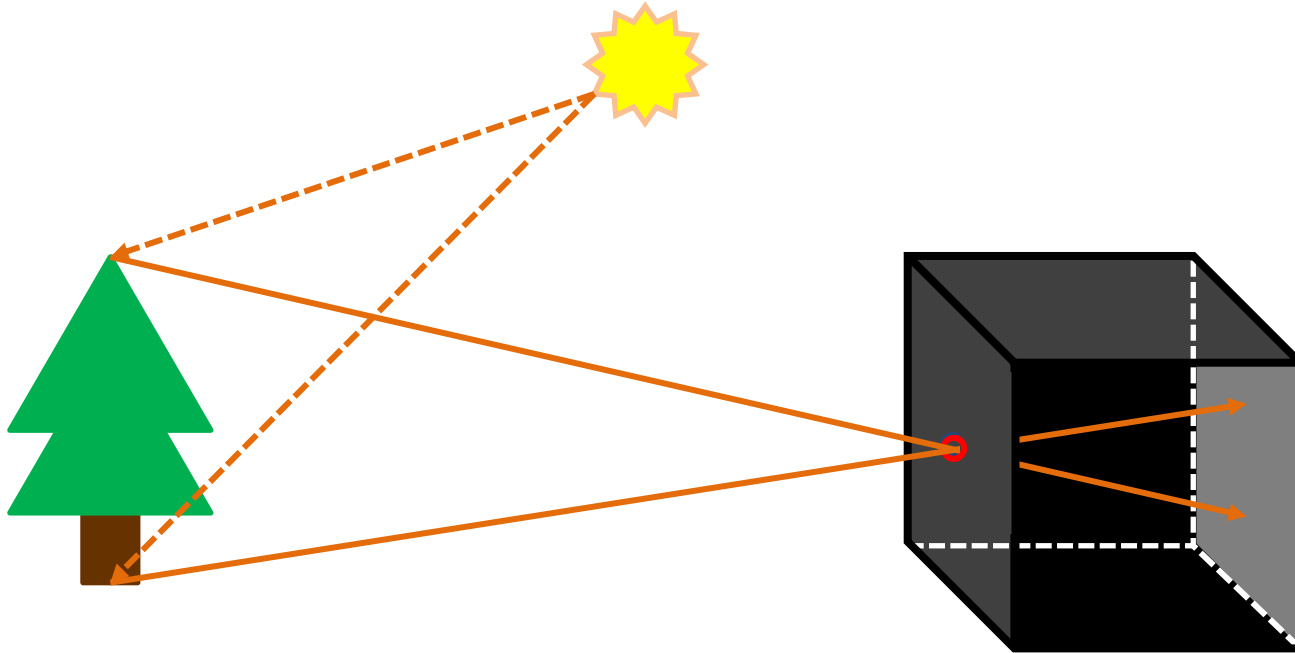


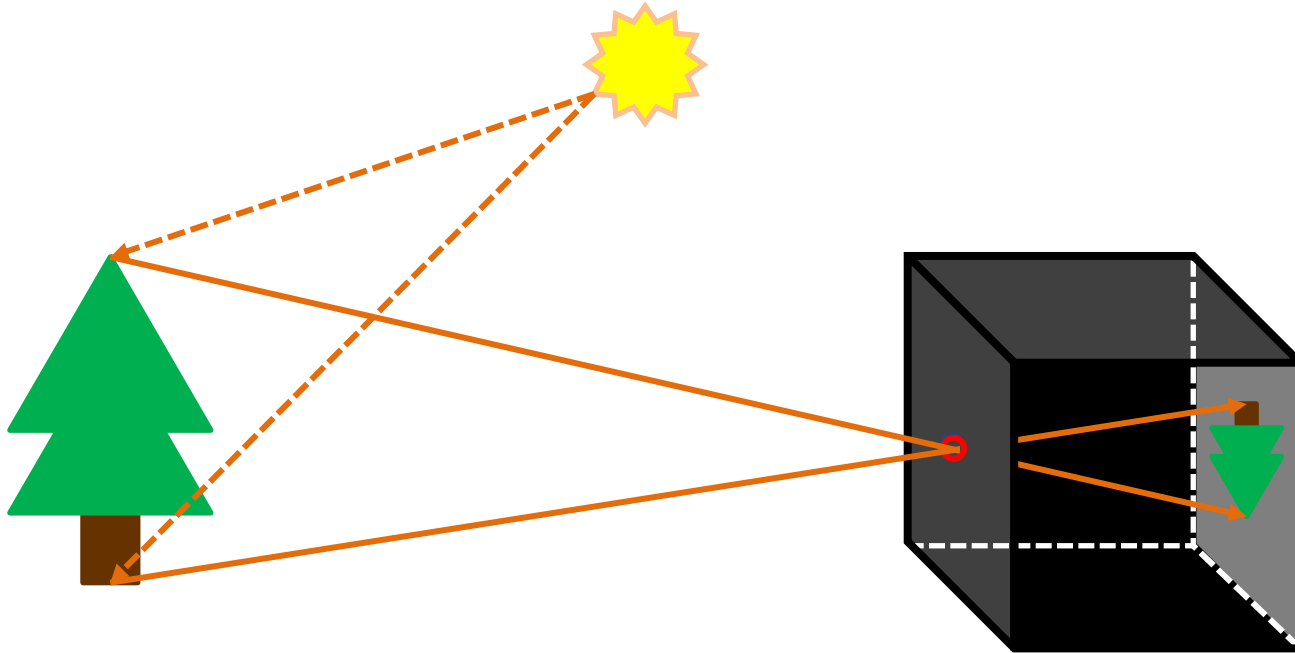












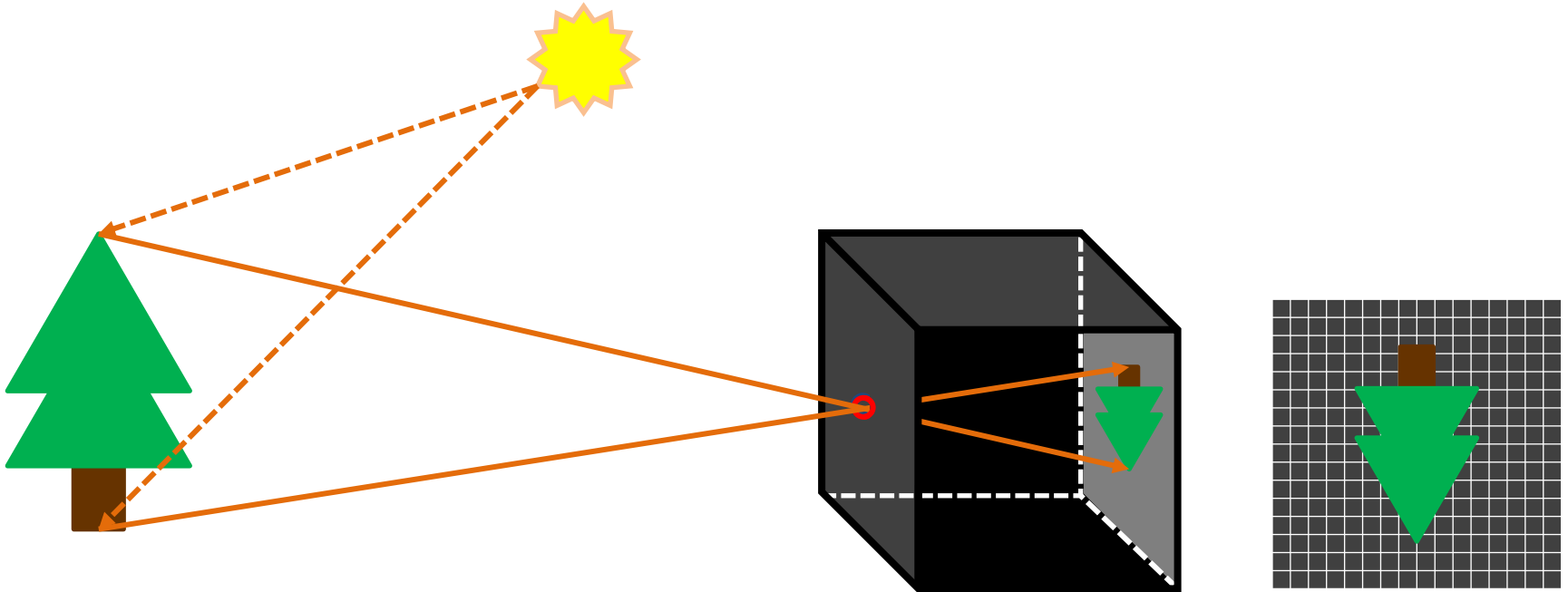
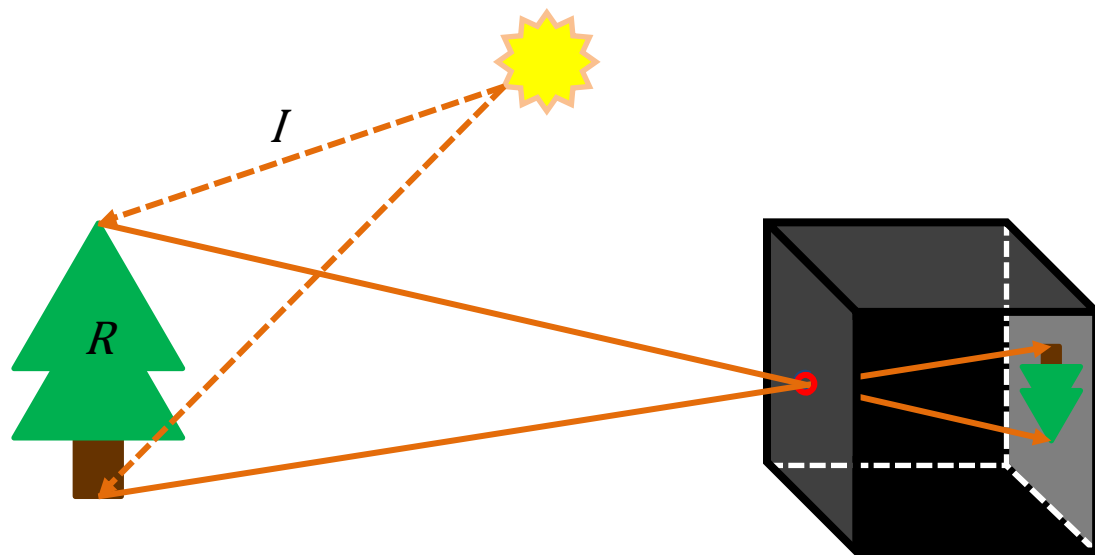


Image acquisition



I : luminance
 $0 < i(x,y) < \infty$

R : reflectance
 $0 < r(x,y) < 1$

$$f(x, y) = i(x, y) \times r(x, y)$$

$i(x, y)$ (in lux ou lumen/m²)

900	Sunny day
-----	-----------

100	Cloud day
-----	-----------

10	Office
----	--------

0.001	Clear night
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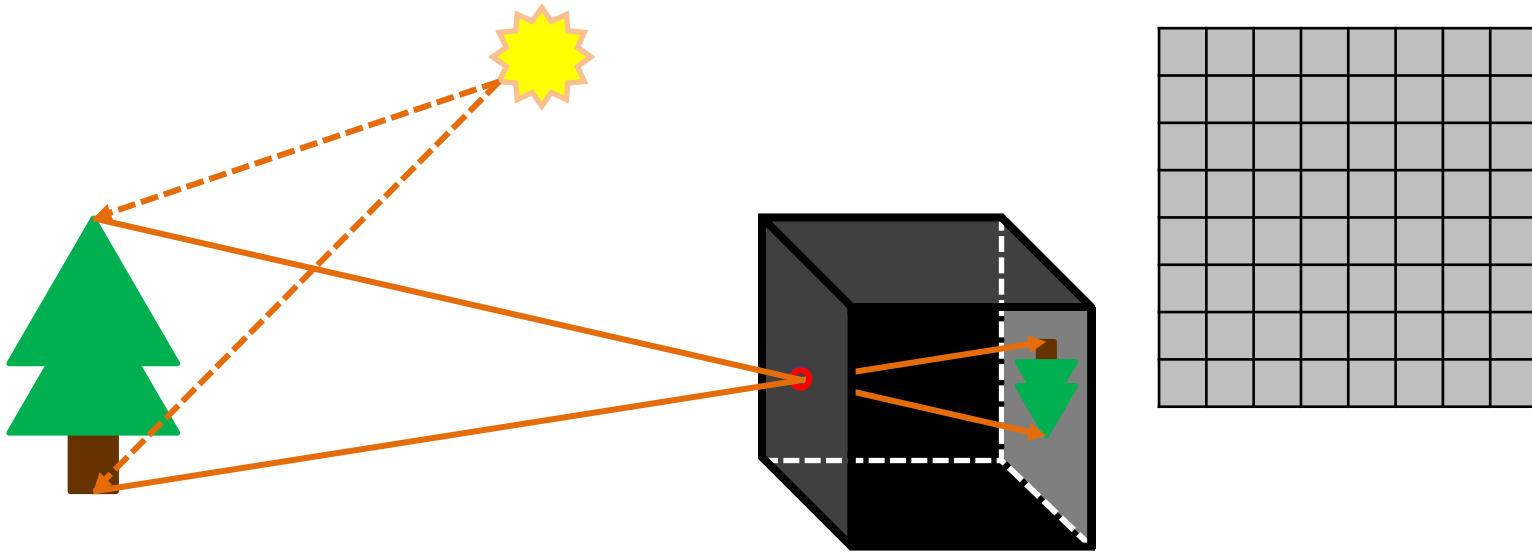
$r(x, y)$

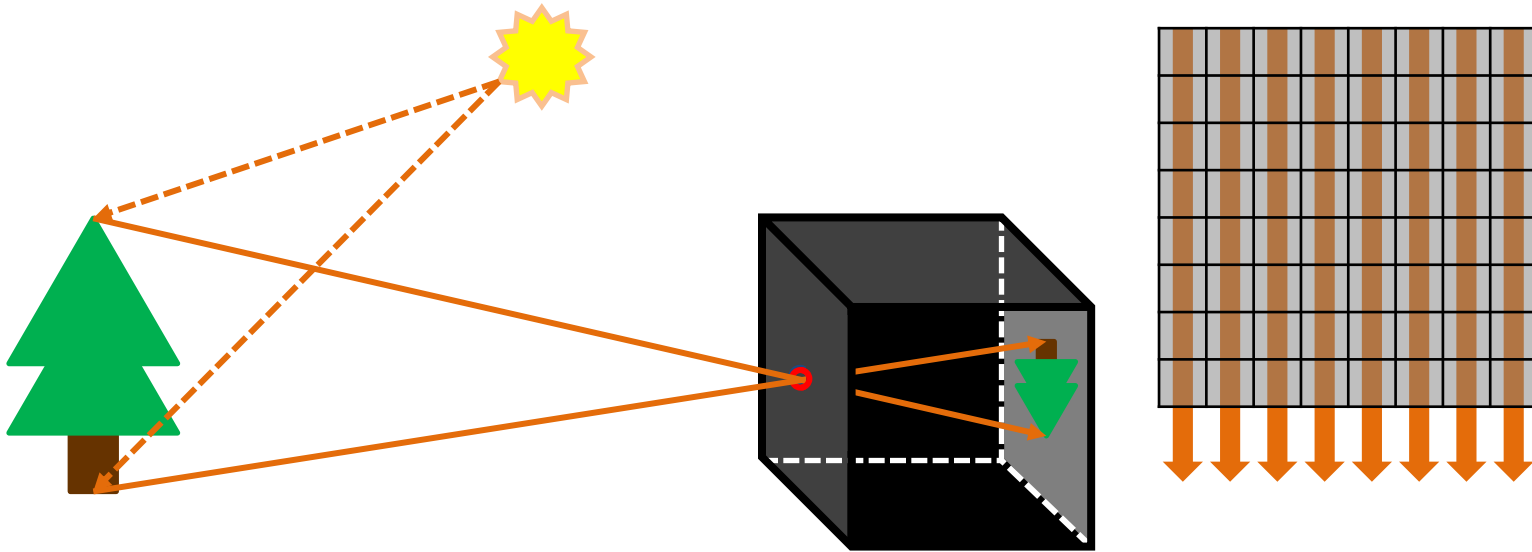
0.93	Snow
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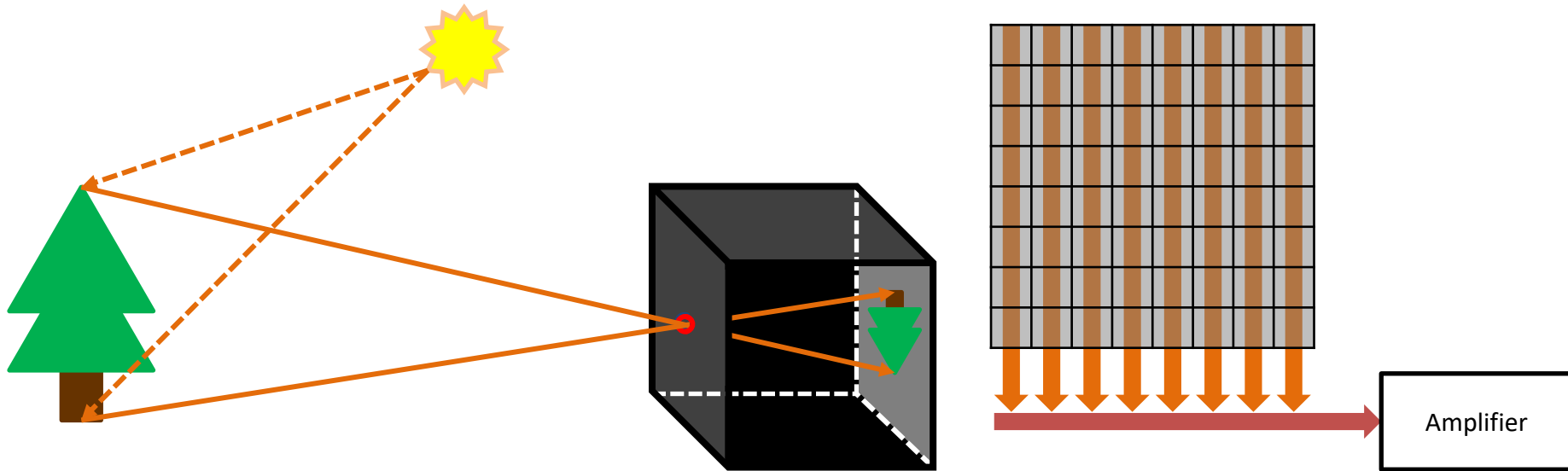
0.80	White wall
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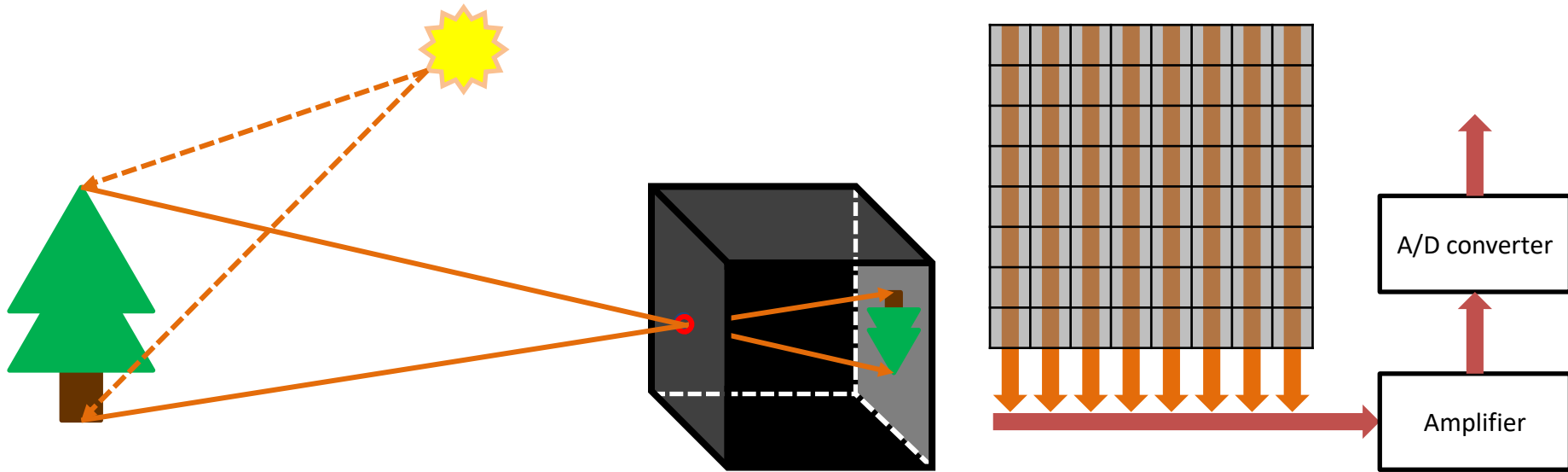
0.65	Stainless steel
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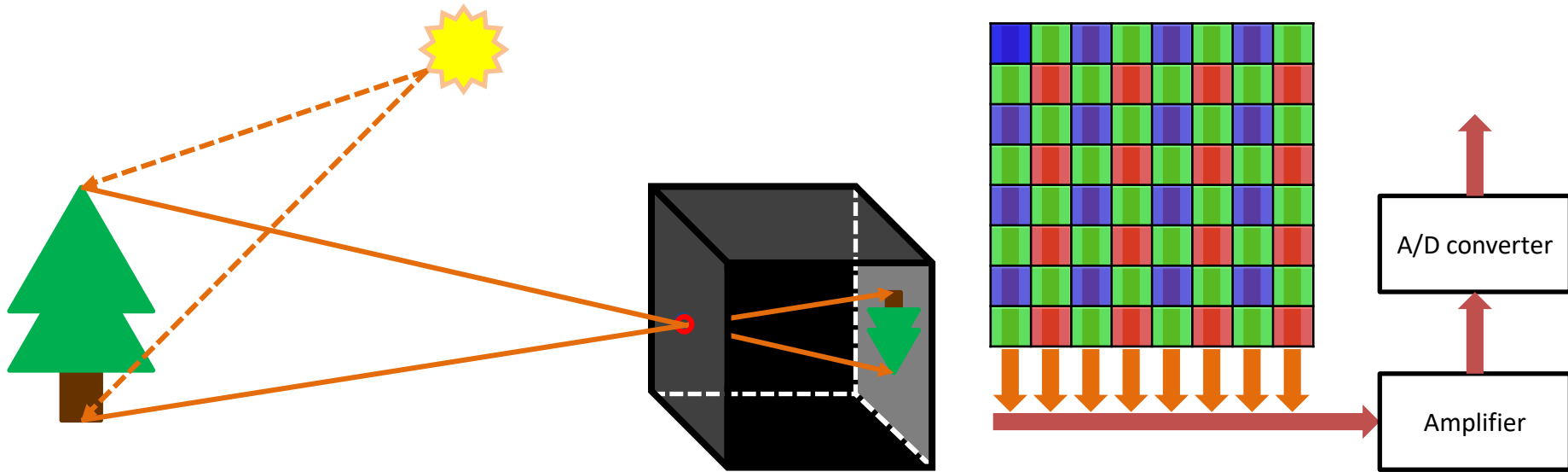
0.01	Black velvet
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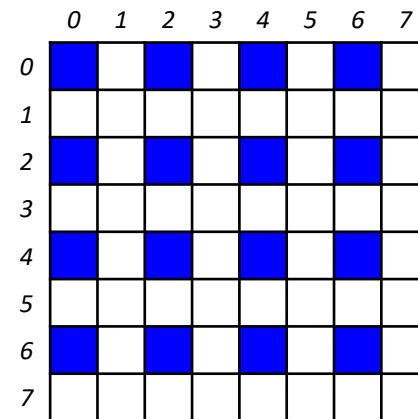
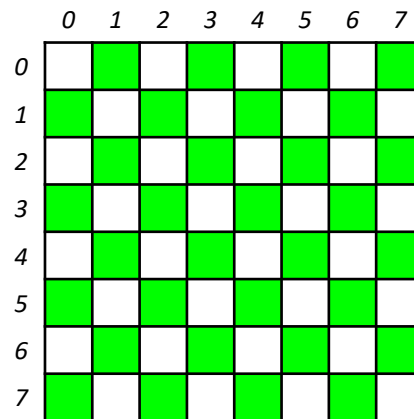
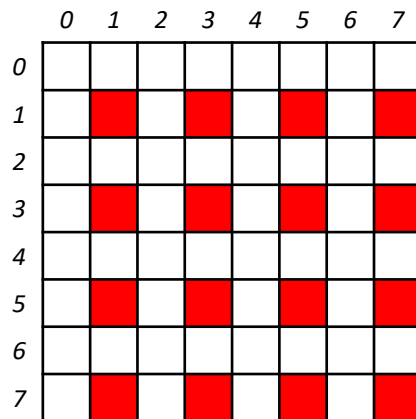
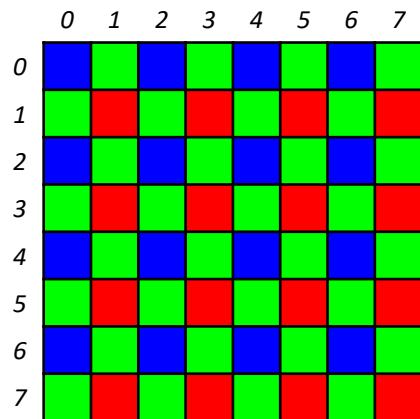




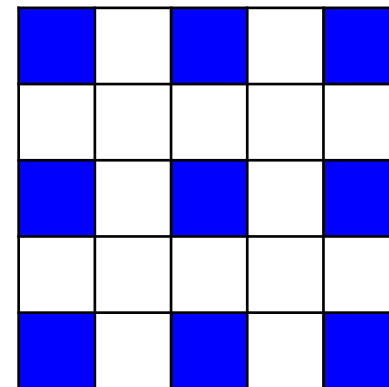
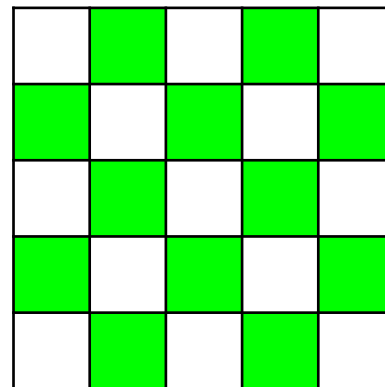
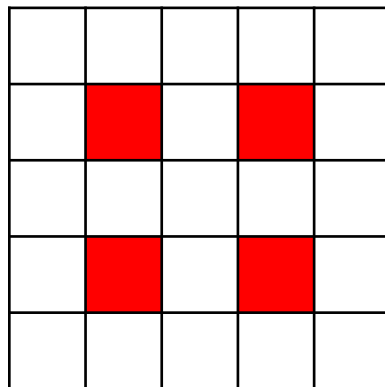
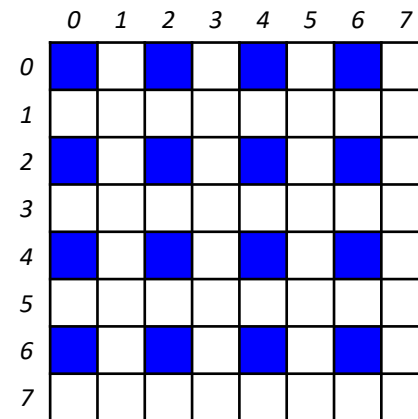
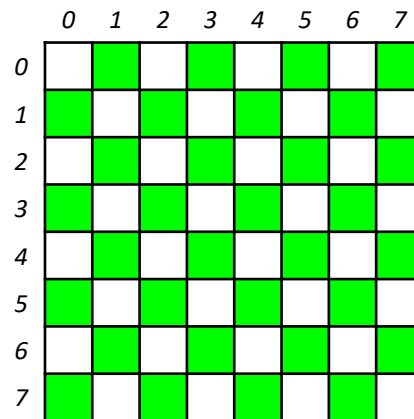
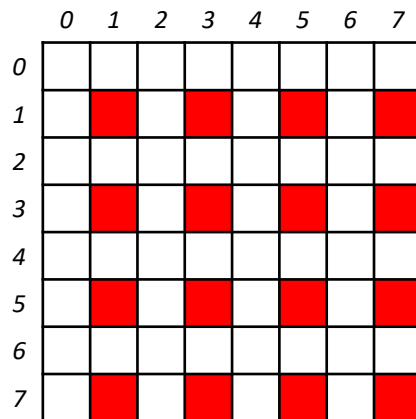
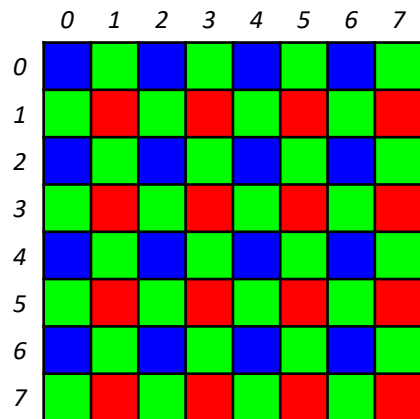
CCD sensors and Bayer pattern

	0	1	2	3	4	5	6	7
0	Blue	Green	Blue	Green	Blue	Green	Blue	Green
1	Green	Red	Green	Red	Green	Red	Green	Red
2	Blue	Green	Blue	Green	Blue	Green	Blue	Green
3	Green	Red	Green	Red	Green	Red	Green	Red
4	Blue	Green	Blue	Green	Blue	Green	Blue	Green
5	Green	Red	Green	Red	Green	Red	Green	Red
6	Blue	Green	Blue	Green	Blue	Green	Blue	Green
7	Green	Red	Green	Red	Green	Red	Green	Red

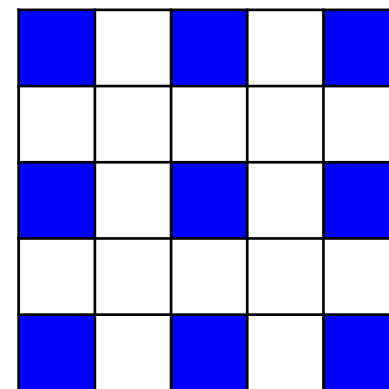
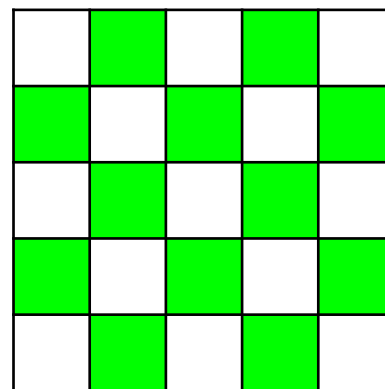
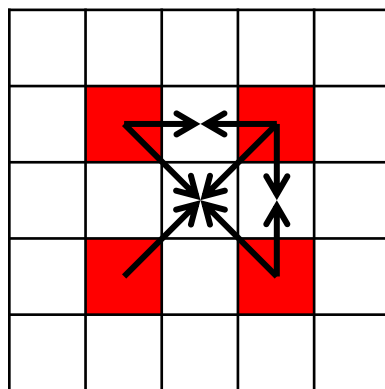
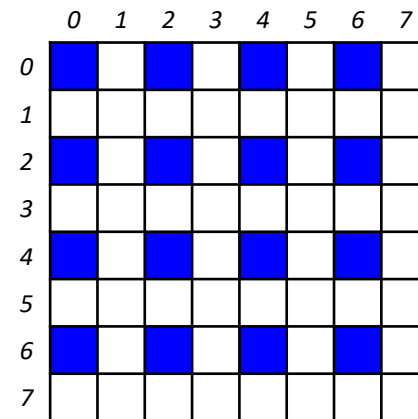
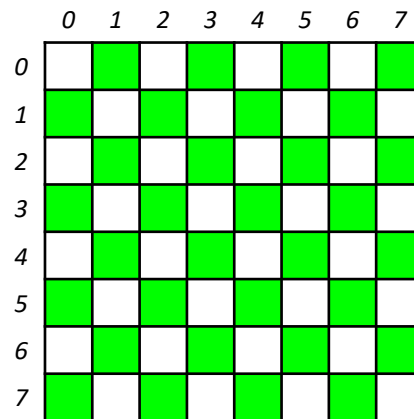
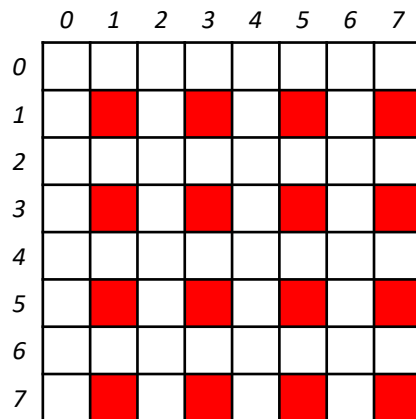
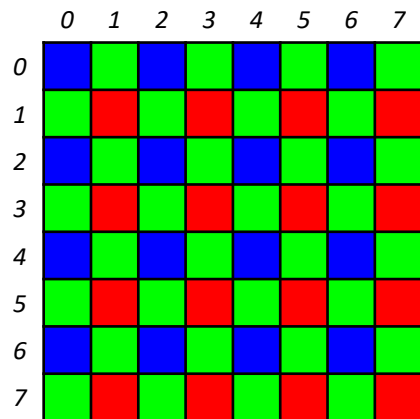
CCD sensors and Bayer pattern



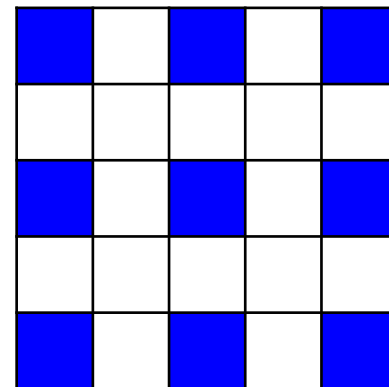
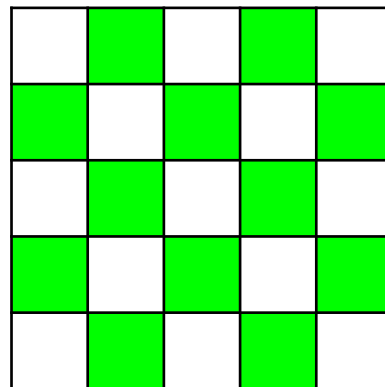
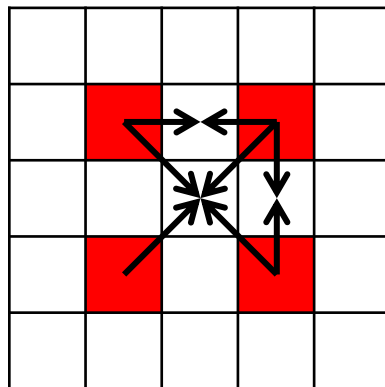
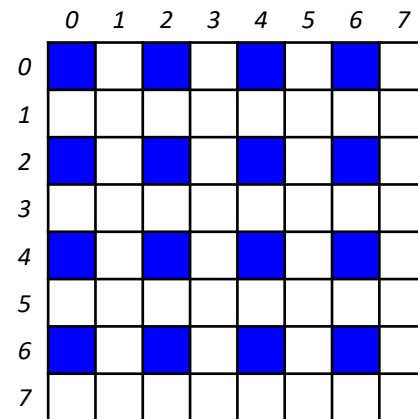
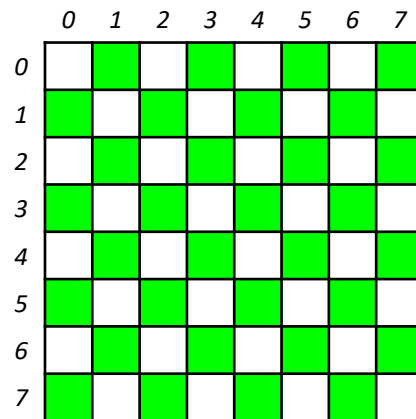
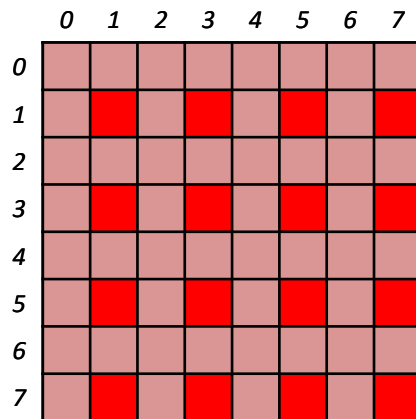
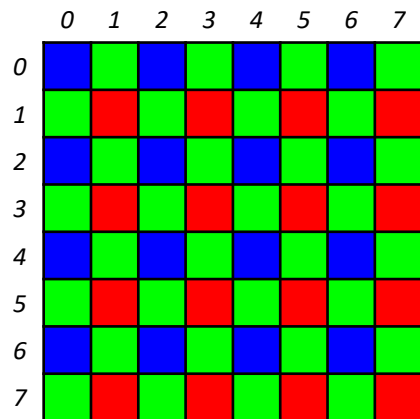
CCD sensors and Bayer pattern



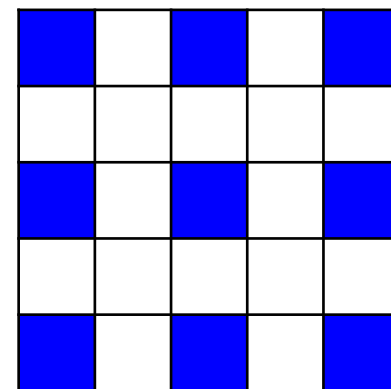
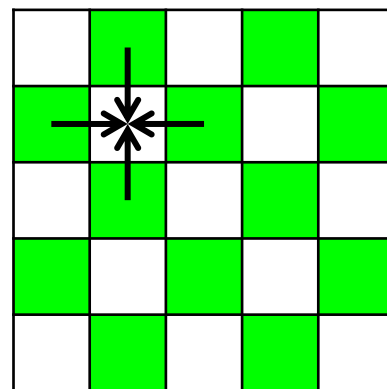
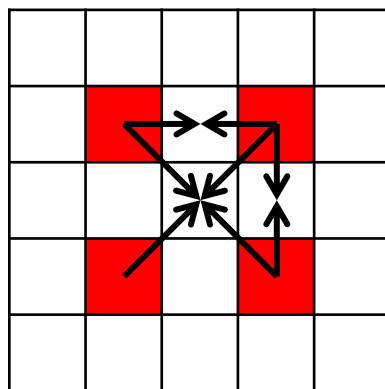
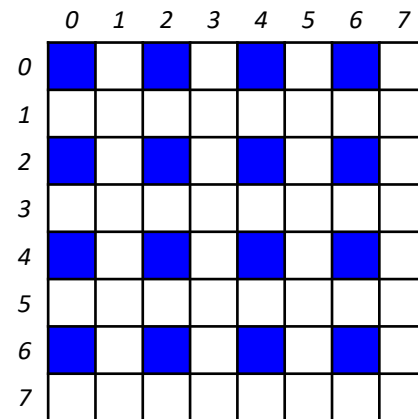
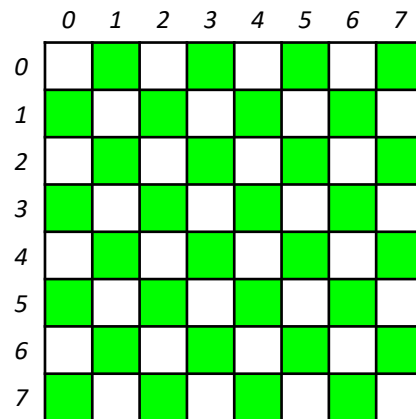
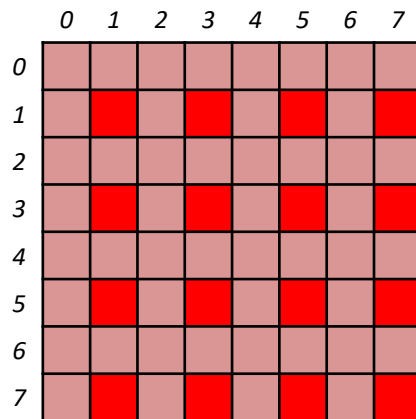
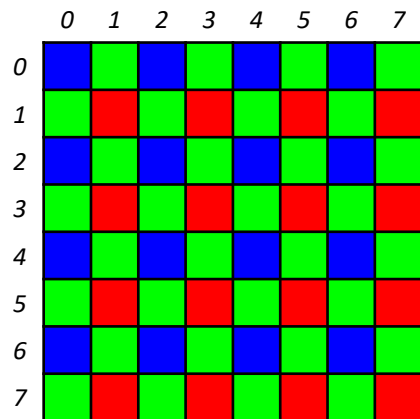
CCD sensors and Bayer pattern



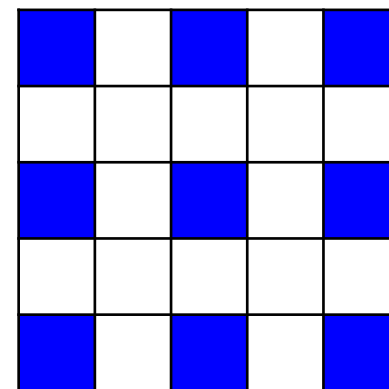
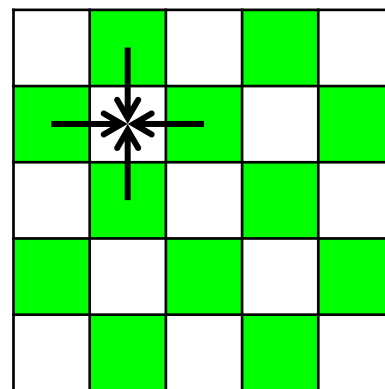
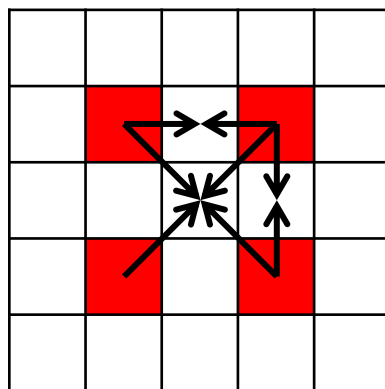
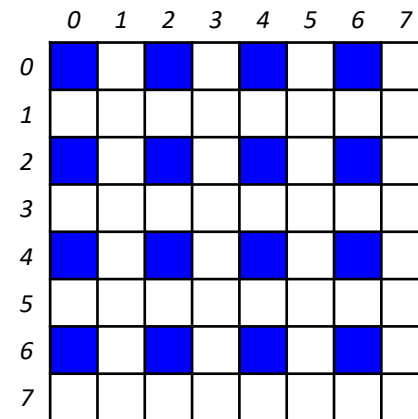
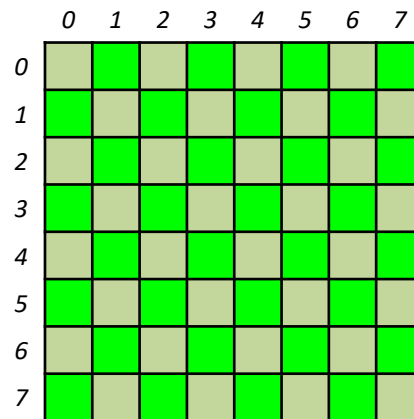
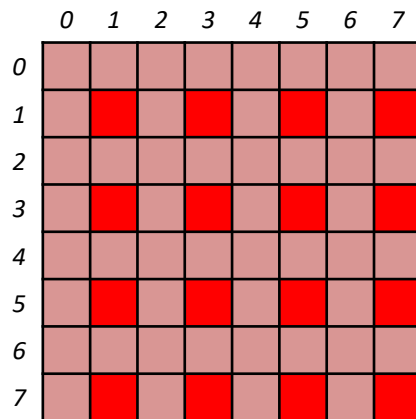
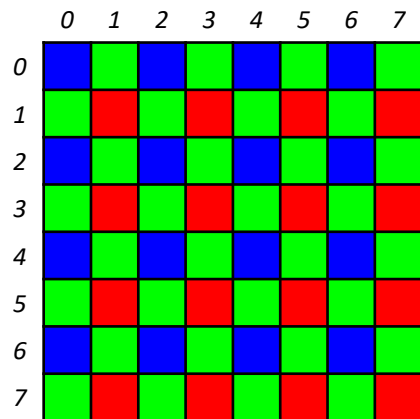
CCD sensors and Bayer pattern



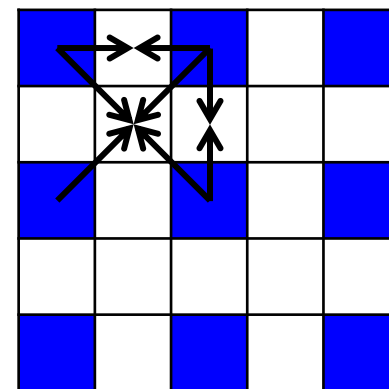
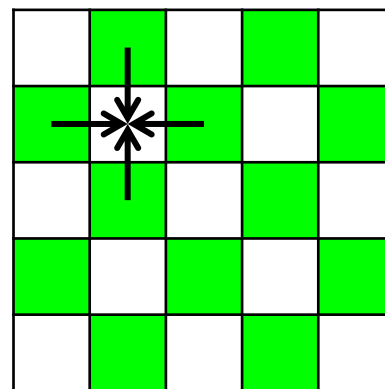
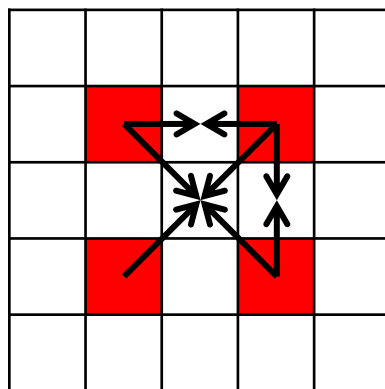
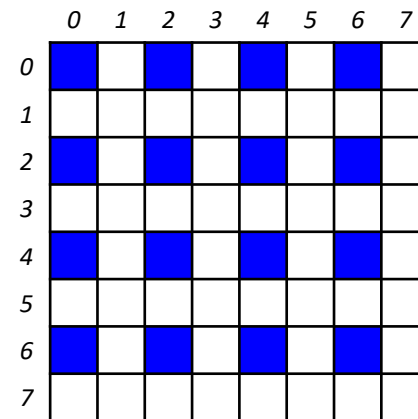
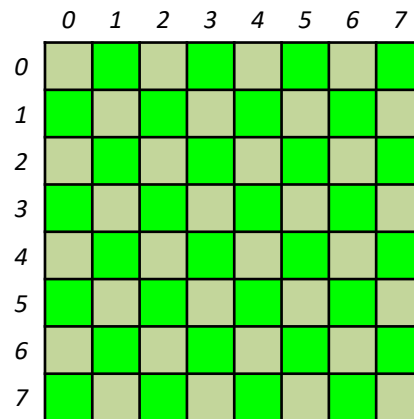
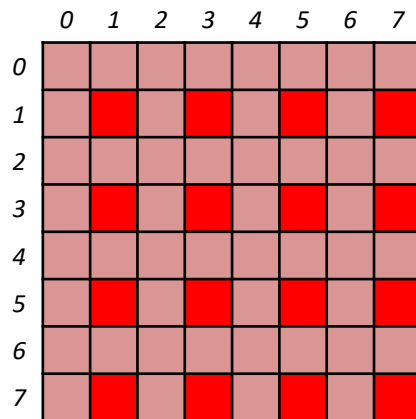
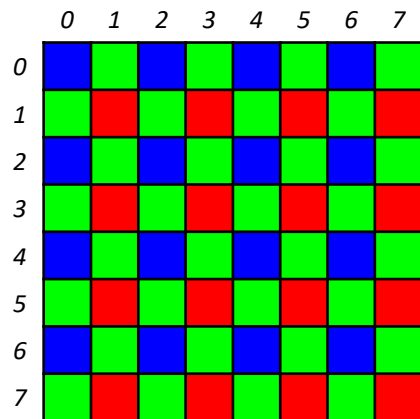
CCD sensors and Bayer pattern



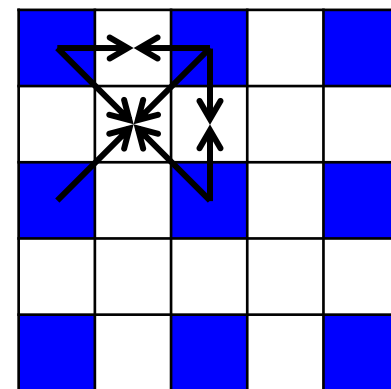
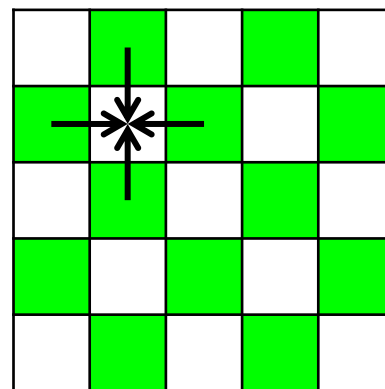
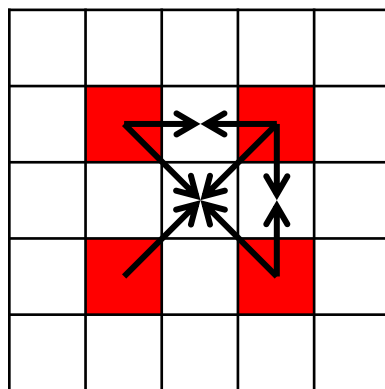
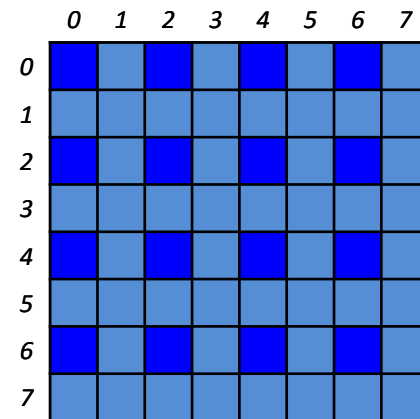
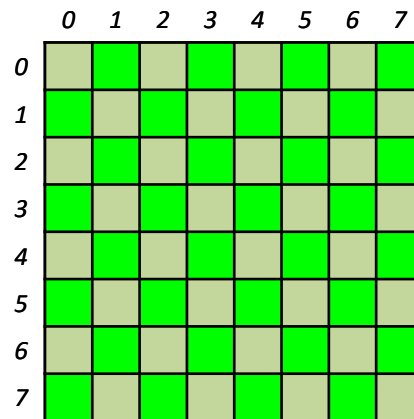
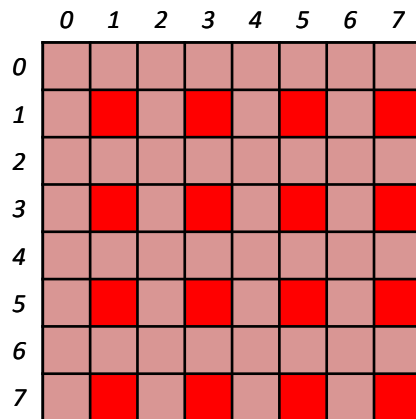
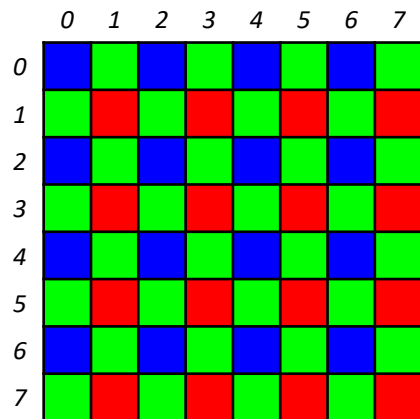
CCD sensors and Bayer pattern

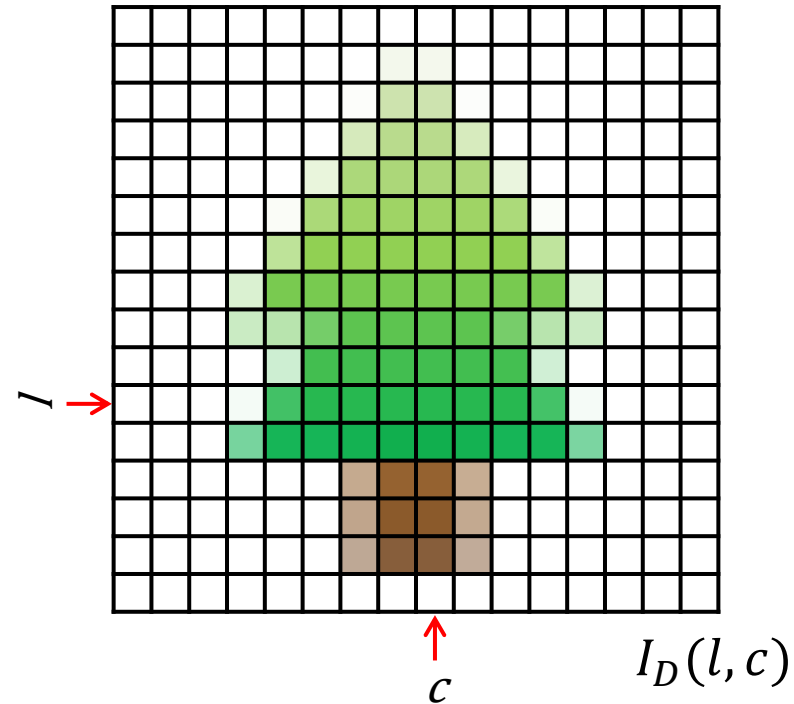
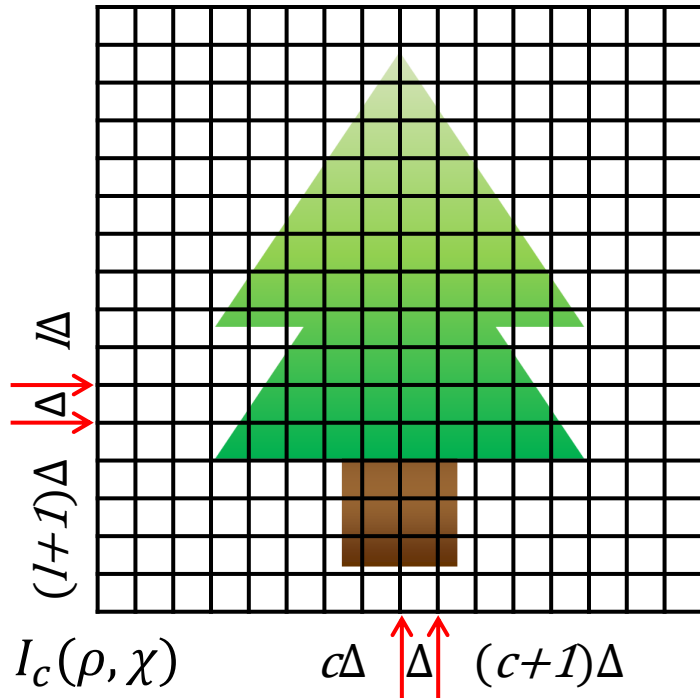


CCD sensors and Bayer pattern



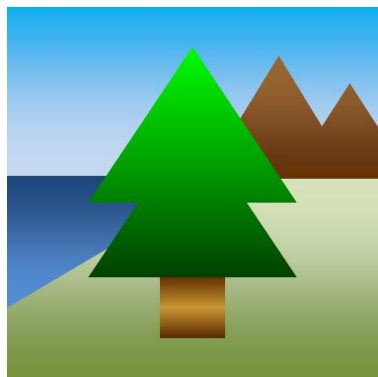
CCD sensors and Bayer pattern



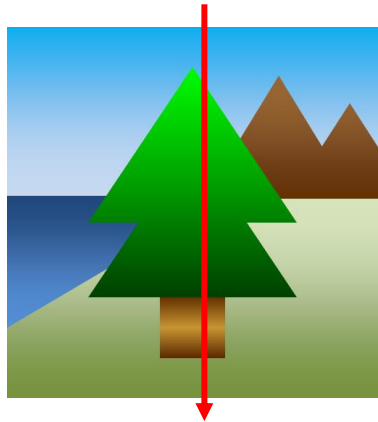


$$I_D = \frac{1}{\Delta^2} \int_{l\Delta}^{(l+1)\Delta} \int_{c\Delta}^{(c+1)\Delta} I_c(\rho, \chi) \delta\rho \delta\chi$$

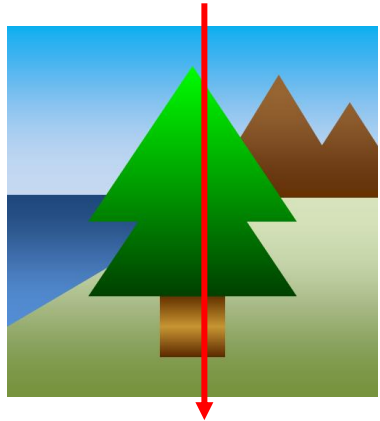
Based on: Alan Peters, 2019.



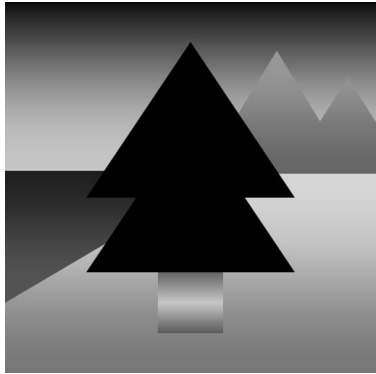
Continuous RGB image



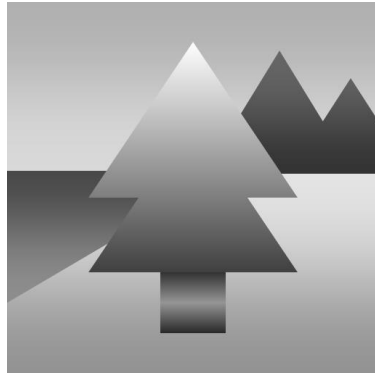
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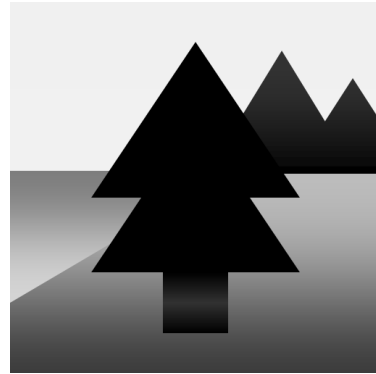
Continuous RGB image



Continuous R image

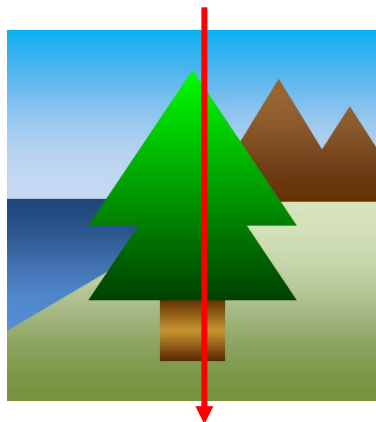


Continuous G image

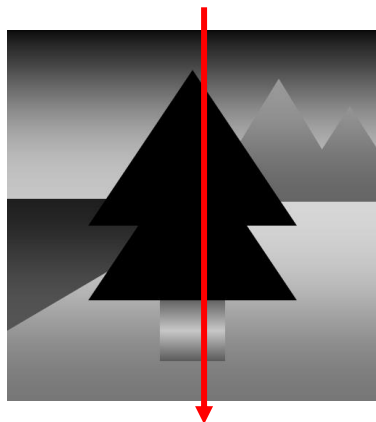


Continuous B image

Sampling



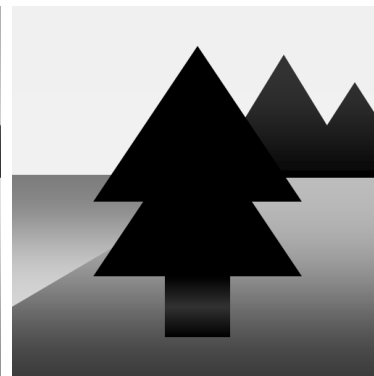
Continuous RGB image



Continuous R image

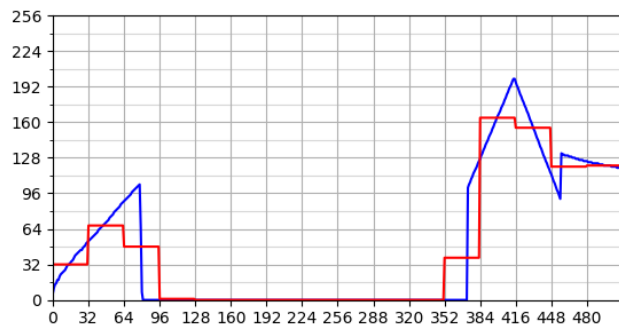


Continuous G image

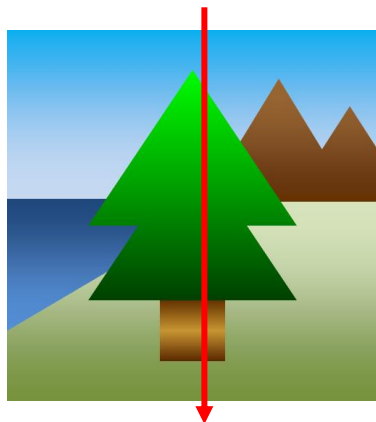


Continuous B image

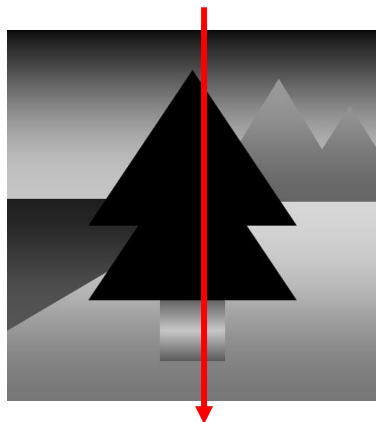
R channel sampling



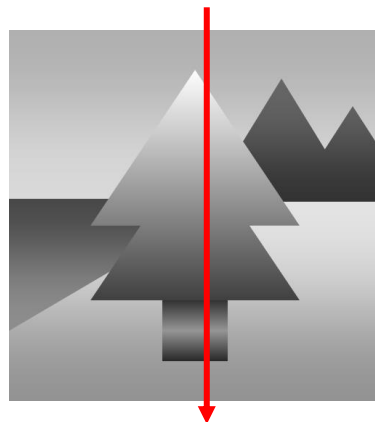
Sampling



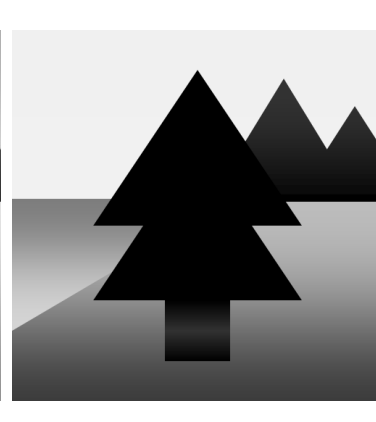
Continuous RGB image



Continuous R image

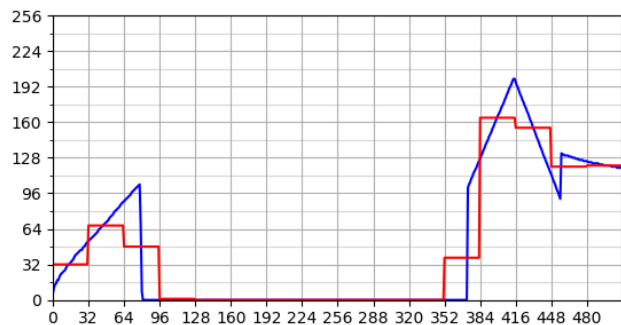


Continuous G image

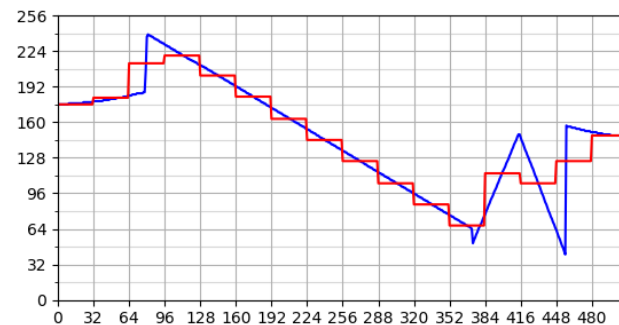


Continuous B image

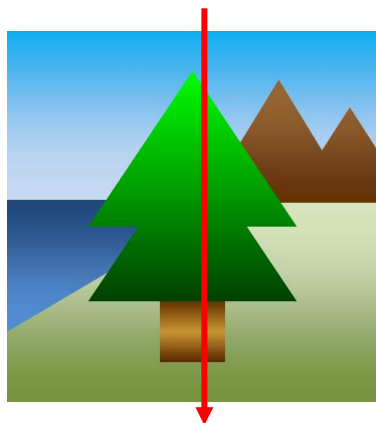
R channel sampling



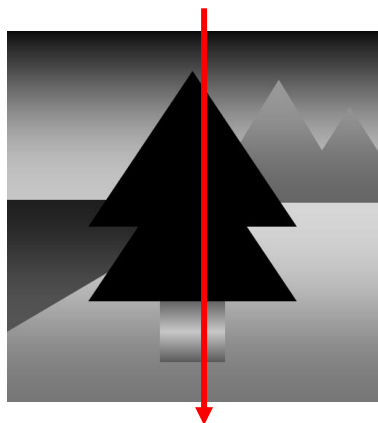
G channel sampling



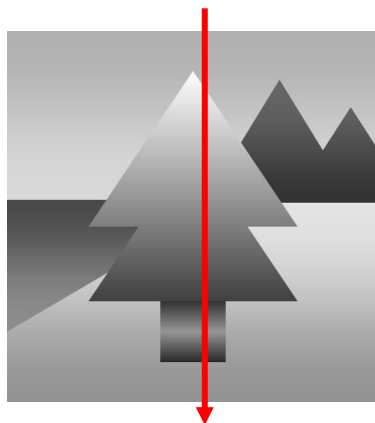
Sampling



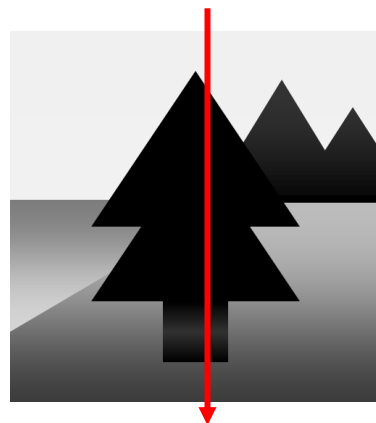
Continuous RGB image



Continuous R image

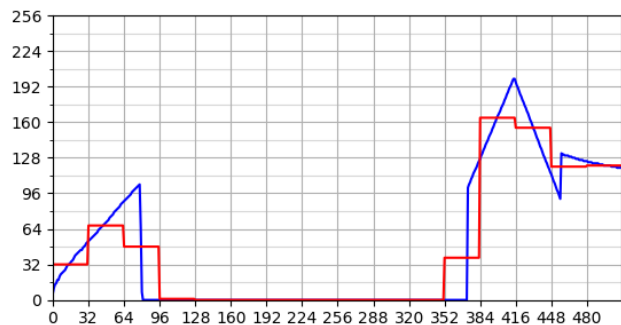


Continuous G image

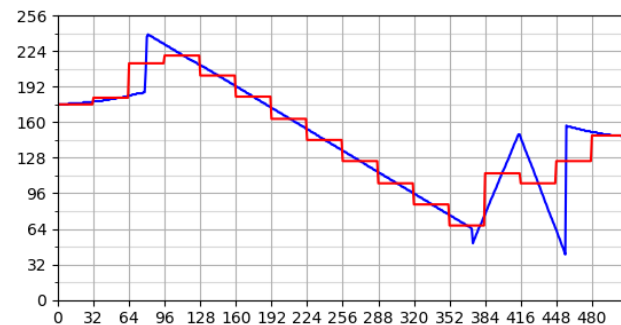


Continuous B image

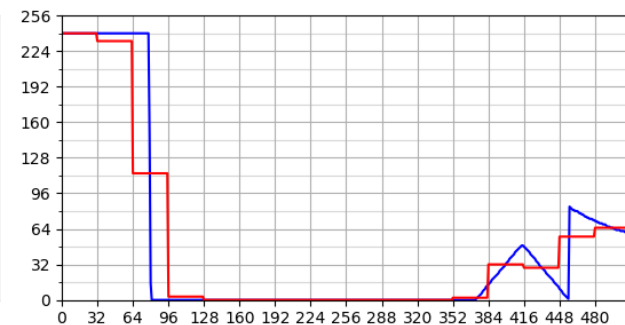
R channel sampling



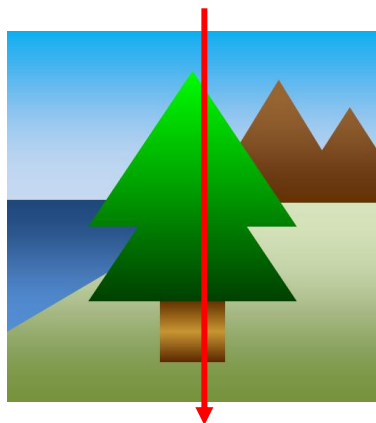
G channel sampling



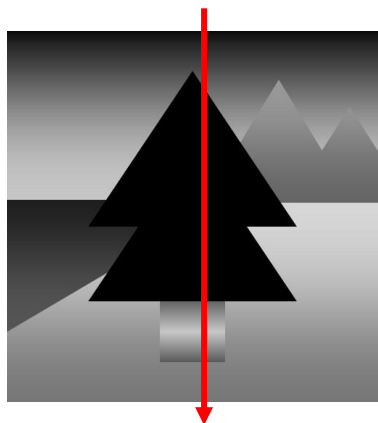
B channel sampling



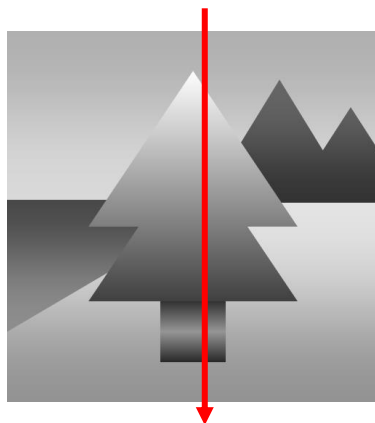
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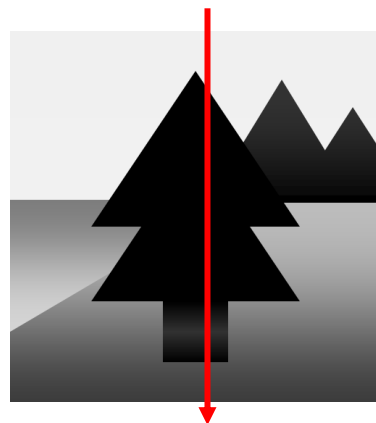
Continuous RGB image



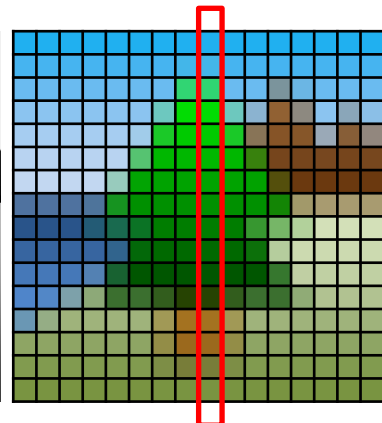
Continuous R image



Continuous G image

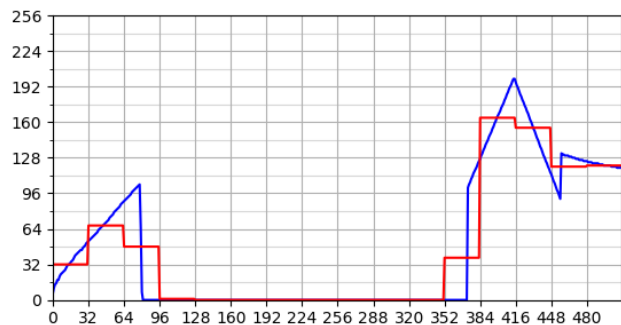


Continuous B image

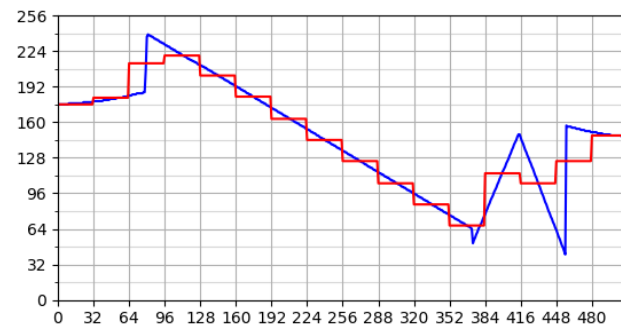


Discrete RGB image (sampled)

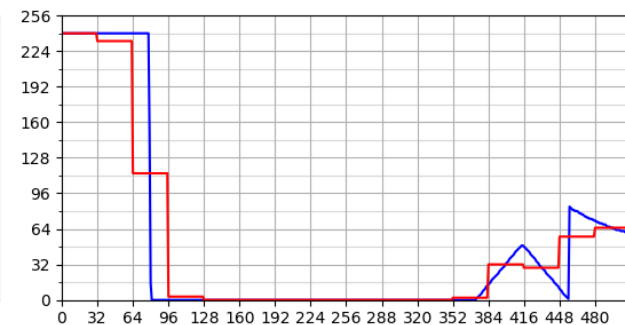
R channel sampling



G channel sampling

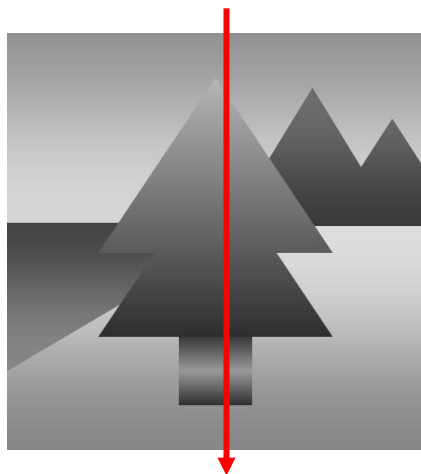


B channel sampling

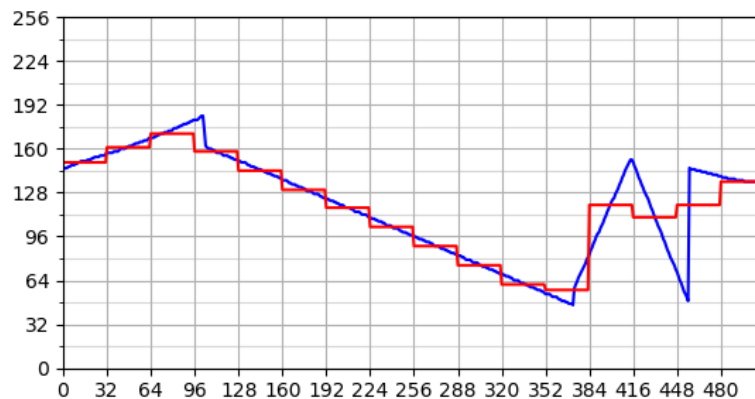




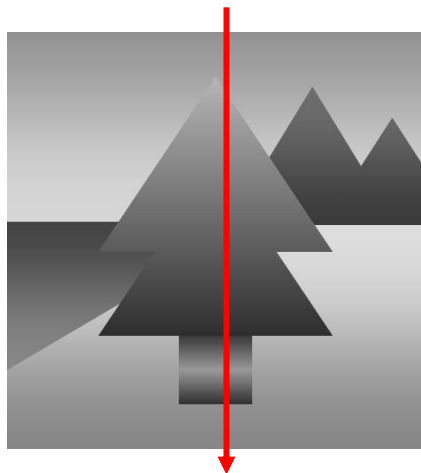
Continuous gray level image



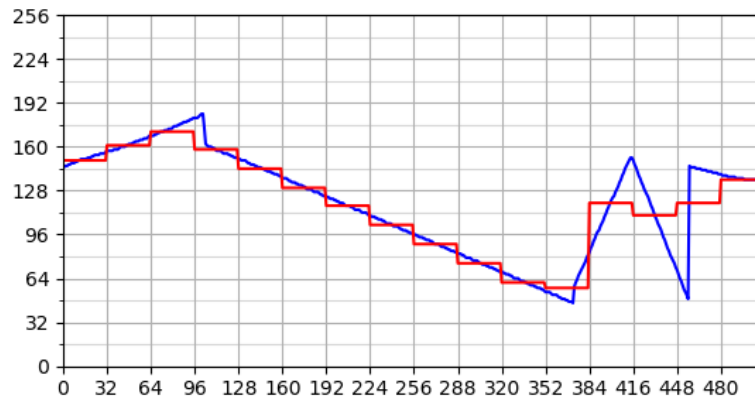
Continuous gray level image



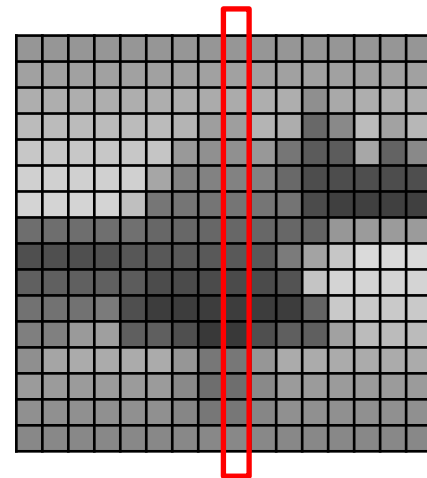
Gray level image sampling



Continuous gray level image



Gray level image sampling



Discrete gray level image (sampled)

1,7 pol



300 ppi – 512 x 512



1,7 pol. a 150 ppi – 256 x 256



1,7 pol. a 75 ppi – 128 x 128



1,7 pol. a ~38 ppi – 64 x 64



1,7 pol. a 19 ppi – 32 x 32

Effects of spatial resolution

1,7 pol.
512 x 512 pixels
300 ppi



0,85 pol.
256 x 256 pixels
300 ppi



0,43 pol.
128 x 128 pixels
300 ppi

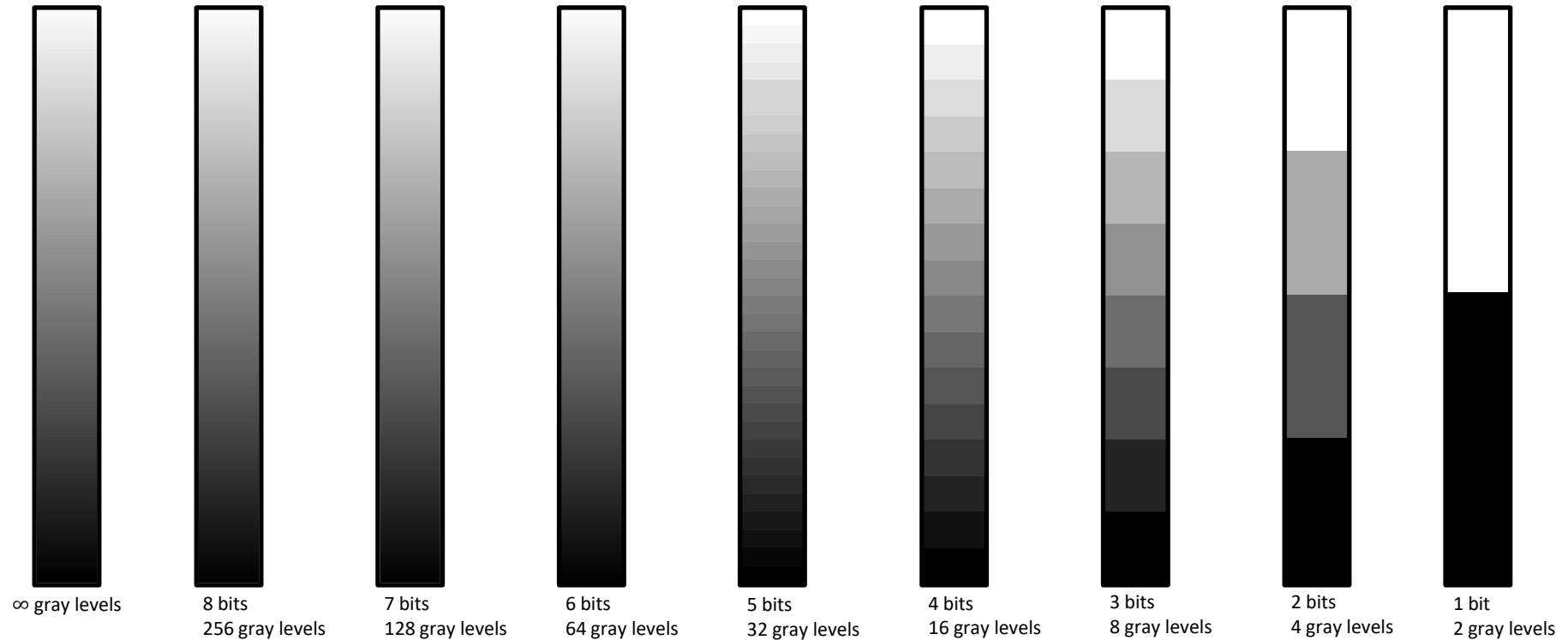


0,21 pol.
64 x 64 pixels
300 ppi

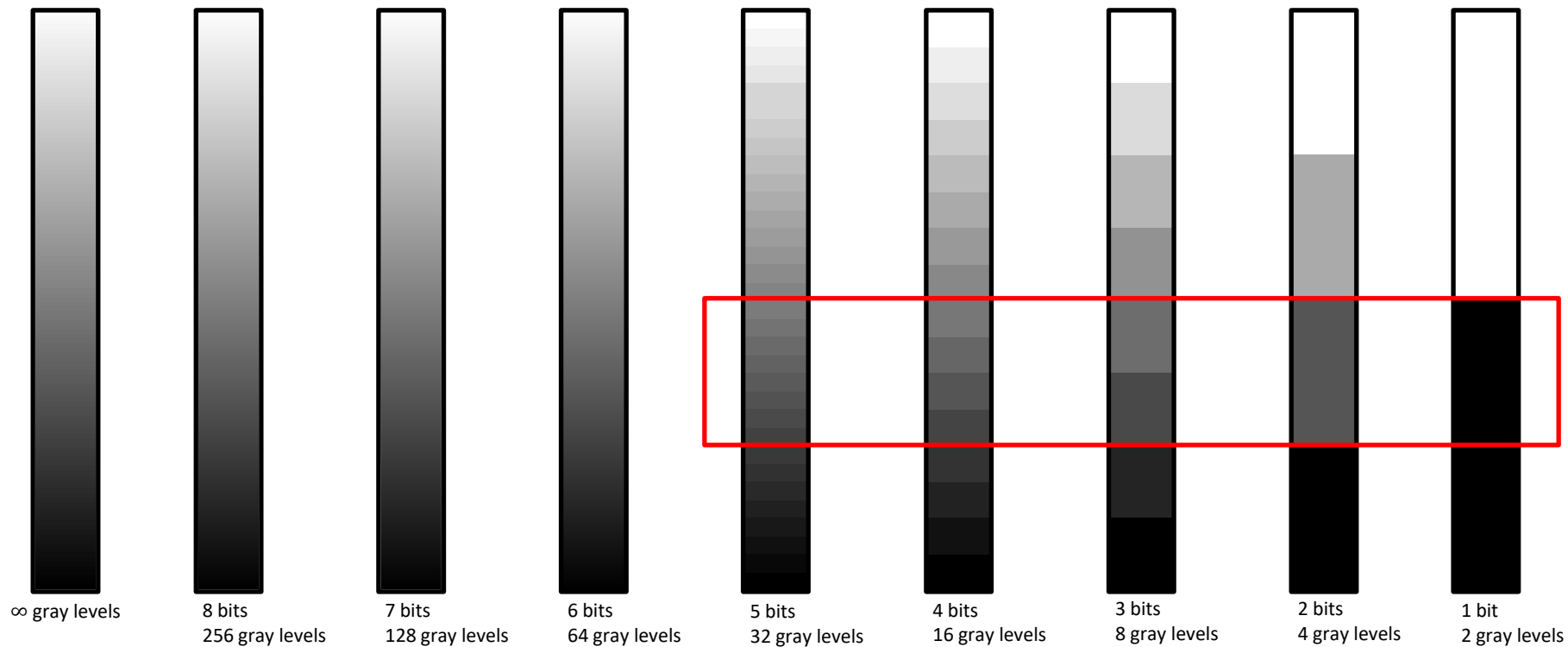


0,11 pol.
32 x 32 pixels
300 ppi





Intensity resolution



Effects of intensity resolution



8 bits. $2^8 = 256$ gray levels



7 bits. $2^7 = 128$ gray levels



6 bits. $2^6 = 64$ gray levels



5 bits. $2^5 = 32$ gray levels



4 bits. $2^4 = 16$ gray levels



3 bits. $2^3 = 8$ gray levels



2 bits. $2^2 = 4$ gray levels



1 bit. $2^1 = 2$ gray levels

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