

# Image Acquisition

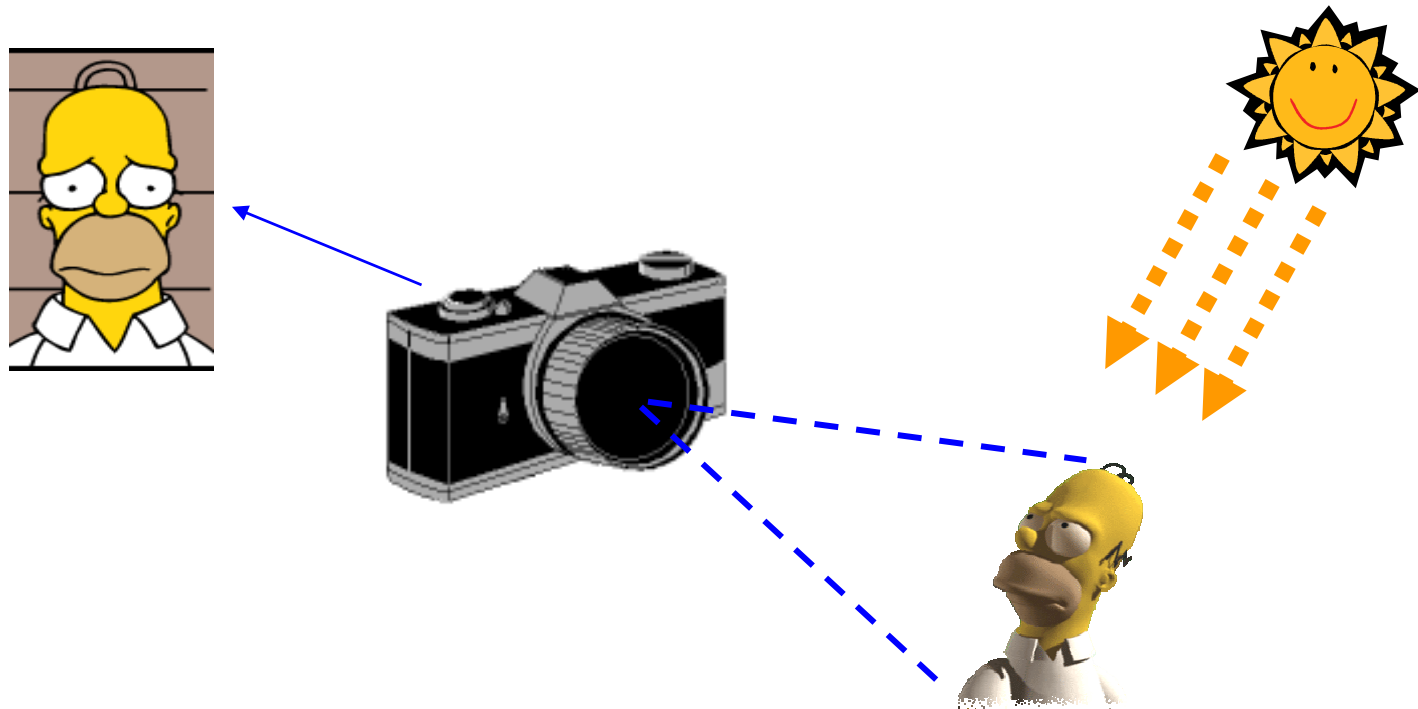
- Image Acquisition
- Image Digitization
  - Spatial domain
  - Intensity domain
- Image Characteristics



# What is an Image ?

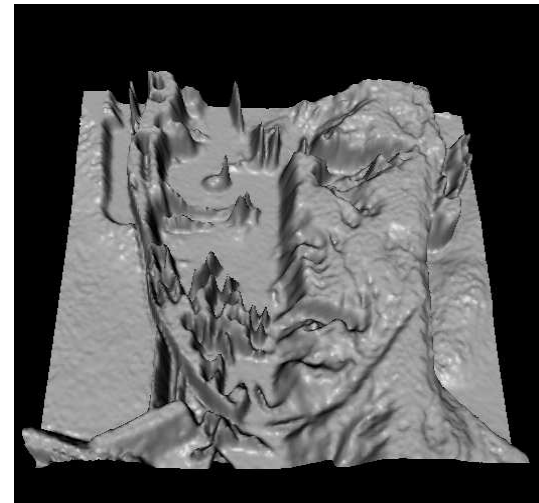
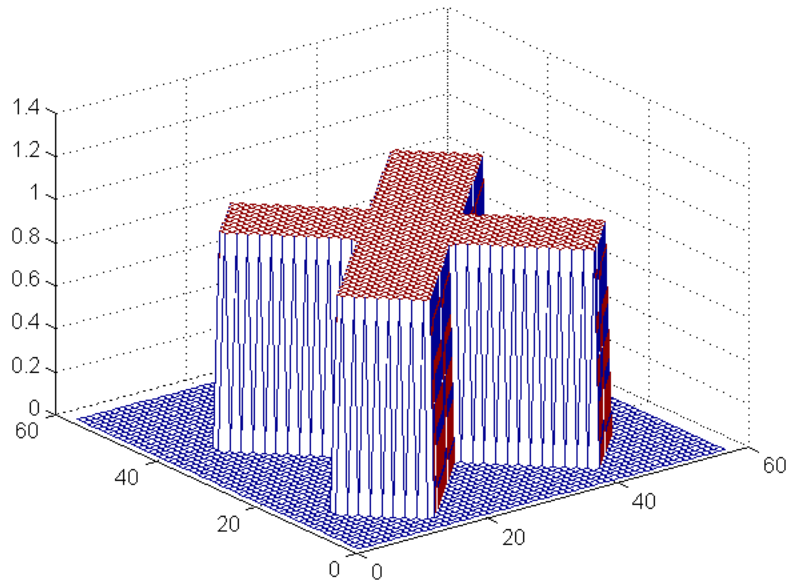
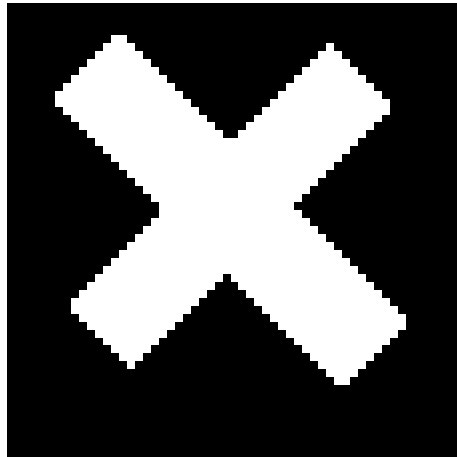
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- An image is a projection of a 3D scene into a 2D *projection plane*.
- An image can be defined as a 2 variable function  $f(x,y): \mathbb{R}^2 \rightarrow \mathbb{R}$  , where for each position  $(x,y)$  in the projection plane,  $f(x,y)$  defines the light intensity at this point.

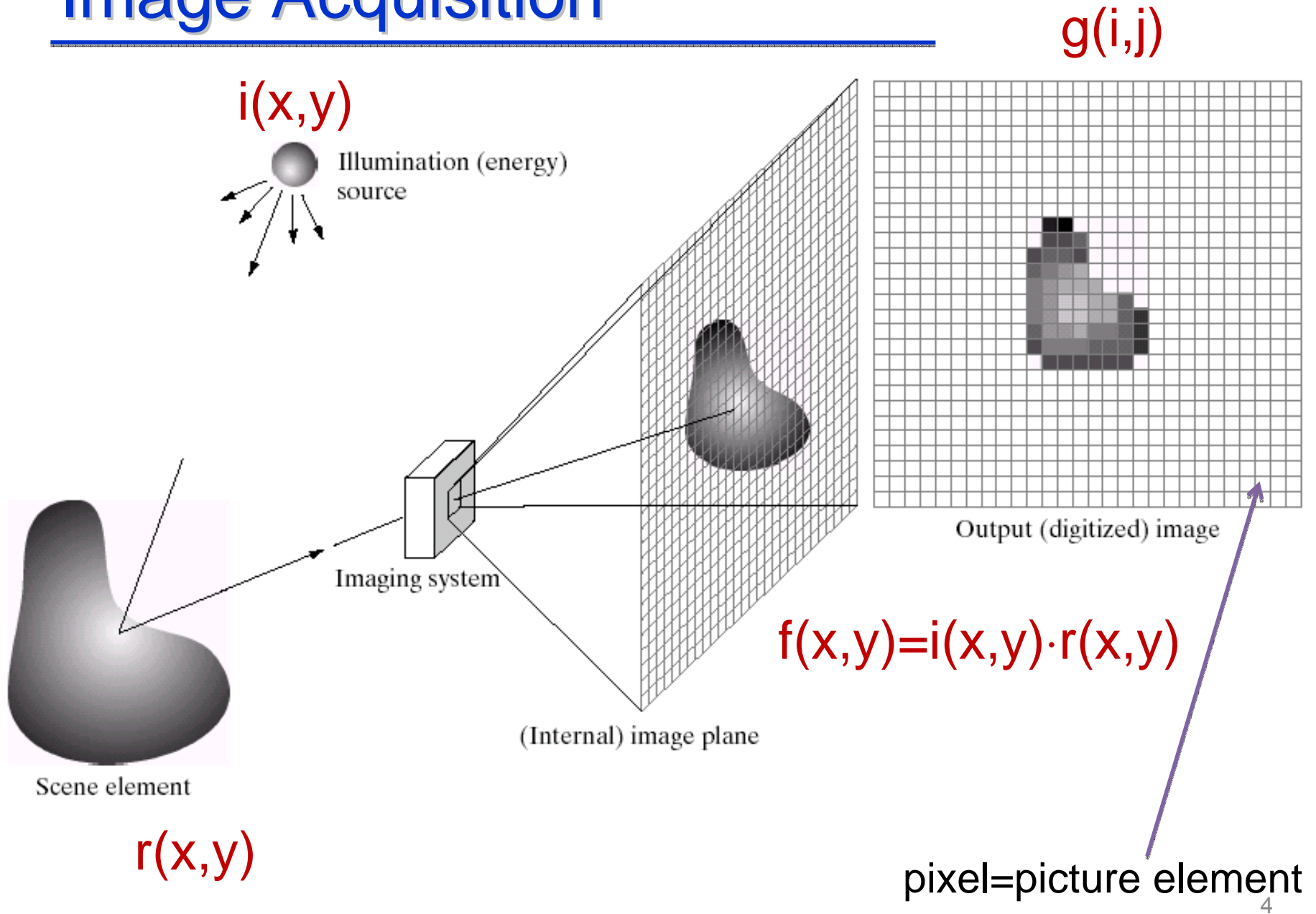


# Image as a function

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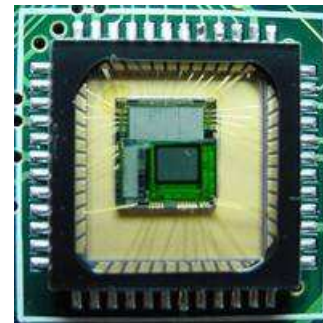
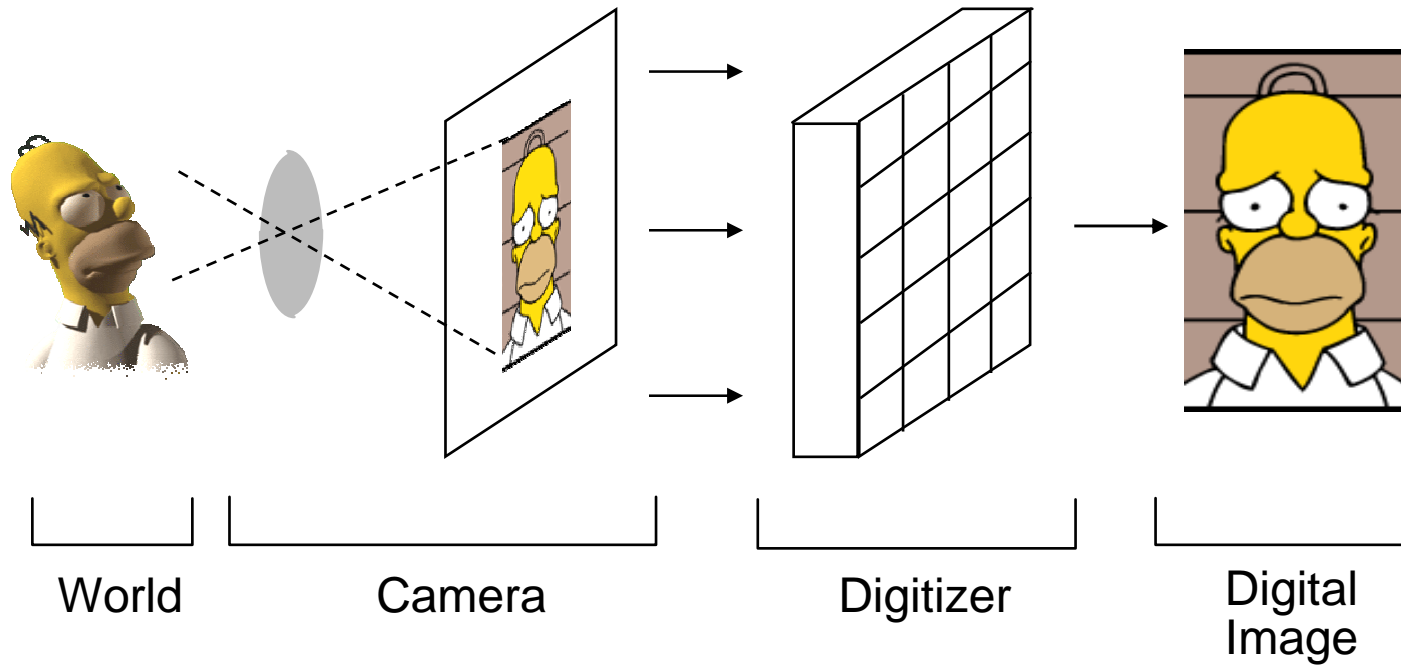


# Image Acquisition



# Acquisition System

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CMOS sensor

# Image Types

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Three types of images:

- Binary images

$$g(x,y) \in \{0, 1\}$$

- Gray-scale images

$$g(x,y) \in C$$

typically  $c=\{0,\dots,255\}$

- Color Images

three channels:

$$g_R(x,y) \in C \quad g_G(x,y) \in C \quad g_B(x,y) \in C$$



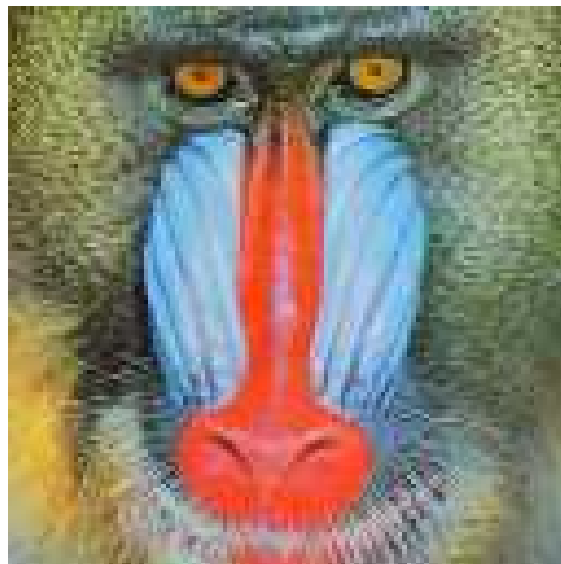
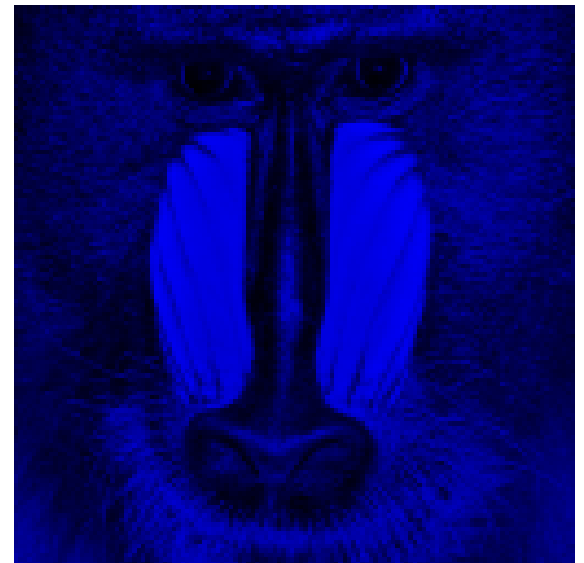
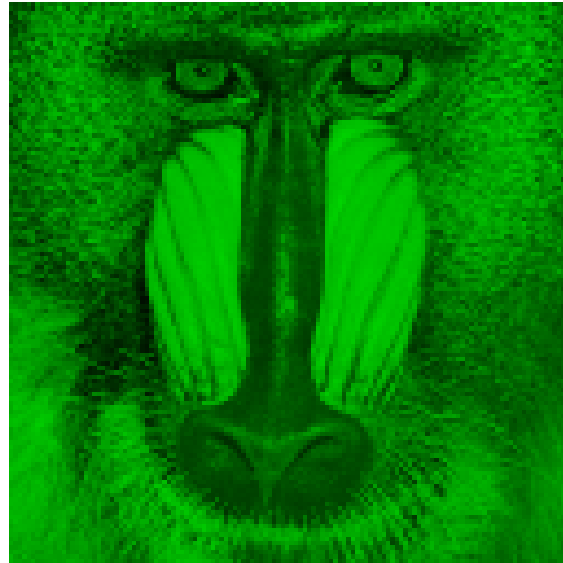
# Gray Scale Image

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x =	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
y =															
41	210	209	204	202	197	247	143	71	64	80	84	54	54	57	58
42	206	196	203	197	195	210	207	56	63	58	53	53	61	62	51
43	201	207	192	201	198	213	156	69	65	57	55	52	53	60	50
44	216	206	211	193	202	207	208	57	69	60	55	77	49	62	61
45	221	206	211	194	196	197	220	56	63	60	55	46	97	58	106
46	209	214	224	199	194	193	204	173	64	60	59	51	62	56	48
47	204	212	213	208	191	190	191	214	60	62	66	76	51	49	55
48	214	215	215	207	208	180	172	188	69	72	55	49	56	52	56
49	209	205	214	205	204	196	187	196	86	62	66	87	57	60	48
50	205	203	202	186	174	185	149	71	63	55	55	45	56		
51	211	199	217	194	183	177	209	90	62	64	52	93	52		
52	209	209	197	194	183	187	187	239	58	68	61	51	56		
53	203	209	195	203	188	185	183	221	75	61	58	60	60		
54	199	236	188	197	183	190	183	196	122	63	58	64	66		
55	202	203	199	197	196	181	173	186	105	62	57	64	63		



# Color Image





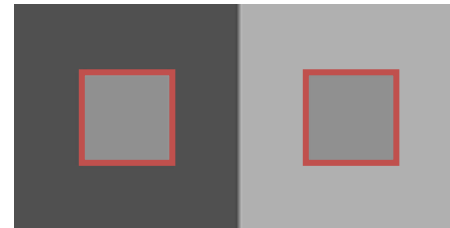
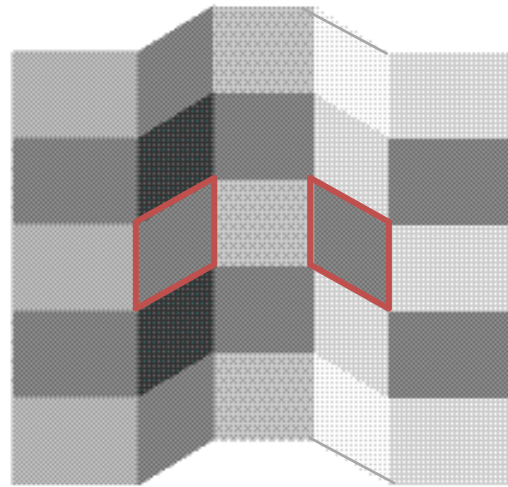
# Notations

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- **Image Intensity** -
  - Light energy emitted from a unit area in the image
  - Device dependence
- **Image Brightness** -
  - The subjective appearance of a unit area in the image
  - Context dependence
  - Subjective
- **Image Gray-Level** -
  - The relative intensity at each unit area
  - Between the lowest intensity (Black value) and the highest intensity (White value)
  - Device independent

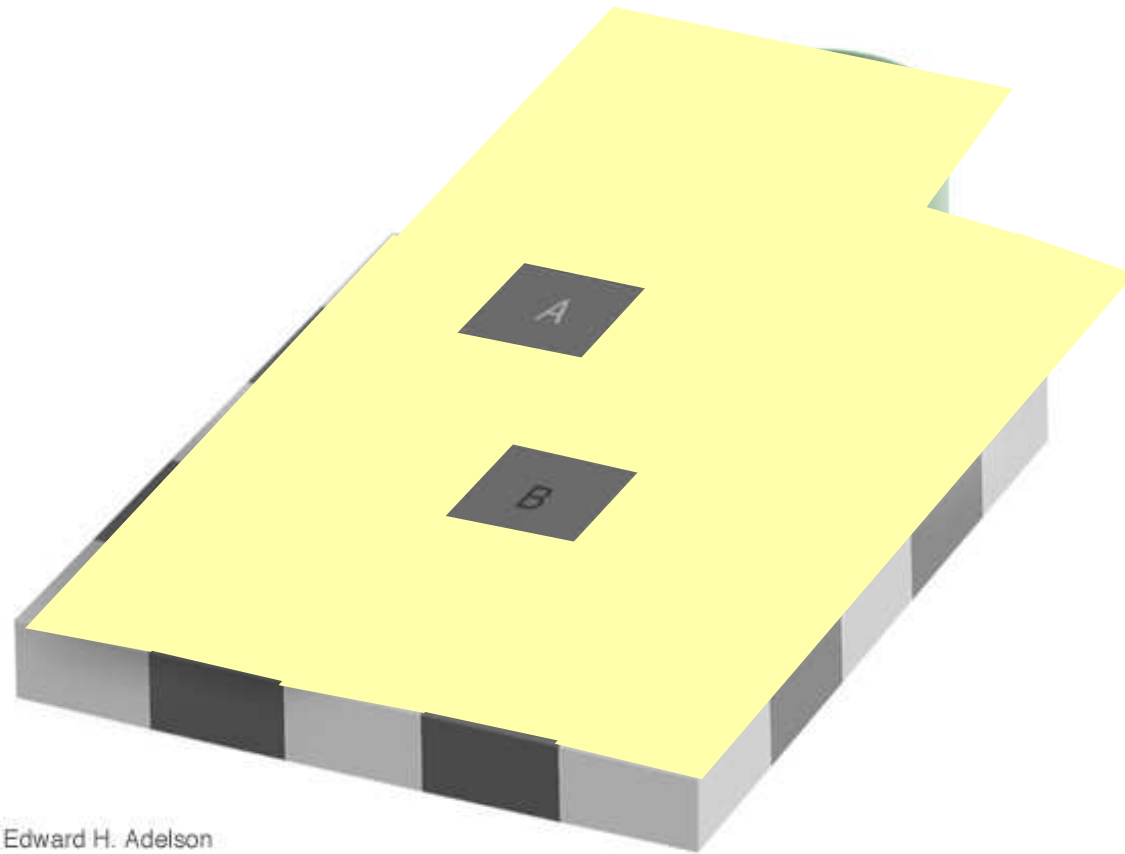
# Intensity vs. Brightness

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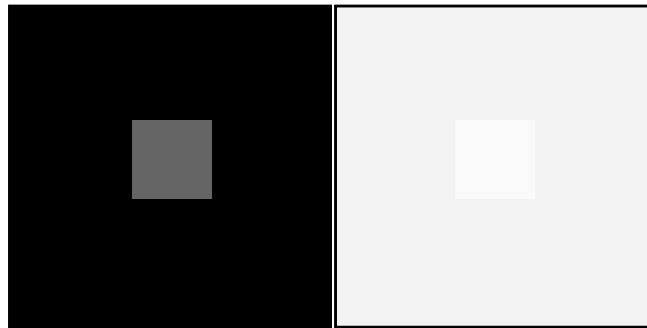
# Intensity vs. Brightness

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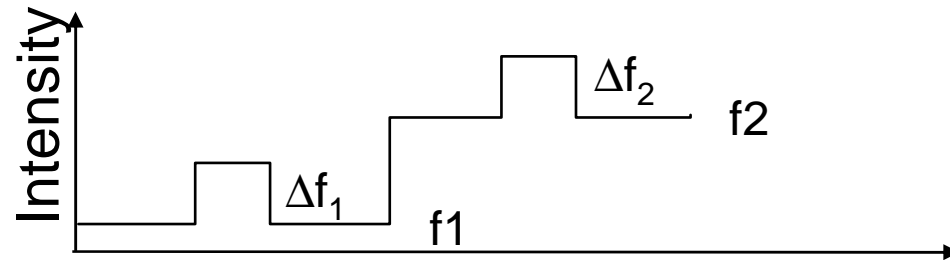


# Intensity vs. Brightness

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$$f_1 < f_2, \Delta f_1 = \Delta f_2$$



Equal intensity steps:



Equal brightness steps:



# Weber Law

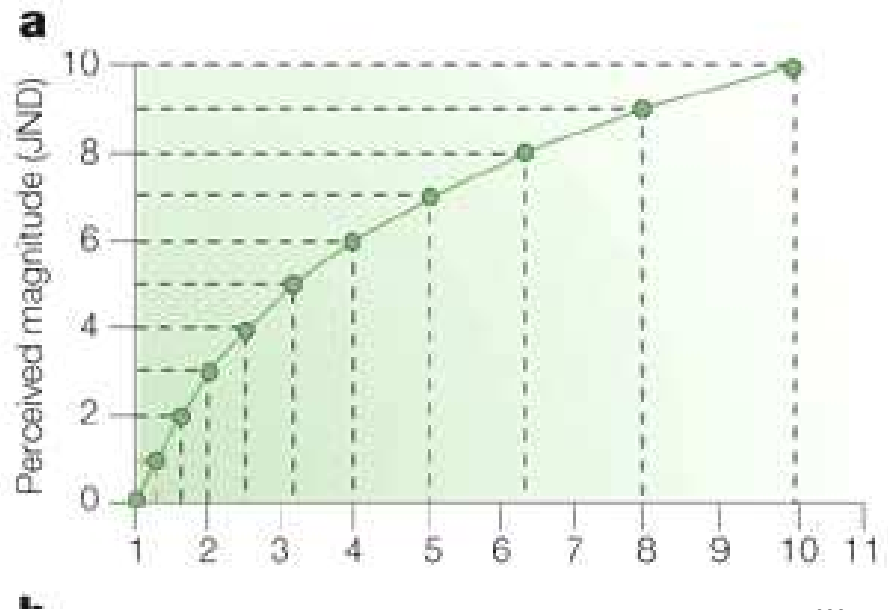
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- Describe the relationship between the physical magnitudes of stimuli and the perceived intensity of the stimuli.
- In general,  $\Delta f$  needed for just noticeable difference (JND) over background  $f$  was found to satisfy:

$$\frac{\Delta f}{f} = \text{const}$$

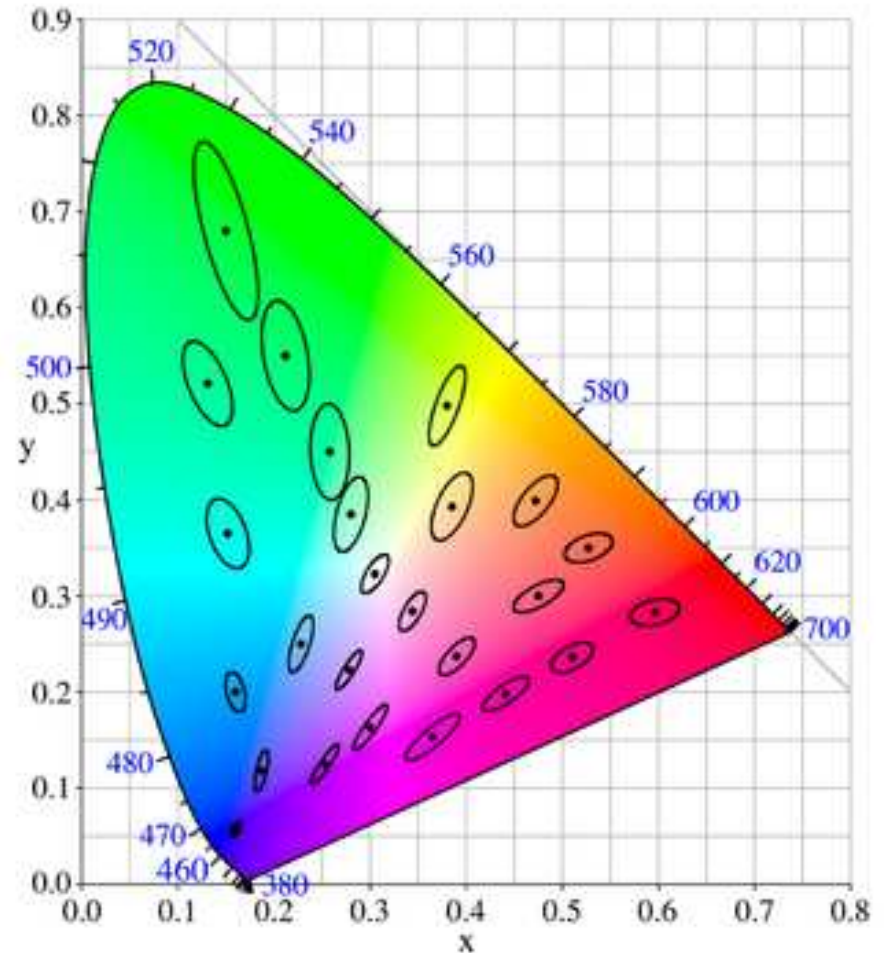


Brightness  $\propto \log(f)$

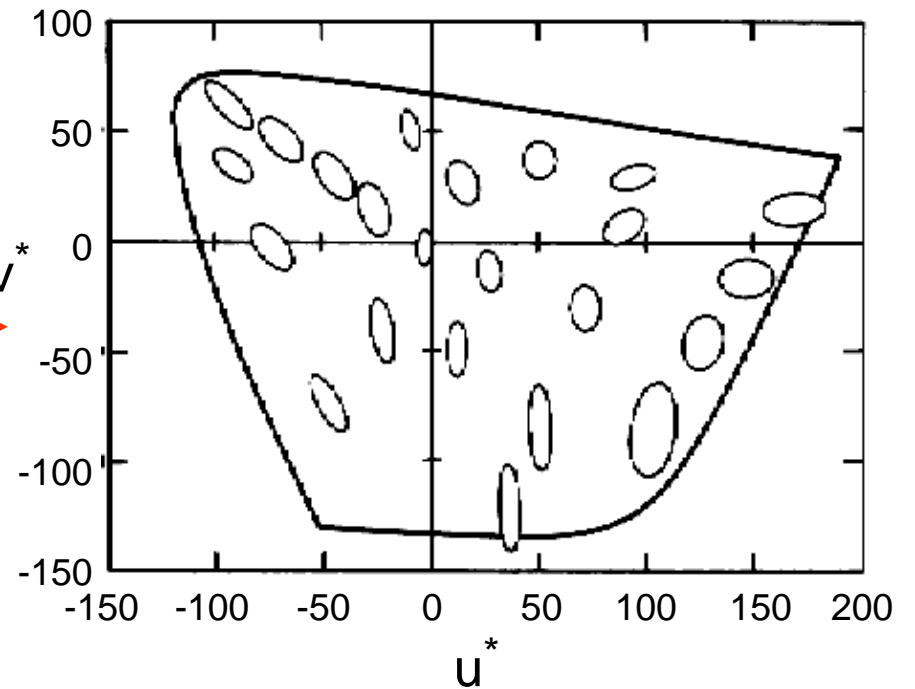
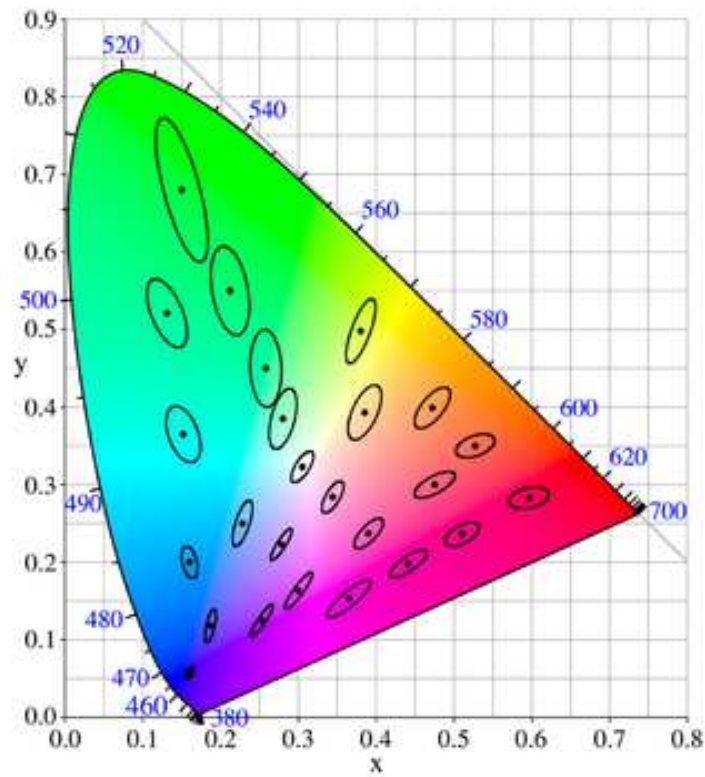


# What about Color Space?

- JND in XYZ color space was measured by Wright and Pitt, and MacAdam in the thirties
- MacAdam ellipses: JND plotted at the CIE-xy diagram
- Conclusion: measuring perceptual distances in the cie-XYZ space is not a good idea

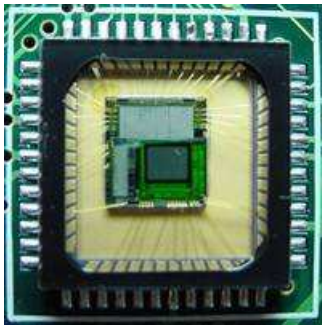
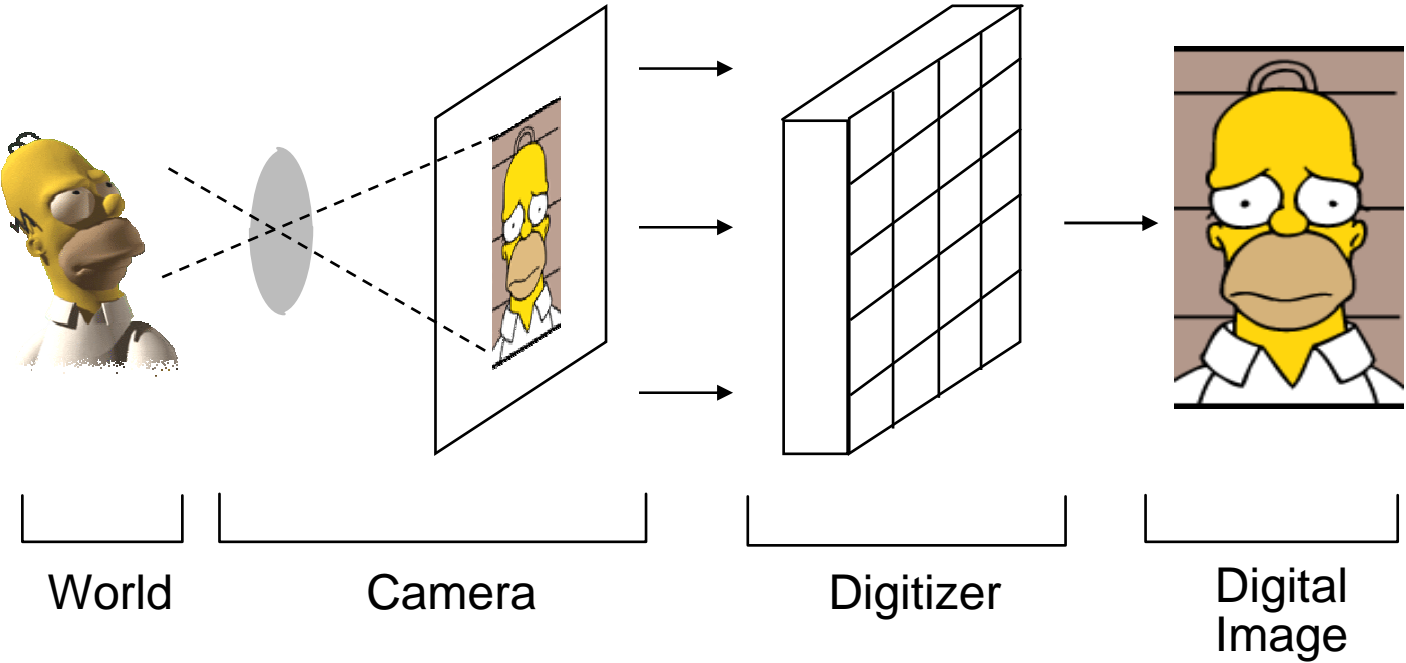


# Perceptually Uniform Color Space



MacAdam Ellipses of JND  
plotted in  
CIE-  $L^*u^*v^*$  Coordinates:

# Acquisition System



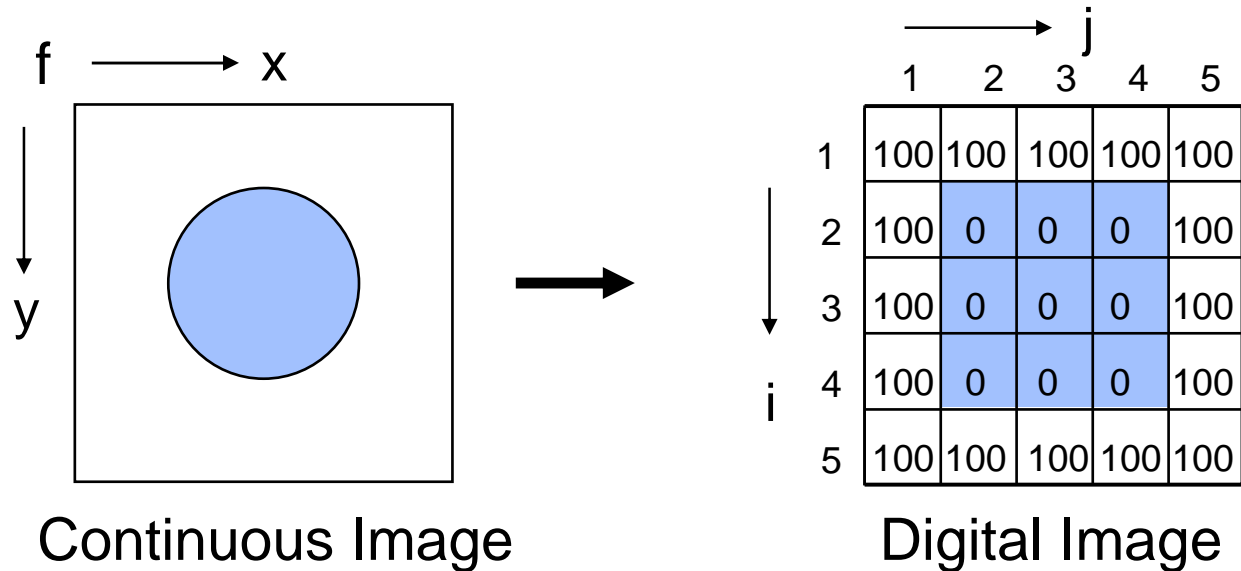
CMOS sensor



# Digitization

Two stages in the digitization process:

- **Spatial sampling:** Spatial domain
- **Quantization:** Gray level



$$f(x,y)$$

$$x,y \in \mathbb{R}$$
$$f(x,y) \in \mathbb{R}$$

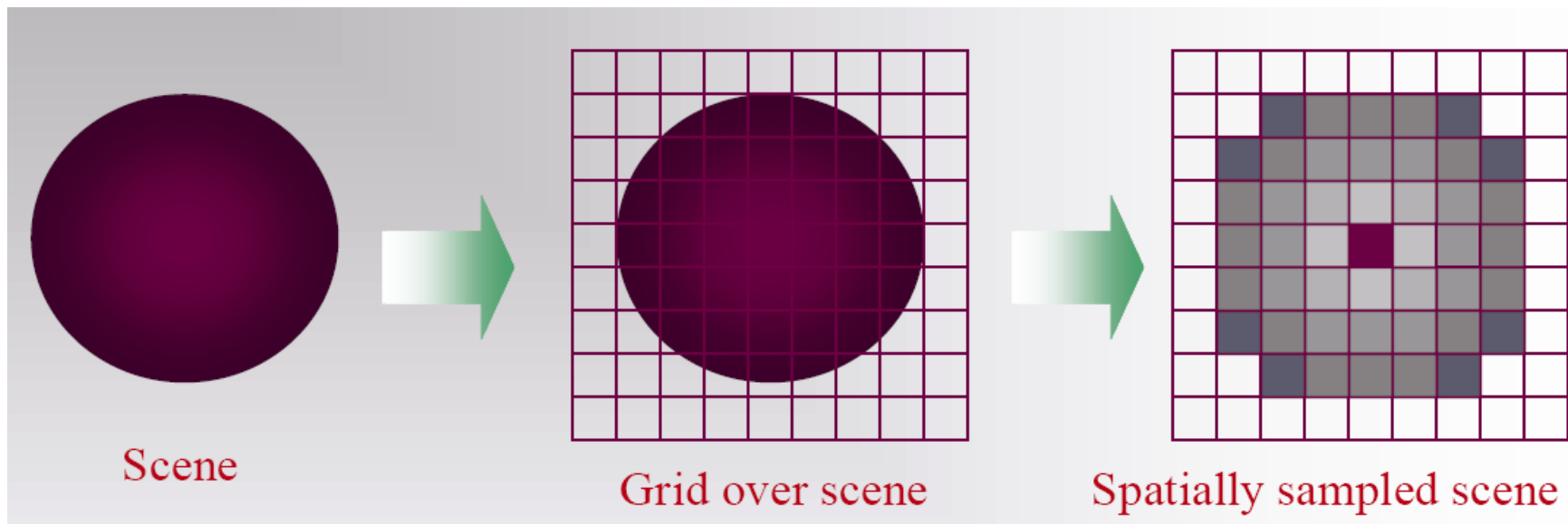
$$g(i,j) \in \mathbb{C}$$

$$g(i,j) \text{ in finite set of values}$$
$$i,j = 1,2,3,\dots,c$$

# Spatial Sampling

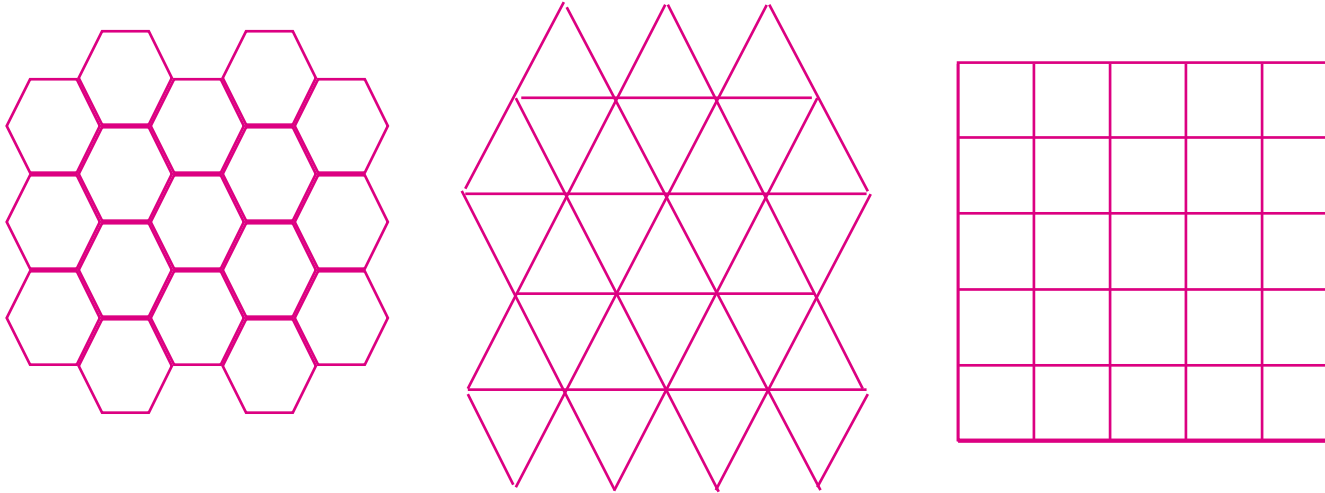
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When a continuous scene is imaged on the sensor, the continuous image is divided into discrete elements - picture elements (pixels)



# Spatial Sampling

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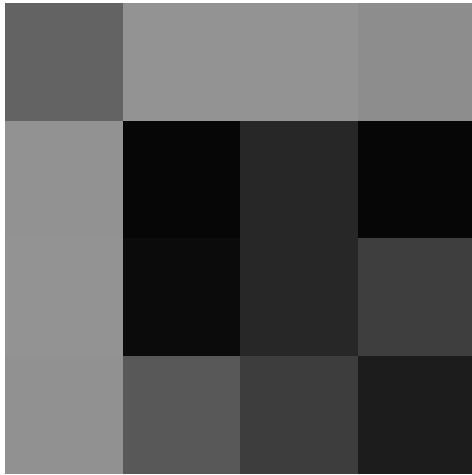
Two principles:

coverage of the image plane

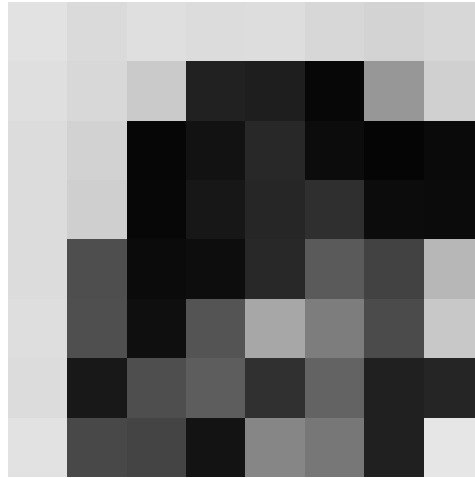
uniform sampling (pixels are same size and shape)

# Spatial Sampling

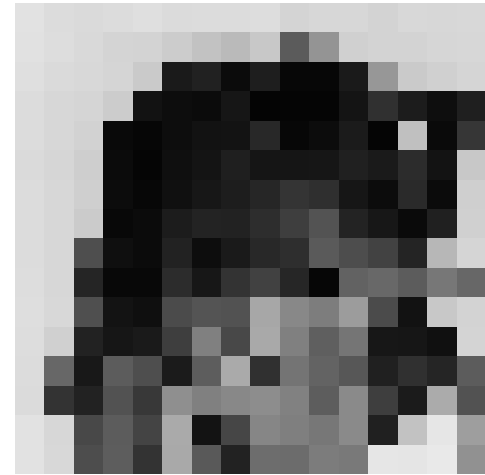
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N = 4



N = 8



N = 16



N = 32



N = 64



N = 128

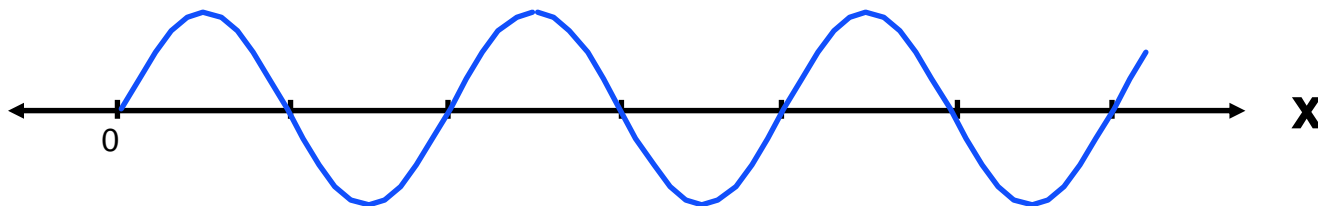
# Sampling - Image Resolution

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- The density of the sampling denotes the separation capability of the resulting image
- **Image resolution** defines the finest details that are still visible by the image
- Cyclic patterns test separation capability of an image

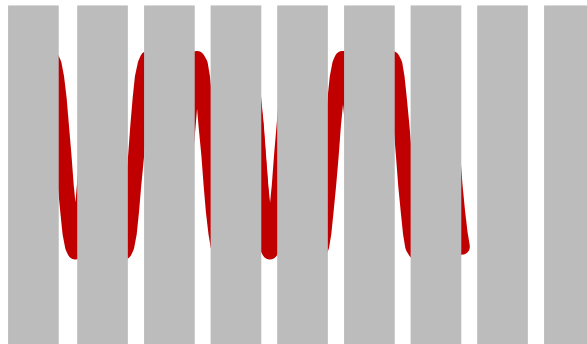
$$\text{Frequency} = \frac{\text{number of cycles}}{\text{unit length}}$$

$$\text{Wavelength} = \frac{1}{\text{frequency}}$$



# Sampling Rate

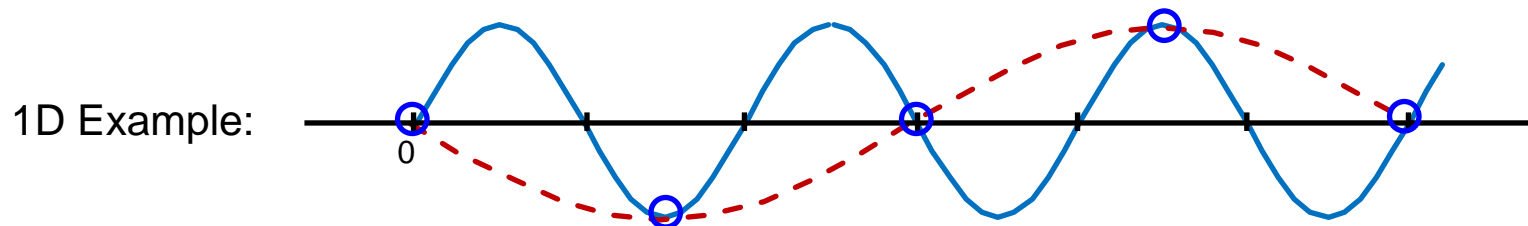
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# Nyquist Frequency

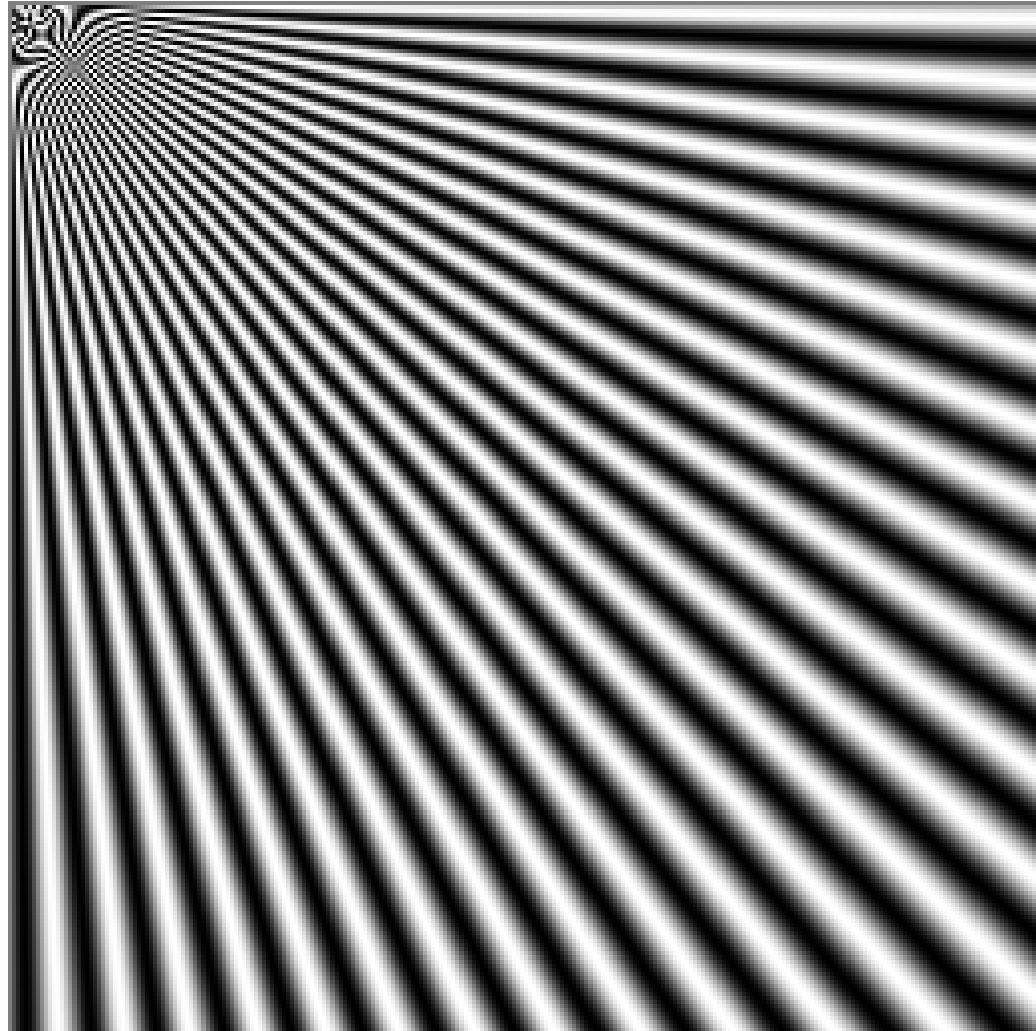
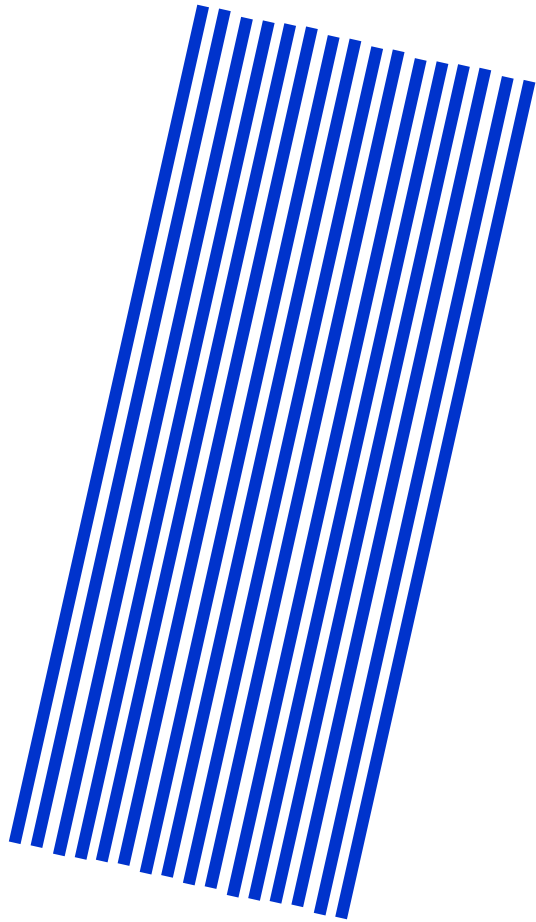
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- **Nyquist Rule:** To observe details at frequency  $f$  (wavelength  $d$ ) one must sample at frequency  $> 2f$  (sampling intervals  $< d/2$ )
- The Frequency  $2f$  is the **Nyquist Frequency**.
- **Aliasing:** If the pattern wavelength is less than  $2d$  erroneous patterns may be produced.



# Aliasing - Moiré Patterns

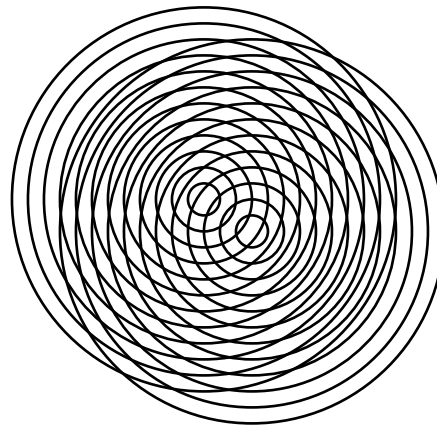
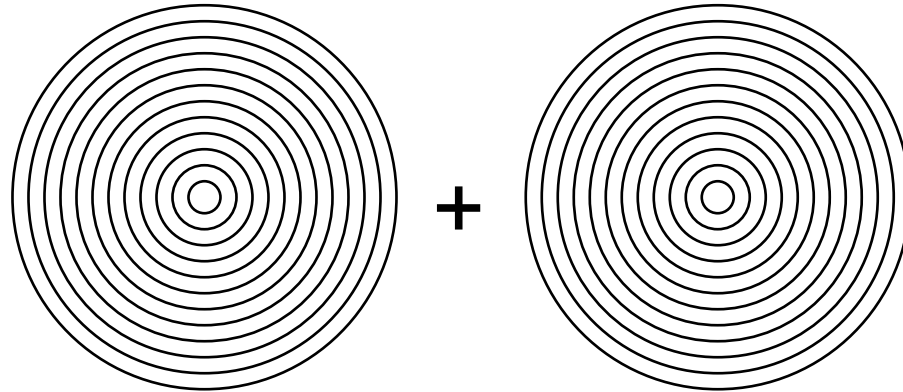
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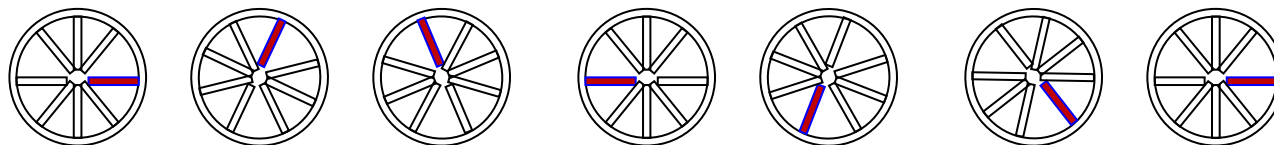
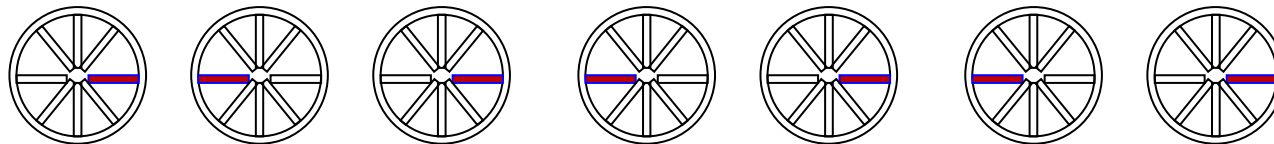
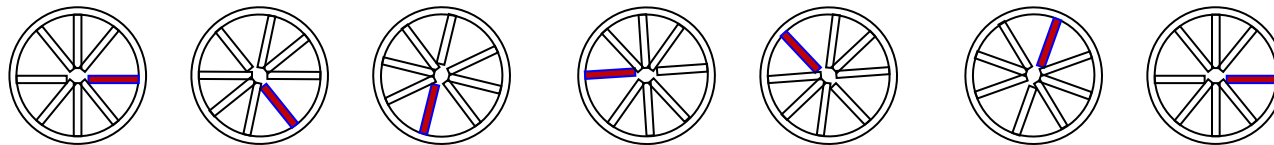
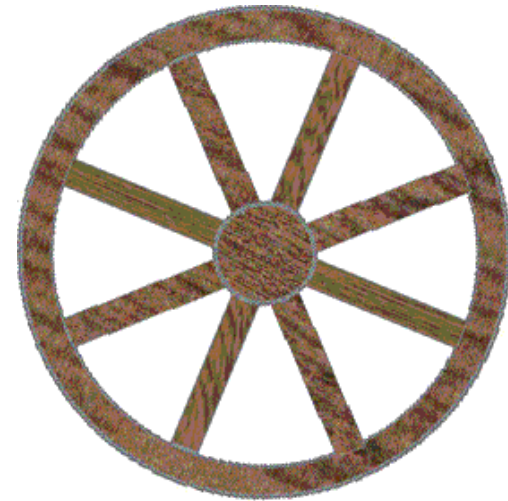
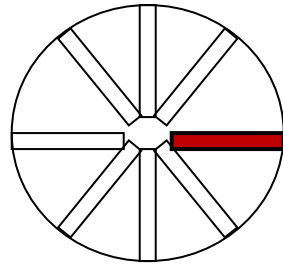
# Aliasing - Moiré Patterns

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# Temporal Aliasing

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# Temporal Aliasing Example

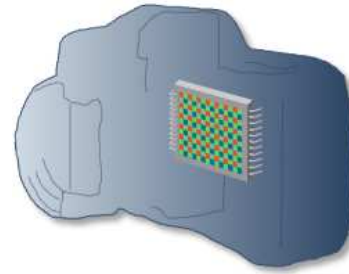
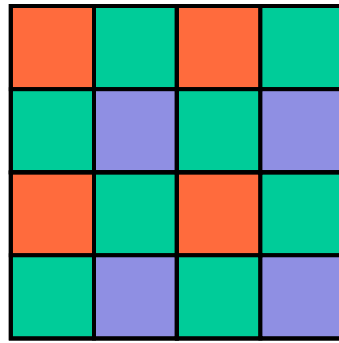
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# Image De-mosaicing

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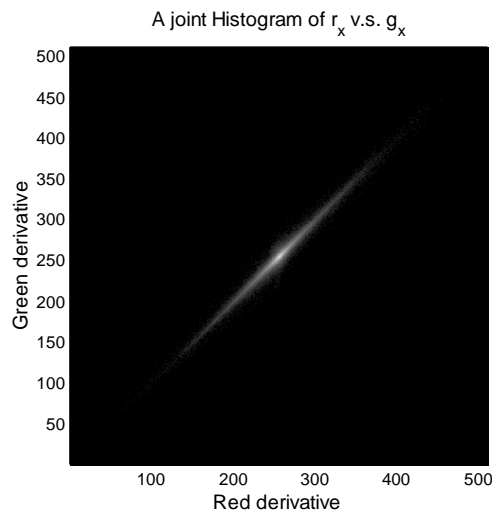
- Can we do better than Nyquist?



# Image De-mosaicing

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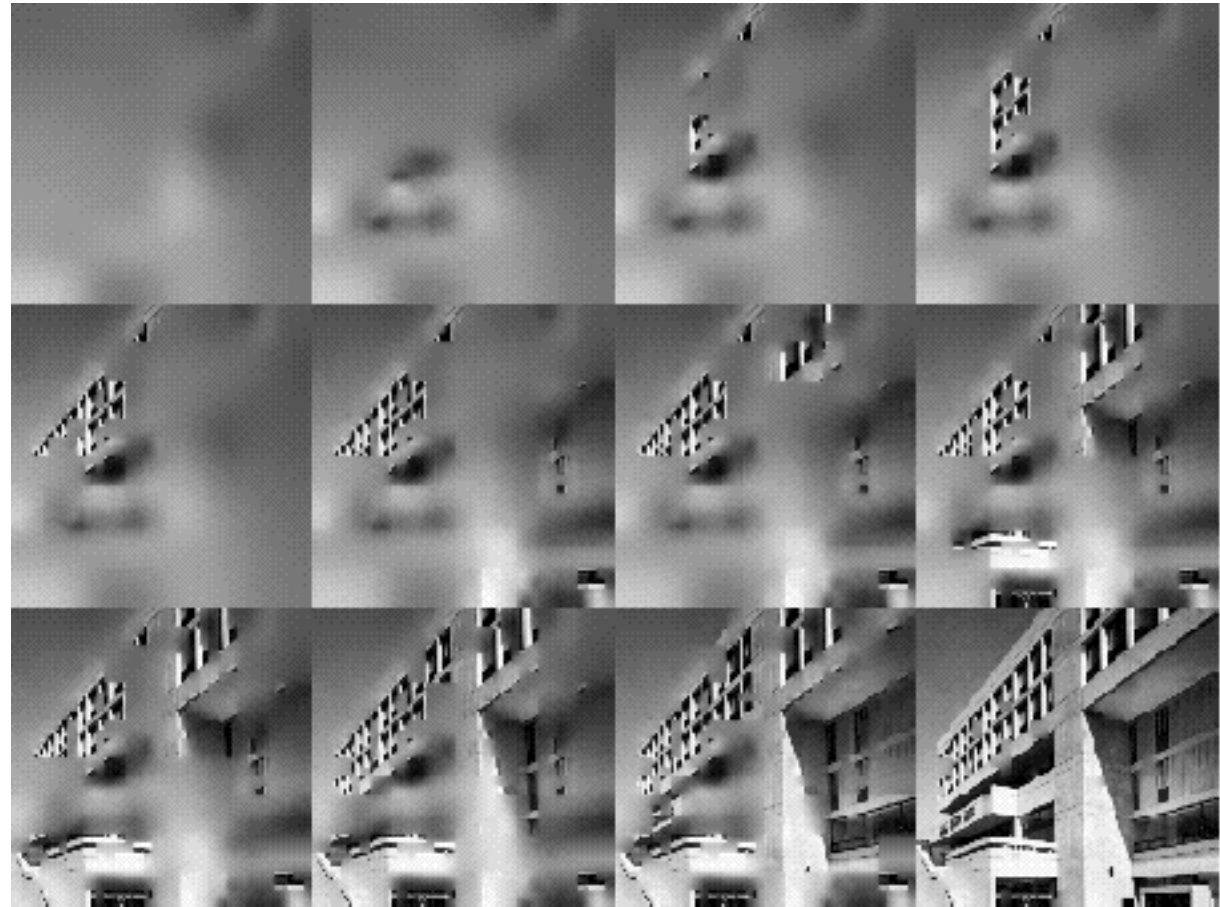
- Basic idea: use correlations between color bands



# Non Uniform Sampling

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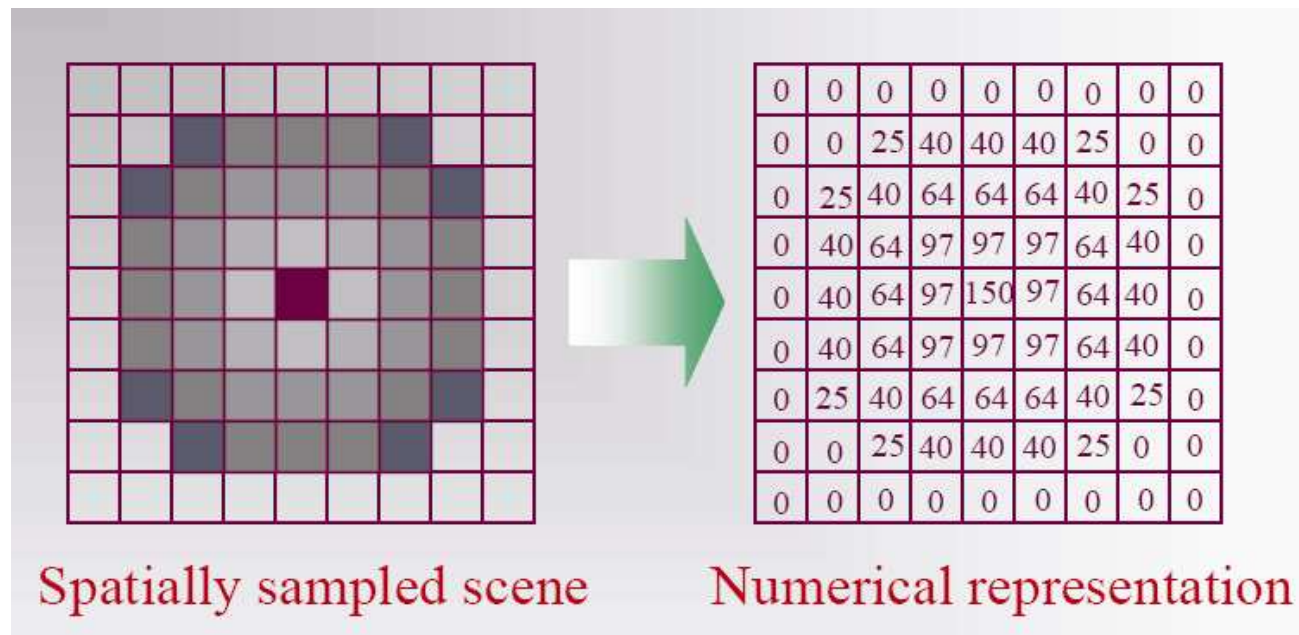
0	120		121
	63	64	122
	63	62	
2	3		



# Quantization

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- Choose number of gray levels (according to number of assigned bits)
- Divide continuous range of intensity values





# Quantization – Number of Gray Levels

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256



64



16



8



4



2





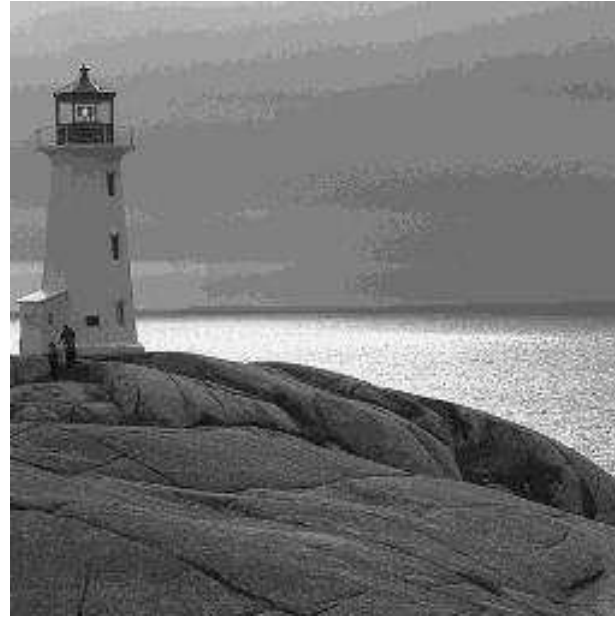
# Quantization

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- Low freq. areas are more sensitive to quantization



8 bits image



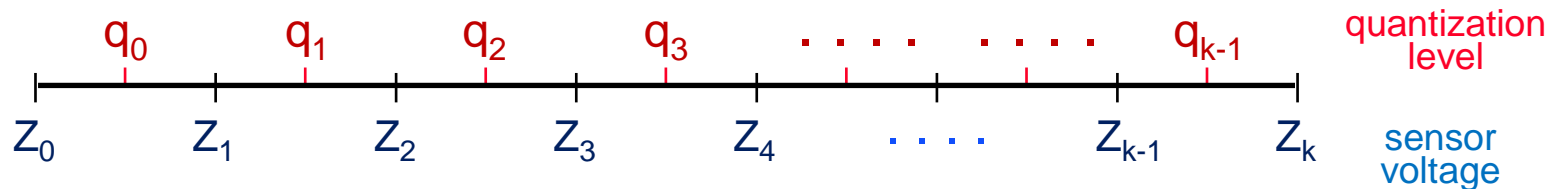
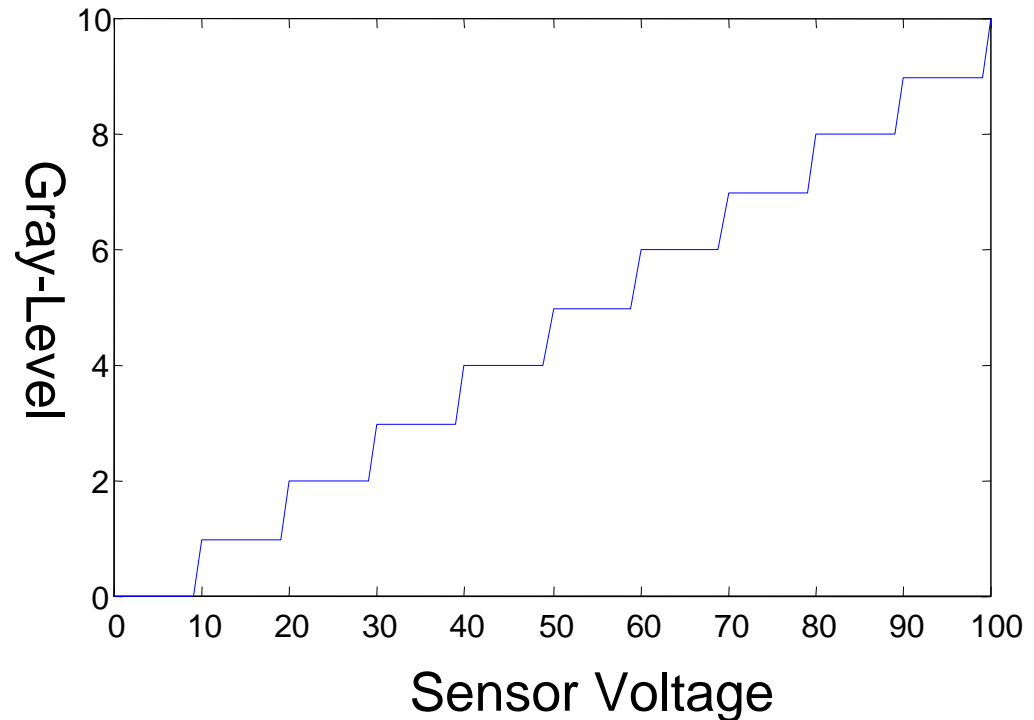
4 bits image

# How should we quantize an image?

- Simplest approach: **uniform quantization**

$$Z_{i+1} - Z_i = \frac{Z_k - Z_0}{K}$$

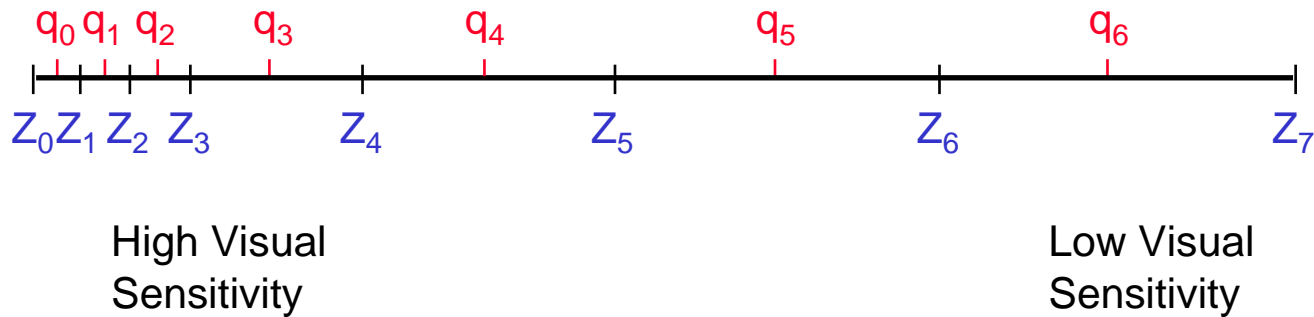
$$q_i = \frac{Z_{i+1} + Z_i}{2}$$



# Non-uniform Quantization

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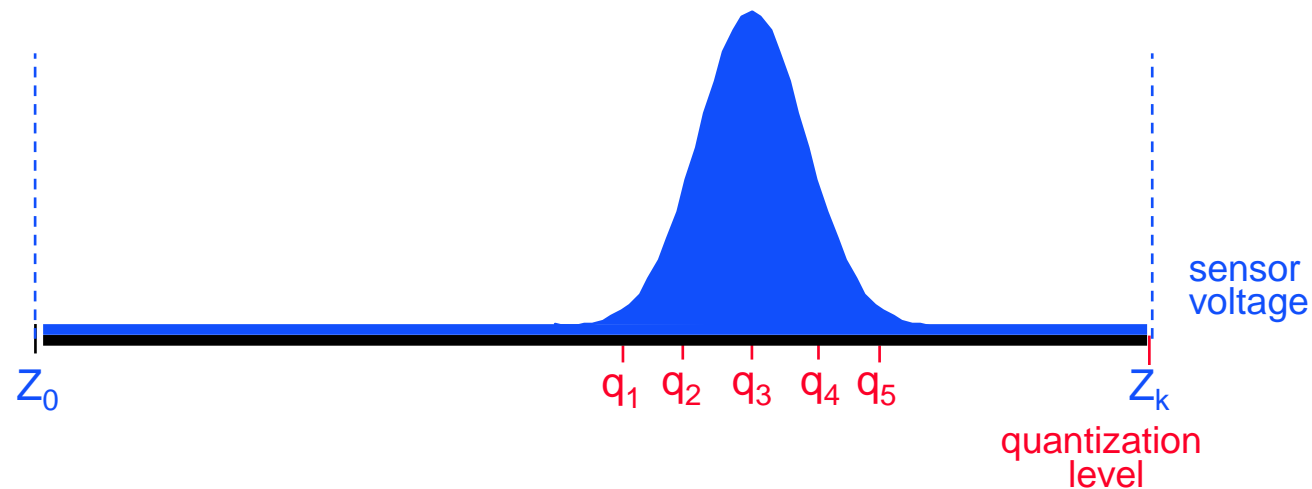
- Quantize according to visual sensitivity (Weber's Law)



# Non-uniform Quantization

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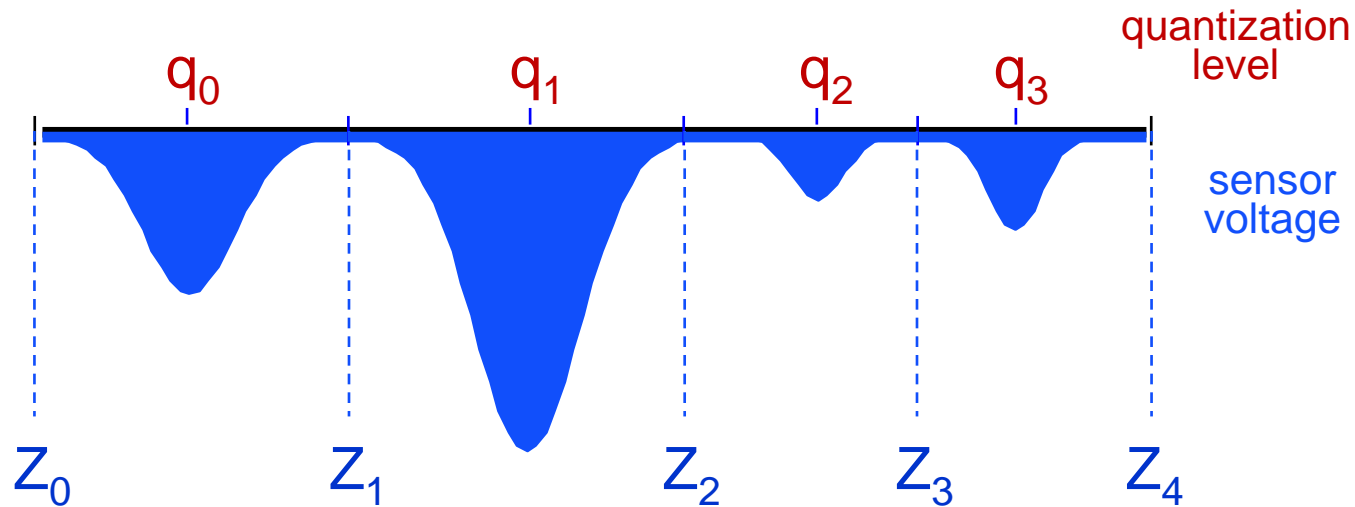
- Non uniform sensor voltage distribution



# Optimal Quantization (Lloyd-Max)

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- Content dependant
- Minimize quantization error



# Optimal Quantization (Lloyd-Max)

- Also known as Lloyd-Max quantizer
- Denote  $P(z)$  the probability of sensor voltage
- The quantization error is :

$$E = \sum_{i=0}^{k-1} \int_{z_i}^{z_{i+1}} P(z)(z - q_i)^2 dz$$

- Solution:



$$q_i = \frac{\int_{z_i}^{z_{i+1}} zP(z)dz}{\int_{z_i}^{z_{i+1}} P(z)dz} \quad z_i = \frac{q_{i-1} + q_i}{2}$$

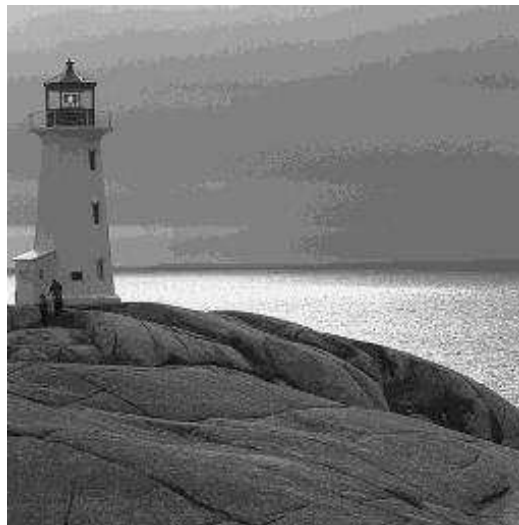
- Iterate until convergence (but optimal minimum is not guaranteed).

# Example

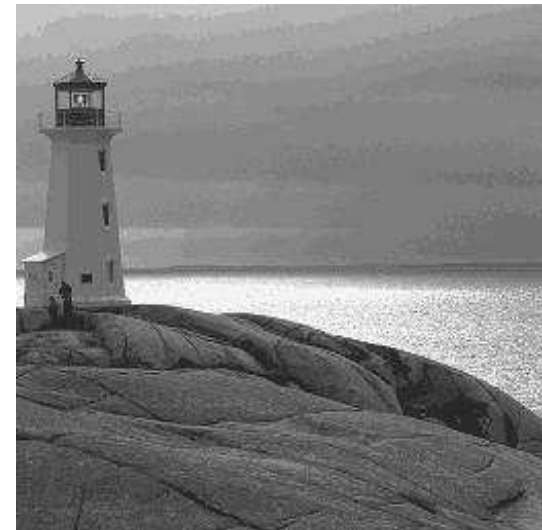
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8 bits image



4 bits image  
Uniform quantization



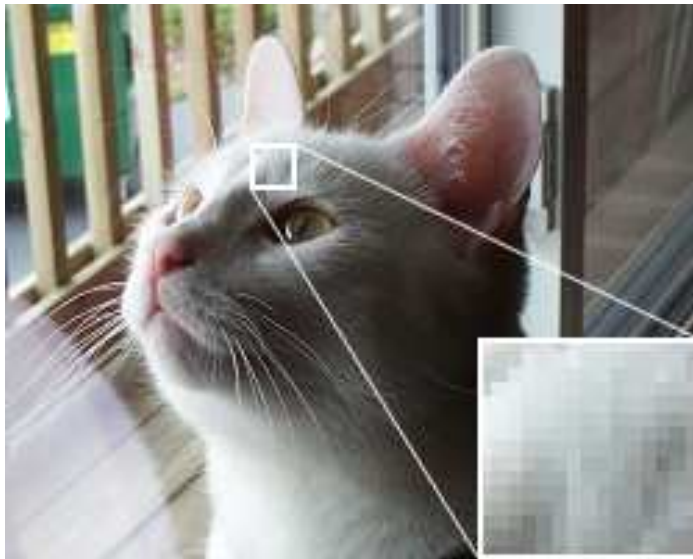
4 bits image  
Optimal quantization

# Color Quantization

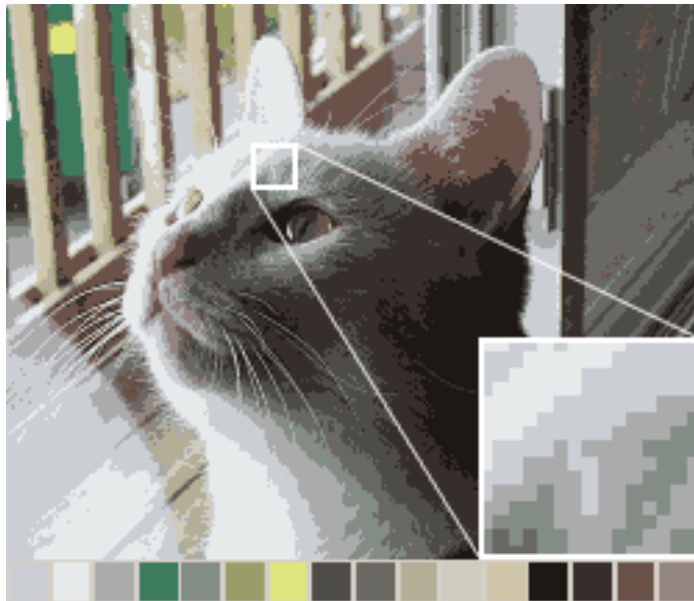
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- Typically 256 levels for each **Red**, **Green**, **Blue** channels, or  $256^3 = 16777216$  colors.
- How can an image be displayed with fewer colors than it contains?
- Select a subset of colors (the colormap or pallet) and map the rest of the colors to them.

24 bit



4 bit  
(16 colors)



from: Daniel Cohen-Or



# Digital Grayscale Image



**Digitization:**  
Sampling  
Quantization

	x = 58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
y = 41	210	209	204	202	197	247	143	71	64	80	84	54	54	57	58
42	206	196	203	197	195	210	207	56	63	58	53	53	61	62	51
43	201	207	192	201	198	213	156	69	65	57	55	52	53	60	50
44	216	206	211	193	202	207	208	57	69	60	55	77	49	62	61
45	221	206	211	194	196	197	220	56	63	60	55	46	97	58	106
46	209	214	224	199	194	193	204	173	64	60	59	51	62	56	48
47	204	212	213	208	191	190	191	214	60	62	66	76	51	49	55
48	214	215	215	207	208	180	172	188	69	72	55	49	56	52	56
49	209	205	214	205	204	196	187	196	86	62	66	87	57	60	48
50	208	209	205	203	202	186	174	185	149	71	63	55	55	45	56
51	207	210	211	199	217	194	183	177	209	90	62	64	52	93	52
52	208	205	209	209	197	194	183	187	187	239	58	68	61	51	56
53	204	206	203	209	195	203	188	185	183	221	75	61	58	60	60
54	200	203	199	236	188	197	183	190	183	196	122	63	58	64	66
55	205	210	202	203	199	197	196	181	173	186	105	62	57	64	63