COMP0026: Image Processing

The Digital Image

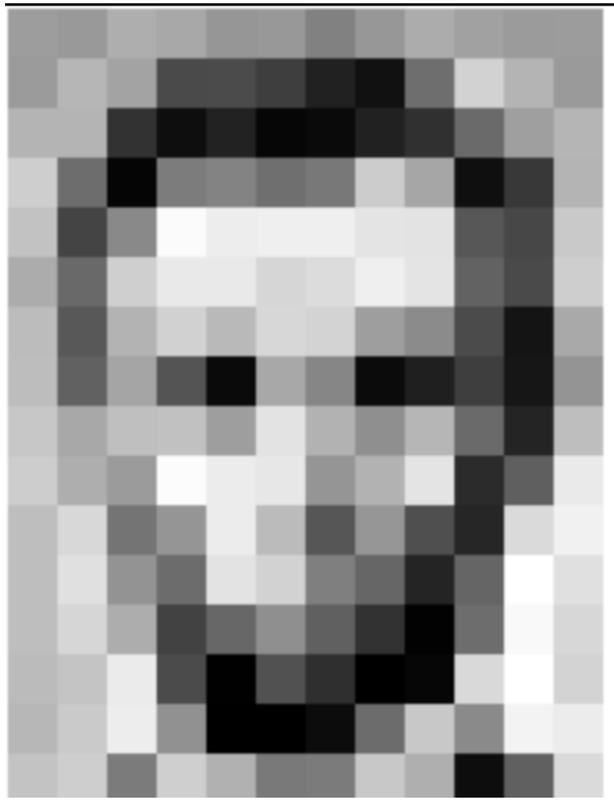
Lectures will be Recorded

Outline

- **What is an image?**
- **What is a pixel?**
- **How do we store pixels?**

What is an Image?

What is an Image?



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

157	153	174	168	150	152	129	151	172	161	155	156
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206	109	5	124	131	111	120	204	166	15	56	180
194	68	137	251	237	239	239	228	227	87	71	201
172	105	207	233	233	214	220	239	228	98	74	206
188	88	179	209	185	215	211	158	139	75	20	169
189	97	165	84	10	168	134	11	31	62	22	148
199	168	191	193	158	227	178	143	182	106	36	190
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190	216	116	149	236	187	86	150	79	38	218	241
190	224	147	108	227	210	127	102	36	101	255	224
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183	202	237	145	0	0	12	108	200	138	243	236
195	206	123	207	177	121	123	200	175	13	96	218

What is an Image?

What is an Image?

Single channel

Black & White

0	1	0	1	0	1	0	1
1	0	1	0	1	0	1	0
0	1	0	1	0	1	0	1
1	0	1	0	1	0	1	0
0	1	0	1	0	1	0	1
1	0	1	0	1	0	1	0
0	1	0	1	0	1	0	1
1	0	1	0	1	0	1	0

1 bit per pixel.
Values 0 – 1
Height x Width

Grayscale

8	120	221	189	145	212	33	244
149	20	30	72	205	177	208	173
47	19	3	249	102	229	161	122
0	78	198	197	28	147	107	94
243	40	131	54	150	18	11	158
123	94	137	10	139	111	241	183
239	217	100	153	131	236	230	113
237	166	62	169	129	32	141	185

8 bits per pixel.
Values 0 – 255
Height x Width

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0	1	0	1	0	1	0	1
1	0	1	0	1	0	1	0
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0	1	0	1	0	1	0	1
1	0	1	0	1	0	1	0
0	1	0	1	0	1	0	1
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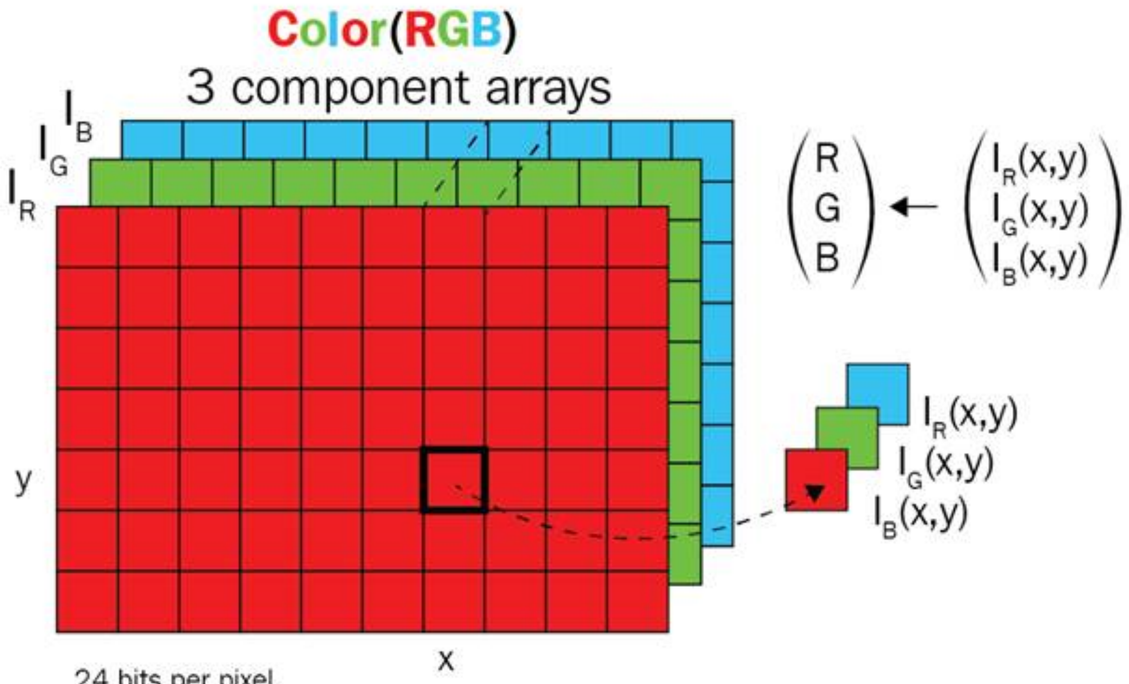
Multiple channel



24 bits per pixel.

RB Red/Green/Blue

Height x Width X 3:

Image as 2D Signal

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  2 variables: xy - coordinates

  3 variables: xy + time (video)

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Image as 2D Signal

- **Signal:** function depending on some variable with physical meaning
- **Image:** continuous function
  2 variables: xy - coordinates
  3 variables: xy + time (video)
- Brightness is usually the value of the function
- But can be other physical values too: temperature, pressure, depth, etc.

Examples 2D images

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ultrasound

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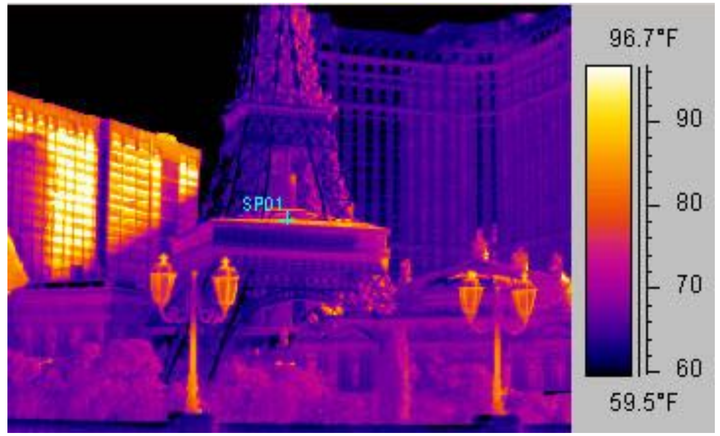
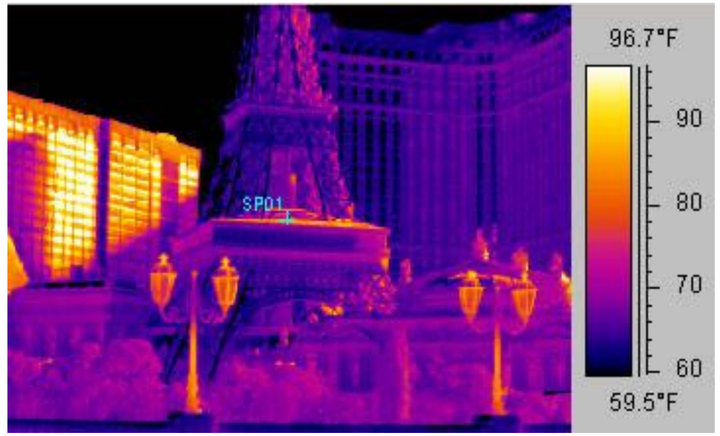
ultrasound



temperature

Examples 2D images

ultrasound

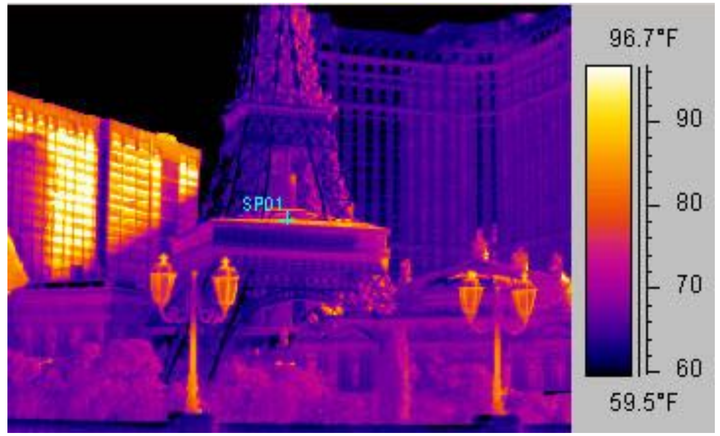


temperature

camera image

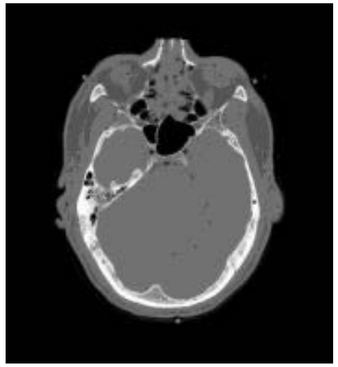
Examples 2D images

ultrasound



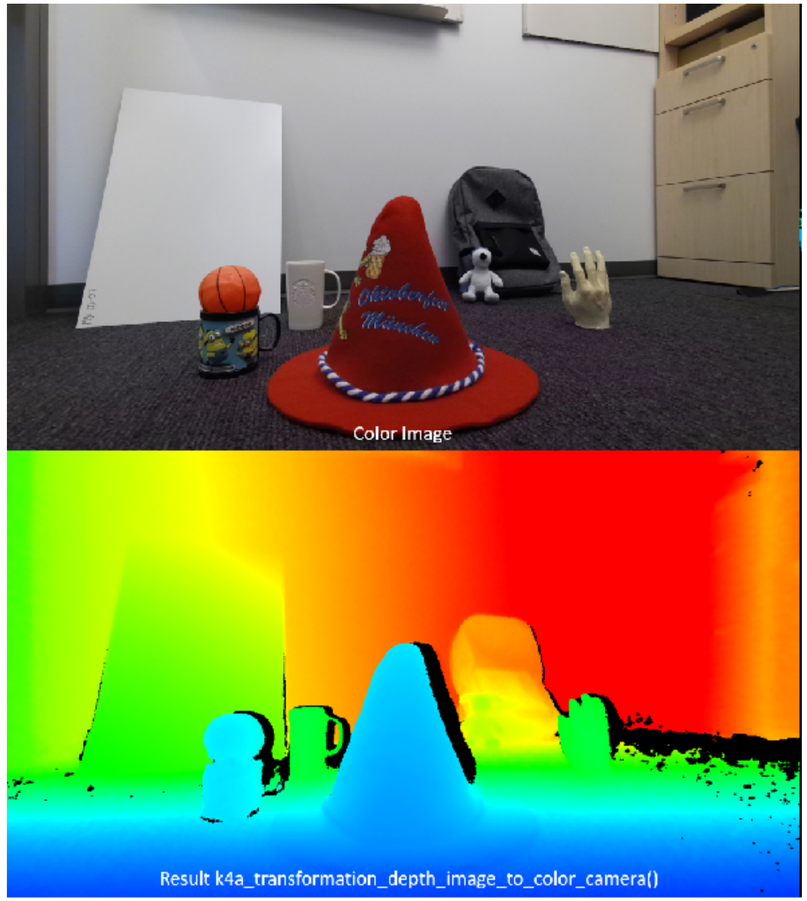
temperature

camera image



CT

Depth Cameras



Image?

```
>> t=rand(256,256);
>> imshow(t)
```

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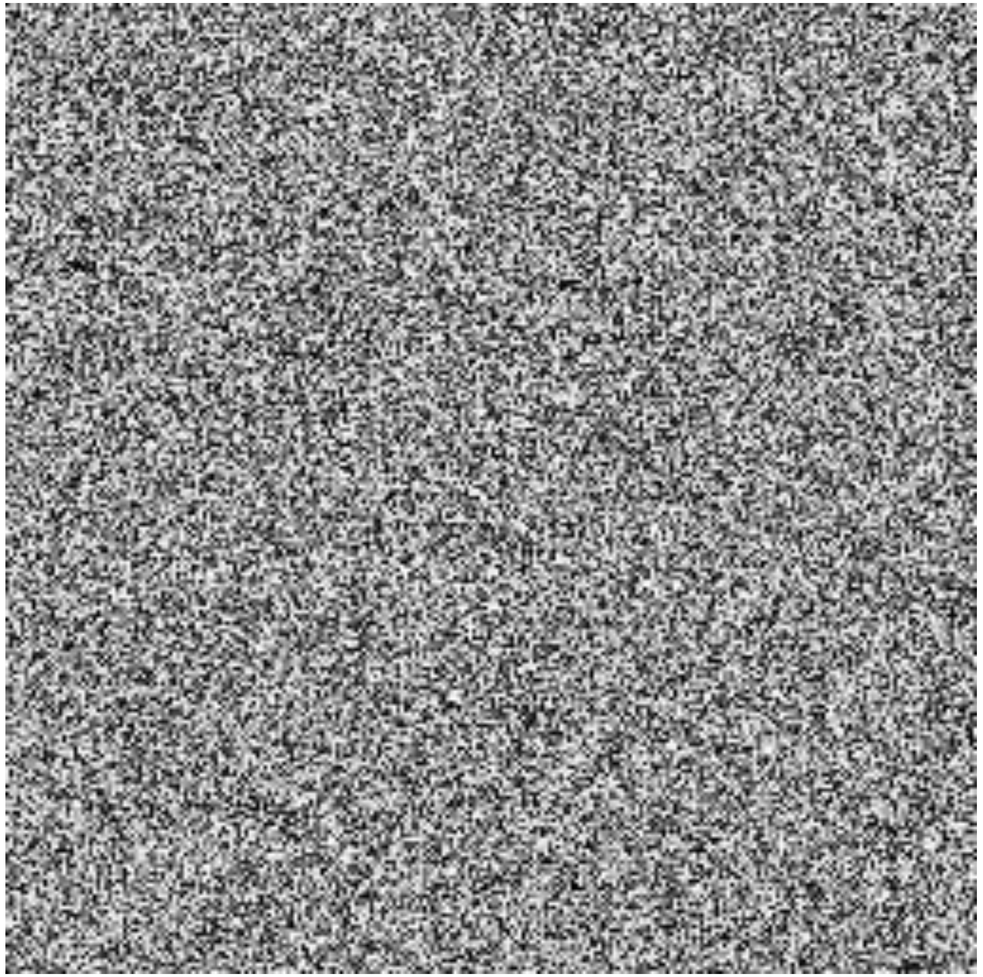

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- **In digital form, e.g.,**

$$I : \{1, \ldots, M\} \times \{1, \ldots, N\} \to S$$

- **For greyscale CCD images,**

$$n = 2,\ S = \mathbb{R}^+$$

What is a Pix-el?

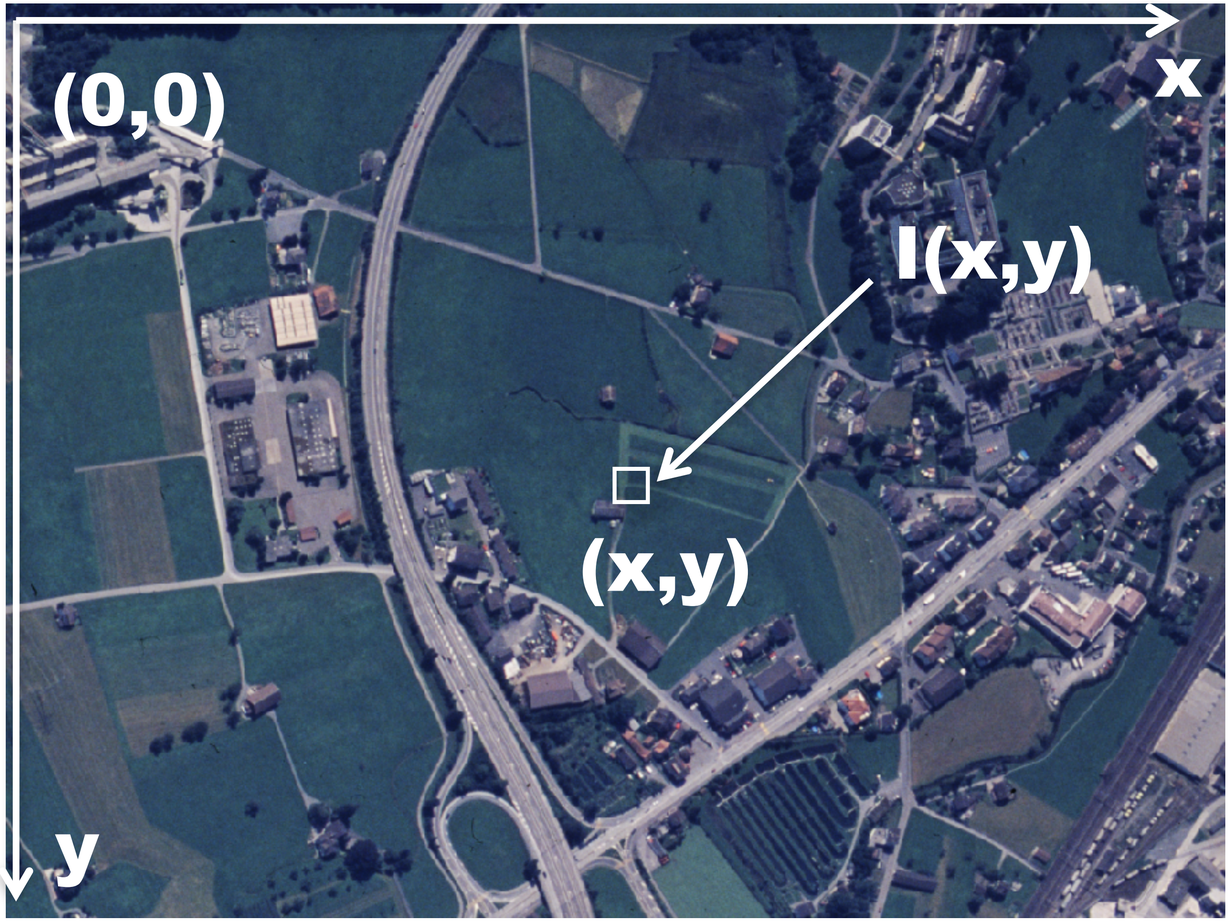

Image Sources

Image Sources

- **Digital cameras**

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- **MRI scanners**

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- **MRI scanners**
- **Computer graphics packages**

Image Sources

- Digital cameras
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- Laser range finders

Image Sources

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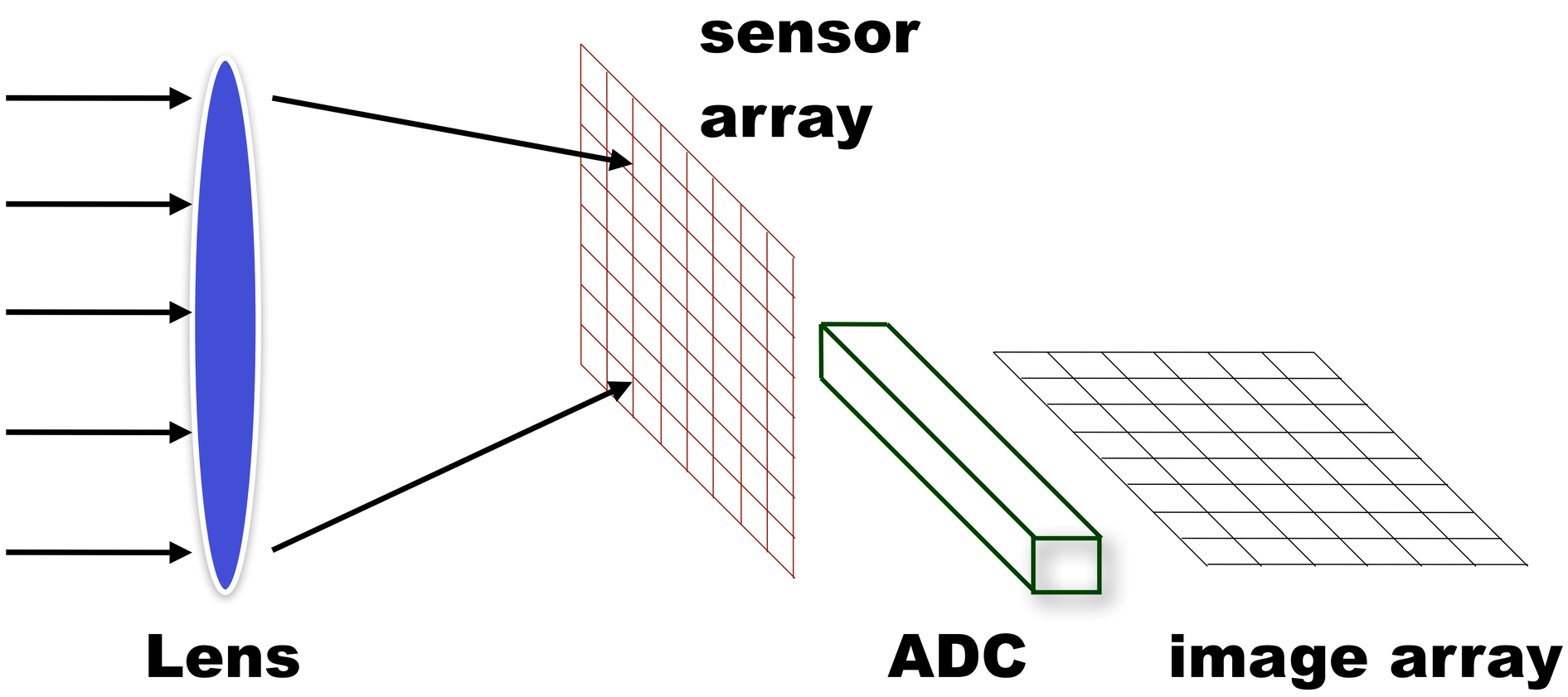
- Laser range finders

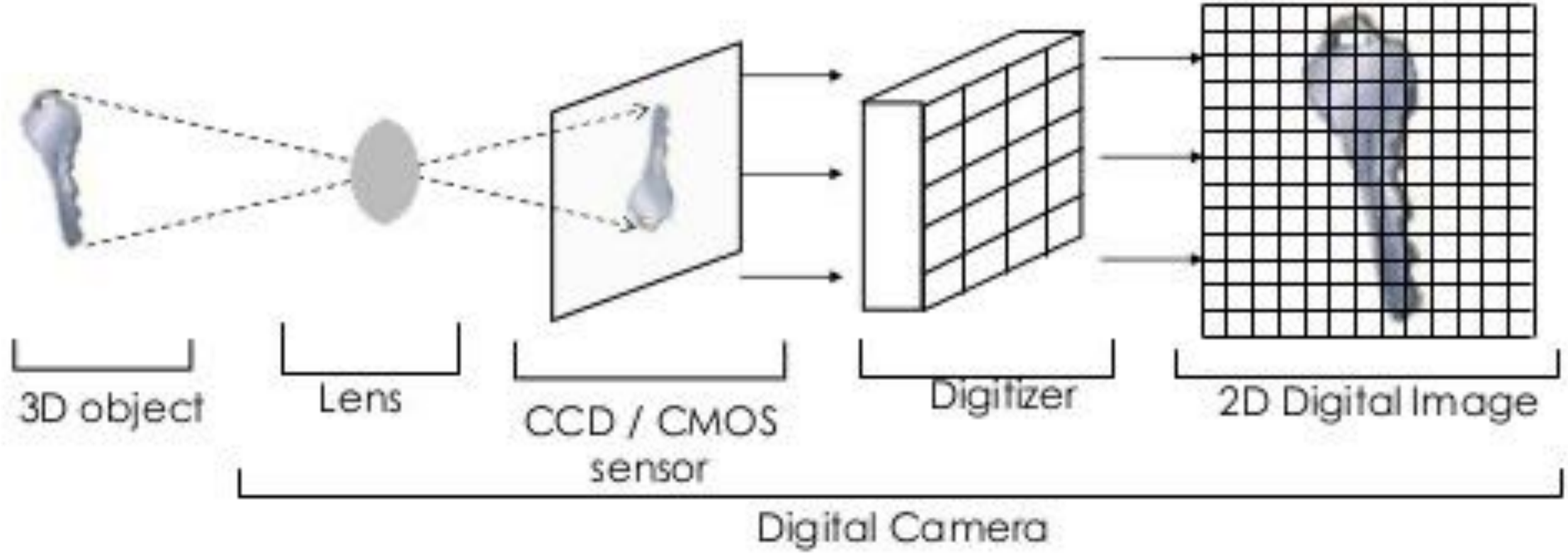
- Many more

Camera Setup

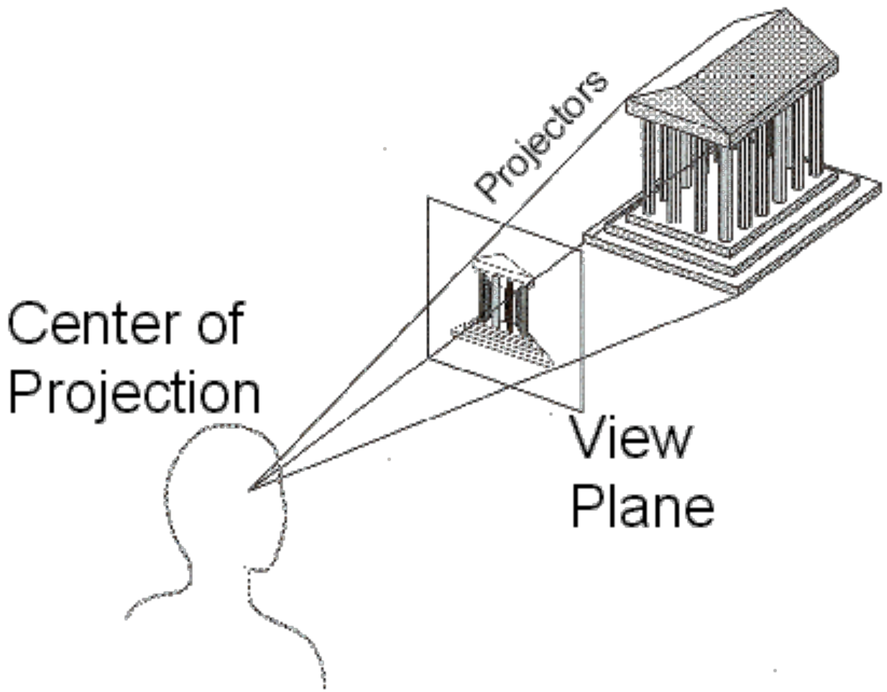
Charge Coupled Device (CCD)



Digital image formation

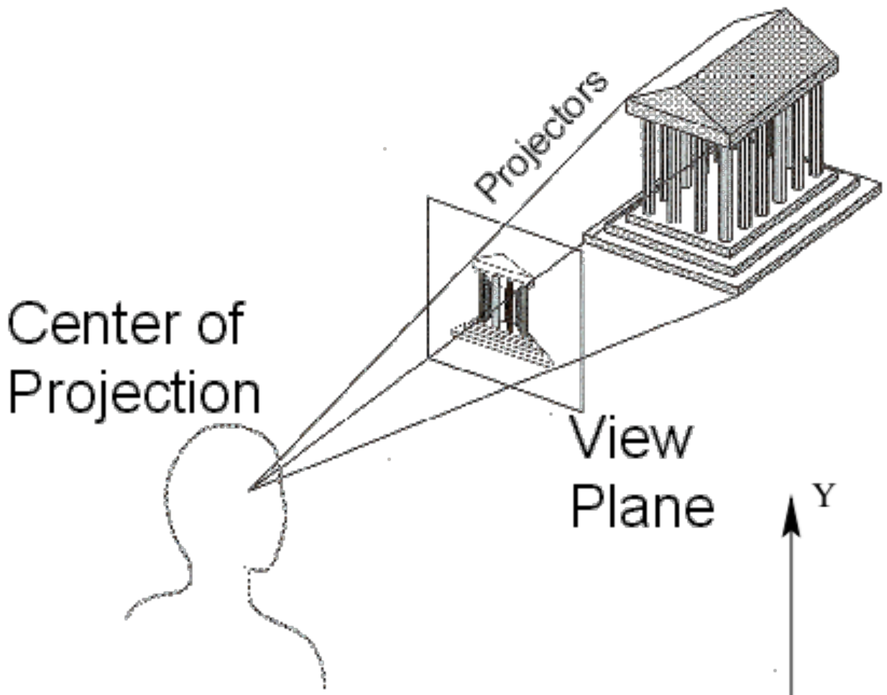


Perspective projection



$$x = f\frac{X}{Z} \qquad y = f\frac{Y}{Z}$$

Perspective projection



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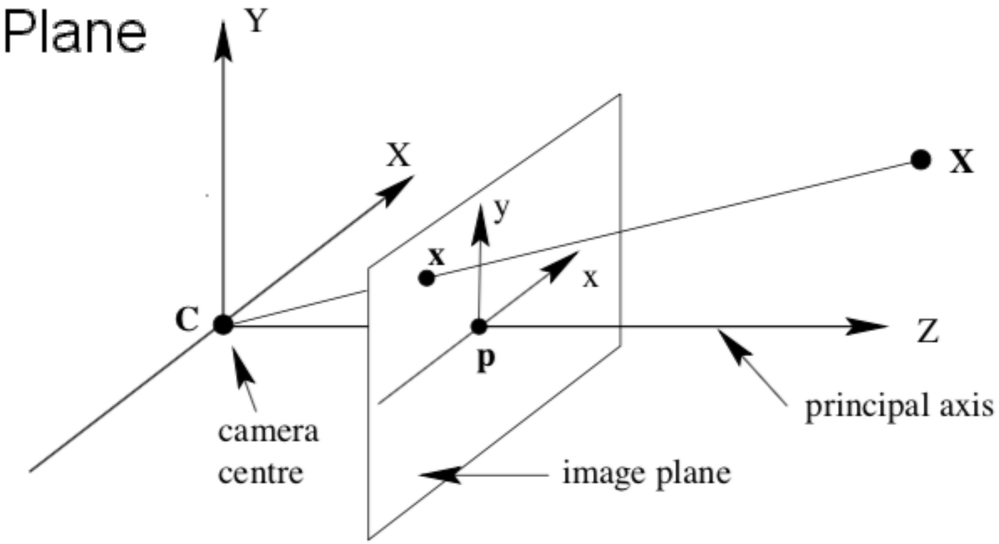
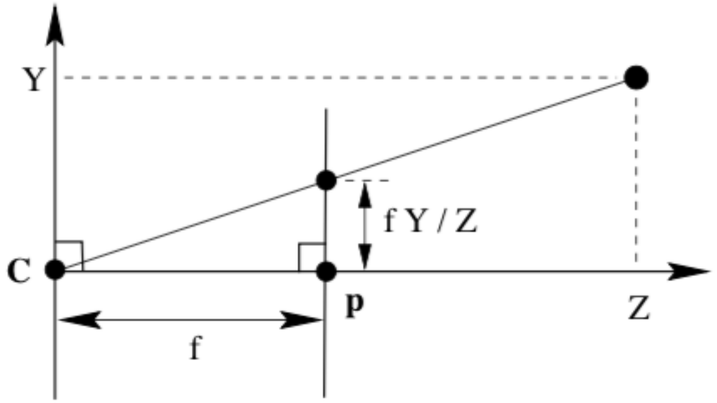
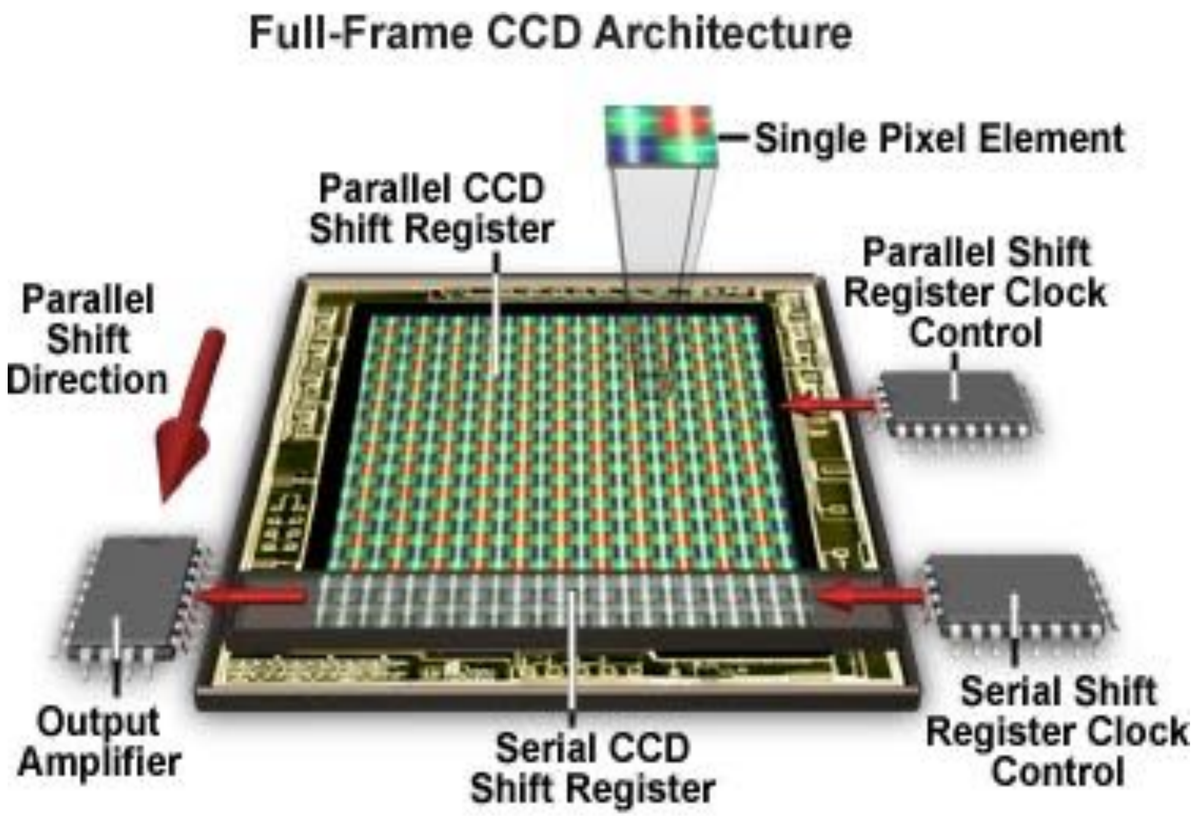




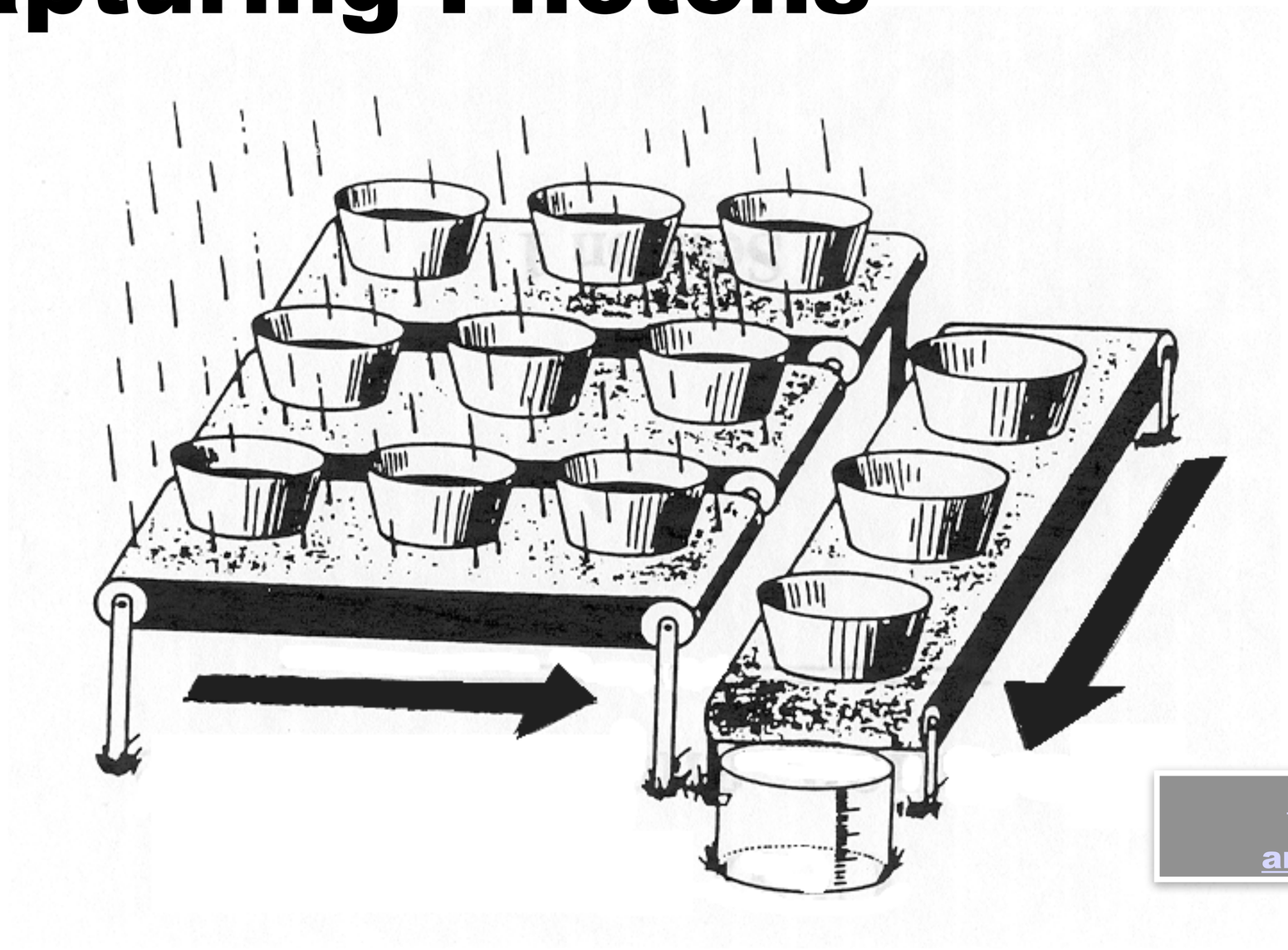
CCD (Charged Couple Device) Array



- Converts light into electrons (charge/voltage)
- Analog device
- Silicon chip that contains an array of photosensitive sites (photosites)
- Voltage is read from each site to reconstruct an image
- Output is converted to a digital signal by an analog-to-digital converter
- Lower framerate as reading of the pixels needs waiting for a CCD's charge transfer
- High quality, low noise, expensive

http://www.astro.virginia.edu/class/oconnell/astr121/im/CCD-fullframearc-FSU.jpg

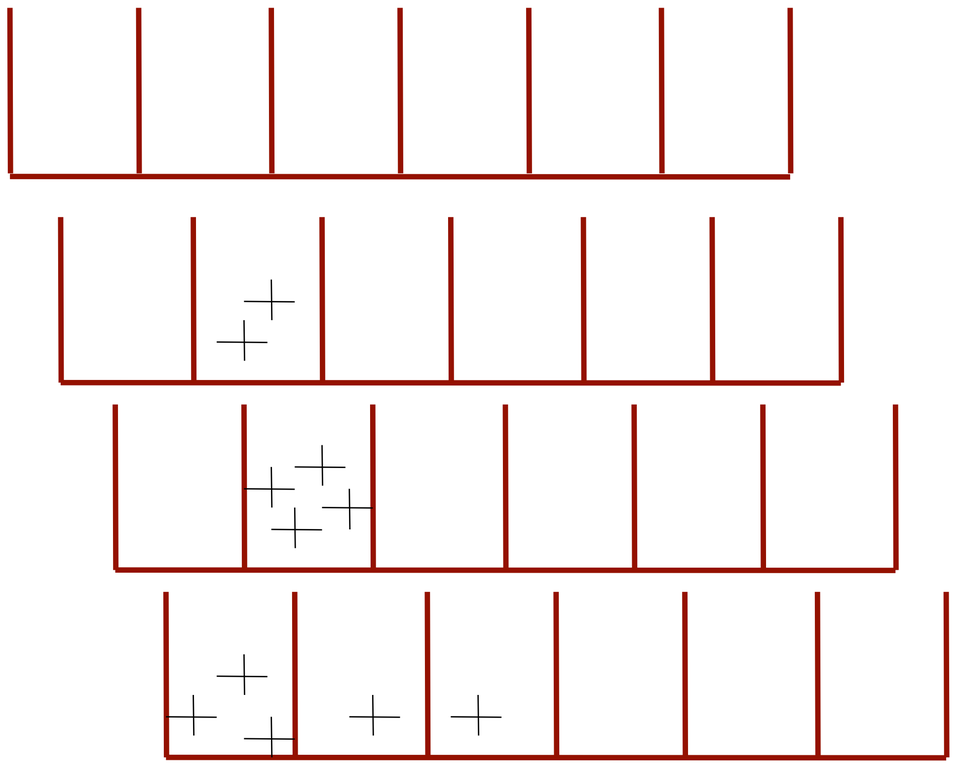
Capturing Photons



From: Lecture Notes – EAAE

and/or Science “Nuggets” 2000

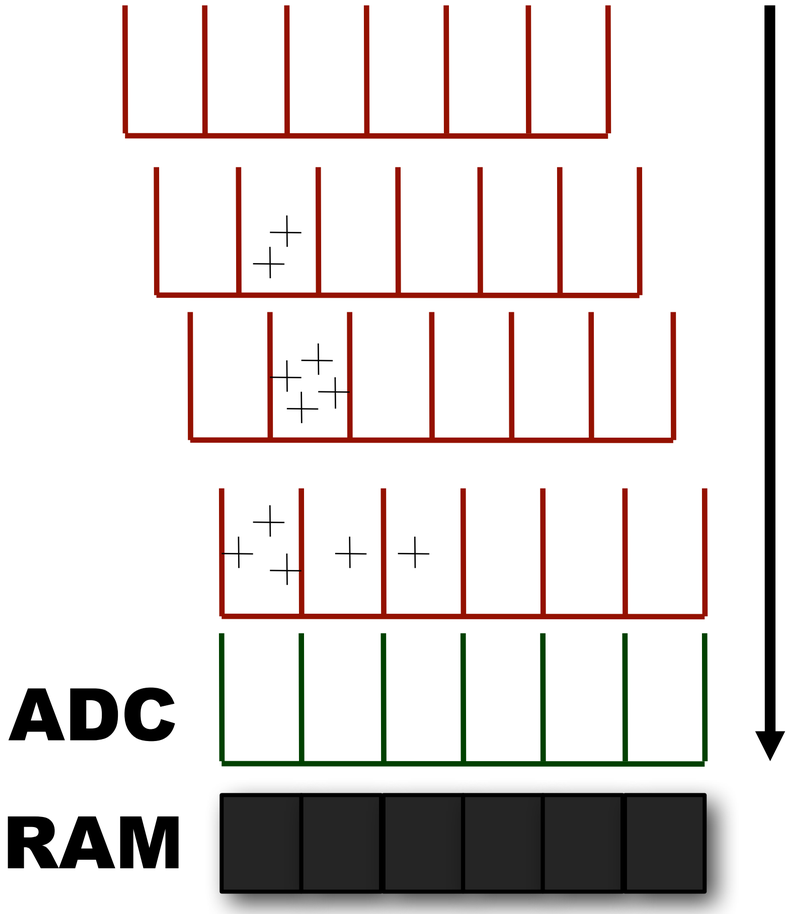
Sensor Array



- Can be < 1cm²
- An array of photosites
- Each photosite is a bucket of electrical charge
- They contain charge proportional to the incident light intensity during exposure

AD Conversion

- The ADC measures the charge and digitizes the result.
- Conversion happens line by line.
- The charges in each photosite move down through the sensor array.



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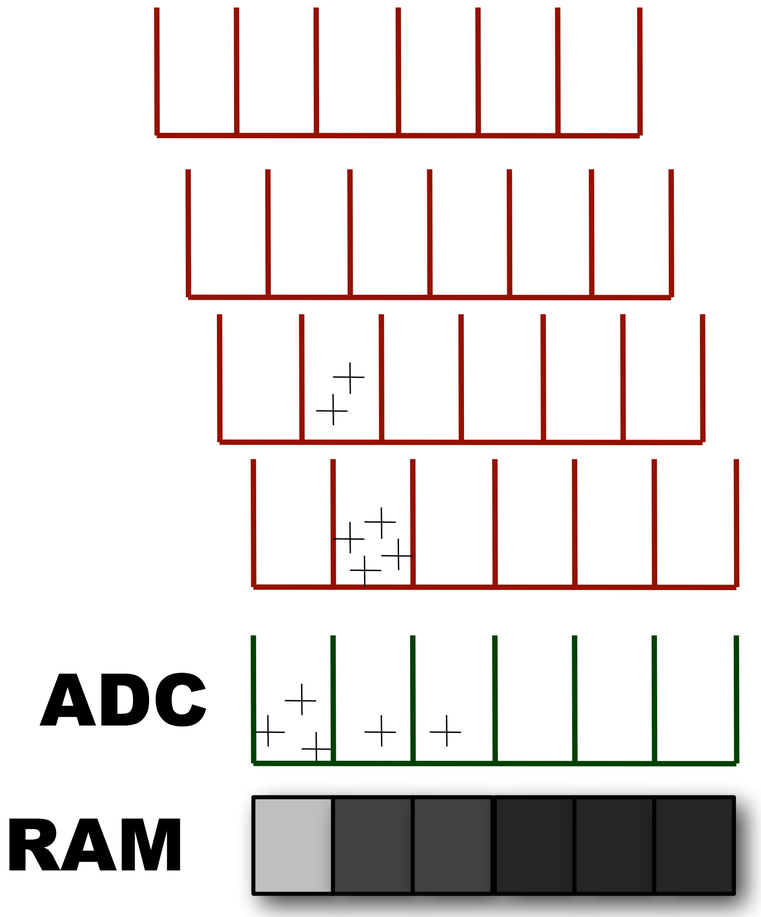

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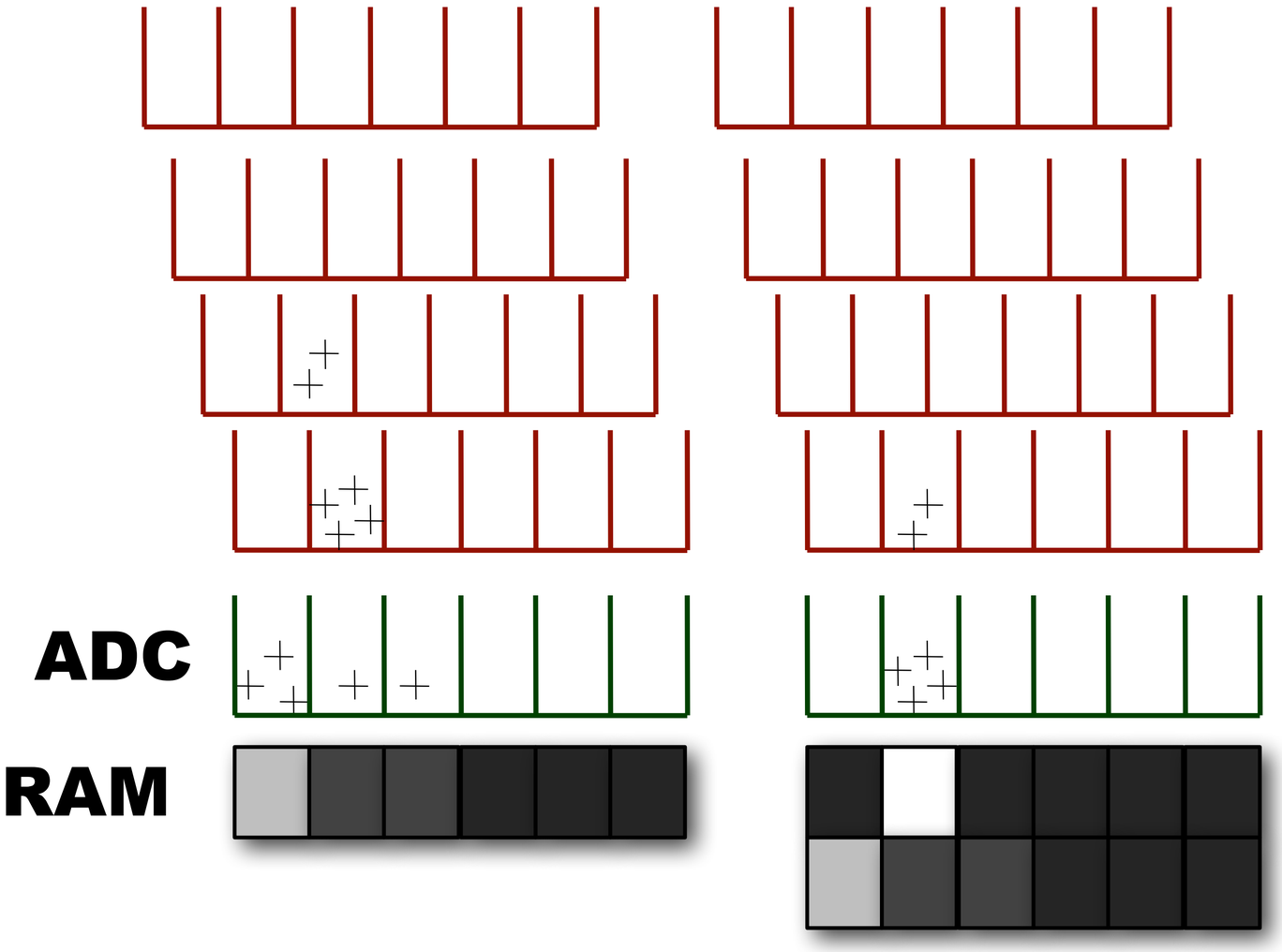
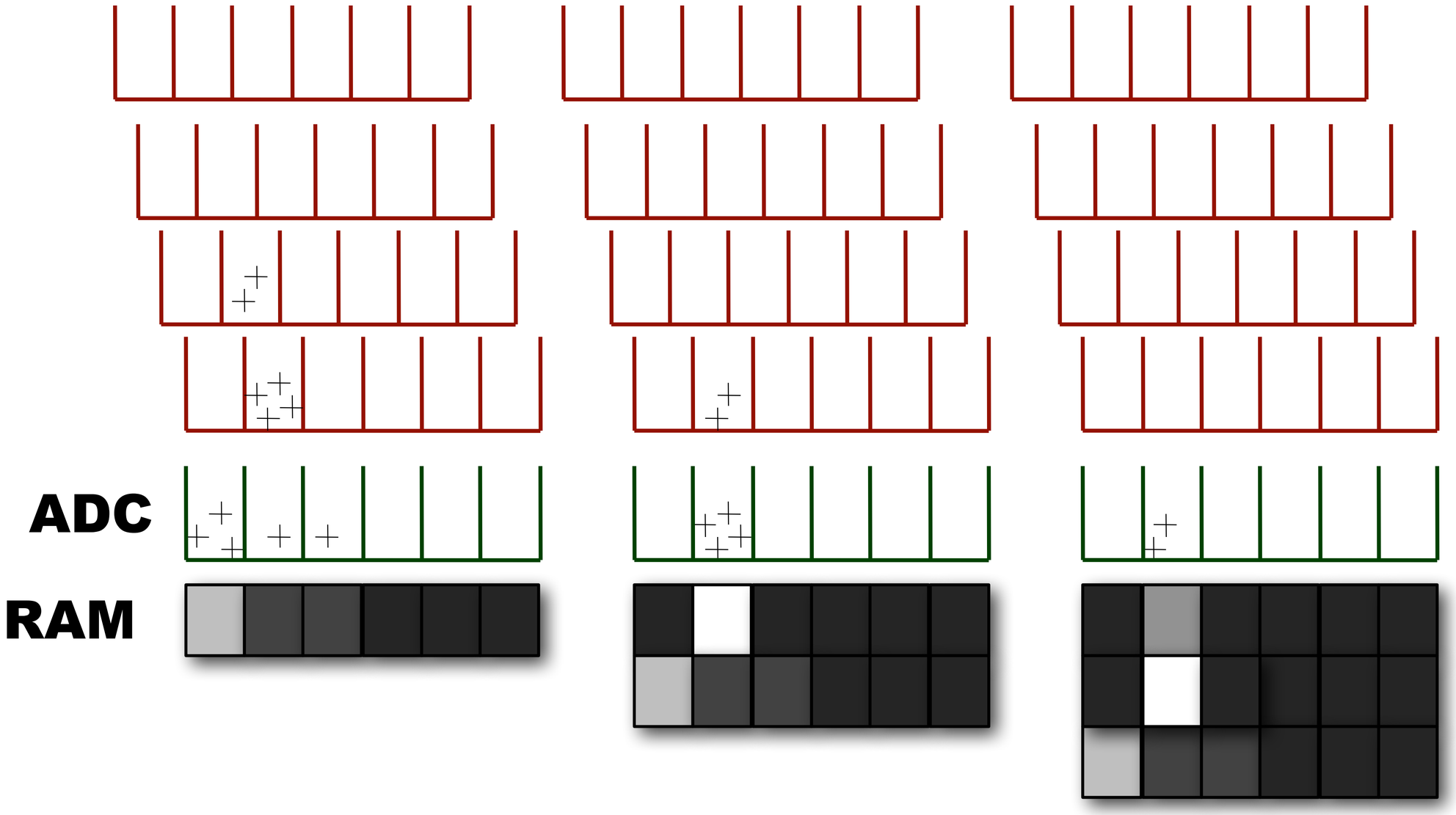


AD Conversion

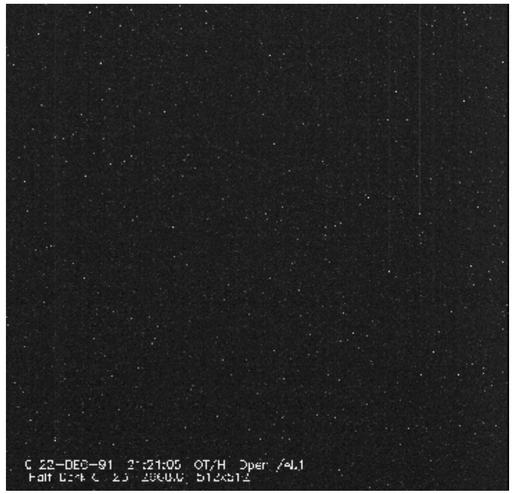


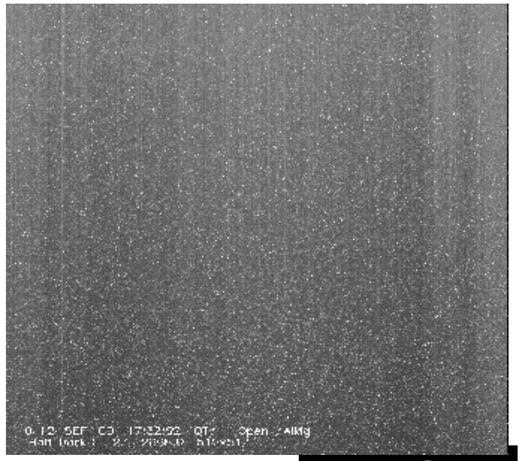
Blooming/Vertical Smear

- **The buckets have finite capacity**
- **Photosite saturation causes blooming**

Dark Current

- CCDs produce thermally-generated charge
- They give non-zero output even in darkness
- Partly, this is the dark current
- Fluctuates randomly

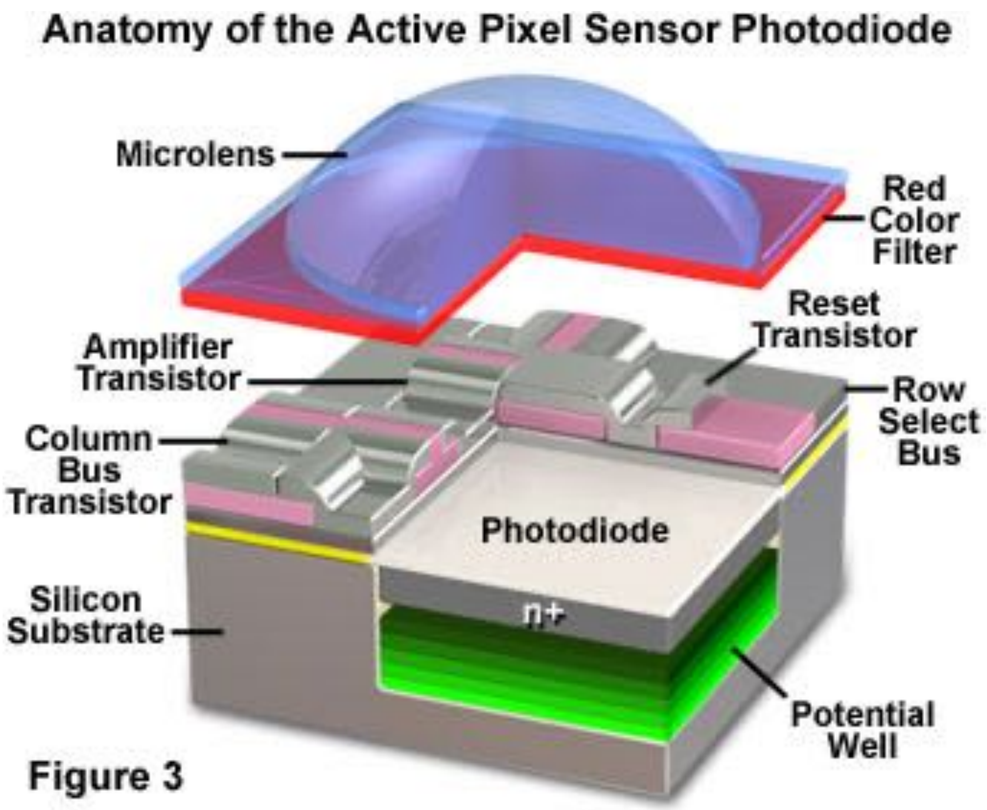




- How can we reduce dark current?

From: Lecture Notes - EAAE

CMOS (Complementary metal-oxide-semiconductor)

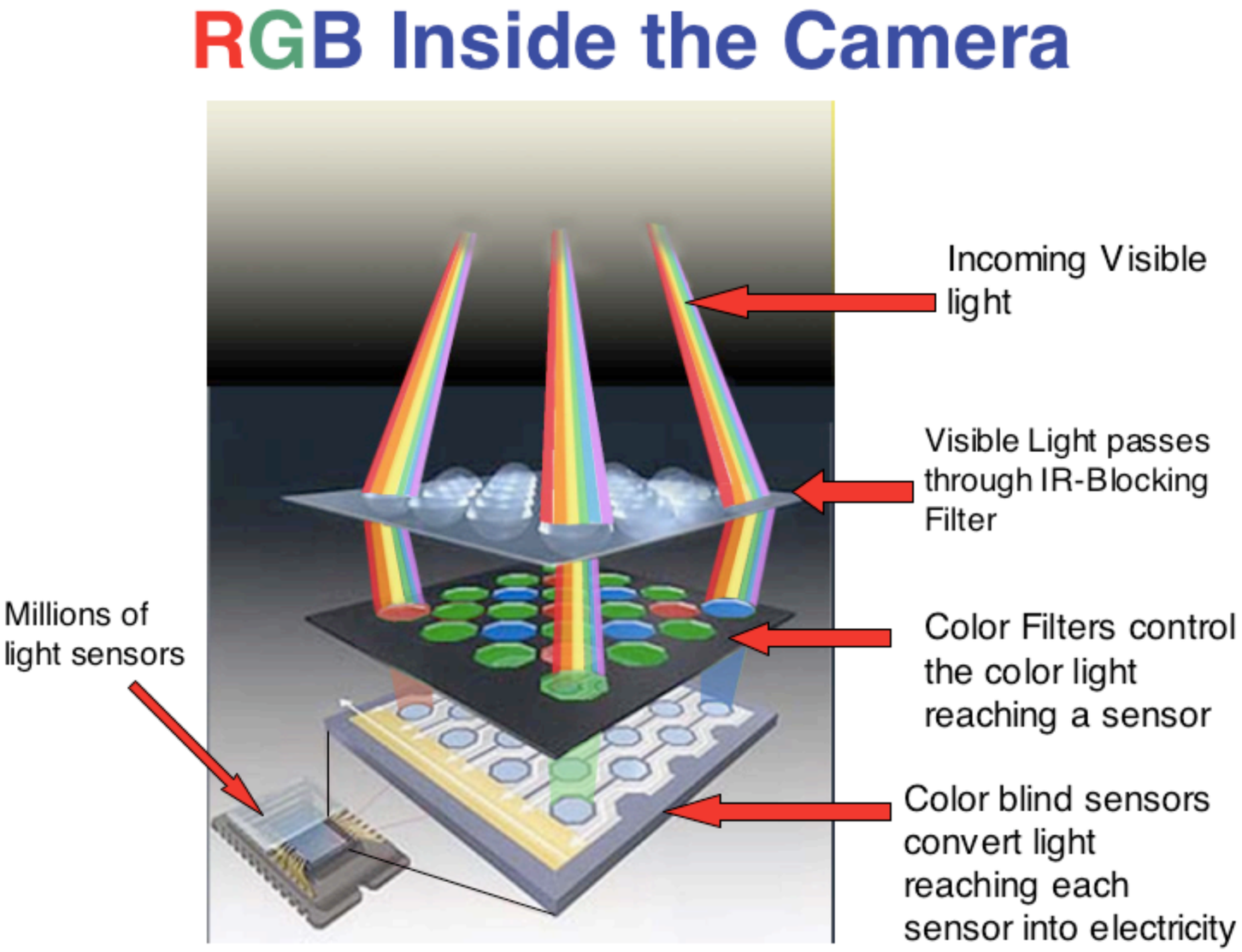


- CMOS sensor is a digital device
- Converts the charge from a photosensitive pixel to a voltage at the pixel site
- Low power
- Standard chip — can be mass produced in standard silicon production line
- Low sensitivity, higher frame rate
- Rolling shutter

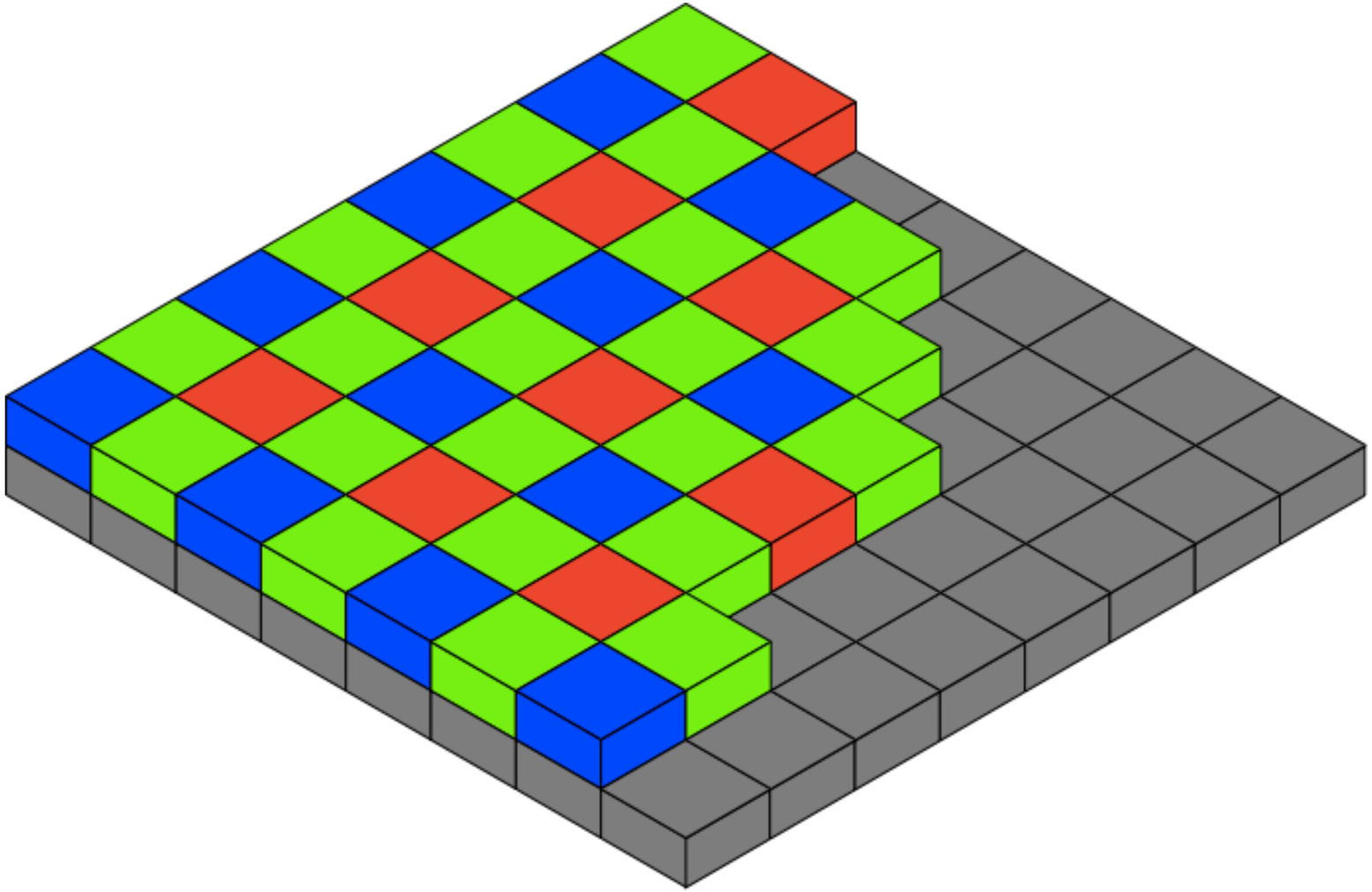
From Abramowitz & Davidson

(See Active Pixel Sensors for more about converting light into bits)

Colors


RGB Inside the Camera
Incoming Visible light
Visible Light passes through IR-Blocking Filter
Color Filters control the color light reaching a sensor
Color blind sensors convert light reaching each sensor into electricity
Millions of light sensors

Bayer Pattern



CCD

- Well-established
- Low noise
- “Clear view” of light
- Requires up to 5 different voltages, power-hungry
- Typically high(er) resolution
- Interlaced or Progressive Scan (better!)

CMOS

- Only useful since late 90’s
- Transistors (can) block photodiode
- Can use 100x less power
- Easy to manufacture (any standard silicon production line)
- Rolling shutter

Back-illuminated CMOS

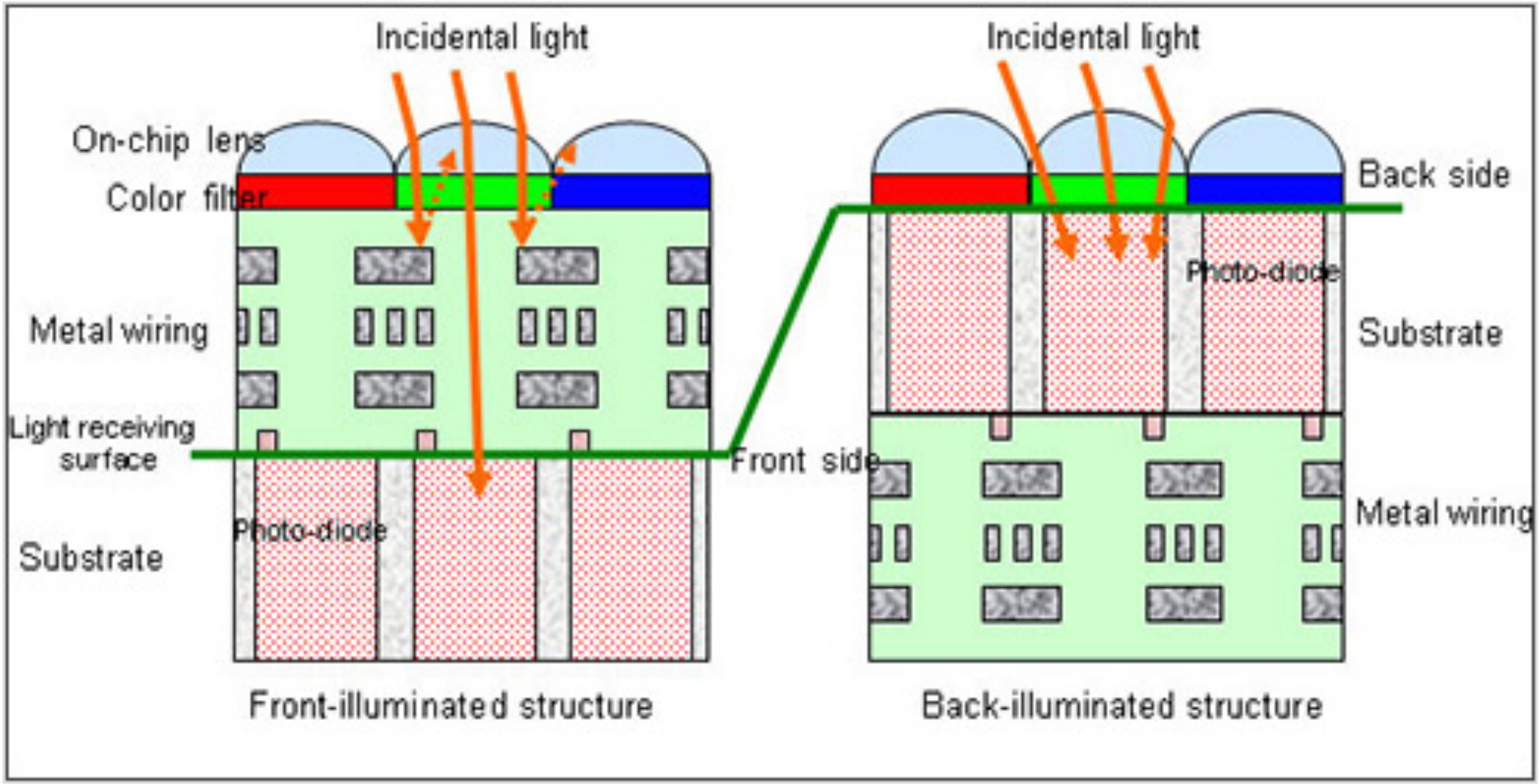
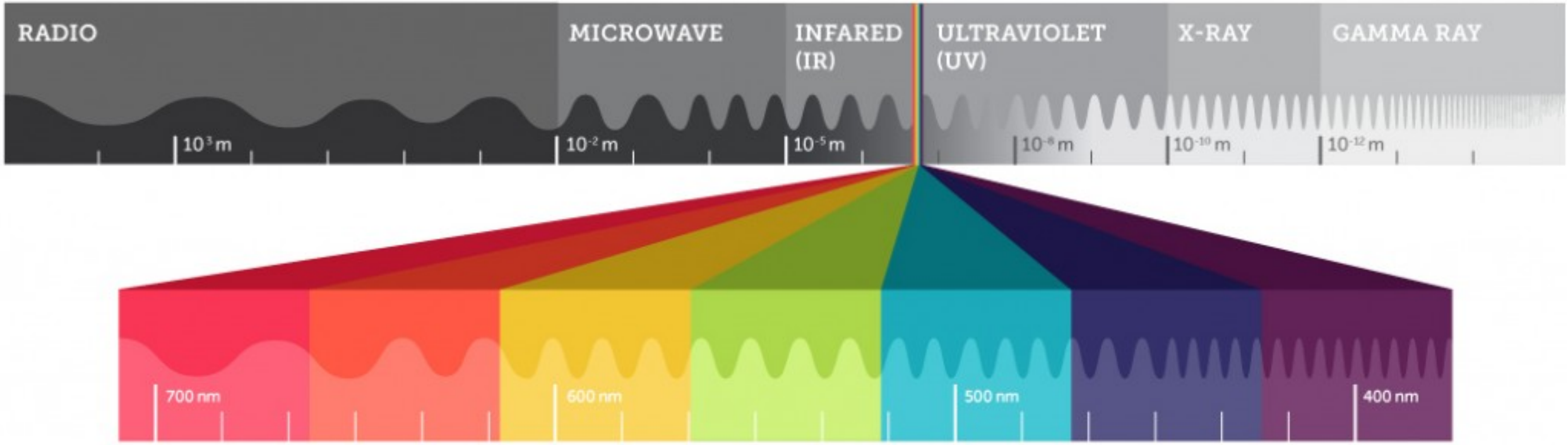


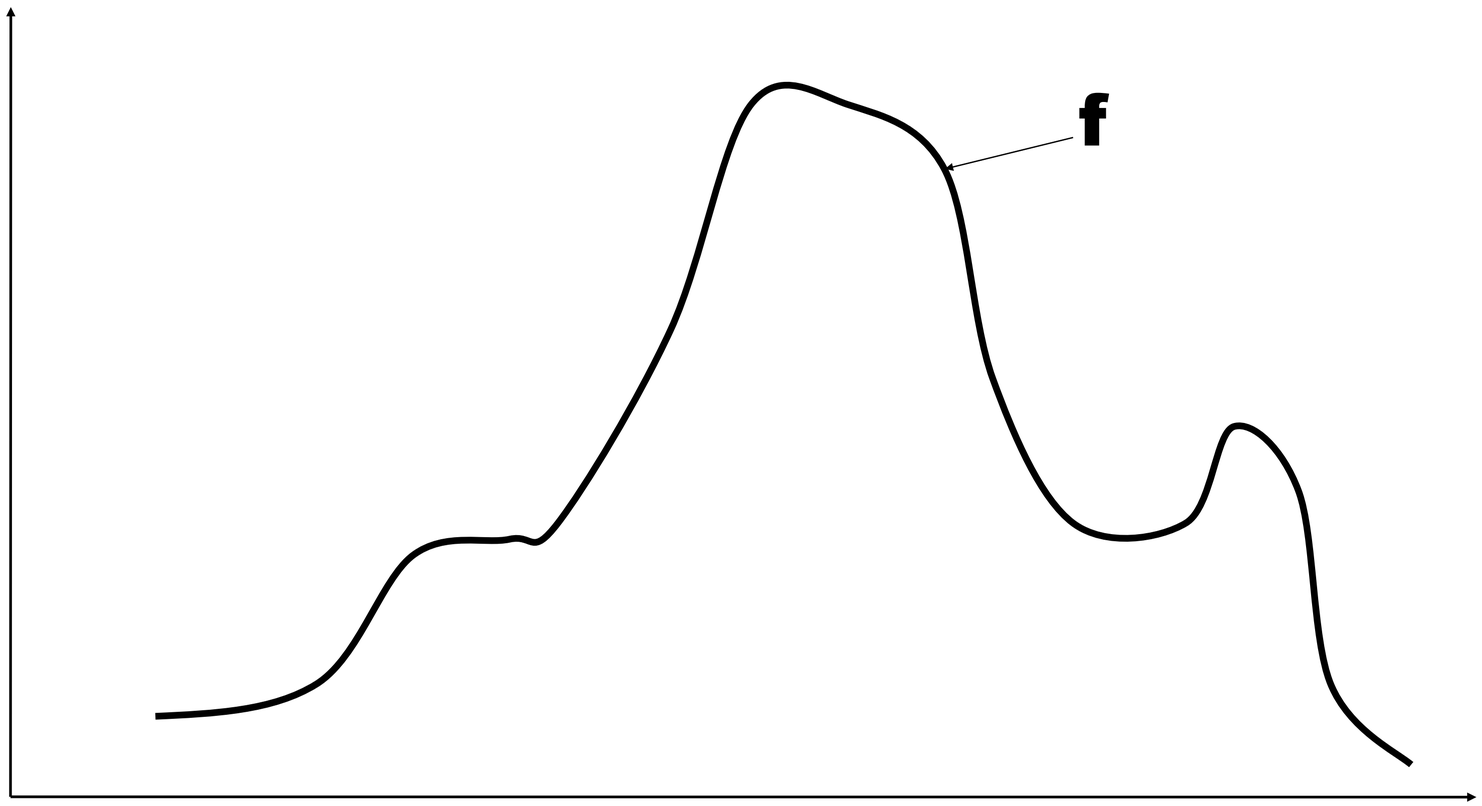
Diagram from Sony article [“Back to Front”]

Light spectrum



[https://possibility.teledyneimaging.com/invisible-becomes-visible/]

Sampling



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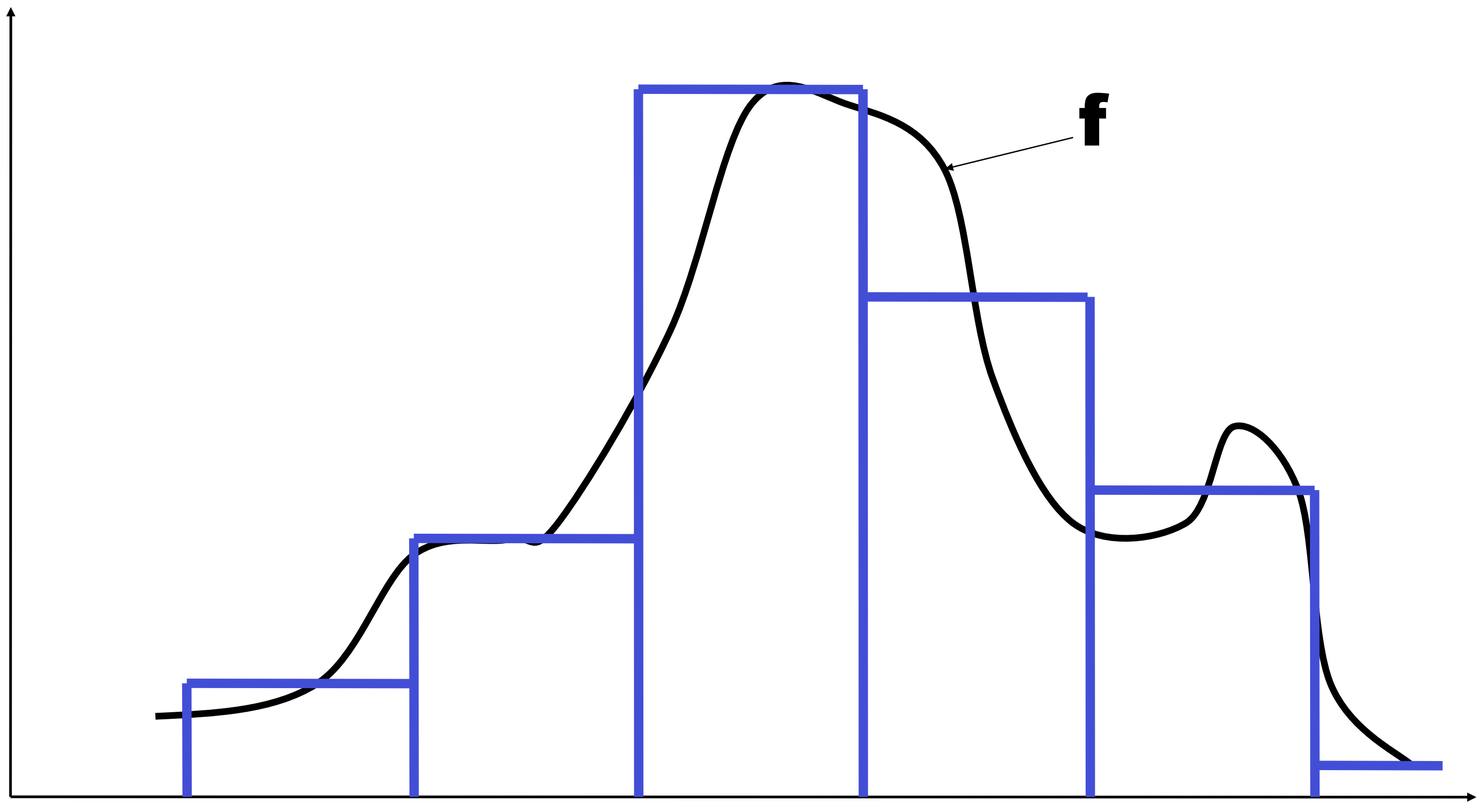

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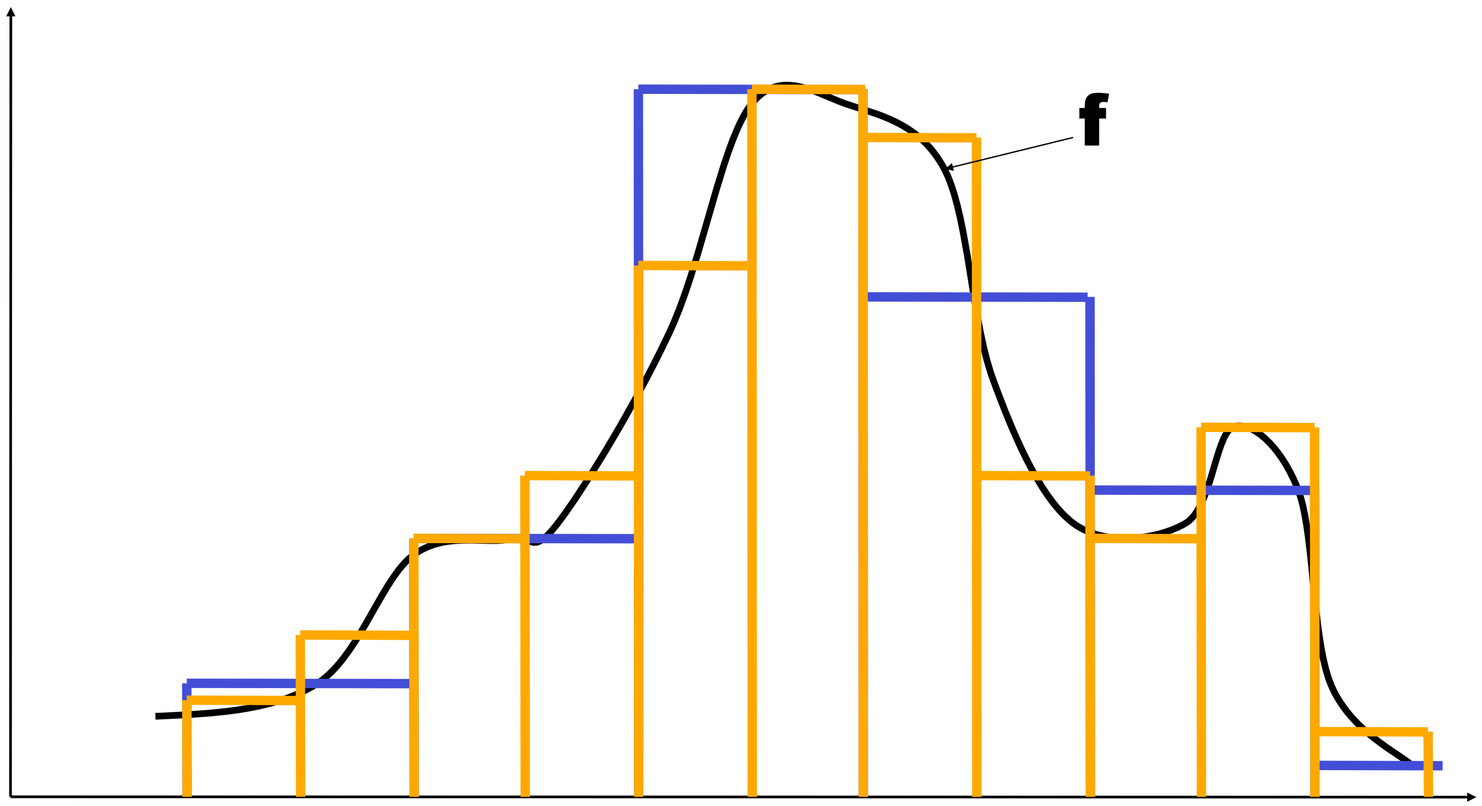

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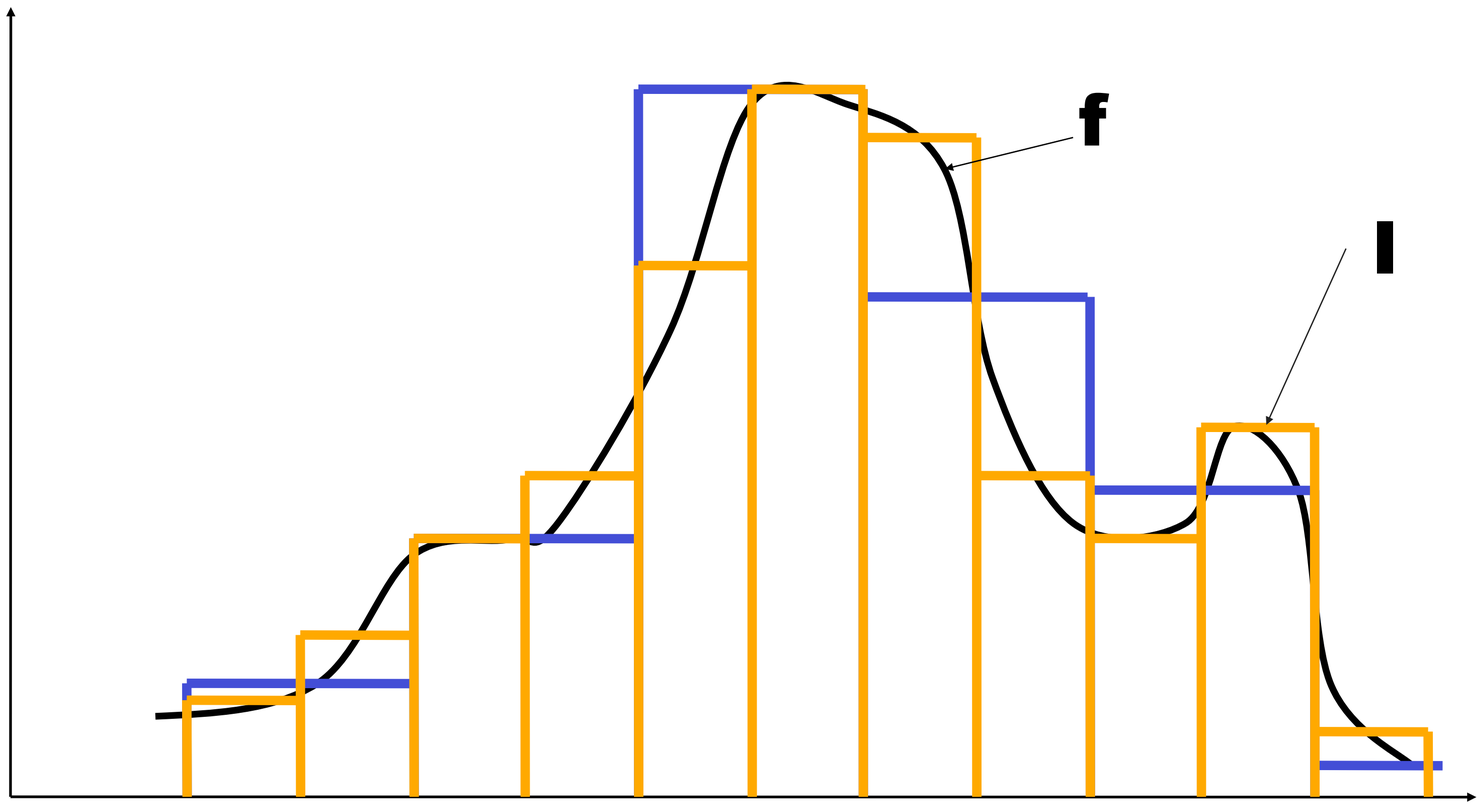
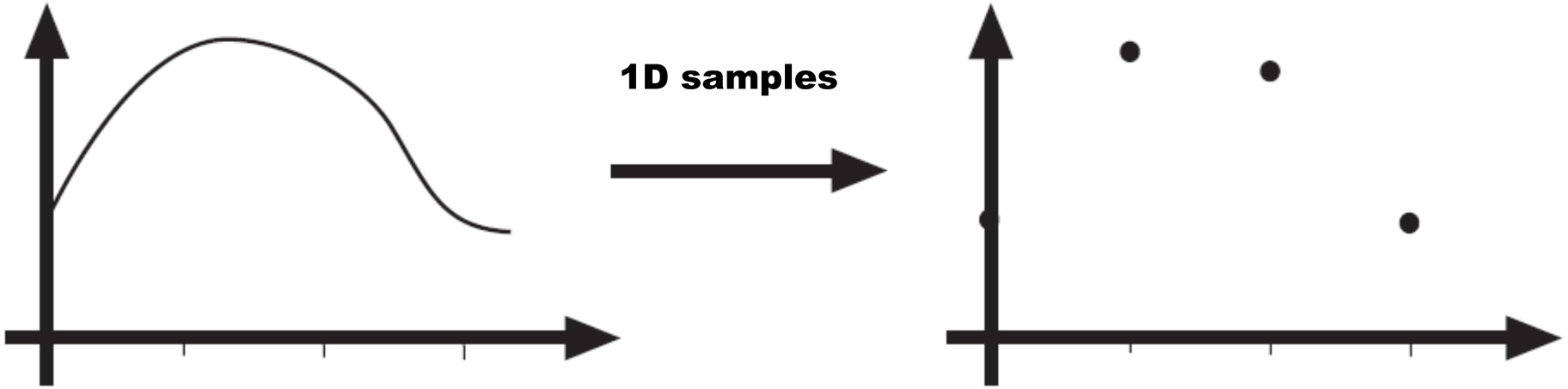
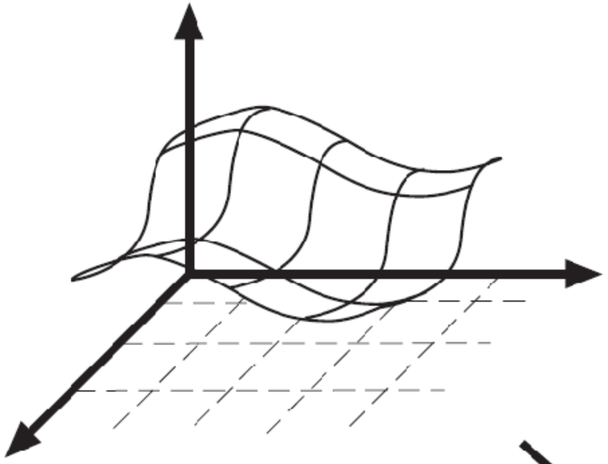


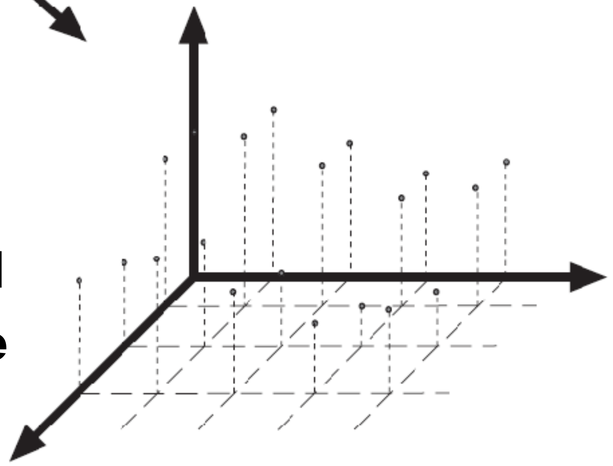
Sampling 1D

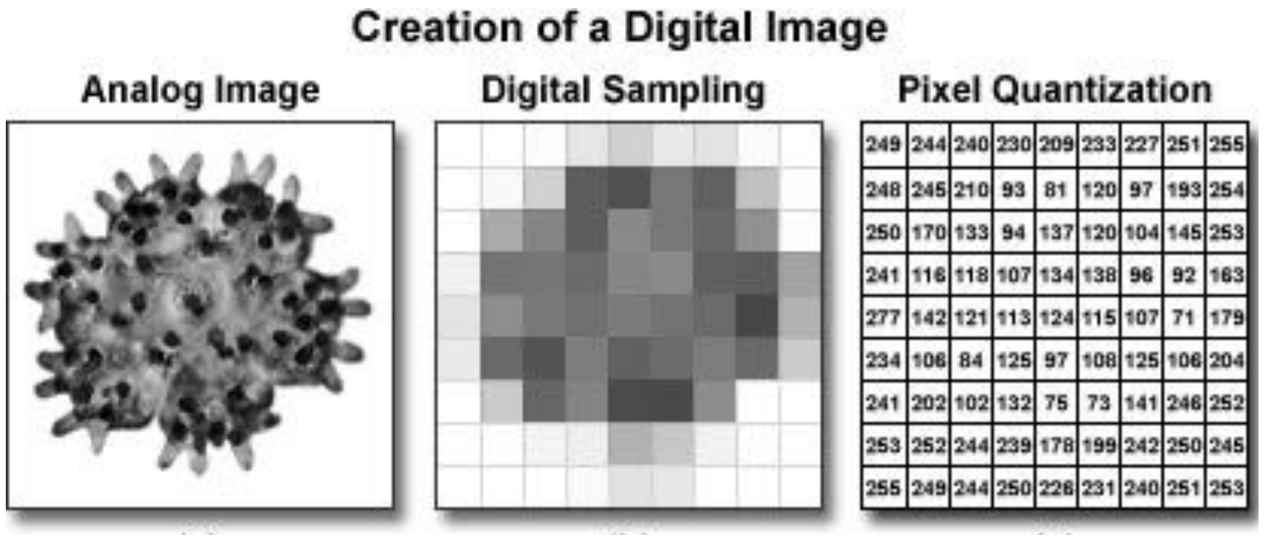


Sampling 2D



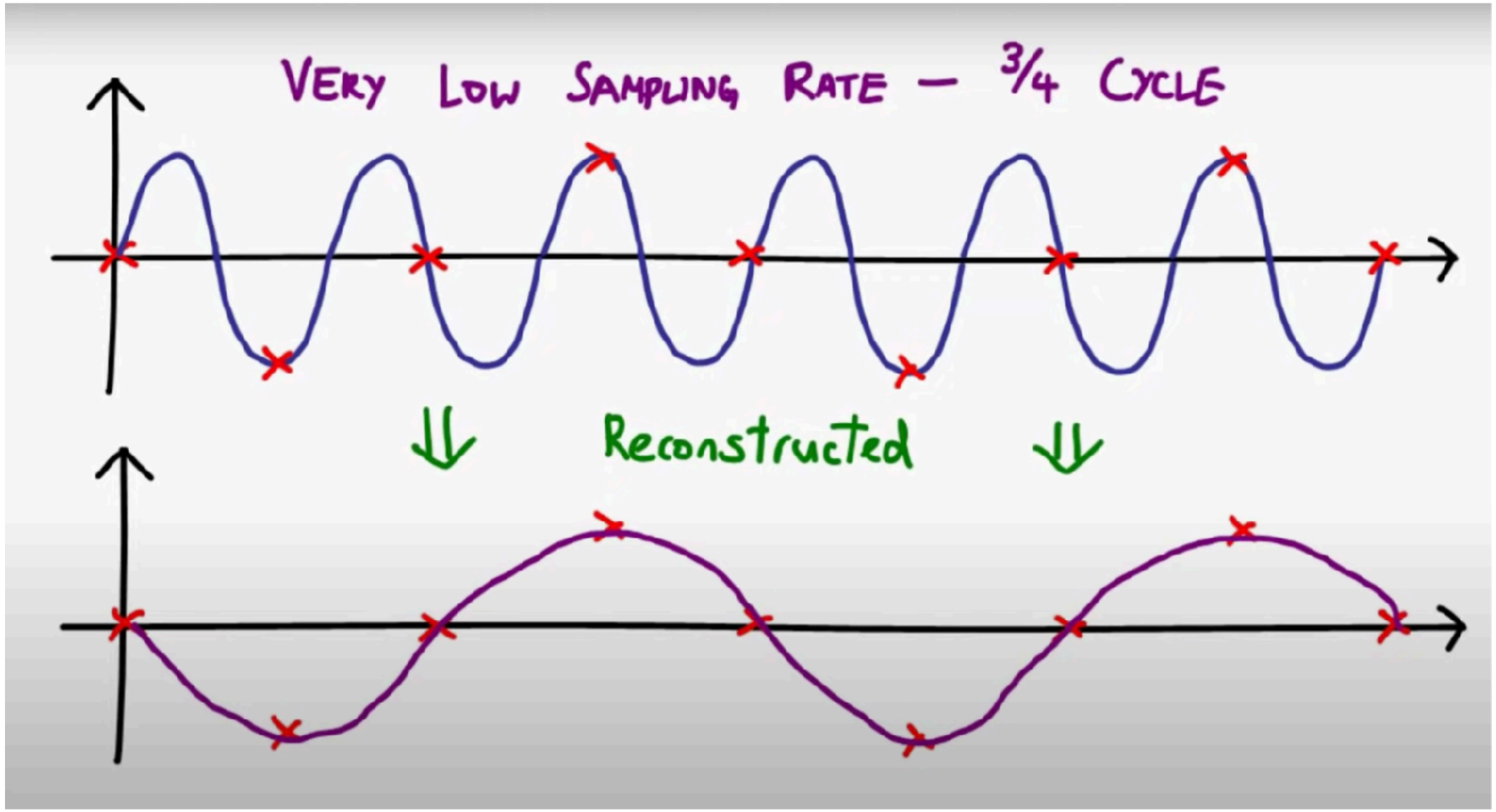
2D samples



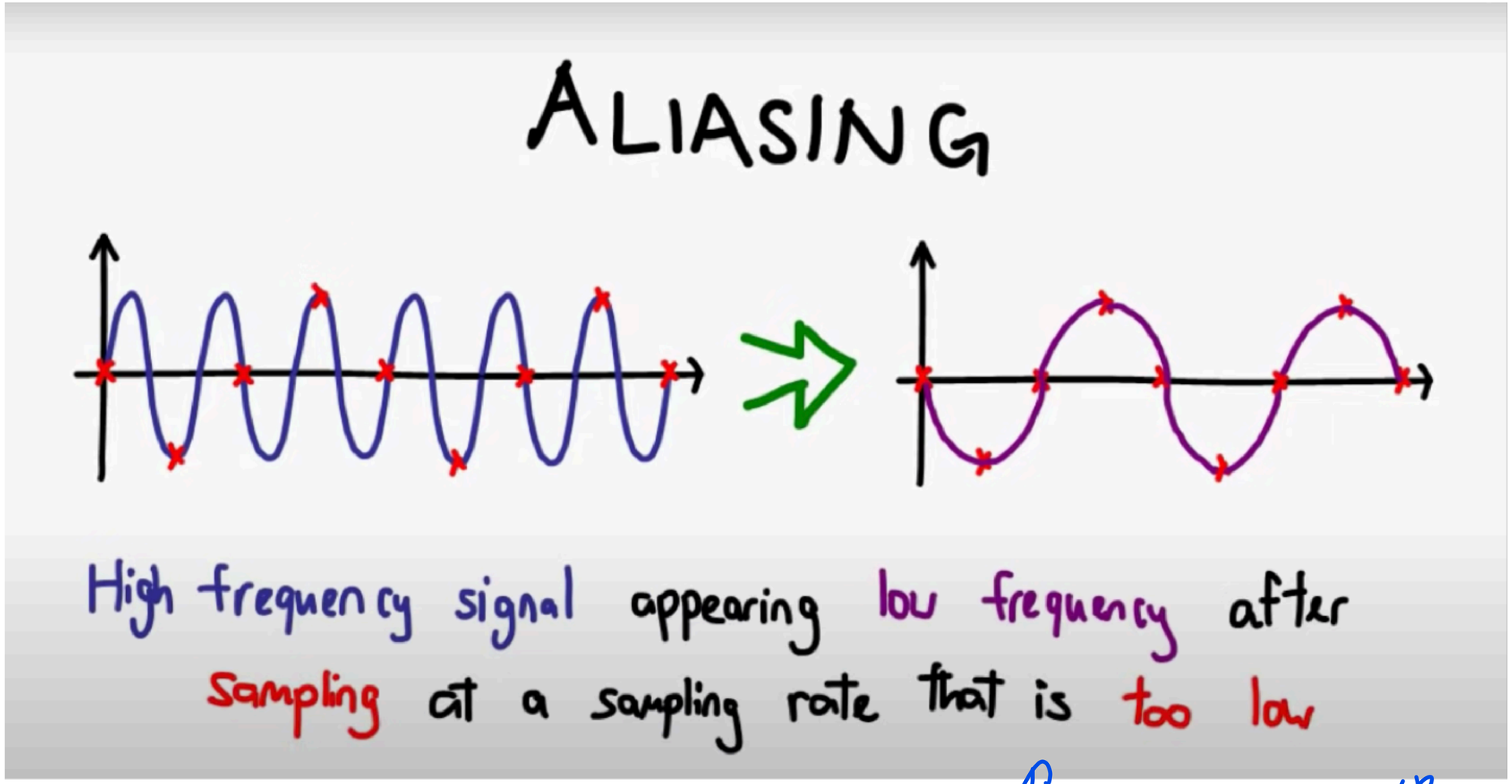


Sampling in 2D takes a function and returns an array; we allow the array to be infinite dimensional and to have negative as well as positive indices.

Aliasing



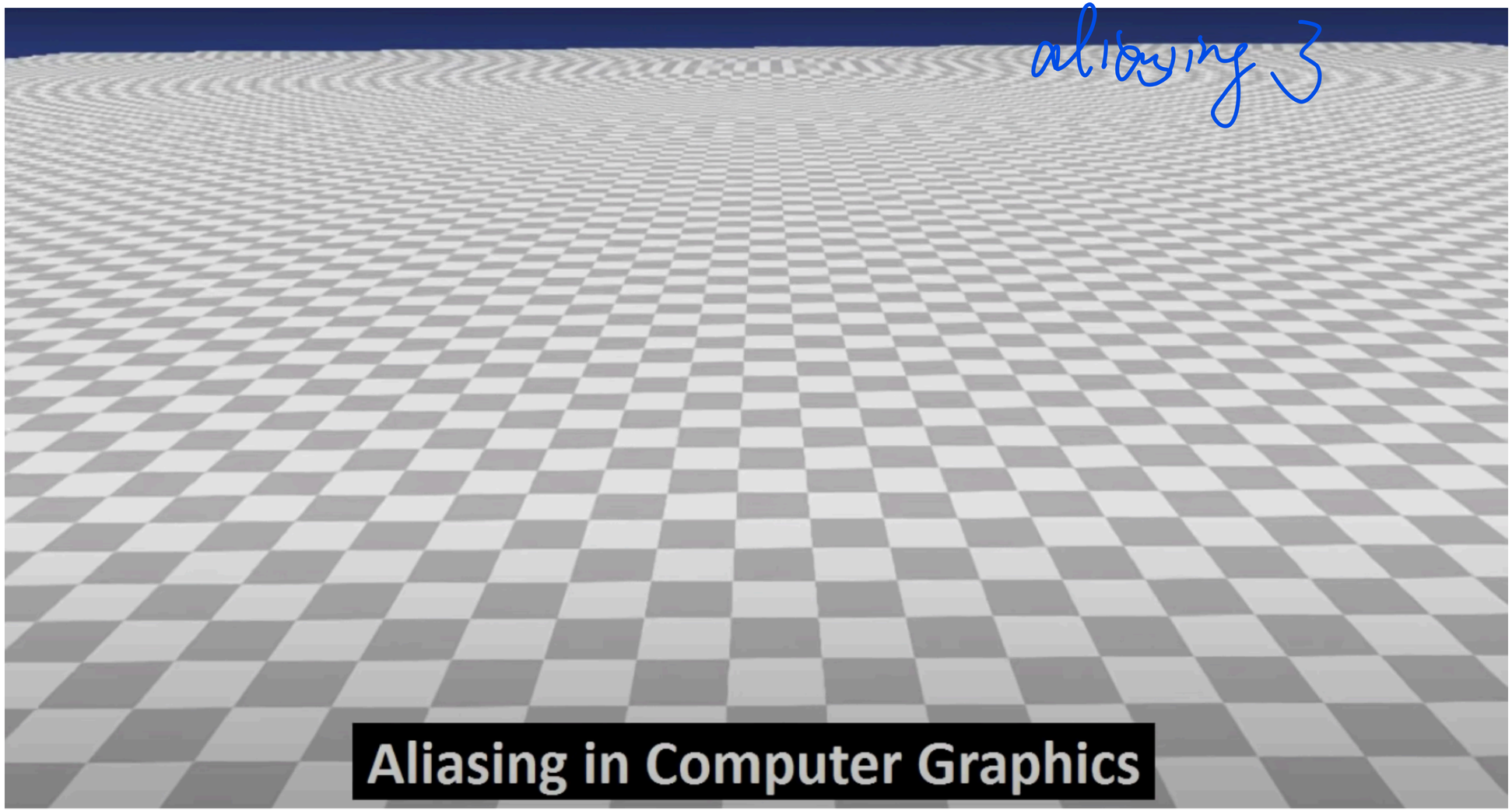
Aliasing



采样采得太慢了

Aliasing

图片 500×500 → 降采样 100×100
采样图片就会丢失信息
aliasing了



←摩纹?

Aliasing

解决

① pixels → area sampled averaged

② high-frequency filter 过滤掉高频信号

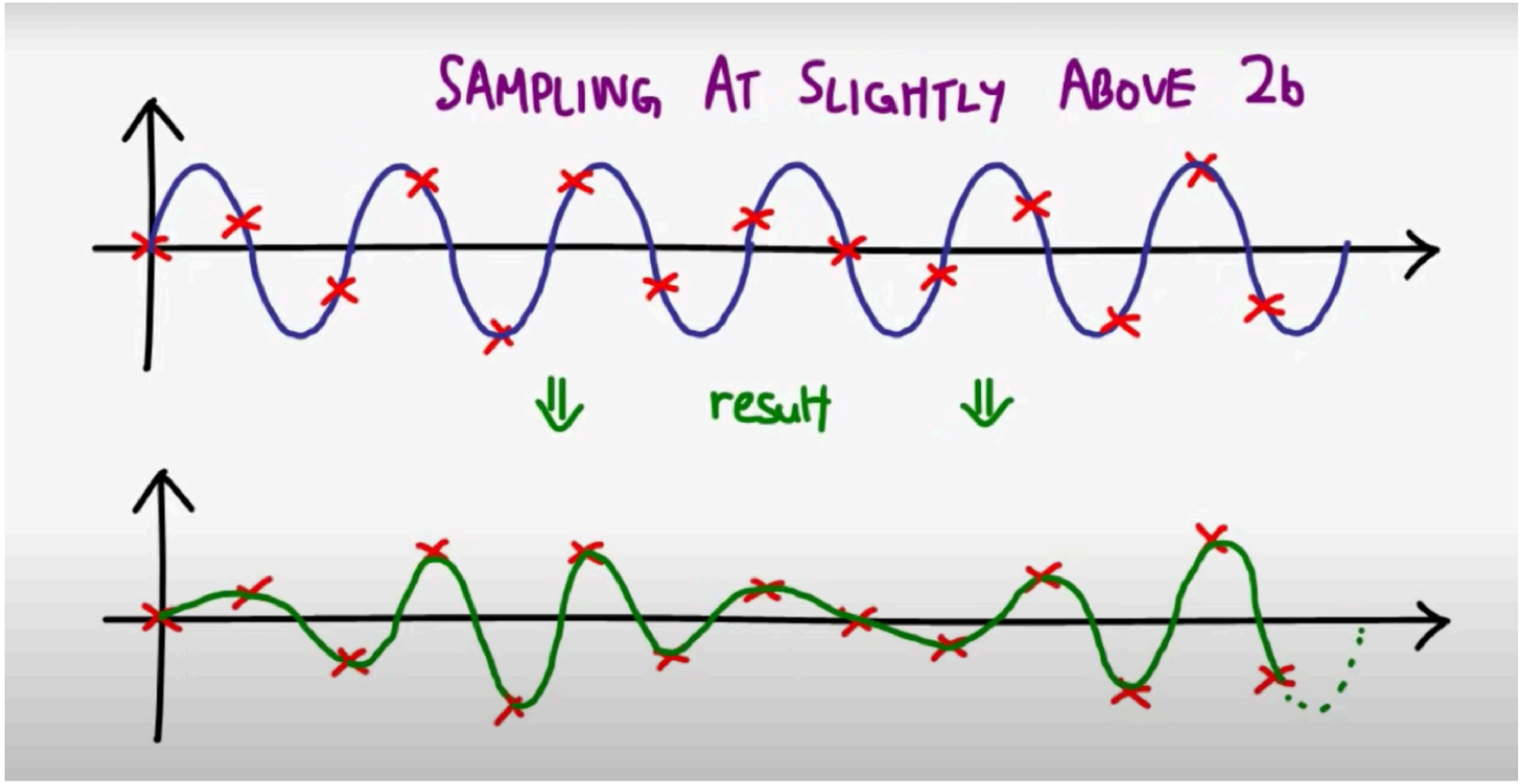
NYQUIST SAMPLING THEOREM

Sampling rate should be double the max. frequency

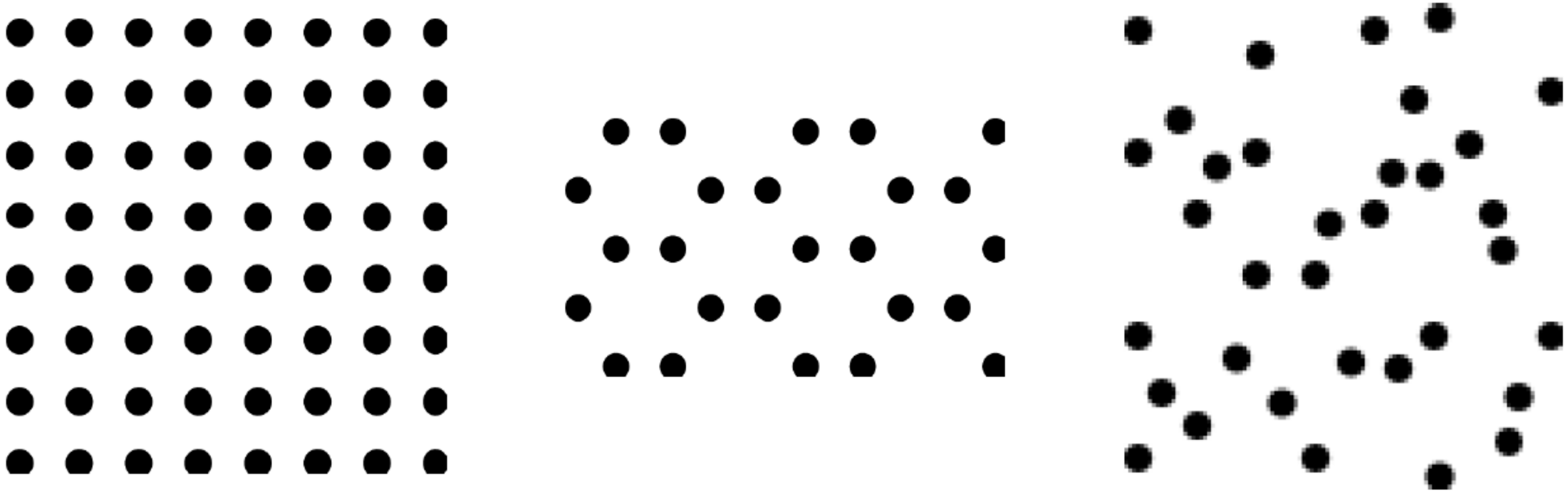
To be precise...

Sampling rate = 2b ⇒ All frequencies LESS THAN b will not alias

Aliasing



Sampling Grids



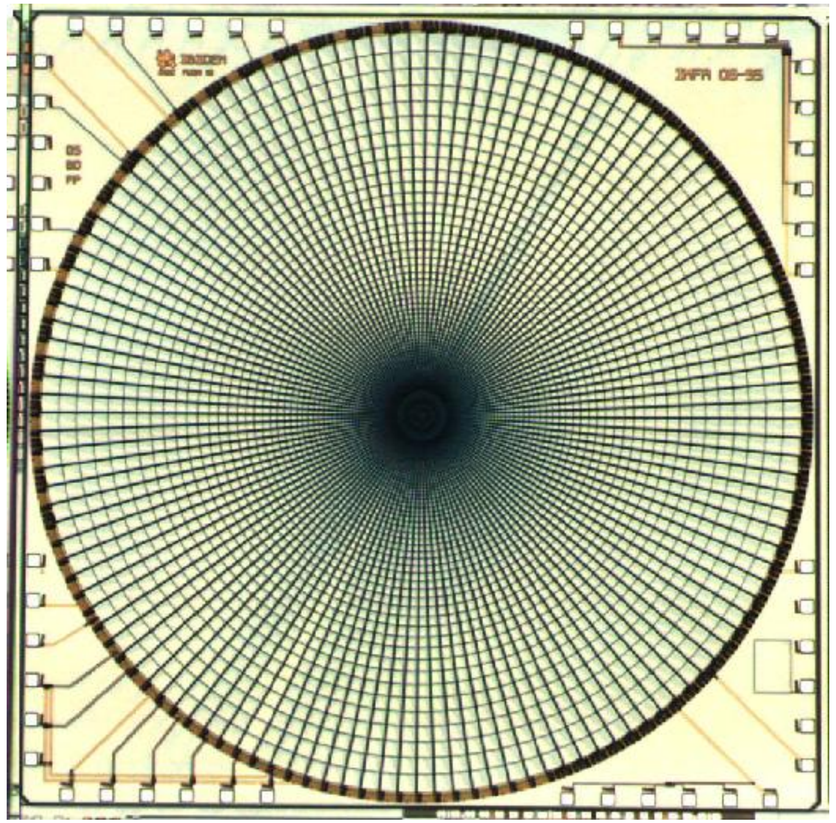
Cartesian sampling

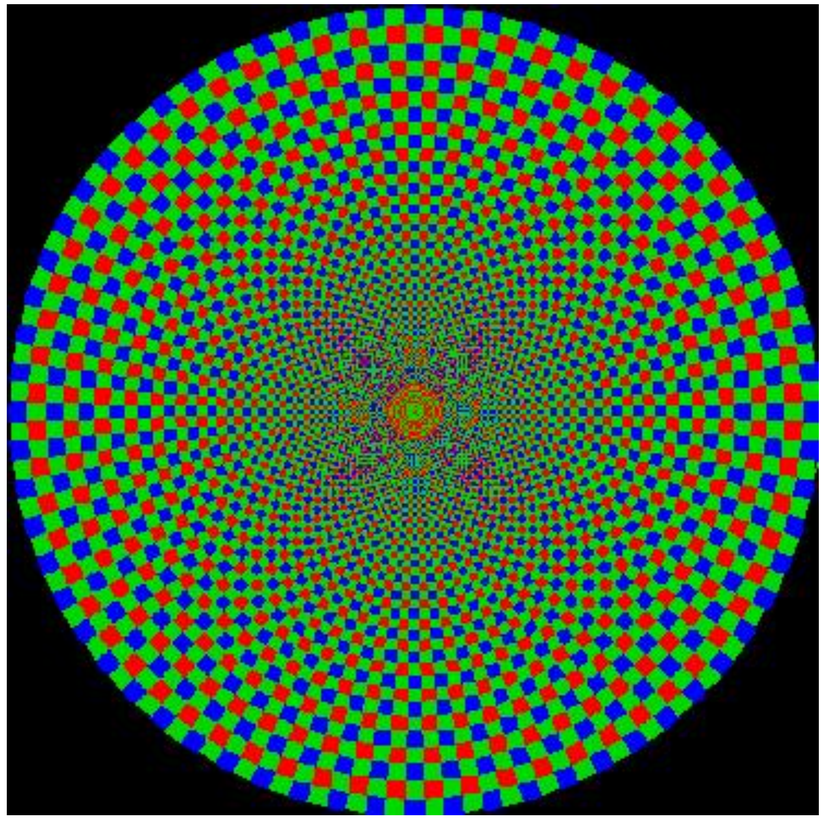
Hexagonal sampling

Non-uniform sampling

边缘形成

Retina-like Sensors





Quantization

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  – integer values

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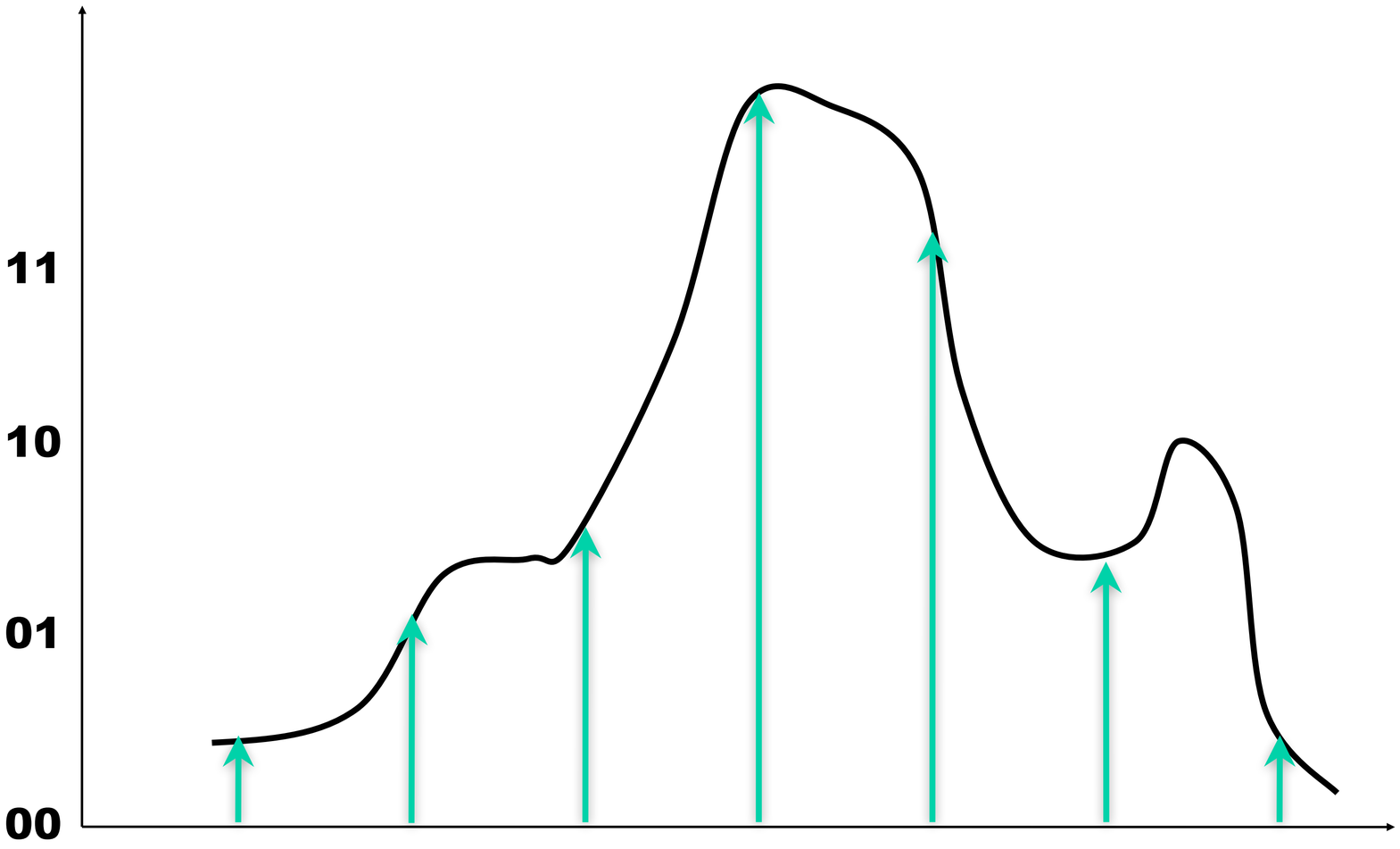
Quantization

量化？

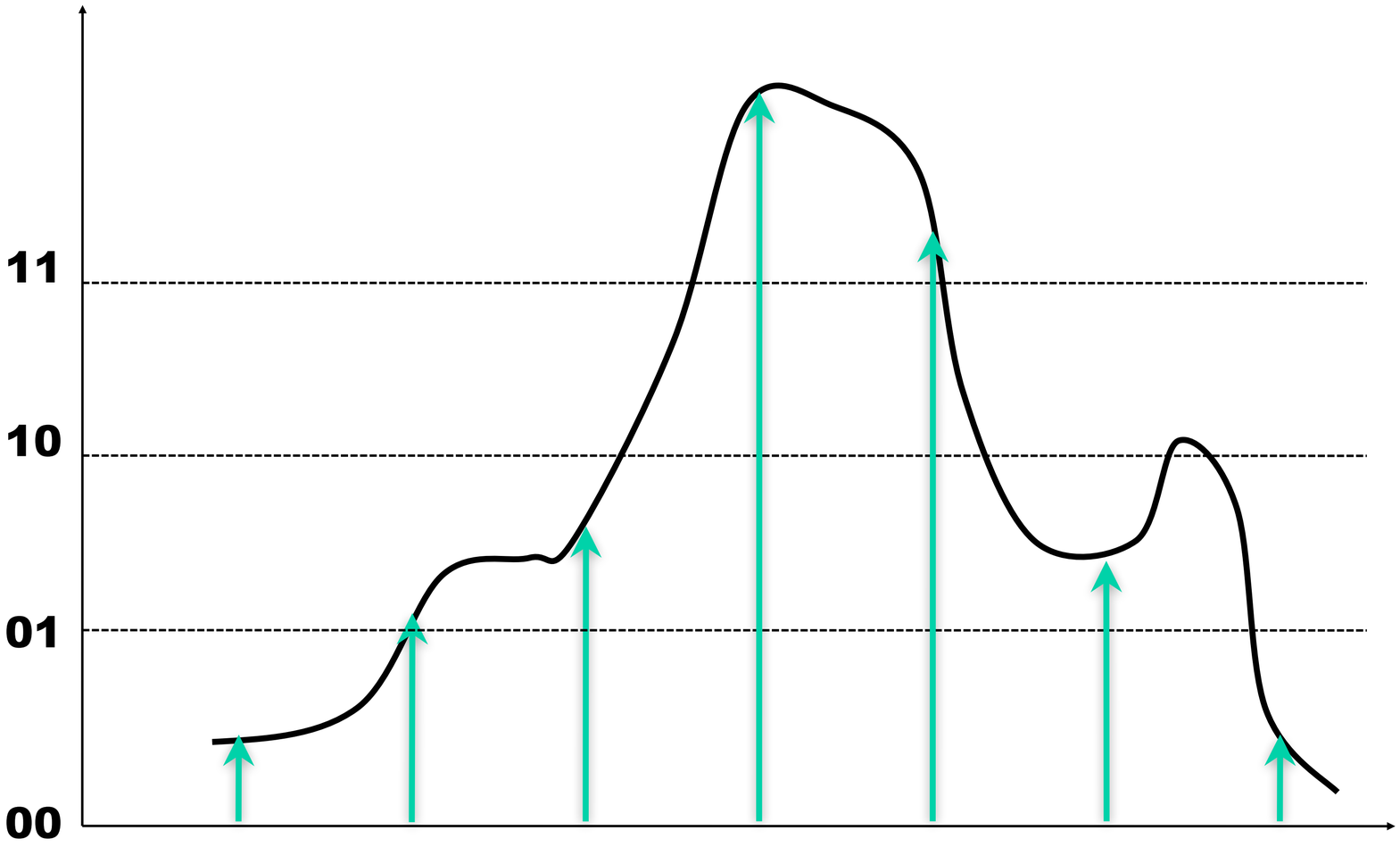
连续 → 点数

- **Real valued function will get digital values**
  - **integer values**
- **Quantization is lossy!!**
  - **After quantization,**
    the original signal cannot be reconstructed anymore
- **This is in contrast to sampling, as a sampled but not quantized signal can be reconstructed**
- **Simple quantization uses equally spaced levels with k intervals with** $k = 2^d$

Quantization



Quantization



Usual Quantization Intervals

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$$8 \text{ bit} = 2^8 = 256 \text{ grayvalues}$$

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- **12bit or 16bit from some sensors**
- **Nonlinear, for example log-scale**

HDR

Photo: Paulo Barcellos Jr.

Properties

- **Image resolution**
- **Geometric resolution: How many pixels per area**
- **Radiometric resolution: How many bits per pixel**

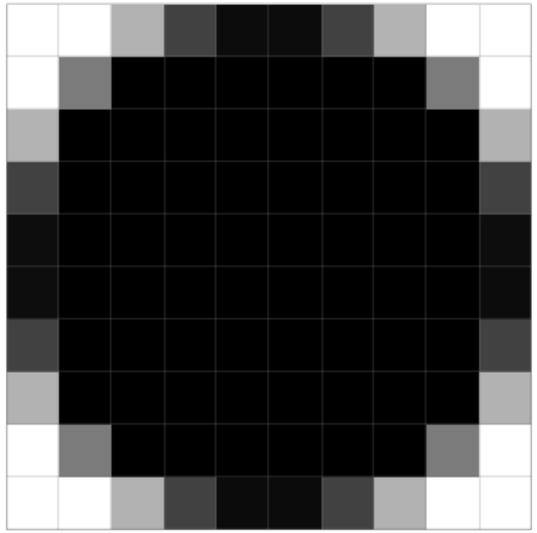
Image Resolution

1024x1024

512x1024

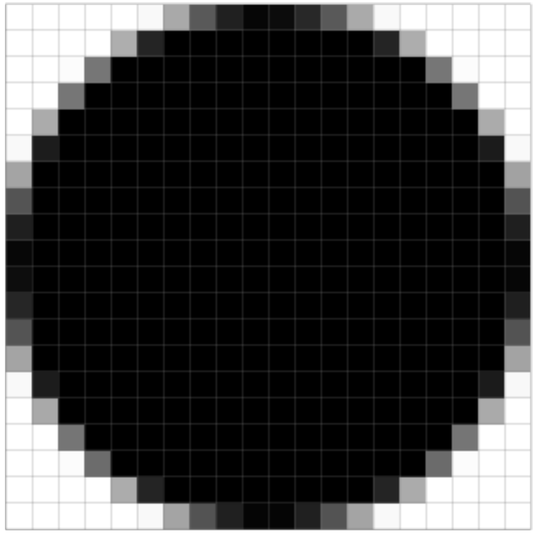
512x512

Geometric Resolution



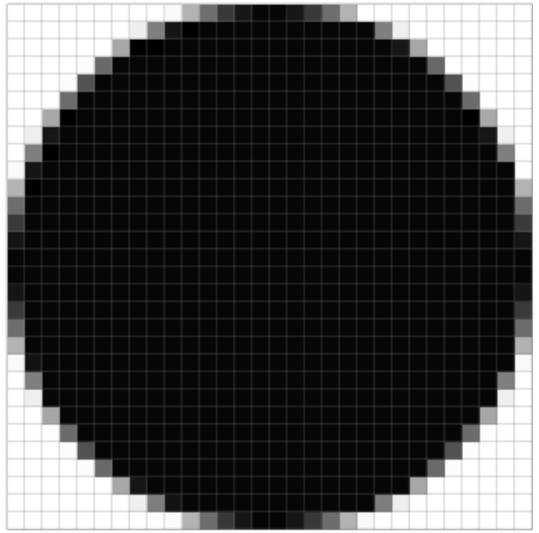
1x

(10 x 10 px)



2x

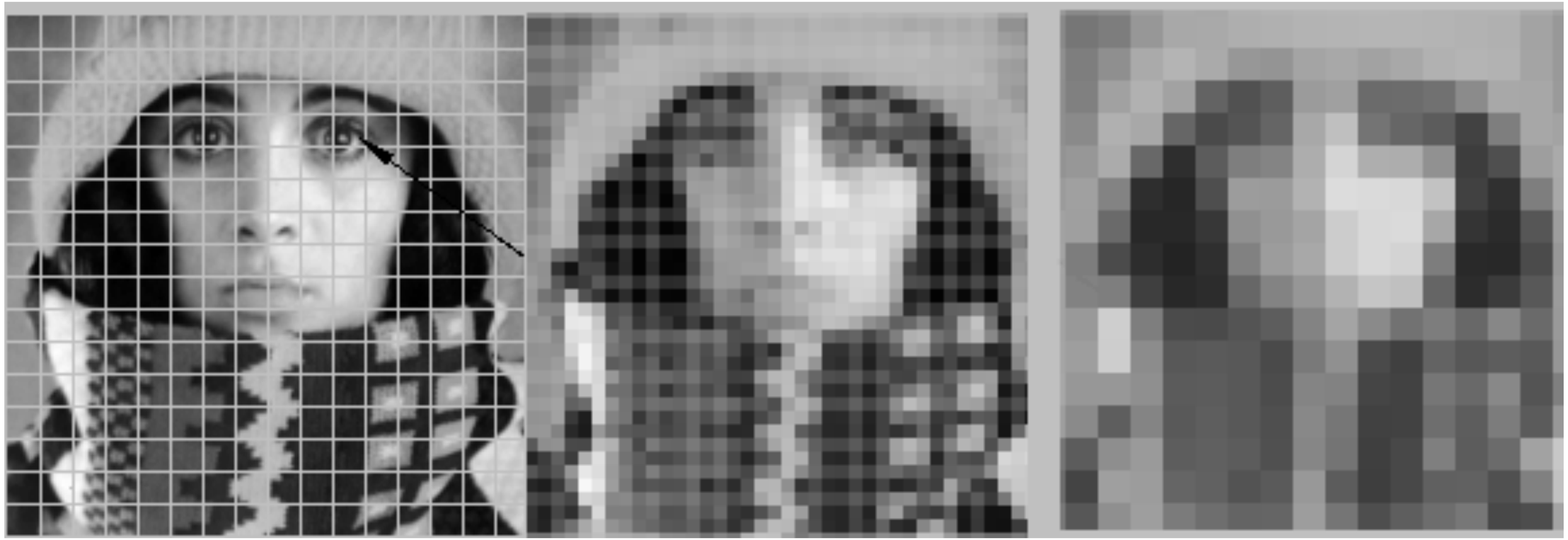
(20 x 20 px)



3x

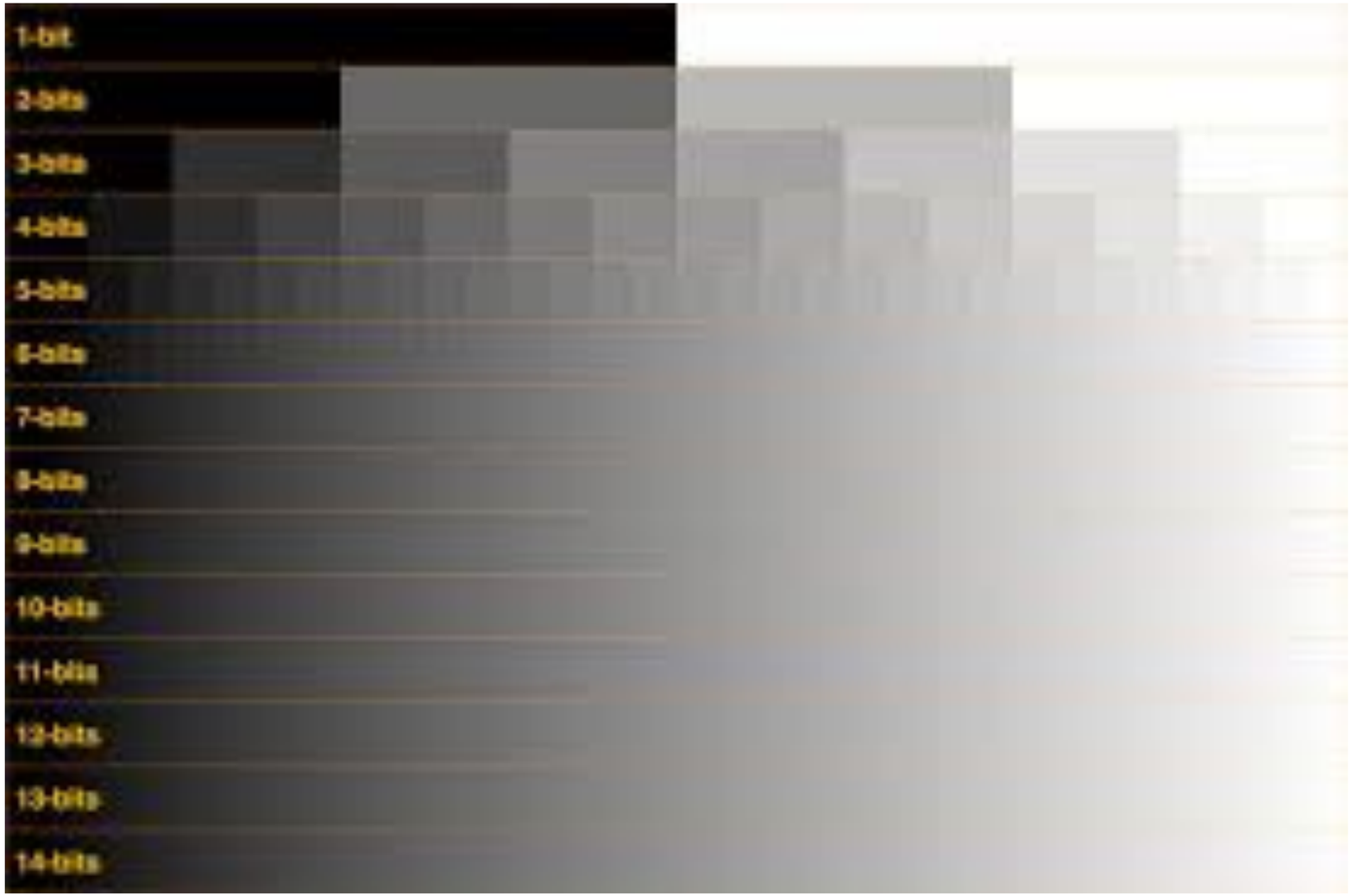
(30 x 30 px)

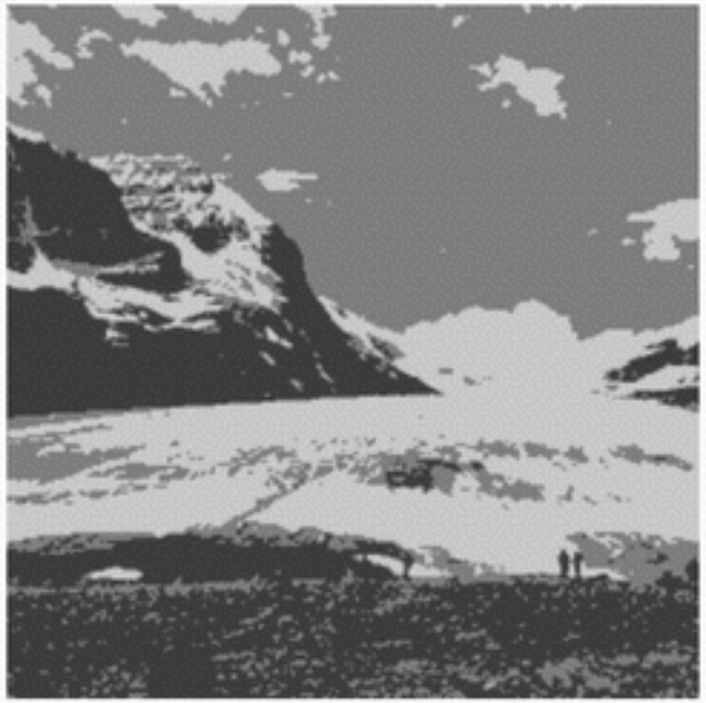
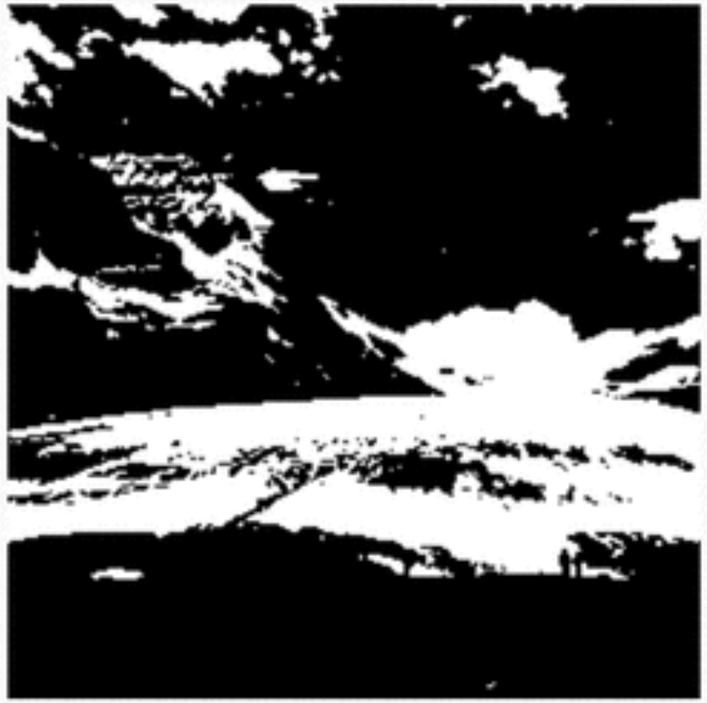
Geometric Resolution



Radiometric Resolution

增强度
测量



Radiometric Resolution

8 bit Resolution $2^8 = 256$ levels	2 bit Resolution $2^2 = 4$ levels	1 bit Resolution $2^1 = 2$ levels