Image Acquisition

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

What is an Image ?

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

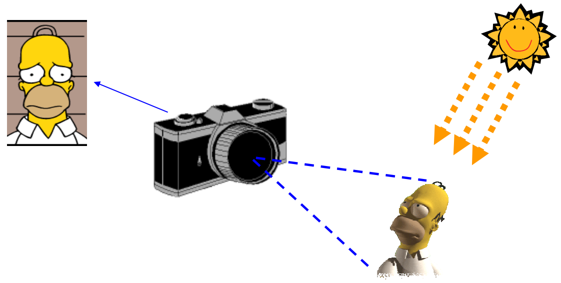


Image as a function

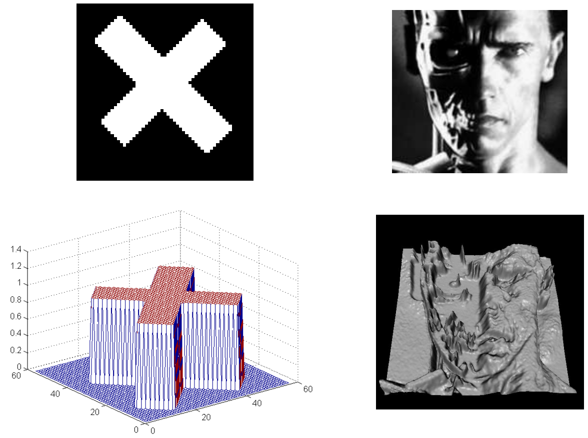
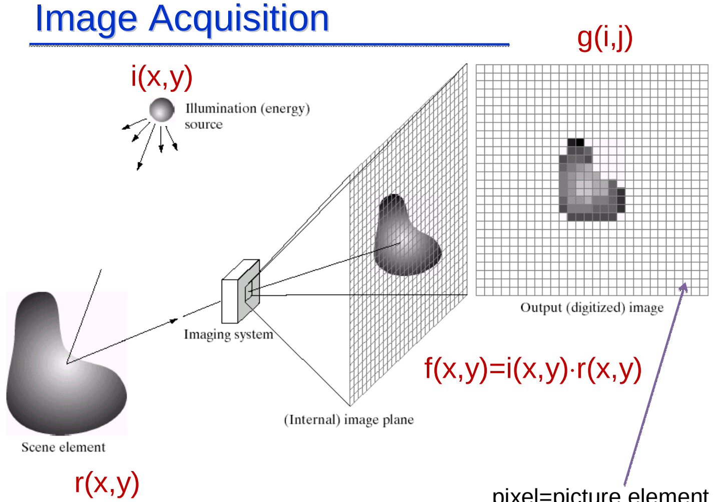


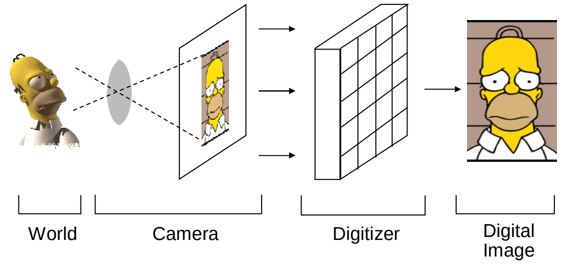
Image Acquisition



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

pixel=picture element

Acquisition System



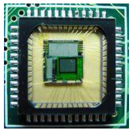

CMOS sensor

Image Types

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

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
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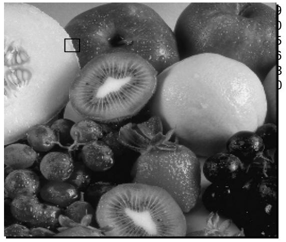
49	209	205	214	205	204	196	187	196	86	62	66	87	57	60	48
[illegible]	[illegible]	[illegible]	205	203	202	186	174	185	149	71	63	55	55	45	56
[illegible]	[illegible]	[illegible]	211	199	217	194	183	177	209	90	62	64	52	93	52
[illegible]	[illegible]	[illegible]	209	209	197	194	183	187	187	239	58	68	61	51	56
[illegible]	[illegible]	[illegible]	203	209	195	203	188	185	183	221	75	61	58	60	60
[illegible]	[illegible]	[illegible]	199	236	188	197	183	190	183	196	122	63	58	64	66
[illegible]	[illegible]	[illegible]	202	203	199	197	196	181	173	186	105	62	57	64	63

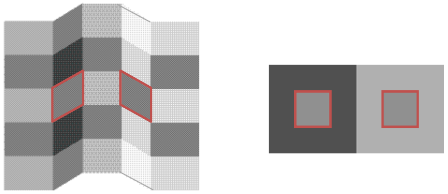


Color Image

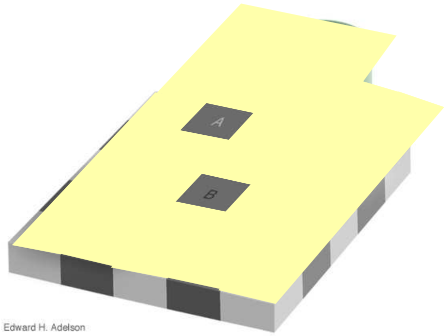
Notations

- 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

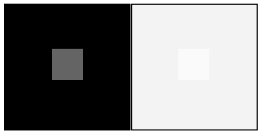
Intensity vs. Brightness



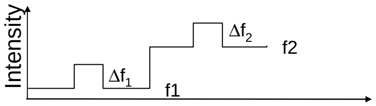
Intensity vs. Brightness



Intensity vs. Brightness



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



Equal intensity steps:

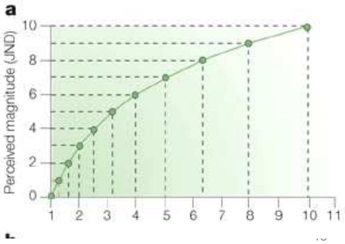
Equal brightness steps:

Weber Law

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

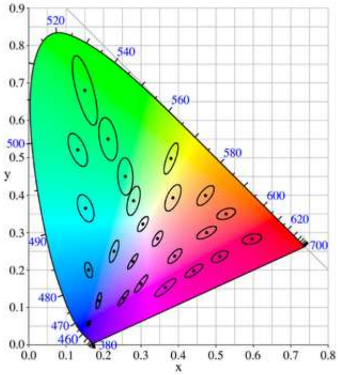
$$\frac{\Delta f}{f} = const$$

Brightness ∝ log(**f**)

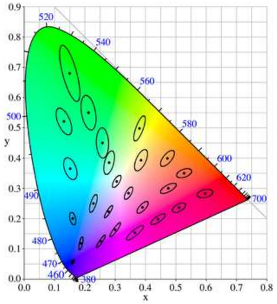


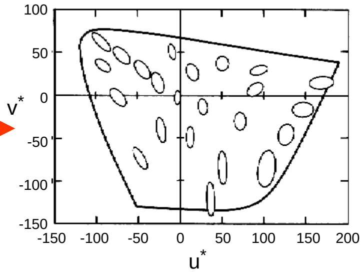
What about Color Space?

- 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



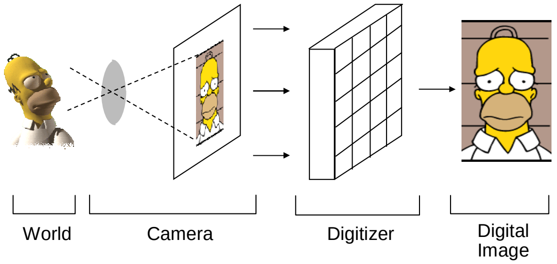
Perceptually Uniform Color Space

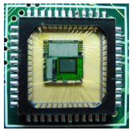




MacAdam Ellipses of JND plotted in CIE- $L^*u^*v^*$ Coordinates:

Acquisition System



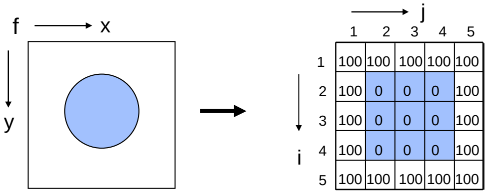


CMOS sensor

Digitization

Two stages in the digitization process:

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



	1	2	3	4	5
1	100	100	100	100	100
2	100	0	0	0	100
3	100	0	0	0	100
4	100	0	0	0	100
5	100	100	100	100	100

Continuous Image

f(x,y)

x,y - R
f(x,y) - R

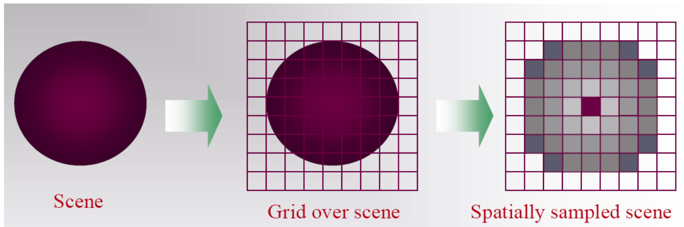
Digital Image

$g(i,j) \in C$

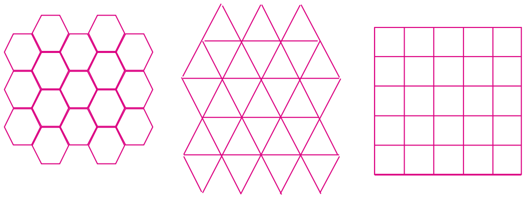
g(i,j) in finite set of values
i,j = 1,2,3,....,c

Spatial Sampling

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

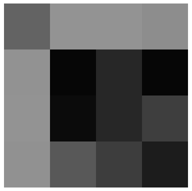


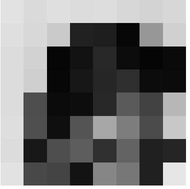
Spatial Sampling

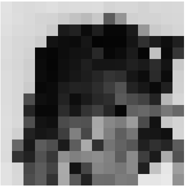


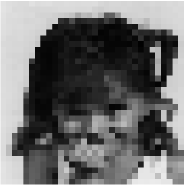
Two principles:
coverage of the image plane
uniform sampling (pixels are same size and shape)

Spatial Sampling


N = 4


N = 8


N = 16


N = 32


N = 64

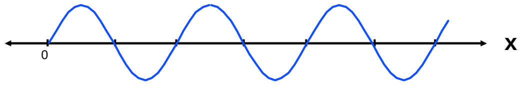

N = 128

Sampling - Image Resolution

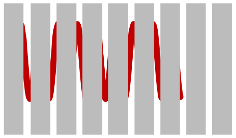
- The density of the sampling denotes the separation capability of the resulting image
- **Image resolution** defines the finest details that are still visible by the image
- Cyclic patterns test separation capability of an image

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

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

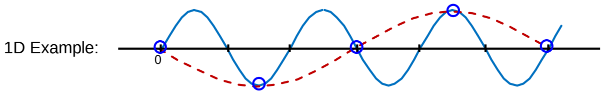


Sampling Rate

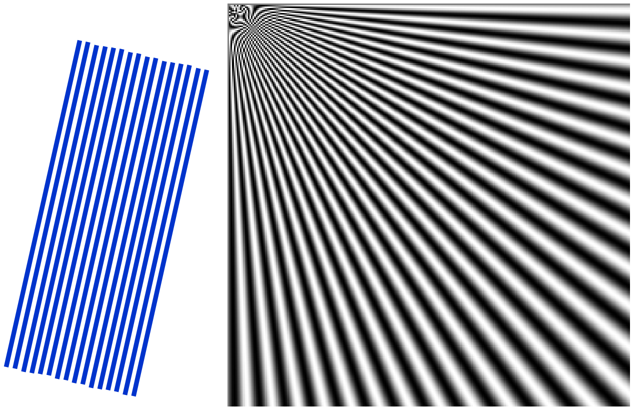


Nyquist Frequency

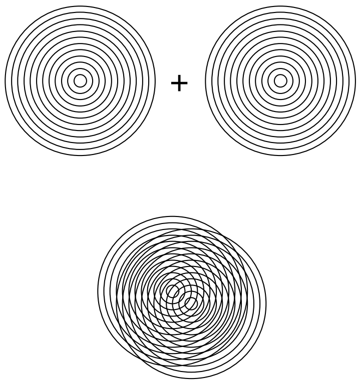
- **Nyquist Rule**: To observe details at frequency f (wavelength d) one must sample at frequency > 2f (sampling intervals < d/2)
- The Frequency 2f is the **Nyquist Frequency**.
- **Aliasing**: If the pattern wavelength is less than 2d erroneous patterns may be produced.



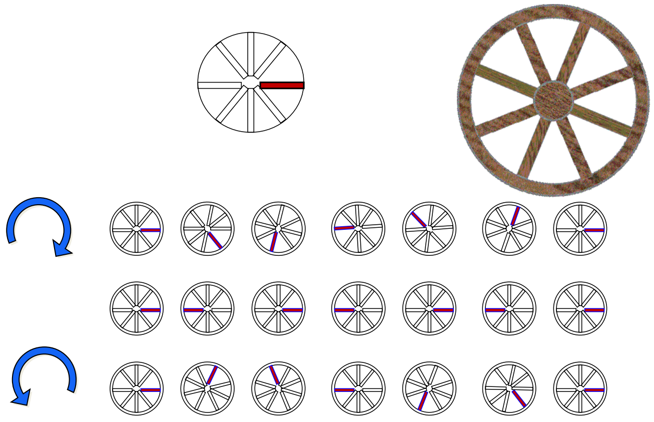
Aliasing - Moiré Patterns



Aliasing - Moiré Patterns



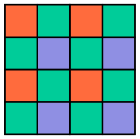
Temporal Aliasing



Temporal Aliasing Example

Image De-mosaicing

- Can we do better than Nyquist?



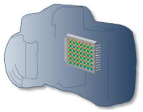
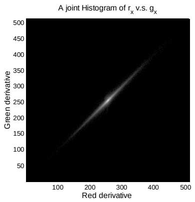
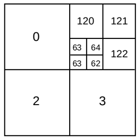


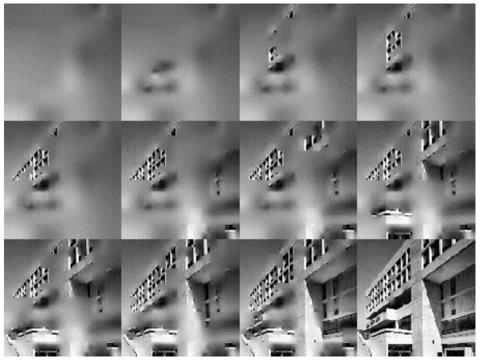
Image De-mosaicing

- Basic idea: use correlations between color bands



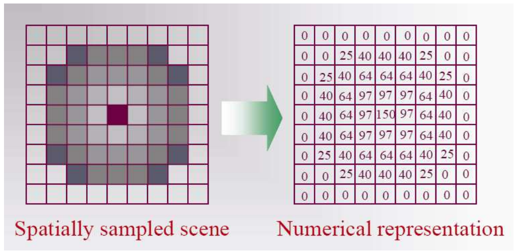
Non Uniform Sampling





Quantization

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



0	0	0	0	0	0	0	0	0
0	0	25	40	40	40	25	0	0
0	25	40	64	64	64	40	25	0
0	40	64	97	97	97	64	40	0
0	40	64	97	150	97	64	40	0
0	40	64	97	97	97	64	40	0
0	25	40	64	64	64	40	25	0
0	0	25	40	40	40	25	0	0
0	0	0	0	0	0	0	0	0

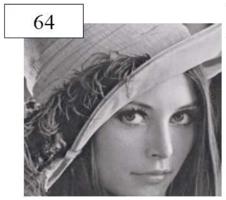
Spatially sampled scene

Numerical representation

Quantization – Number of Gray Levels

256

64



16

8

4

2

Quantization

- Low freq. areas are more sensitive to quantization

8 bits image

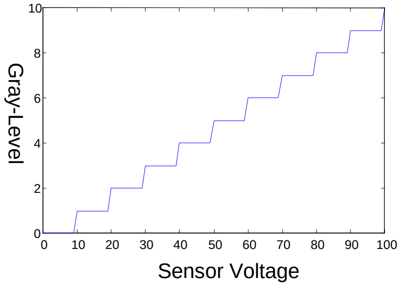
4 bits image

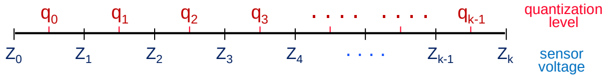
How should we quantize an image?

- Simplest approach: **uniform quantization**

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

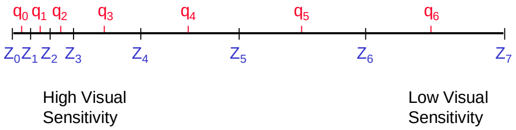
$$q_i=\frac{Z_{i+1}+Z_i}{2}$$





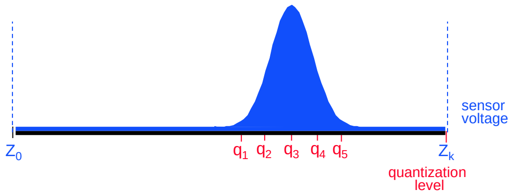
Non-uniform Quantization

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



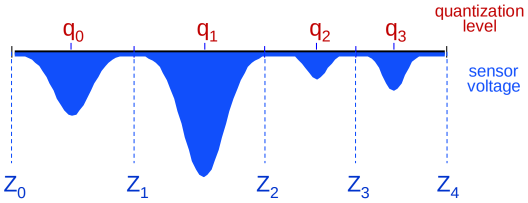
Non-uniform Quantization

- Non uniform sensor voltage distribution



Optimal Quantization (Lloyd-Max)

- Content dependant
- Minimize quantization error



Optimal Quantization (Lloyd-Max)

- Also known as Loyd-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:

demo

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

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

Example

8 bits image

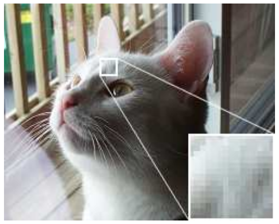
4 bits image
Uniform quantization

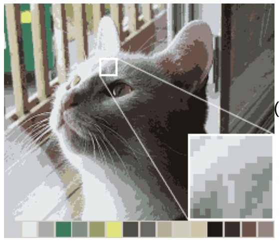
4 bits image
Optimal quantization

Color Quantization

- Typically 256 levels for each Red, Greed, 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

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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