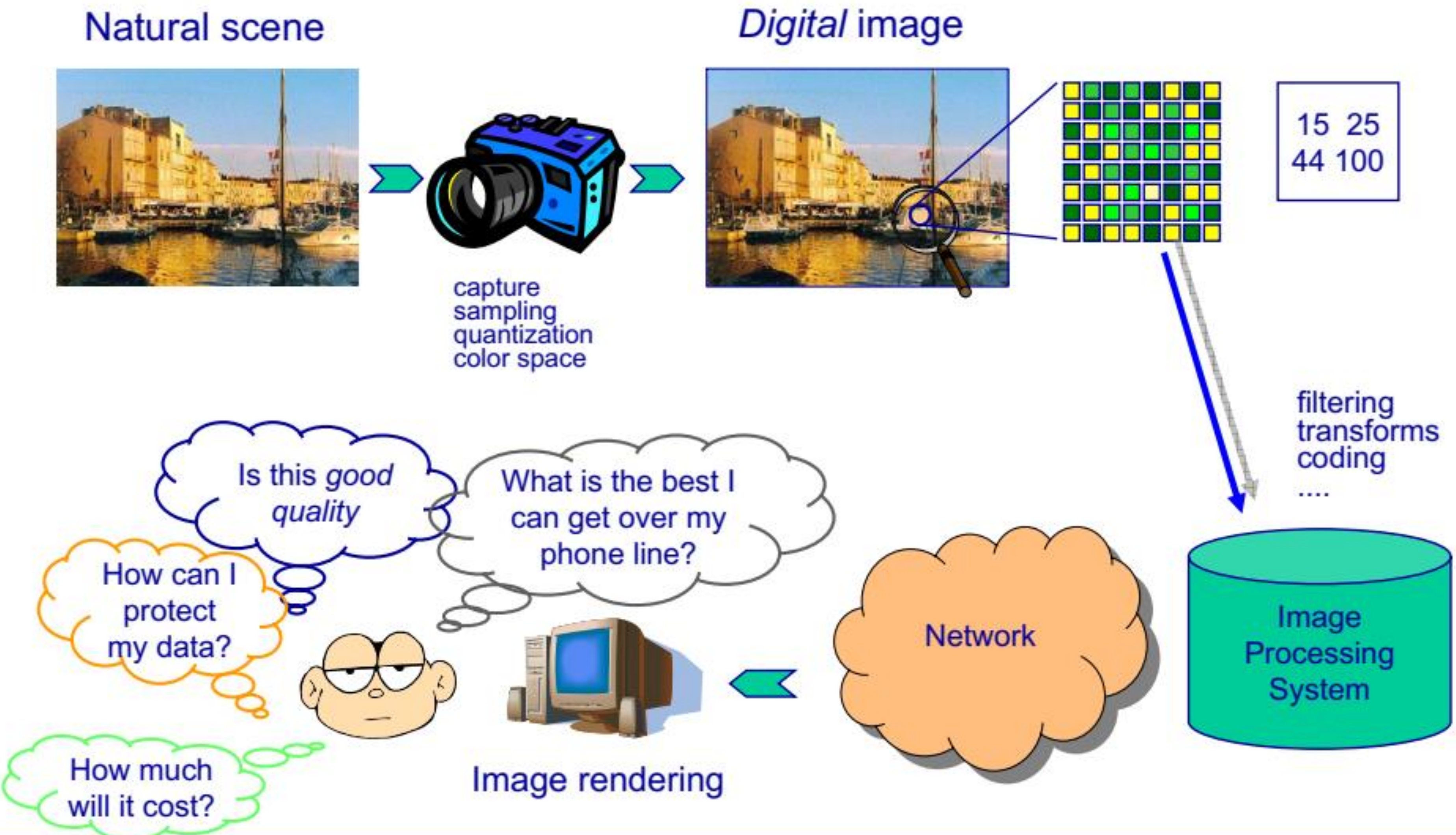
Image Acquisition

- Image Acquisition
- Image Characteristics
- Image Digitization
  - Sampling
  - Quantization
  - Spatial domain
  - Intensity domain
- Image Histogram

Image Processing framework



IP: basic steps

Analog image

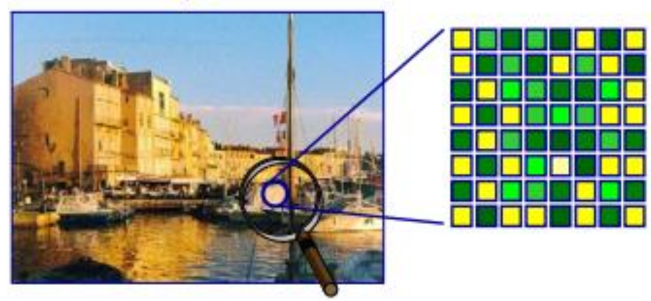
(capturing device)

A/D conversion

Sampling (2D)

Quantization

Digital image



{15,1,2}
{25,44,1}
….

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.

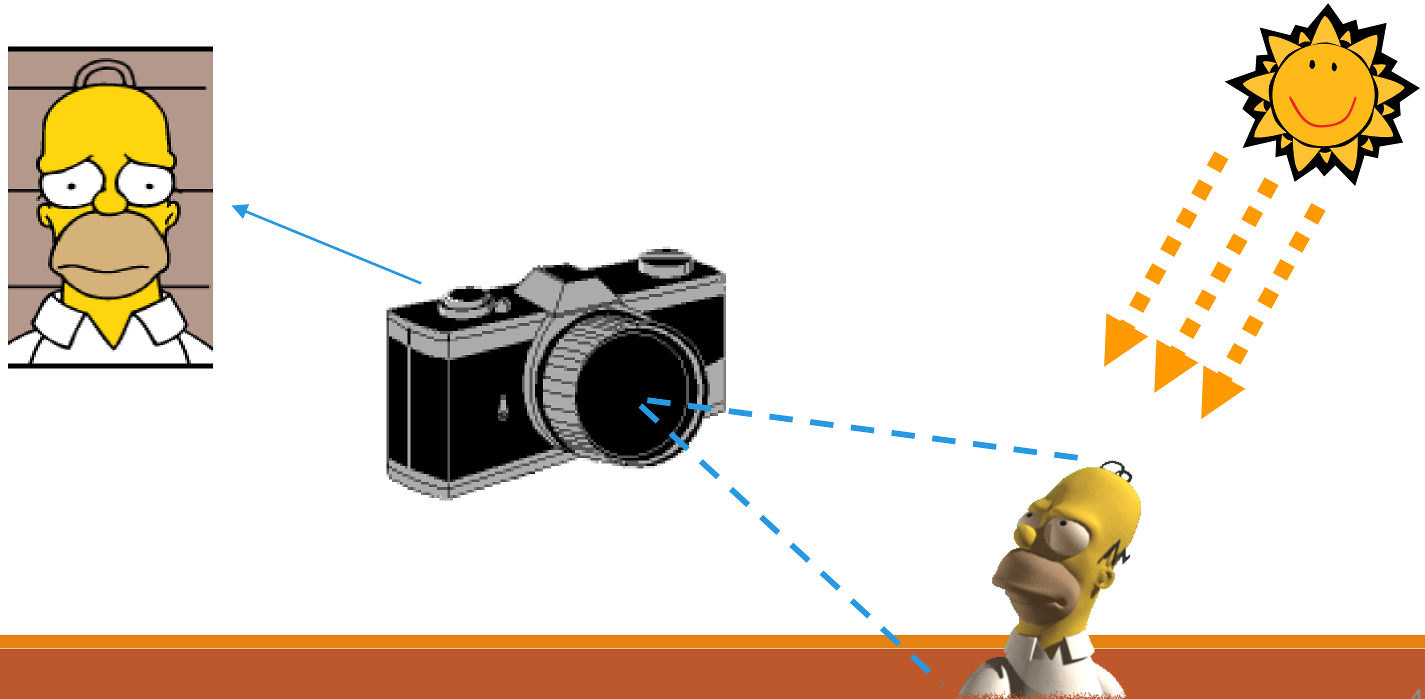
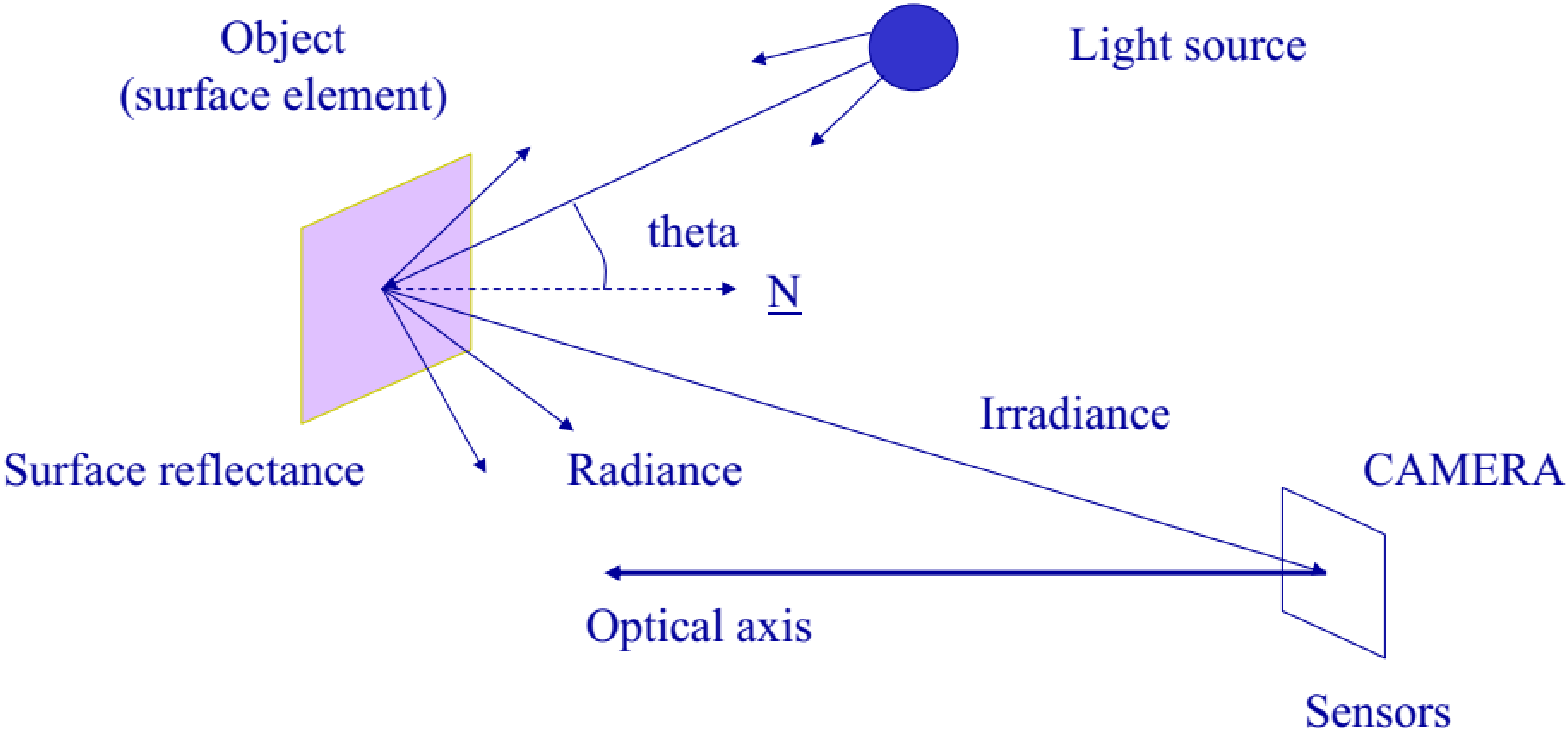
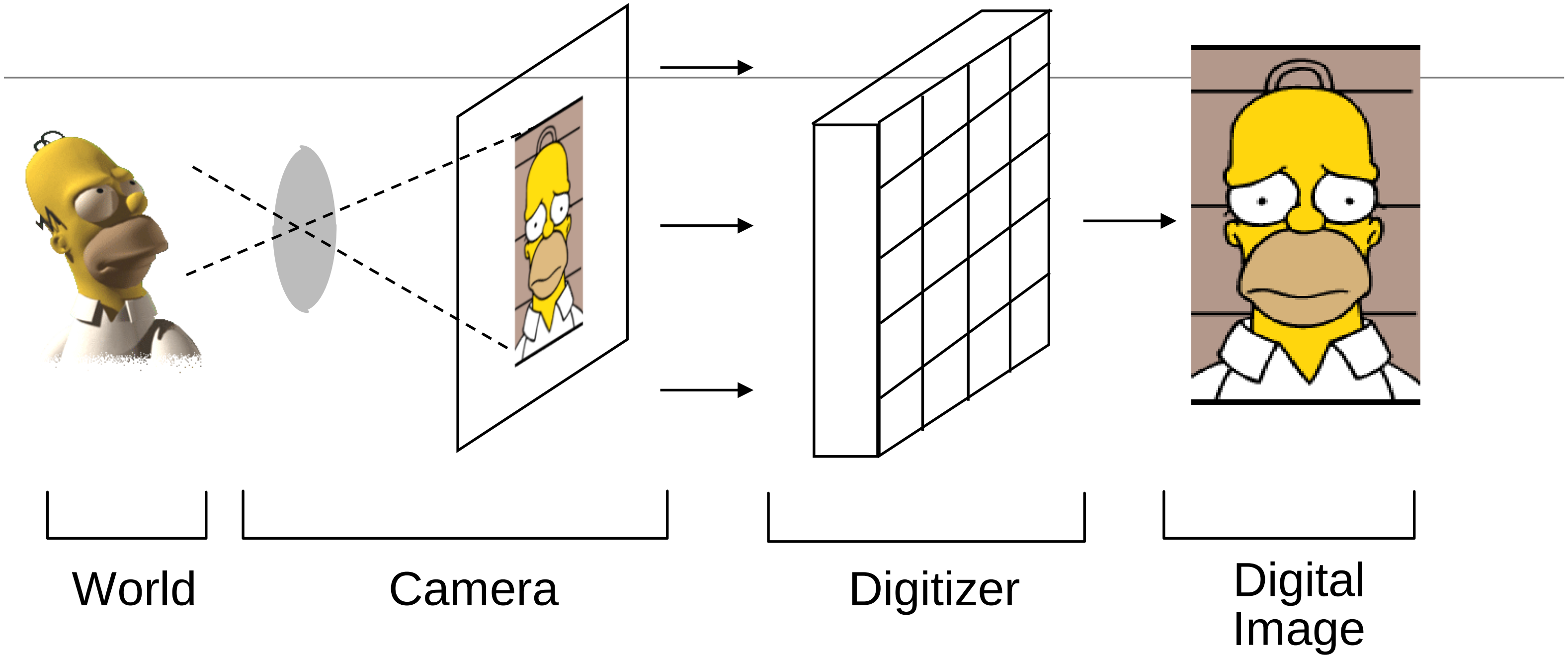
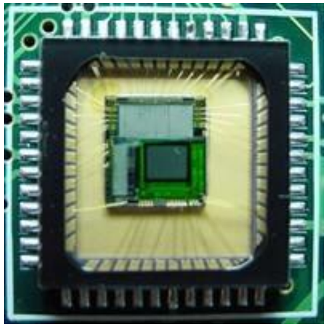


Image capture



Acquisition System





CMOS sensor

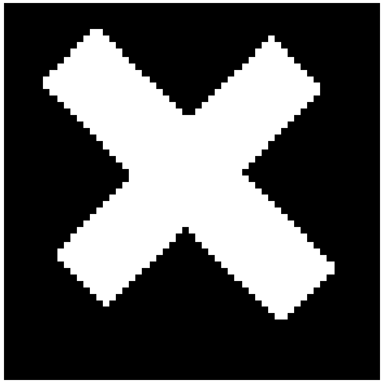
0	10	10	15	50	70	80
0	0	100	120	125	130	130
0	35	100	150	150	80	50
0	15	70	100	10	20	20
0	15	70	0	0	0	15
5	15	50	120	110	130	110
5	10	20	50	50	20	250

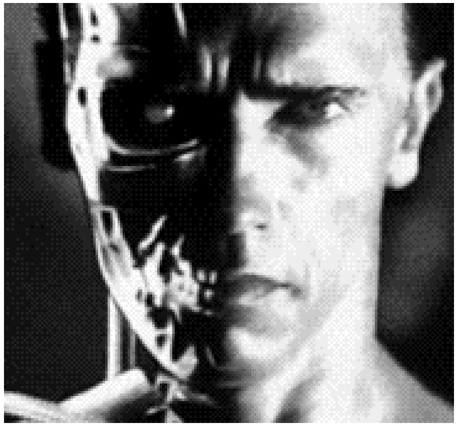
PIXEL
(picture element)

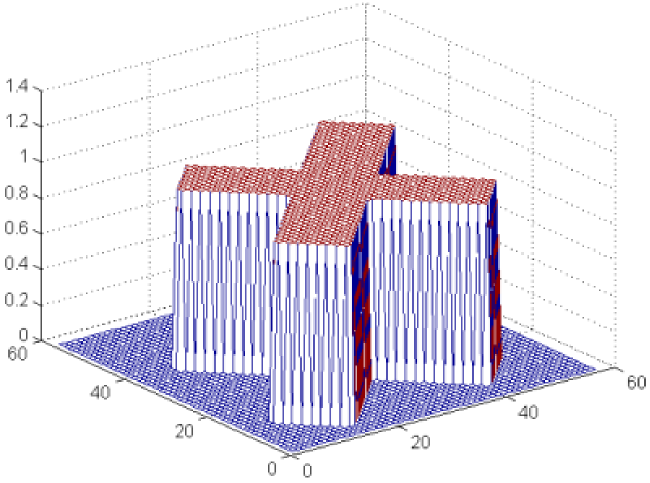
Typically:
0 = black
255 = white

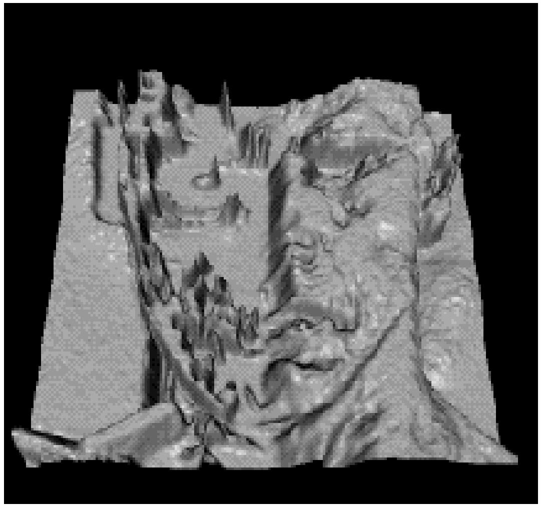
4

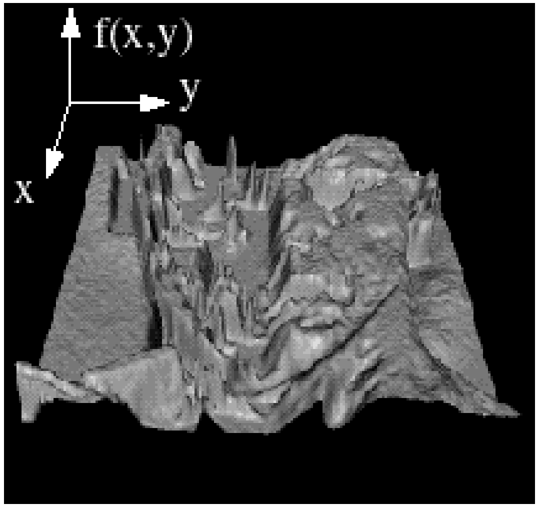
Image as a function





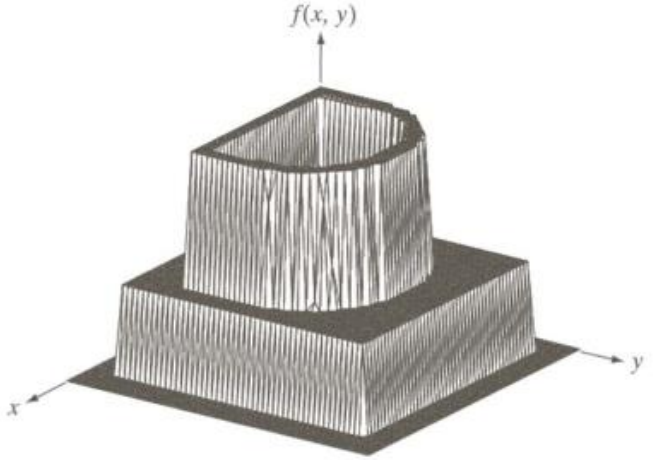


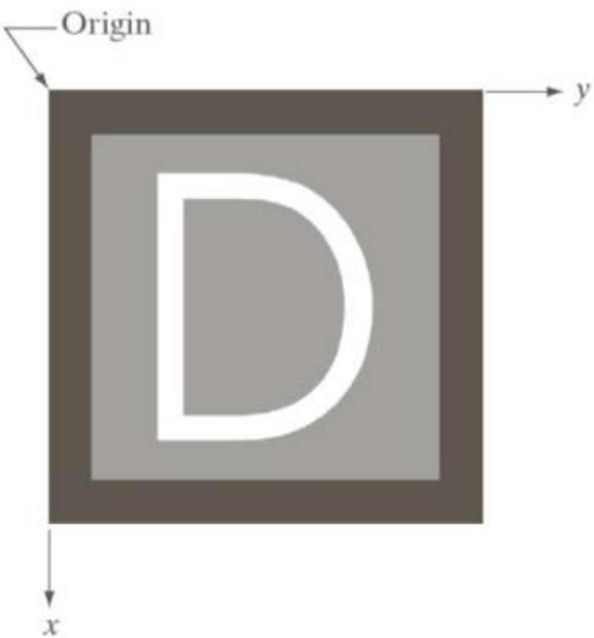


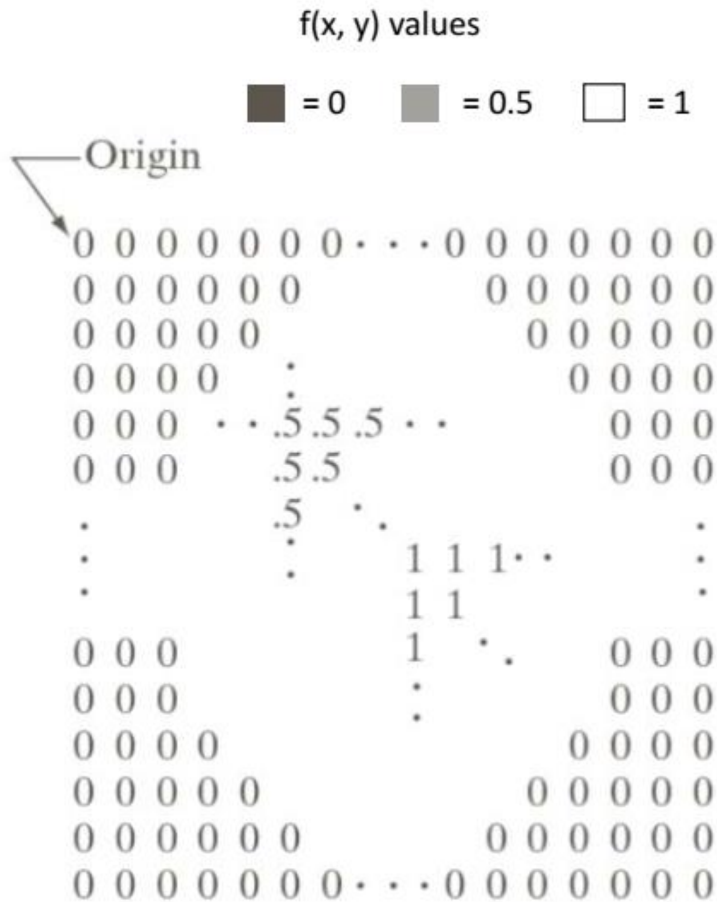


Pixel Values

Pada citra digital nilai minimum graylevel 0, tetpi nilai maximumnya tergantung pada jumlah level kuantisasi untuk mendigitalkan citra, biasanya 256 level , dengan nilai level tertinggi = 255

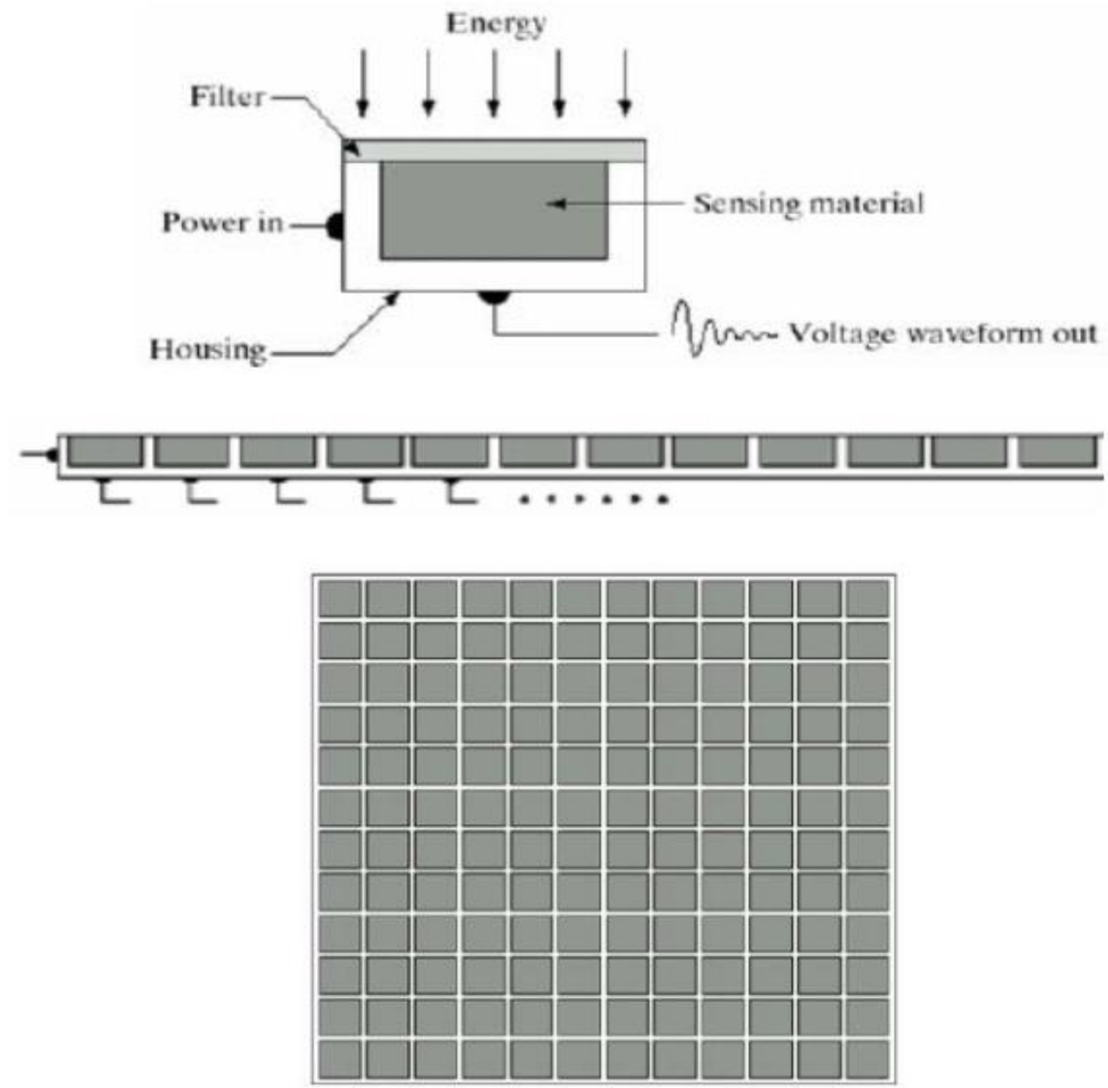




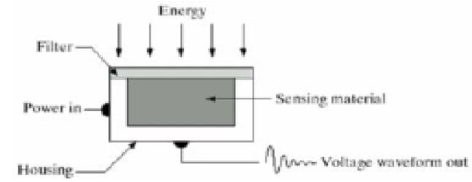


How do we get the numbers?

- Three principal sensor arrangements
  - Single
  - Line
  - and **Array**



Single Sensor: Moving



- Photodiode
  - Constructed of silicon materials whose output voltage waveform is proportional to light
  - Generating a 2D image using a single sensor requires relative displacements in the horizontal and vertical directions between the sensor and area to be imaged

- Microdensitometers are mechanical digitizers that use a flatbed with the **sensor moving** in two linear directions

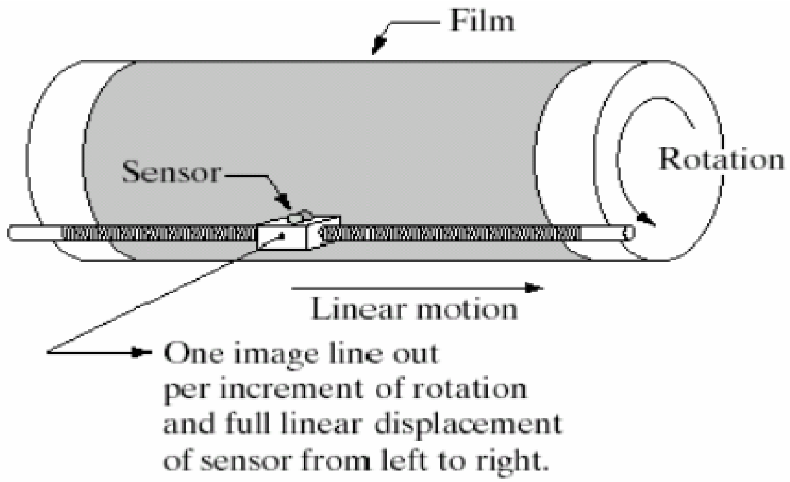
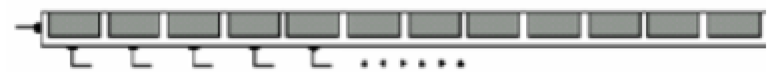


FIGURE 2.13 Combining a single sensor with motion to generate a 2-D image.

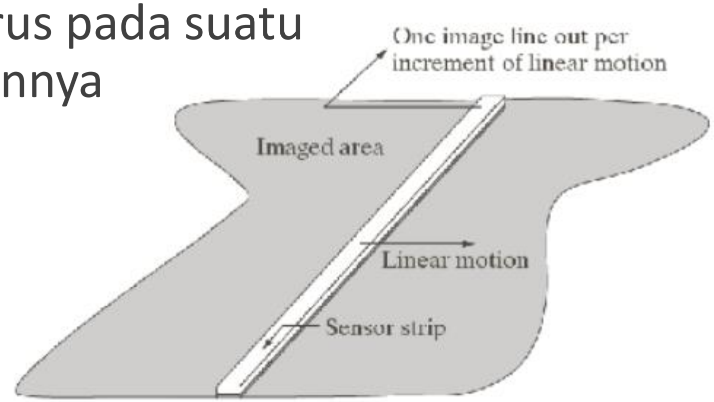
Citra 2-D dan 3-D

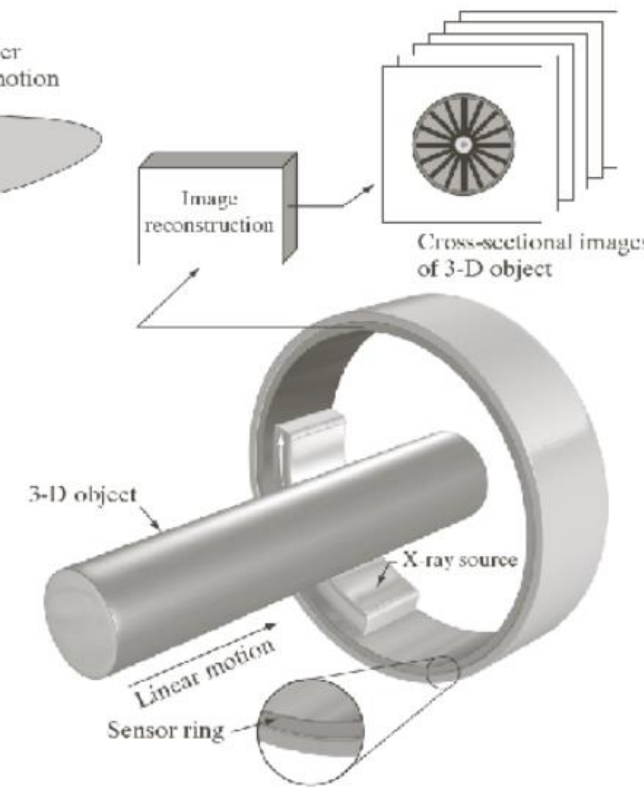
- In-line arrangement sensors :

    - Strip of sensors



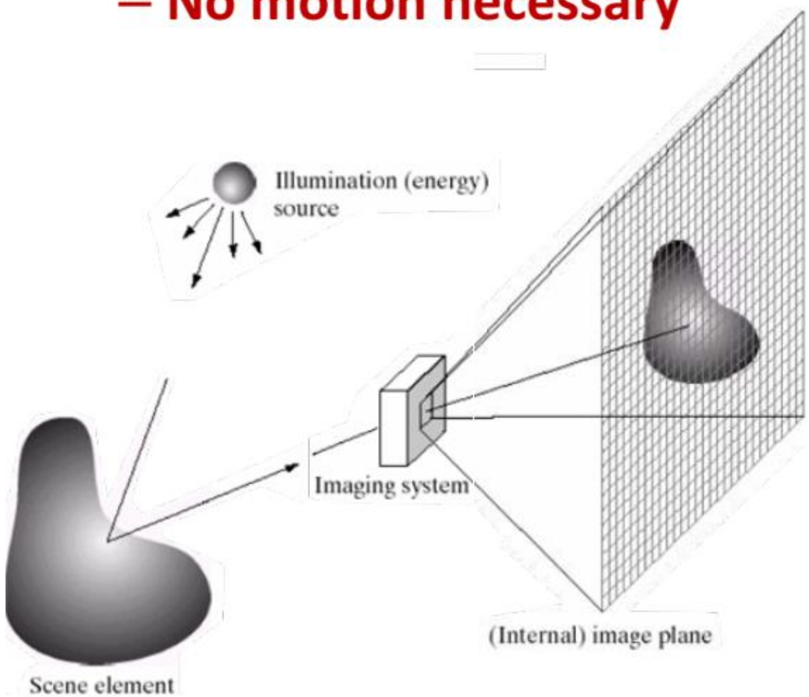
- Strip menyediakan element imaging pada satu arah
- Pergerakan tegak lurus pada suatu strip image diarah lainnya

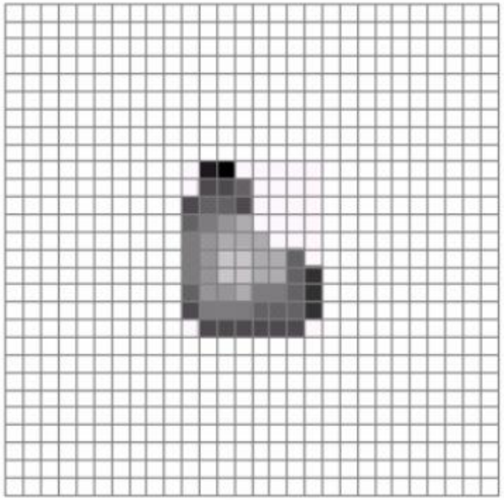




Sensor Array

- Individual sensors are arranged in a 2D array
  - Used in digital cameras
  - Entire image formed at once
  - **No motion necessary**




Output (digitized) image

CCD (Charged Couple Device)

- CCD adalah alat untuk pergerakan beban elektrikal

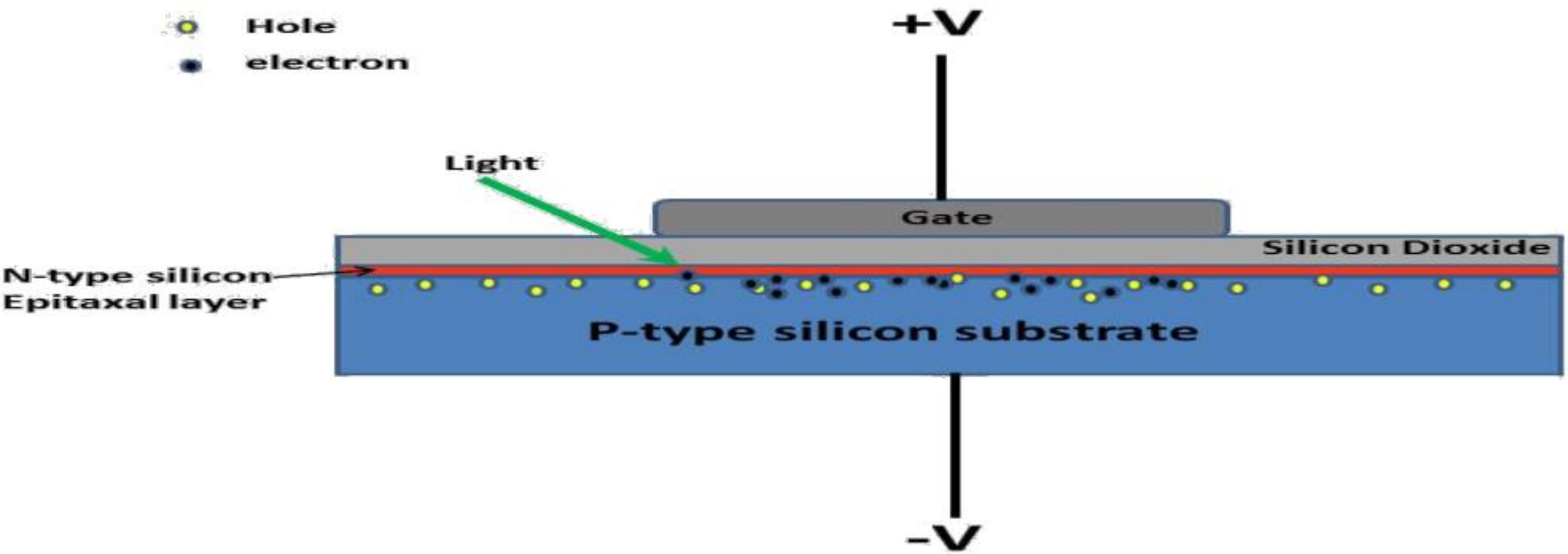
✓ Biasanya dari antar device ke suatu area dimana beban dapat dimanipulasi

  - Sering dikonversi ke nilai digital

✓ Charge ke nilai digital

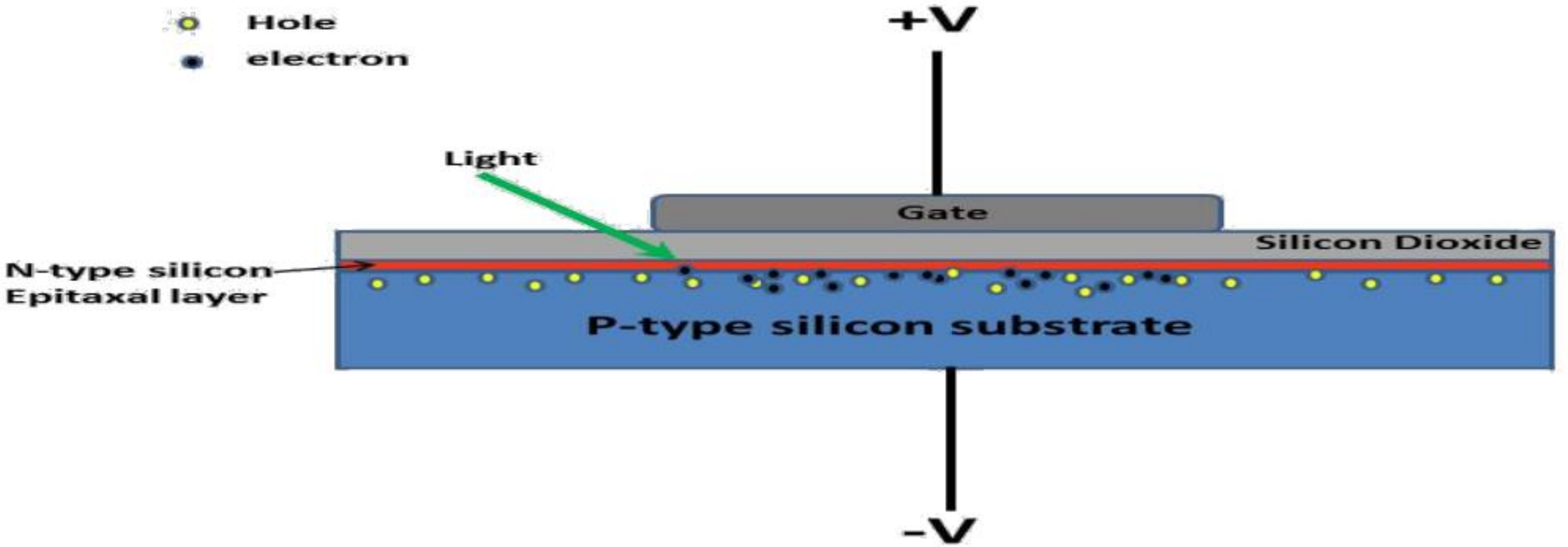
  - Dimana beban ini proporsional terhadap exposure cahaya

Single Pixel of a CCD Array



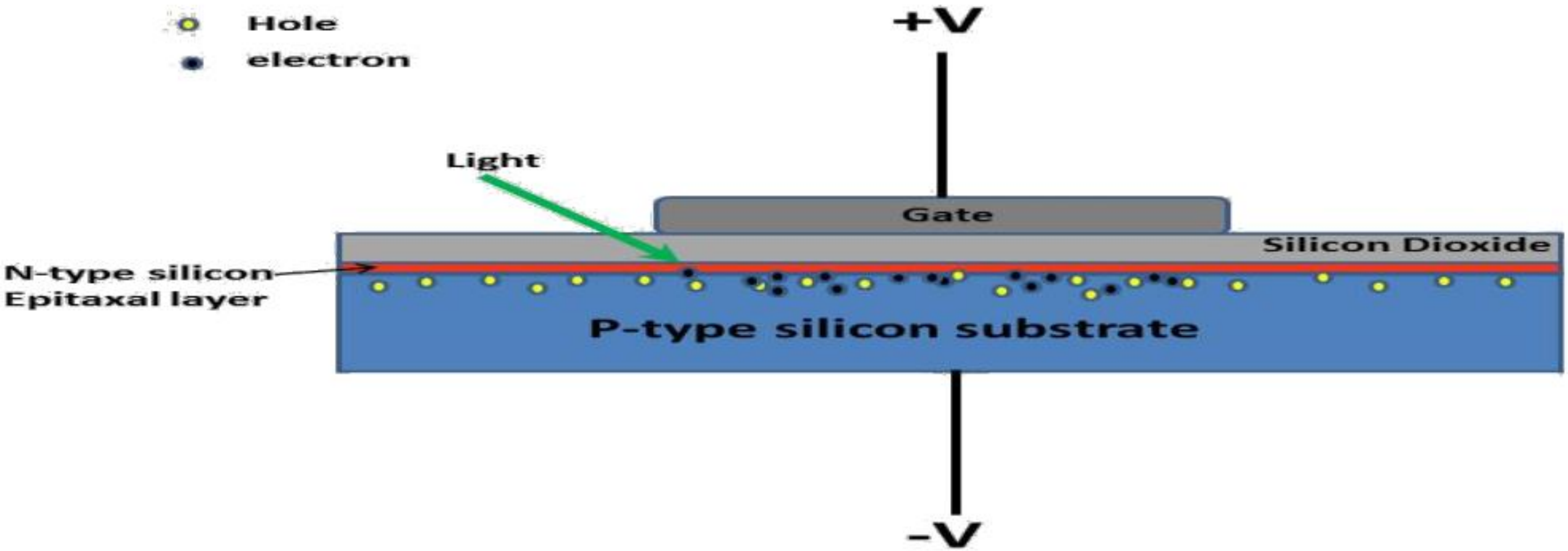
- Below the gate
  Silicon Dioxide = SAND
  - an insulator carrying no electrons
  - keeps electrons away from gate

Single Pixel of a CCD Array



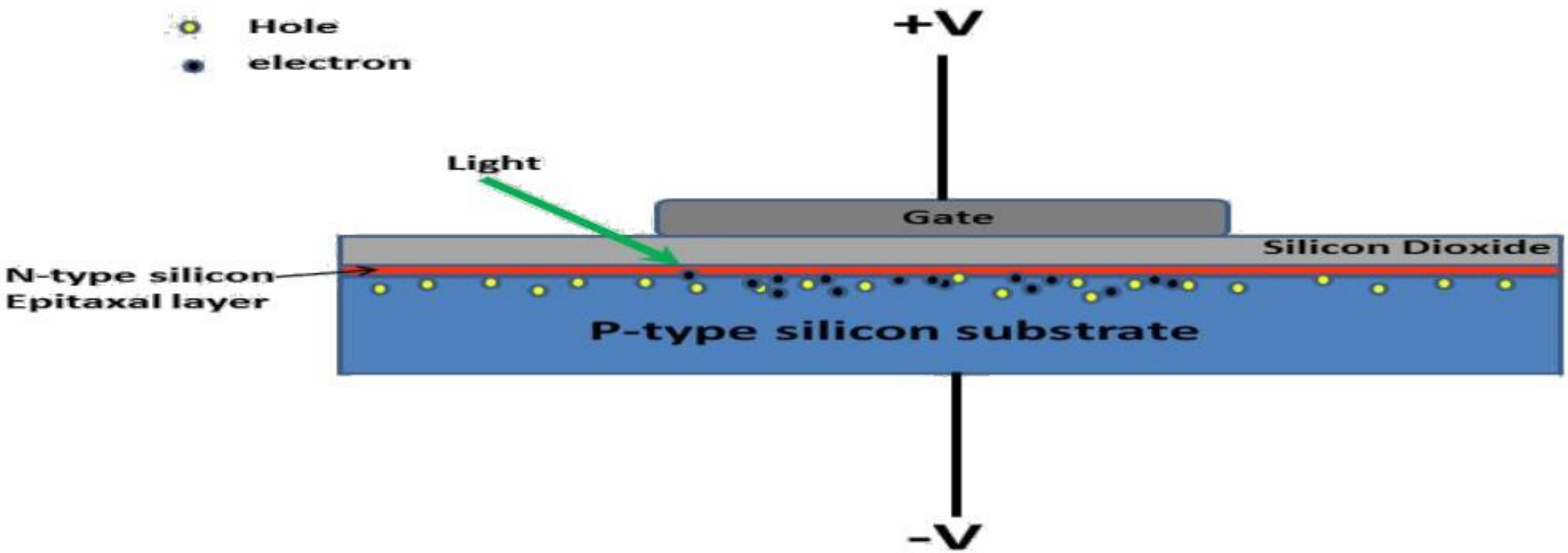
- Below the Epitaxal layer
- P-type silicon layer
  - kept at negative voltage

Single Pixel of a CCD Array



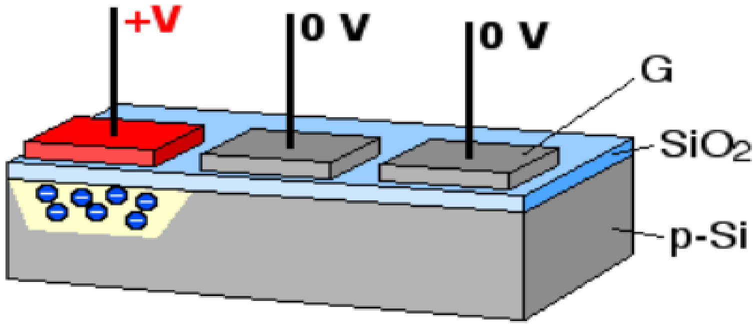
- Light hits the bottom side of this
  - Photoelectrons fill up the holes in the P-Type layer
    - longer exposure means more holes filled up
      - holes are "wells" to collect electrons
        - » maximum number of electrons a well can hold = well capacity

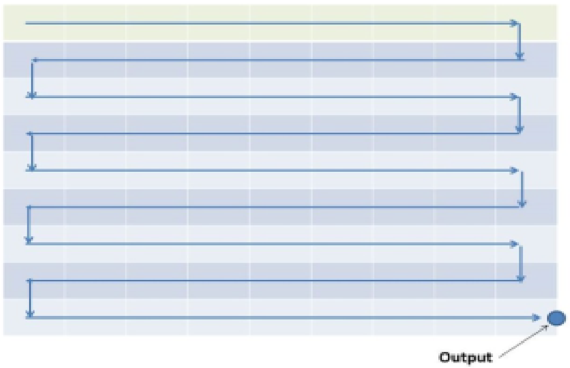
Single Pixel of a CCD Array



- End result
  - Device which stores charge proportional to light exposure
  - Make an array of them

Shift To Get Readout





CCD menggunakan tegangan terprogram untuk menggeser charge antar pixel :

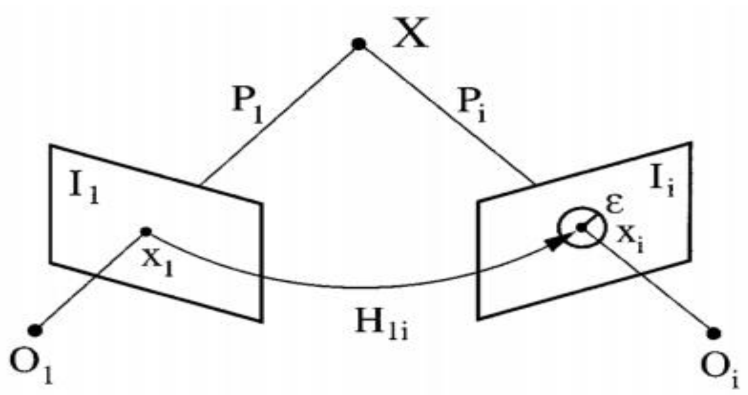
- dengan membawa nilai tegangan pixel ke nilai 0, ini mentrasfer ke pixel yang berdekatan pada tagangan V

- Pergeseran berlanjut sampai mencapai titik pembacaan output

Charge bergerak dari pixel ke pixel , adanya luapan, dimana menghasilkan noise pada sinyal. Noise ini menyebabkan kesalahan pembacaan atau display (sloppy noise)

Image as a function

- Faktanya citra 2 D adalah proyeksi dari fungsi 3 D yang sangat penting untuk beberapa aplikasi



- Pada proses stitching, dimana struktur dari proyeksi dapat digunakan untuk proses transformasi citra dari titik pandang yang berbeda

Citra adalah analog

- Citra didefinisikan sebagai fungsi pada domain continuous, sensor menyajikan gelombang tegangan continus, dimana perilaku amplitude dan spatialnya berrelasi dengan phenomena fisik yang di sensing
- Citra adalah representasi dari dunia analog, harus di convert ke benntuk digital data
- Untuk membawanya ke domain discrete, maka ita harus mendigitasi image / citra

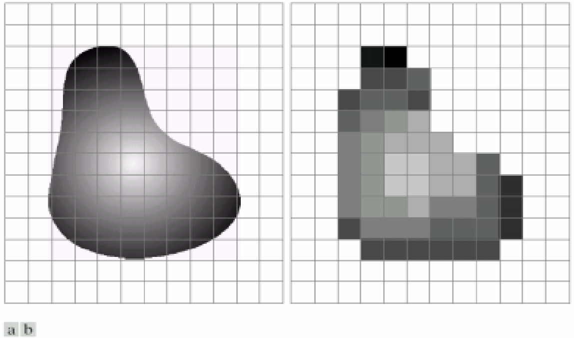


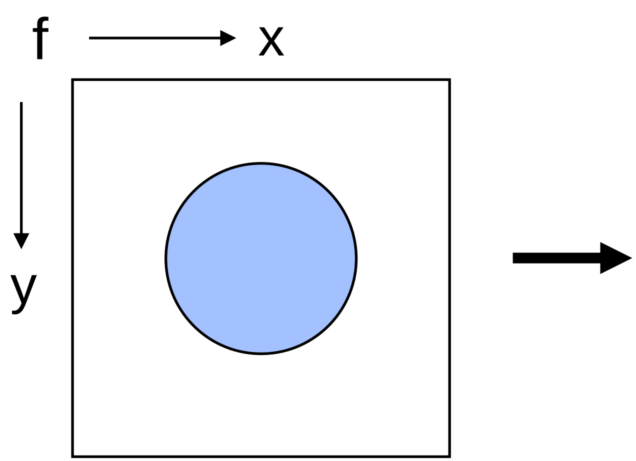
FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.

2 tipe discretization:

1. Sampling → Spatial Resolution jumlah pixel yang terbatas (finite number of pixels)
2. Quantisasi → Grayscale resolution Amplitudo pixel yang direpresentasikan dari jumlah bit (finite number of bits)

Digitization

Two stages in the digitization process:
- **Spatial sampling**: Spatial domain
- **Quantization**: Gray level



Continuous Image

$f(x,y)$

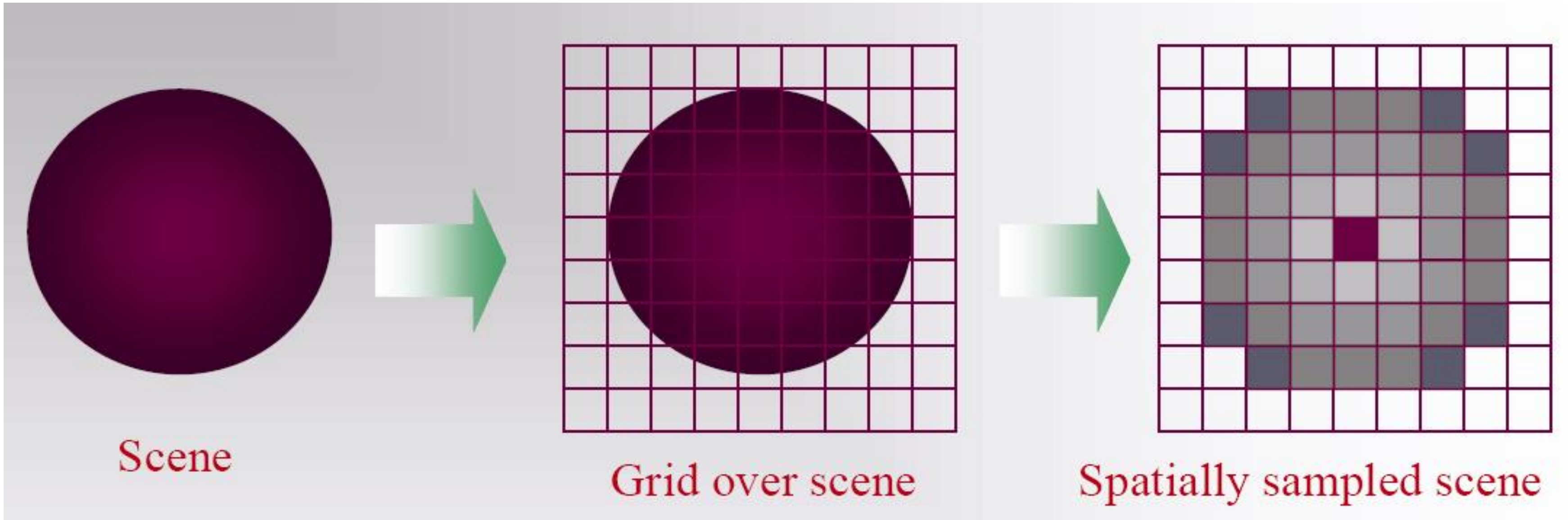
i \ j	1	2	3	4	5
1	100	100	100	100	100
2	100	0	0	0	100
3	100	0	0	0	100
4	100	0	0	0	100
5	100	100	100	100	100

Digital Image

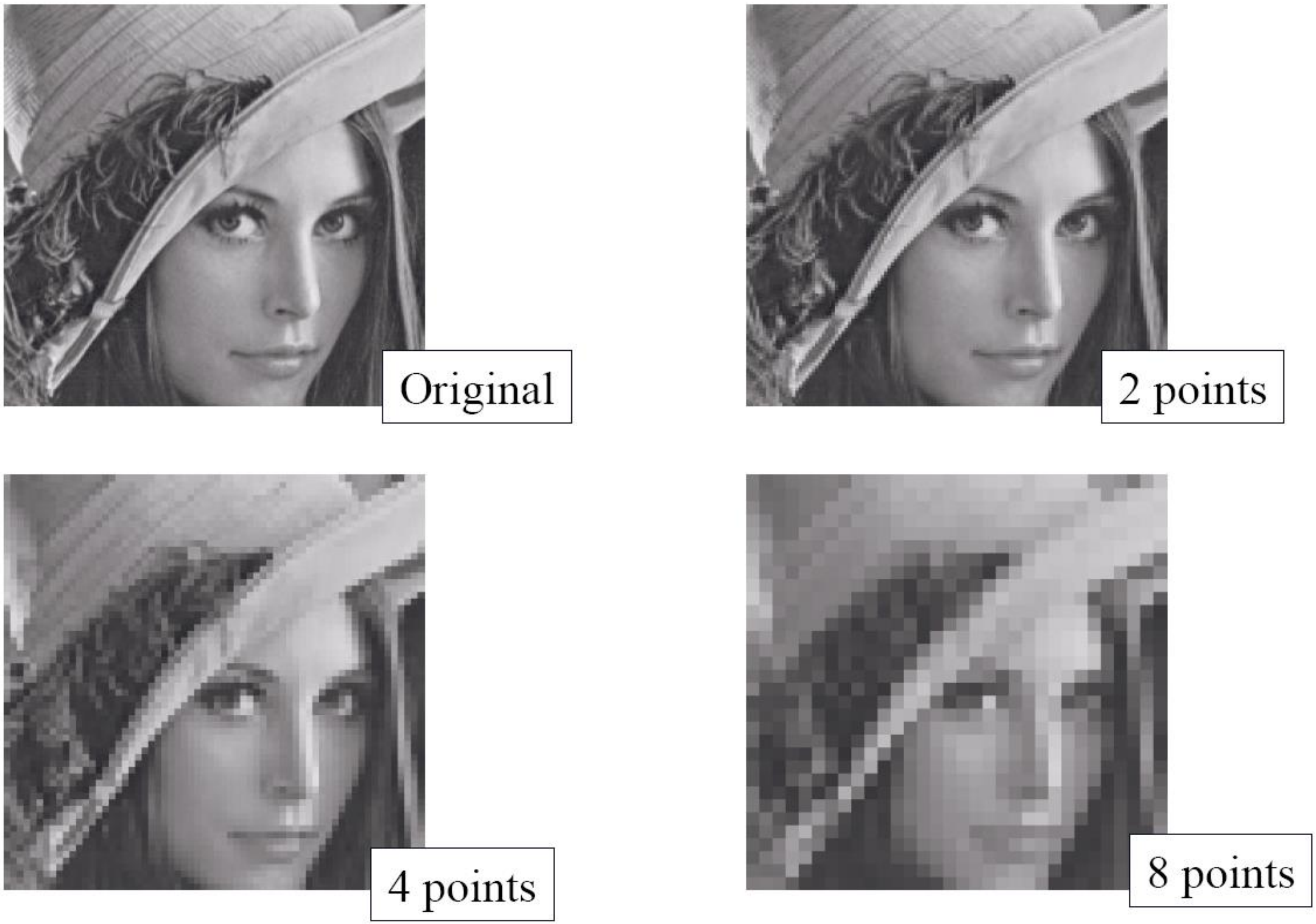
$g(i,j) \in C$

Spatial Sampling

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

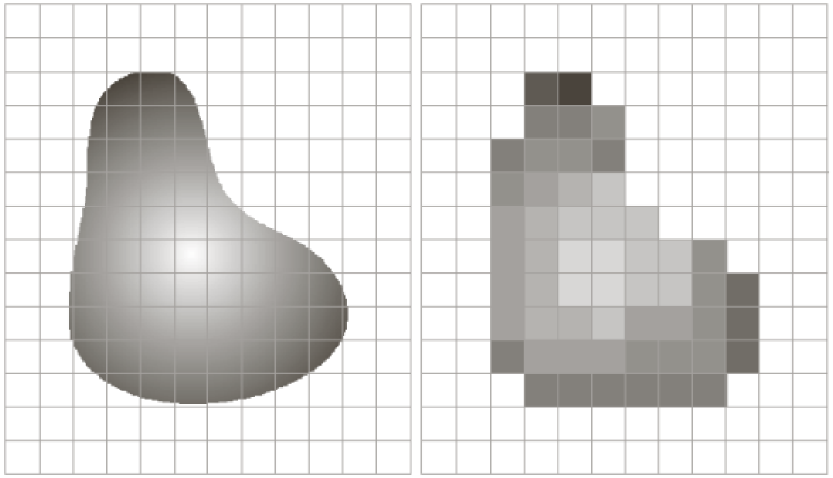


Spatial Sampling



Sampling

Sampling berkorespondensi dengan diskritisasi dari suatu bidang, dari suatu bidang. Dari domain ke suatu fungsi, ke $f: [1, \ldots, N] x\ [1, \ldots, M] \longrightarrow\ R^m$



a b

FIGURE 2.17 (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

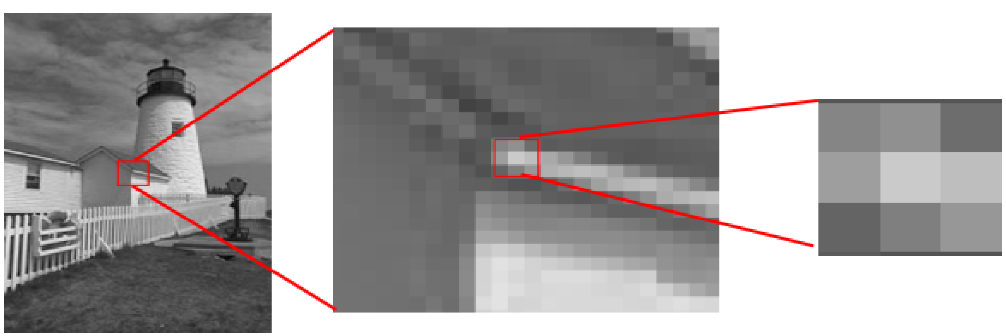
Sampling

Citra dapat dilihat sebagai suatu matrix :

$$f = \begin{bmatrix} f(1,1) & f(1,2) & \cdots & f(1,M) \\ f(2,1) & f(2,2) & \cdots & f(2,M) \\ \vdots & \vdots & \ddots & \vdots \\ f(N,1) & f(N,2) & \cdots & f(N,M) \end{bmatrix}.$$

$$x[n_1,n_2] = \begin{bmatrix} x[0,0] & x[0,1] & \cdots & x[0,N-1] \\ x[1,0] & x[1,1] & \cdots & x[1,N-1] \\ \vdots & \vdots & \ddots & \vdots \\ x[M-1,0] & \cdots & \cdots & x[M-1,N-1] \end{bmatrix}_{MxN}$$

- Elemen terkecil hasil diskritisasi pada suatu bidang disebut pixel
- Untuk citra 3D, element ini disebut voxel (volumetric pixel)



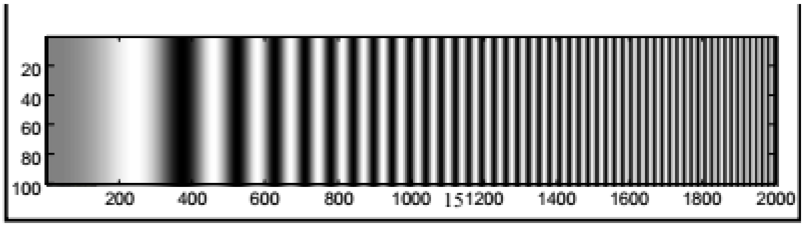
$$\begin{bmatrix} 35 & 45 & 20 \\ 43 & 64 & 52 \\ 10 & 29 & 39 \end{bmatrix}$$

Image resolution

The density of the sampling denotes the separation capability of the resulting image

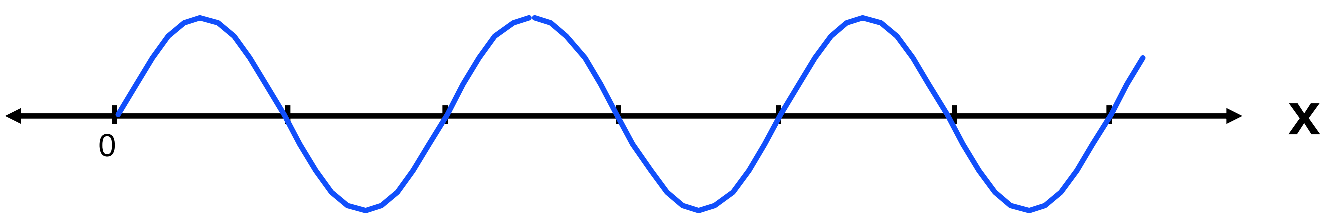
Image resolution defines the finest details that are still visible by the image

We use a cyclic pattern to test the separation capability of an image

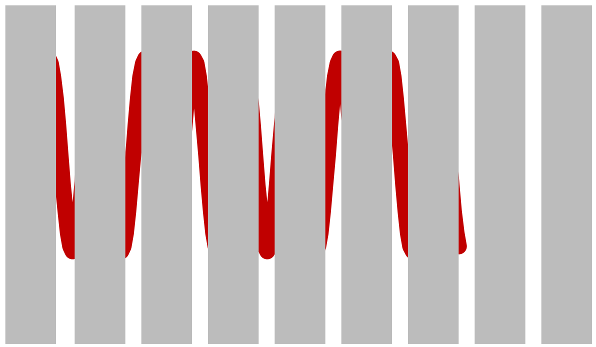


$$\text{Frequency} = \frac{\text{number of cycles}}{\text{unit length}}$$

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



Sampling Rate



Nyquist Frequency

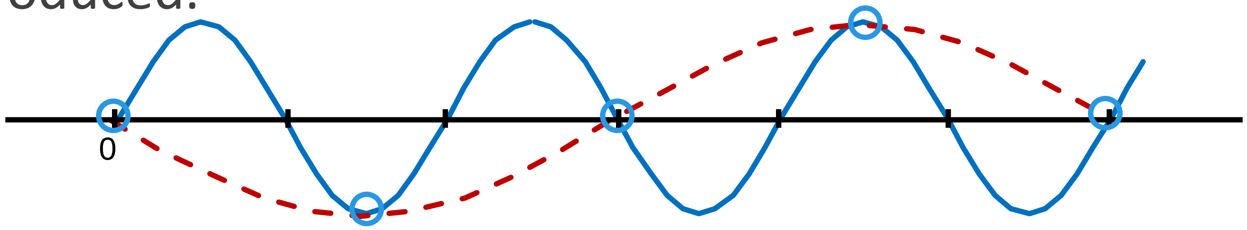
Nyquist Rule: melakukan sampling pada interval = d kemudian salah satnya direcovery pola perputarannya (cyclic pattern) pada panjang gelombang > 2d

Untuk mengobservasi lebih detail pada frequency f, kita harus melakukan sampling pada sample frekuensu 2f

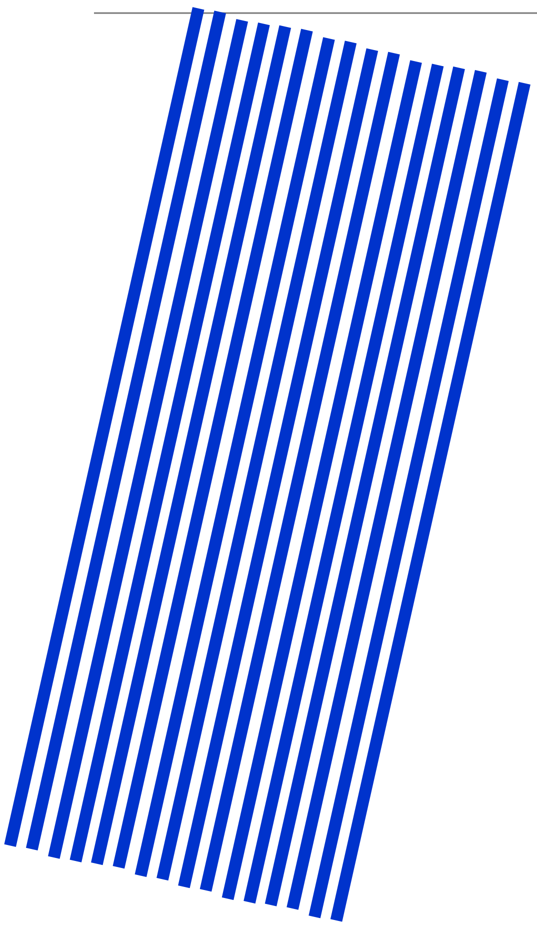
The Frequency 2f is the **Nyquist Frequency**.

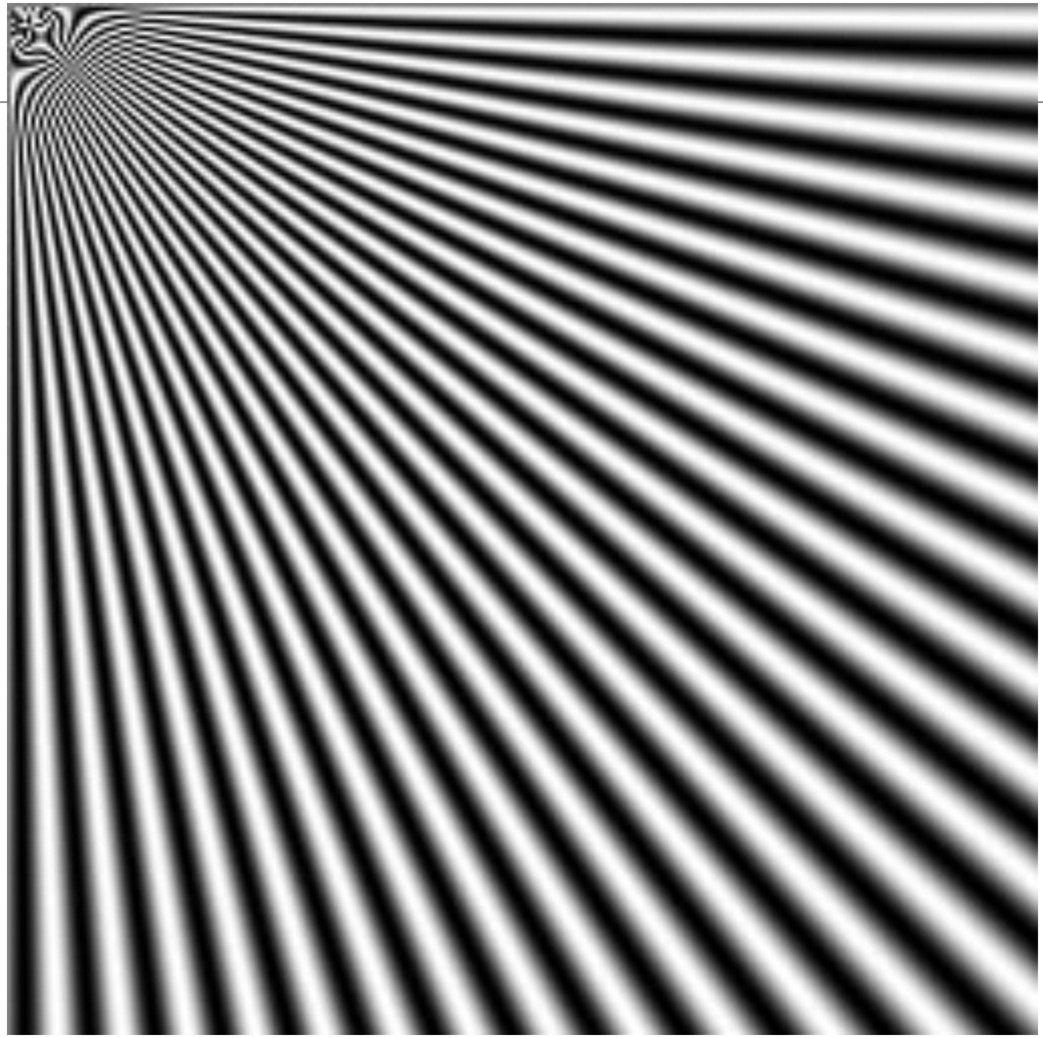
Aliasing: If the pattern wavelength is less than 2d erroneous patterns may be produced.

1D Example:

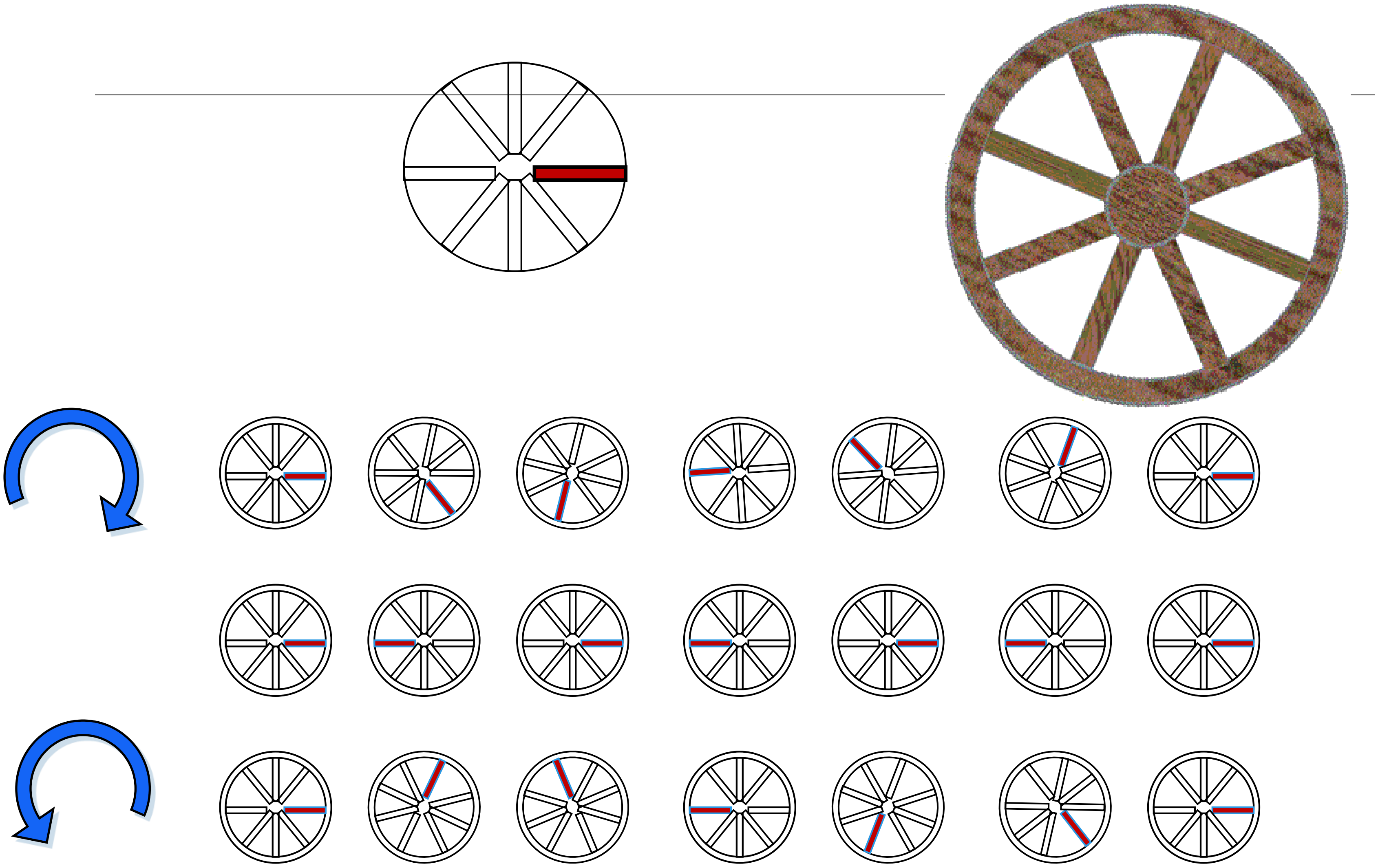


Aliasing - Moiré Patterns





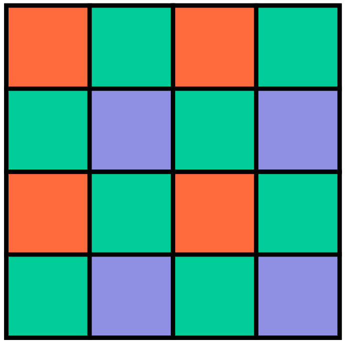
Temporal Aliasing



Temporal Aliasing Example

Image De-mosaicing

Can we do better than Nyquist?



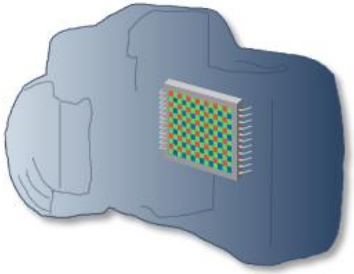
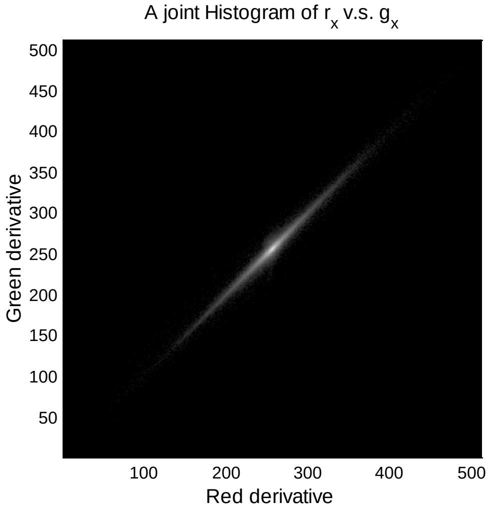


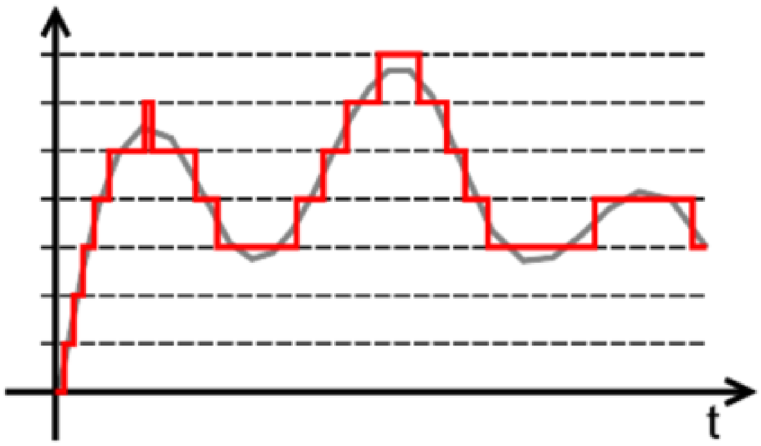
Image De-mosaicing

Basic idea: use correlations between color bands



Quantization

Kuantisasi berkorespondensi dengan diskritisasi nilai intensitas. Fungsi co domain.

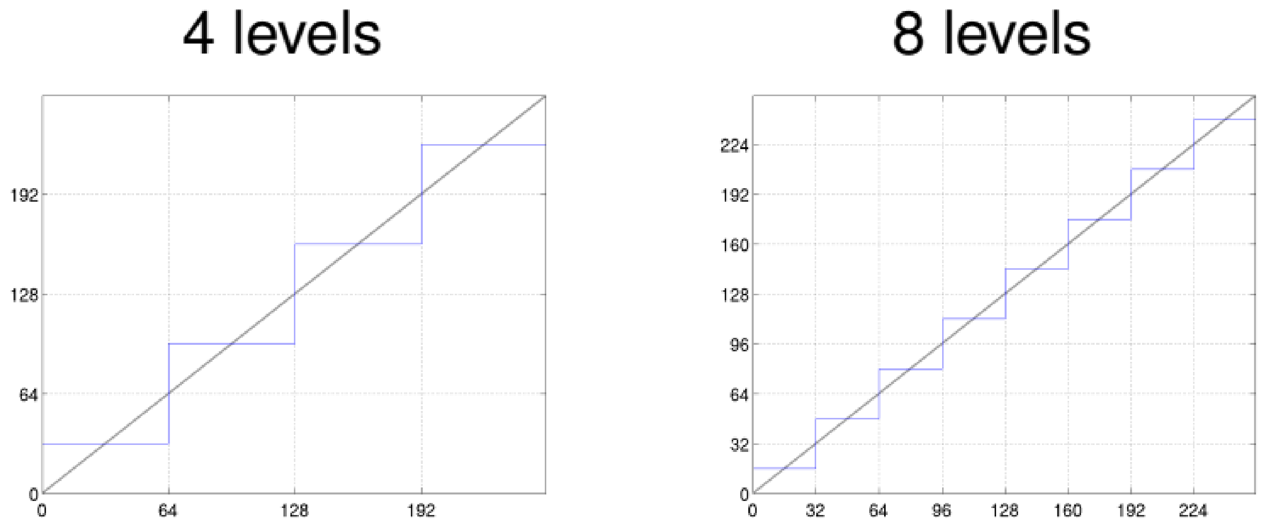


Setelah proses sampling dan kuantisasi, diperoleh :

$f: [1, \ldots, N] x\ [1, \ldots, M] \longrightarrow [0, \ldots, L].$

Quantization

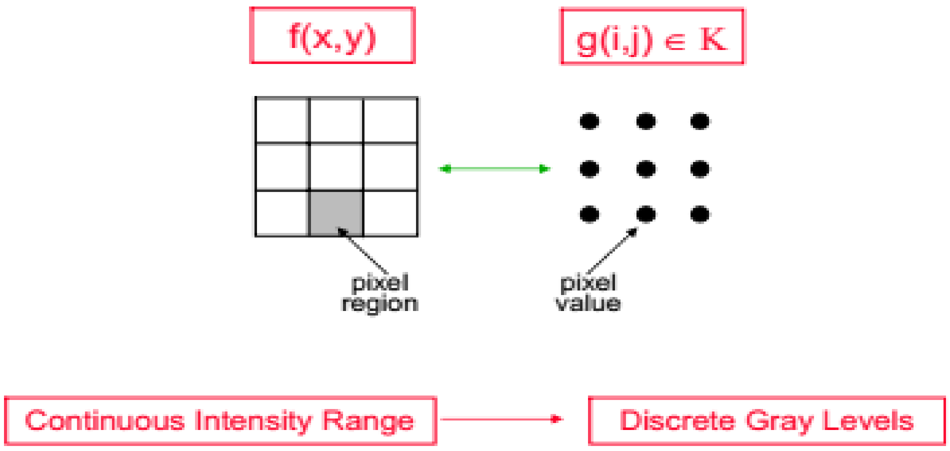
Quantization berkorespodensi ke transformasi Q(f)



n

intensitas. Untuk citra berwarna, 256 level biasanya digunakan untuk tiap intensitas warna.

Quantization



- Pilih banyaknya graylevel (sesuai dengan jumlah bit yang diassign)
- Membagi jangkauan continuos dari nilai intensitasnya.

Take a look at this cross section

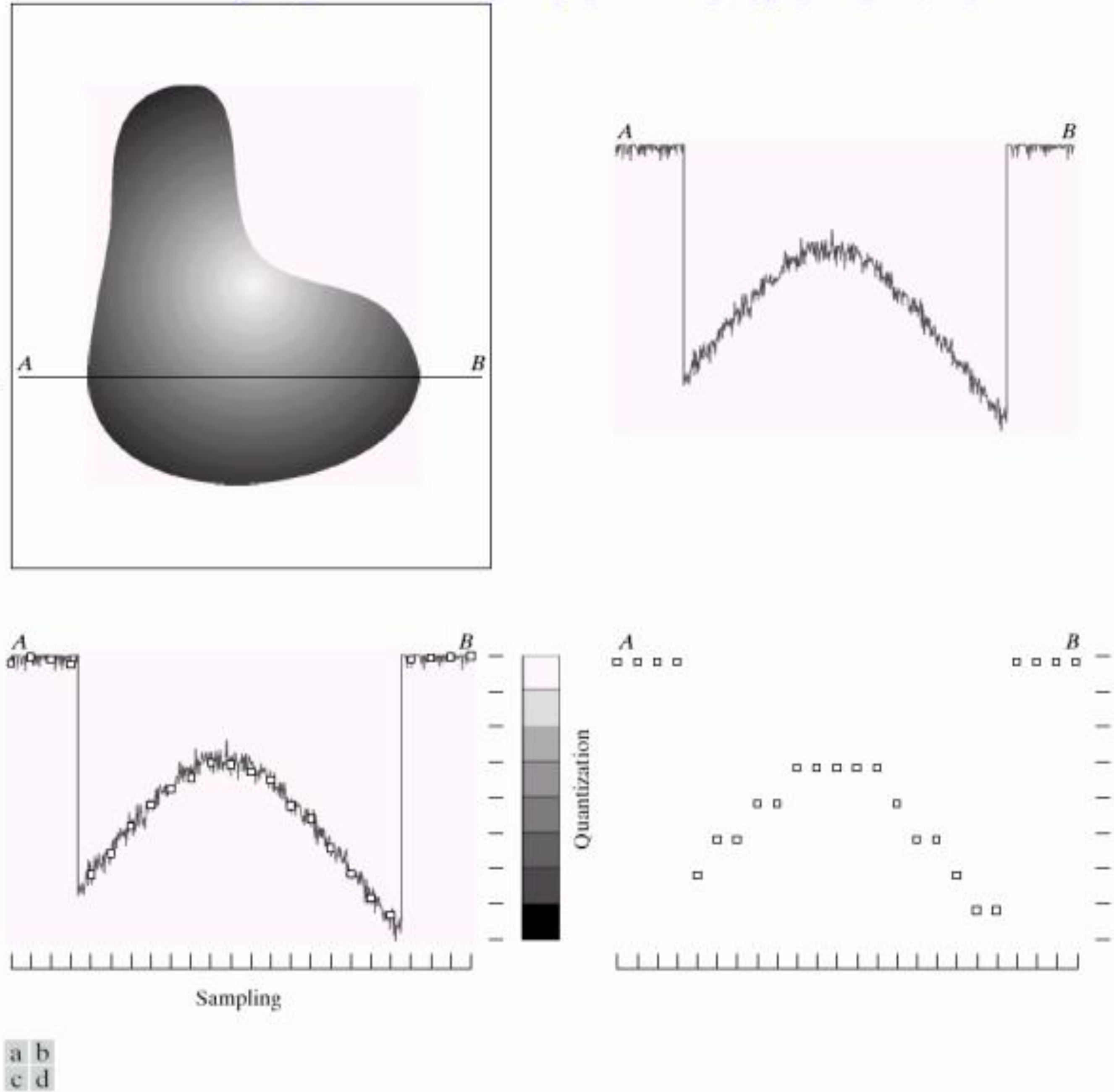
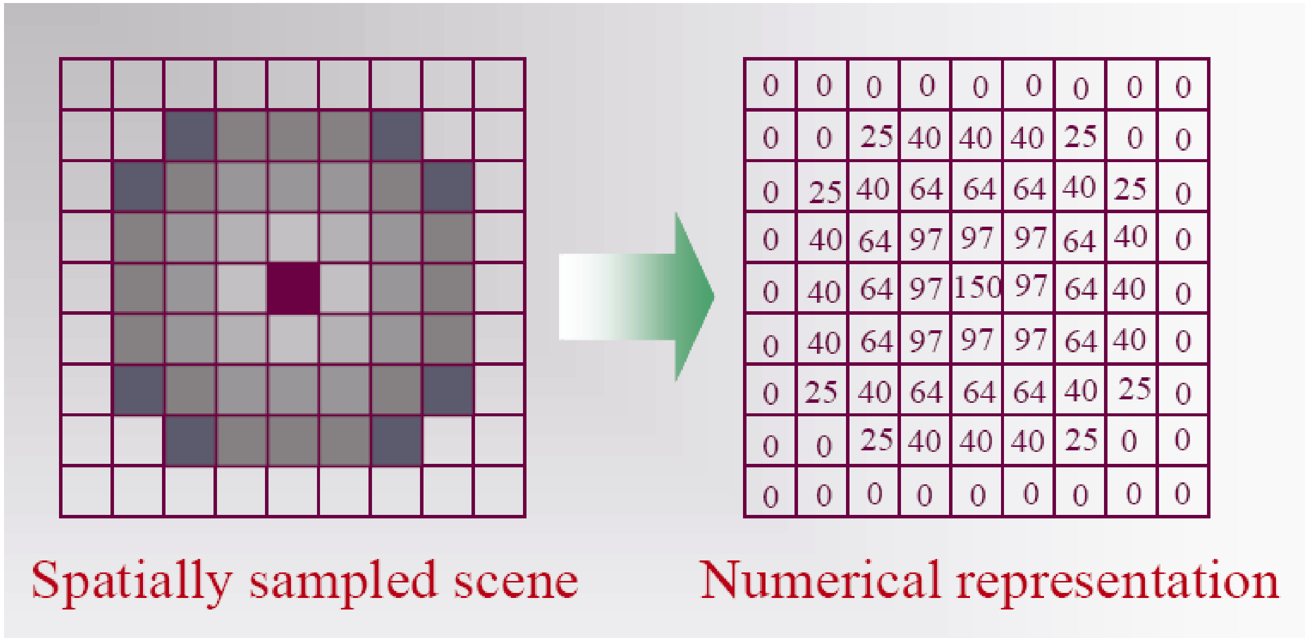


FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

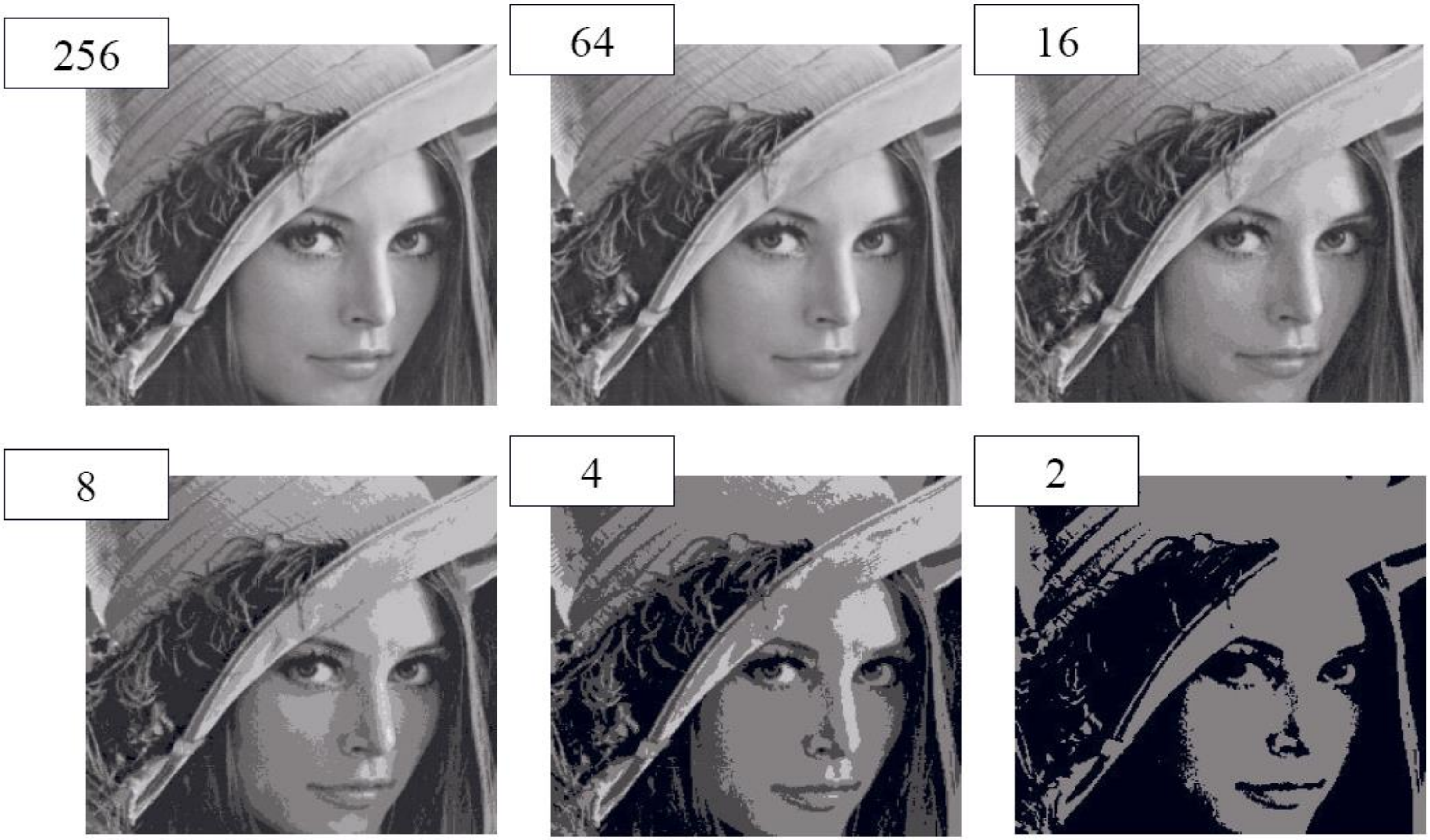
Quantization

Choose number of gray levels (according to number of assigned bits)

Divide continuous range of intensity values



Quantization



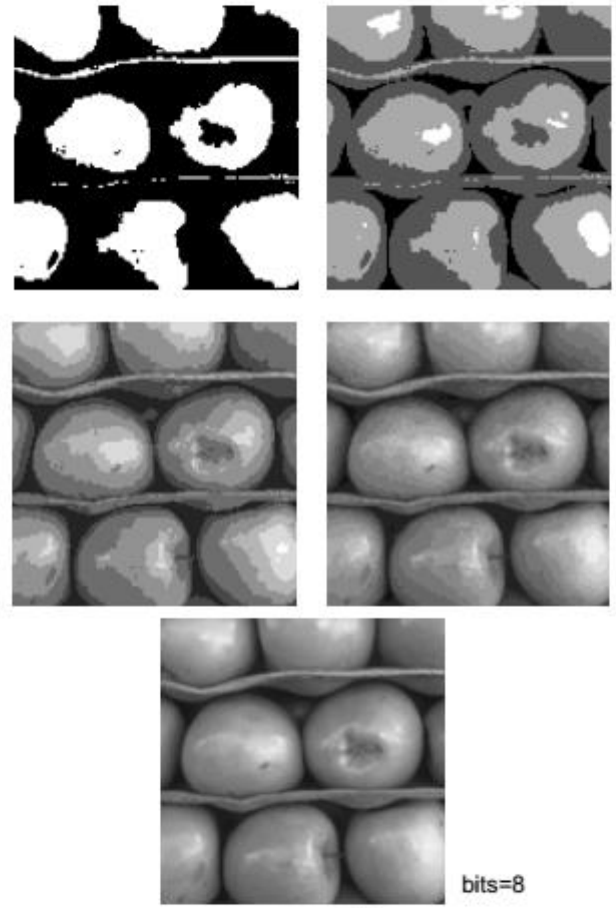
Different Number of Gray Levels

bits=1 bits=2

bits=3 bits=4

bits=8

Different Number of Gray Levels



bits=1 bits=2

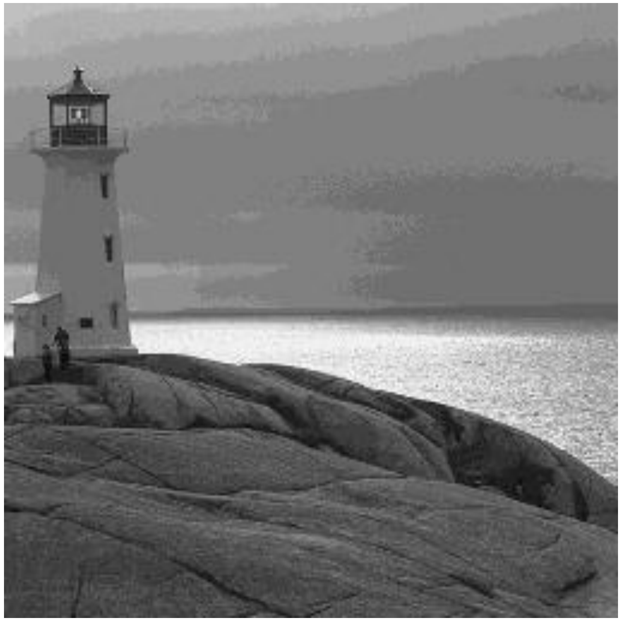
bits=3 bits=4

bits=8

Quantization

- Low freq. areas are more sensitive to quantization

8 bits image



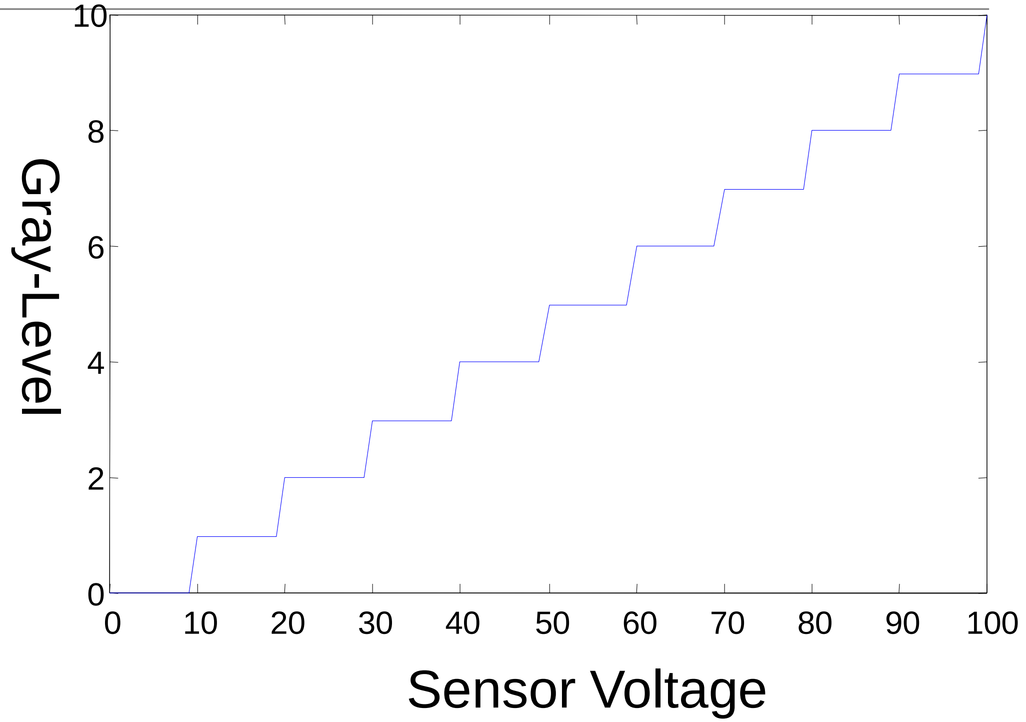
4 bits image

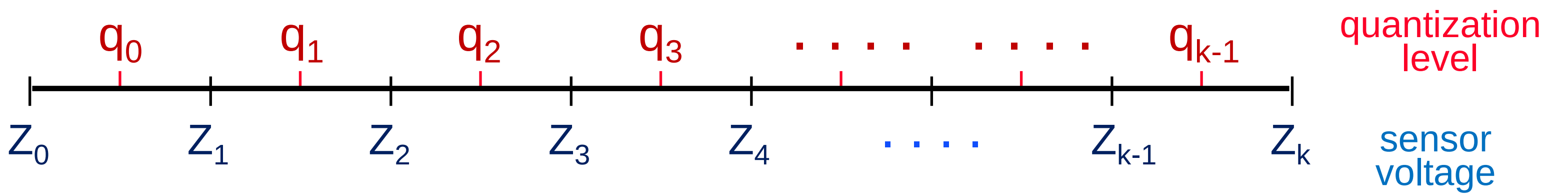
How should we quantize an image?

- Simplest approach: **uniform quantization**

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

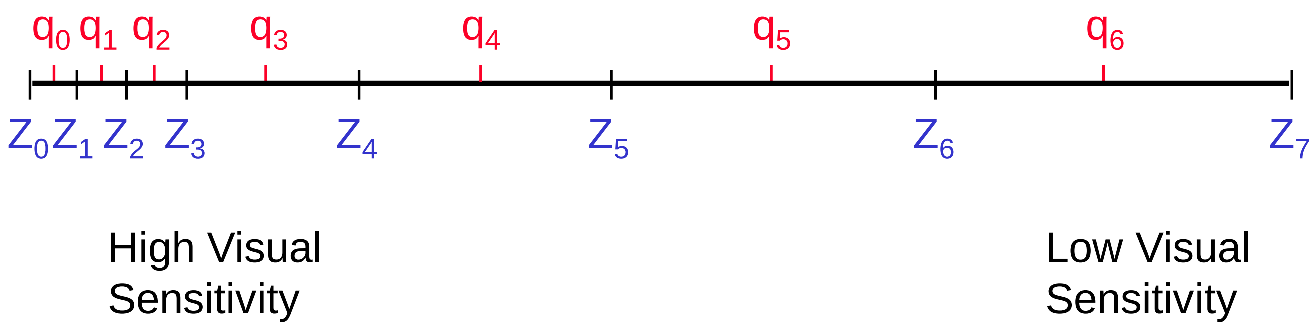
$$q_i = \frac{Z_{i+1} + Z_i}{2}$$



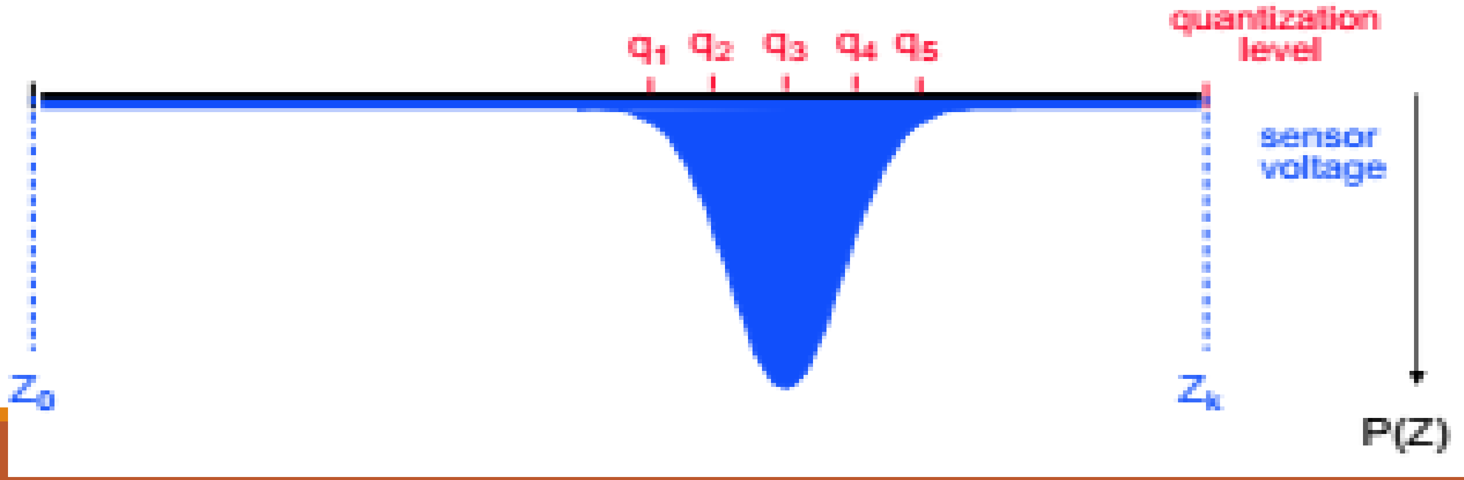


Non-uniform Quantization

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

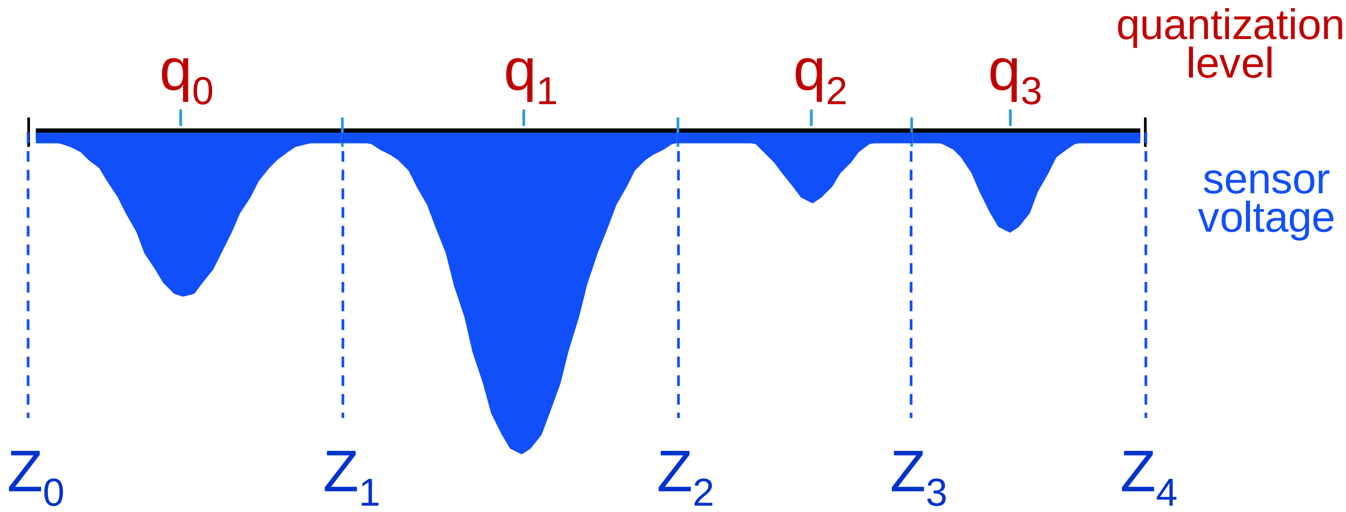


- Non uniform sensor voltage distribution



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:

(weighted average in the range [Z_i ... Z_{i+1}])

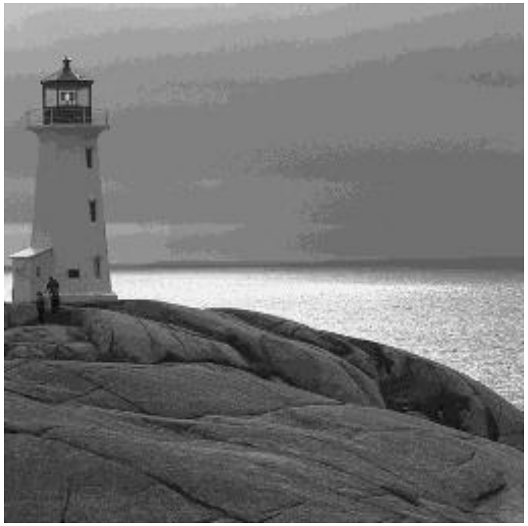
$$q_i = \frac{\int_{z_i}^{z_{i+1}} zP(z)dz}{\int_{z_i}^{z_{i+1}} P(z)dz} \qquad z_i = \frac{q_{i-1} + q_i}{2}$$

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

Example

8 bits image

4 bits image
Uniform quantization



4 bits image
Optimal quantization

Digital Image Acquisition

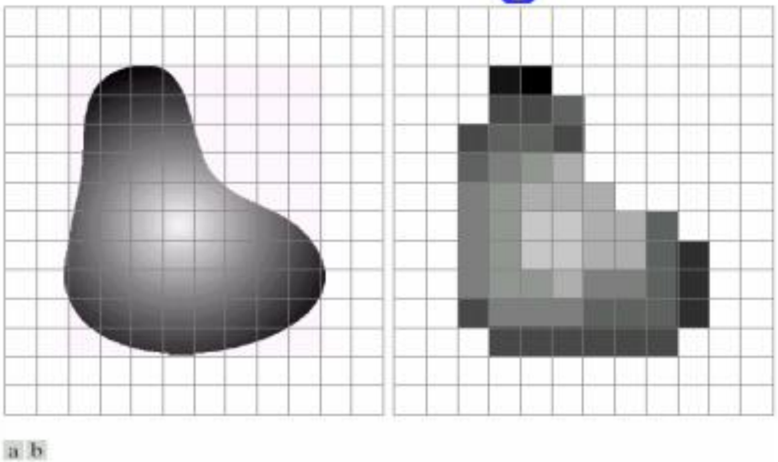
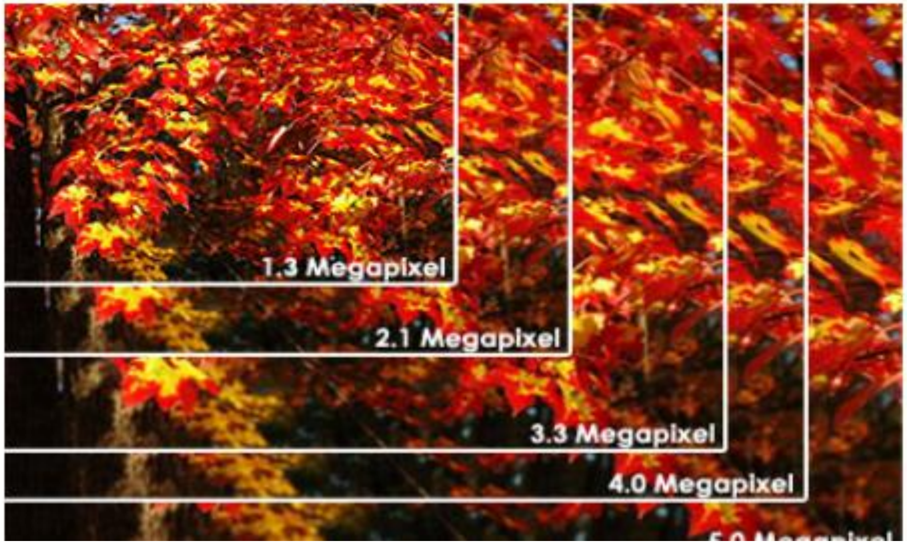


FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.



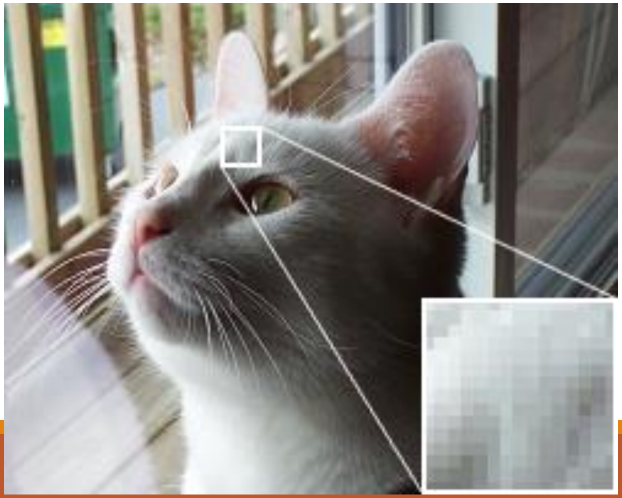
- **256x256** - Found on very cheap cameras, this resolution is so low that the picture quality is almost always unacceptable. This is 65,000 total pixels.
- **640x480** - This is the low end on most "real" cameras. This resolution is ideal for e-mailing pictures or posting pictures on a Web site.
- **1216x912** - This is a "megapixel" image size -- 1,109,000 total pixels -- good for printing pictures.
- **1600x1200** - With almost 2 million total pixels, this is "high resolution." You can print a 4x5 inch print taken at this resolution with the same quality that you would get from a photo lab.
- **2240x1680** - Found on 4 megapixel cameras -- the current standard -- this allows even larger printed photos, with good quality for prints up to 16x20 inches.
- **4064x2704** - A top-of-the-line digital camera with 11.1 megapixels takes pictures at this resolution. At this setting, you can create 13.5x9 inch prints with no loss of picture quality.

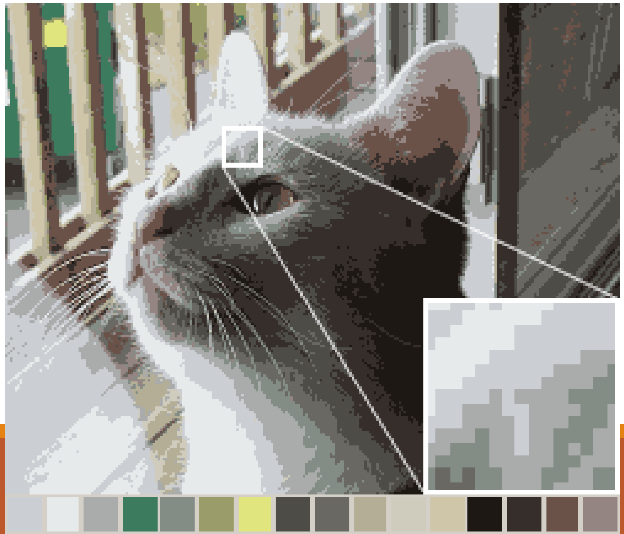
Color Quantization

Common color resolution for high quality images is 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.





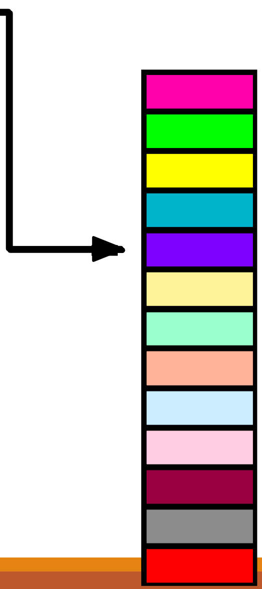
from: Daniel Cohen-Or

Color Quantization

With 8 bits per pixel and color look up table we can display at most 256 distinct colors at a time.

To do that we need to choose an appropriate set of representative colors and map the image into these colors

111	14	126	5	12	36
36	111	36	12	17	111
17	111	200	36	12	36
14	36	12	36	14	36
17	111	14	126	17	111
12	126	200	36	12	36



from: Daniel Cohen-Or

Color Quantization

2
colors

4
colors

16
colors

256
colors

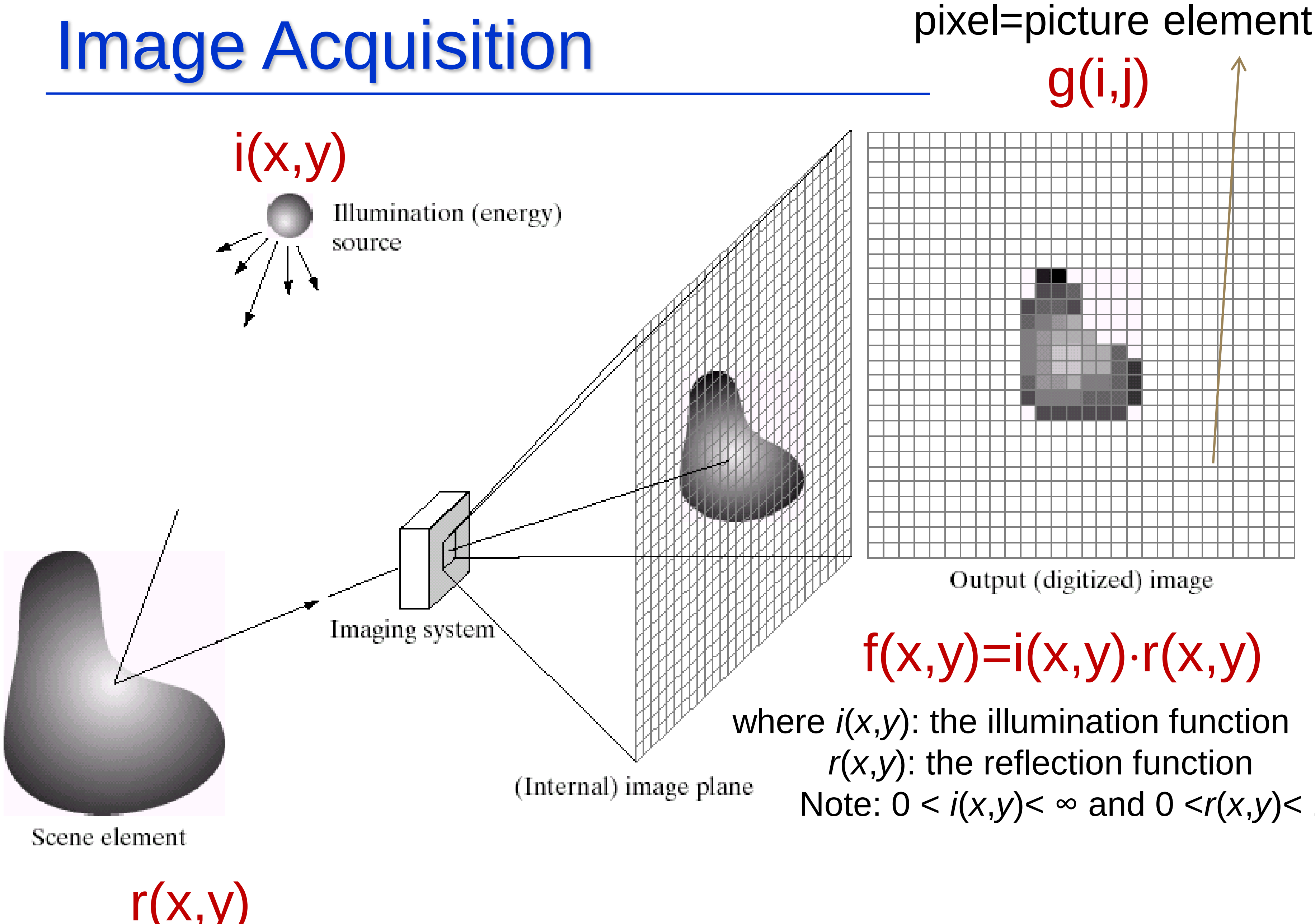
Color Quantization

Naïve (uniform) Color Quantization 24 bit to 8 bit:

Retaining 3-3-2 most significant bits of the R,G and B components.

false contours

Image Acquisition



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

where $i(x,y)$: the illumination function

$r(x,y)$: the reflection function

Note: $0 < i(x,y) < \infty$ and $0 < r(x,y) < 1$.

Fungsi Matematis dari suatu Citra

Image Formation Model :

$$f(x,y) = i(x,y) * r(x,y) + n(x, y)$$

F(x,y)	**$0 < f(x,y) < \infty$**	**Intensitas : proporsional dengan energy yang dipancarkan oleh sumber fisik**
i(x,y)	$0 < i(x,y) < \infty$	Iluminasi : banyaknya sumber iluminasi yang terjadi pada scne yang akan dilihat
r(x,y)	$0 < r(x,y) < 1$	Reflectance : banyaknya iluminasi yang direfleksikan oleh objek pada bidang scene
n(x,y)		Noise : berbagai error pengukuran

Image Types

Three types of images:

- Binary images

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

- Gray-scale images

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

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

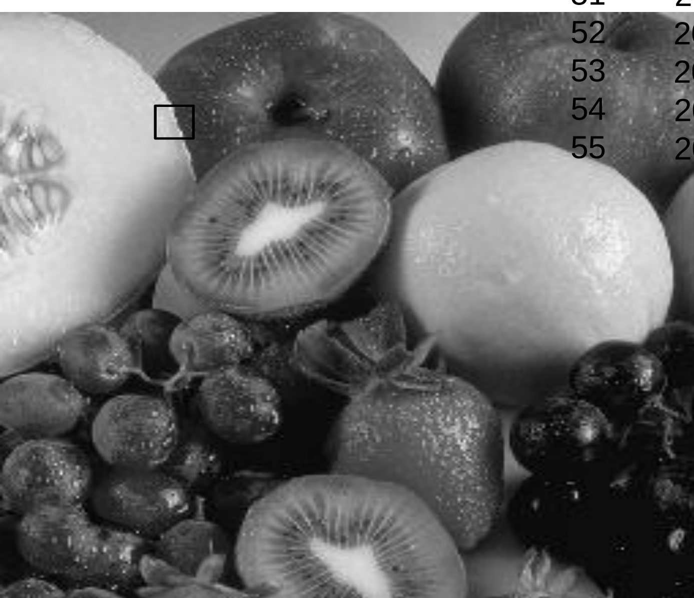
- Color Images

three channels: 3 grayscale image

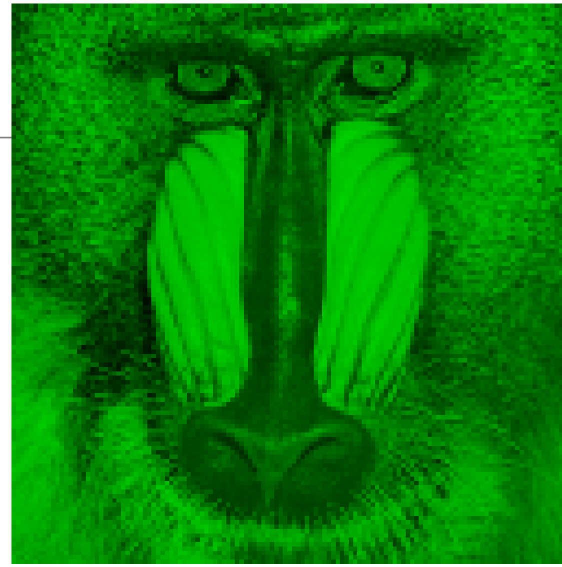
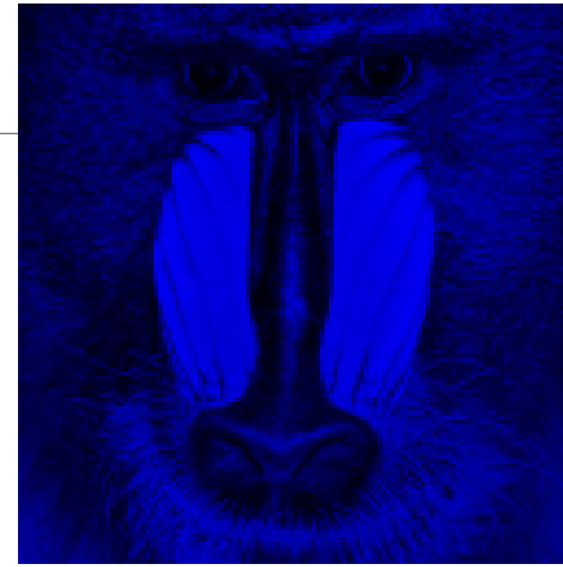
$g_R(x,y)\in C$ $g_G(x,y)\in C$ $g_B(x,y)\in C$

Gray Scale Image

y = \ x =	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
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



Color Image


Sumber Digital Images

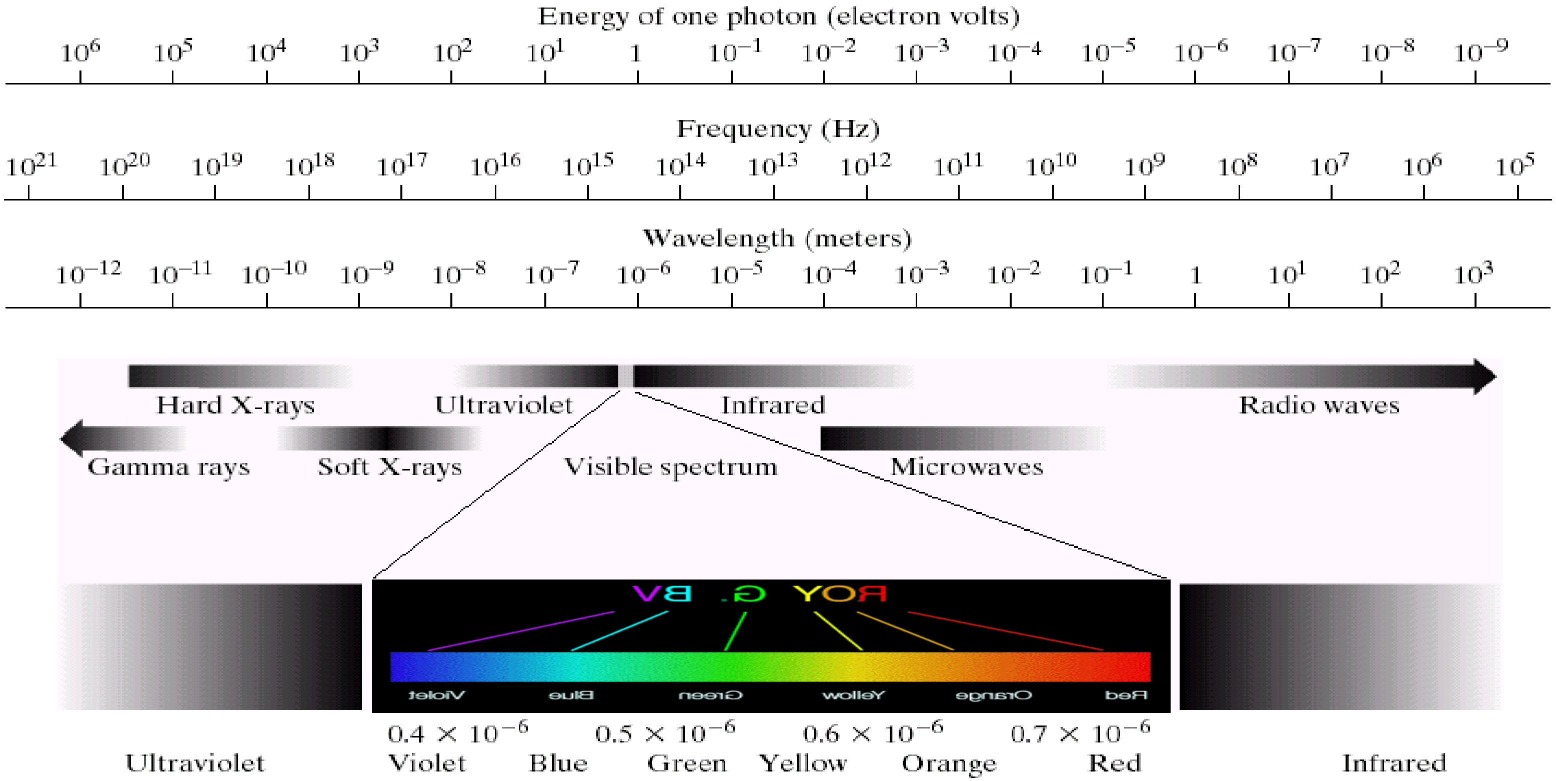


FIGURE 2.10 The electromagnetic spectrum. The visible spectrum is shown zoomed to facilitate explanation, but note that the visible spectrum is a rather narrow portion of the EM spectrum.

Light and Electromagnetic Spectrum

3 Kuantitas dasar untuk mendeskripsikan kualitas Chromatic Sumber Cahaya :

A. Radiance : jumlah total energy yang mengalir dari light source (dapat diukur)
B. Luminance : Banyaknya energy yang dirasakan oleh seorang observer dari light source (dapat diukur)
C. Brightness : Deskripsi subyektif dari persepsi cahaya, merepresentasikan jumlah cahaya yang dipancarkan (tidak dapat diukur)

Nilai suatu Image

Image Intensity -

- Energi cahaya dipancarkan dari unit area pada image
- Tergantung dari alat

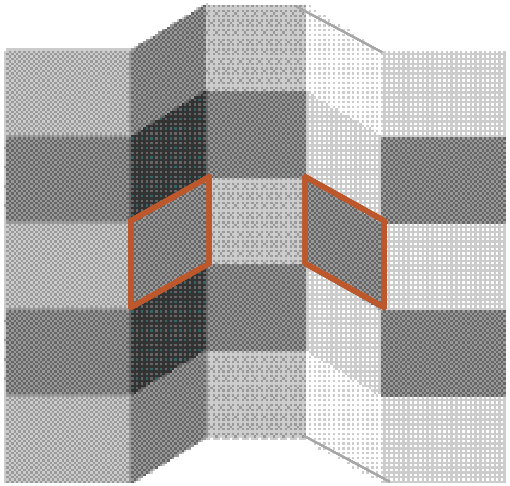
Image Brightness -

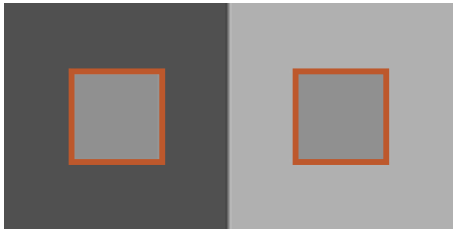
- Penampakan subyektif dari unit area dari suatu image
- Tergantung konteks
- Bersifat Subyektif

Image Gray-Level -

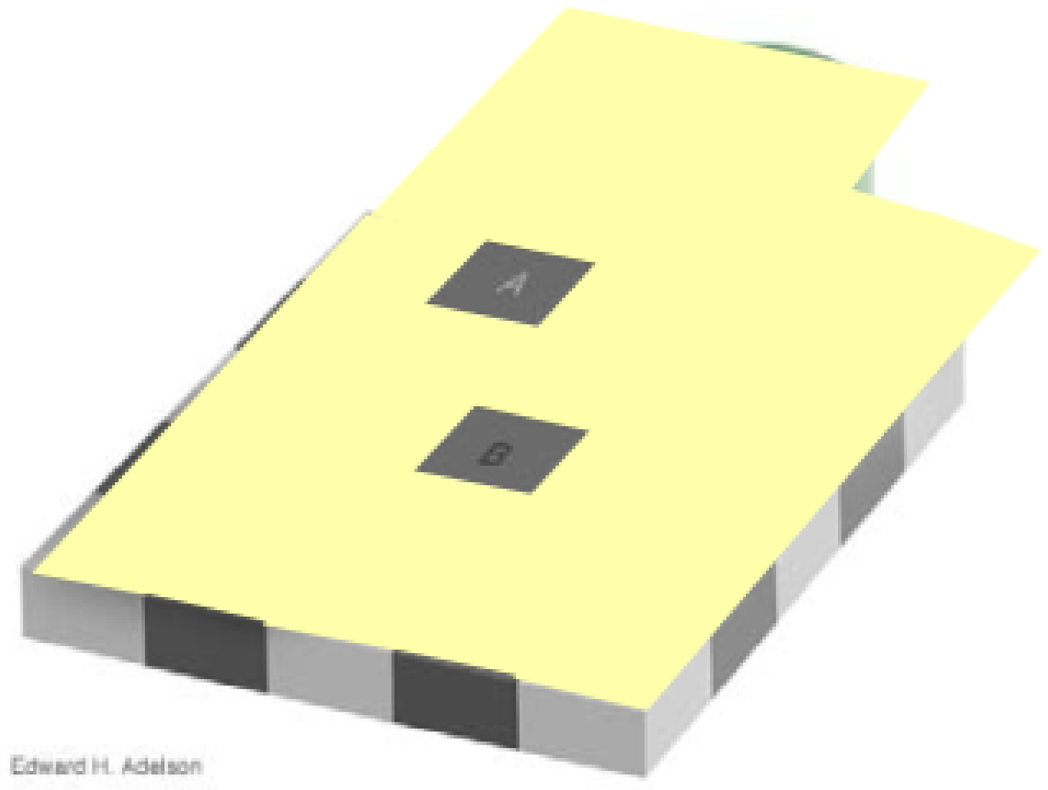
- Intensitas relative pada tiap unit area
- Diantara nilai intensitas terendah (nilai hitam dan intensitas tertinggi (putih)
- Tergantung device

Intensity vs. Brightness

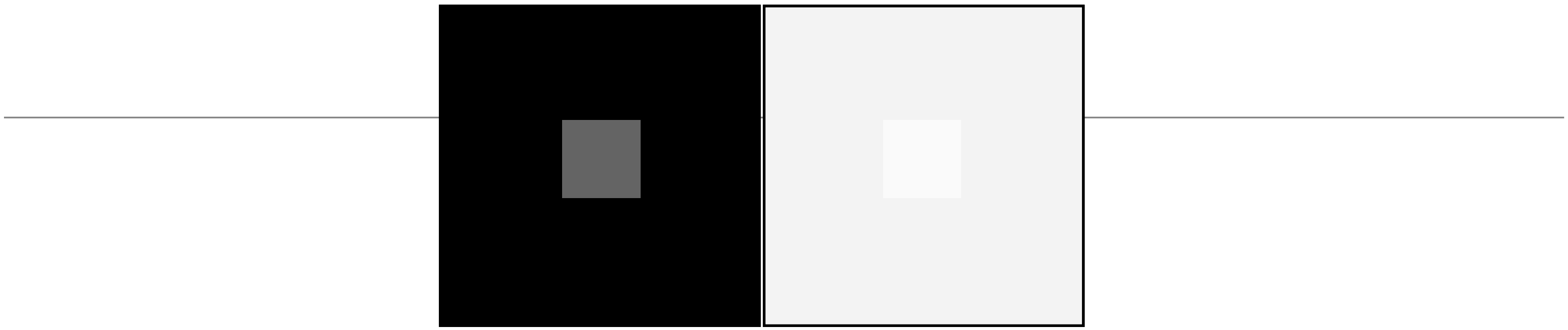




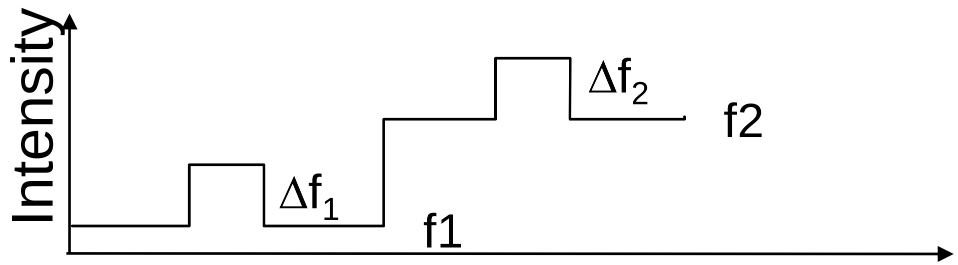
Intensity vs. Brightness



Intensity vs. Brightness



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



Equal intensity steps:

Equal brightness steps:

Weber Law

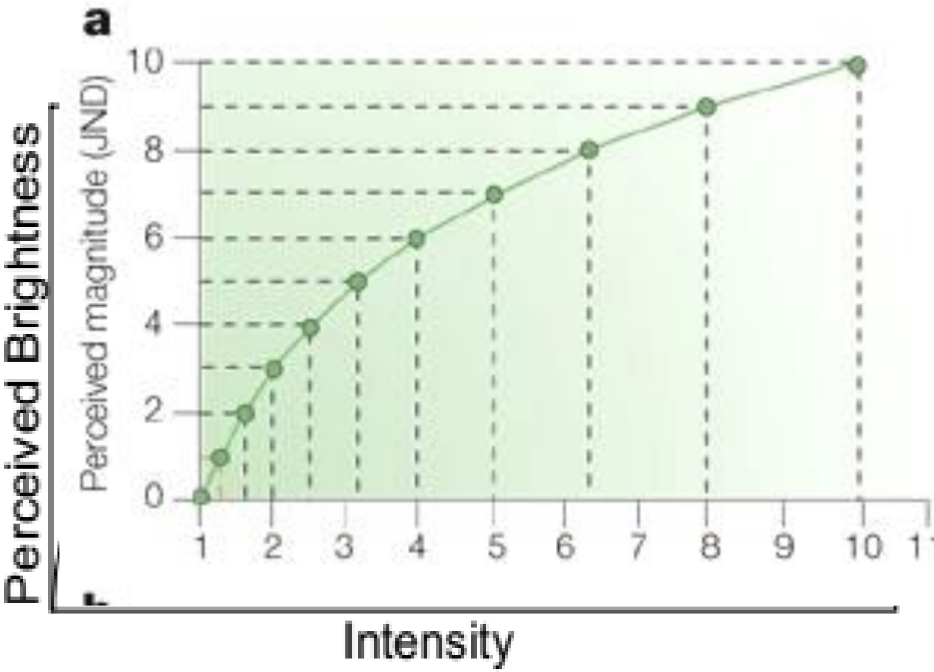
Describe the relationship between the physical magnitudes of stimuli and the perceived intensity of the stimuli.

In general, **ΔI** needed for just noticeable difference (JND) over background **I** was found to satisfy:

I = Intensitas; **ΔI = perubahan intensitas**

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

Perceived Brightness $\propto$ log(**I**)

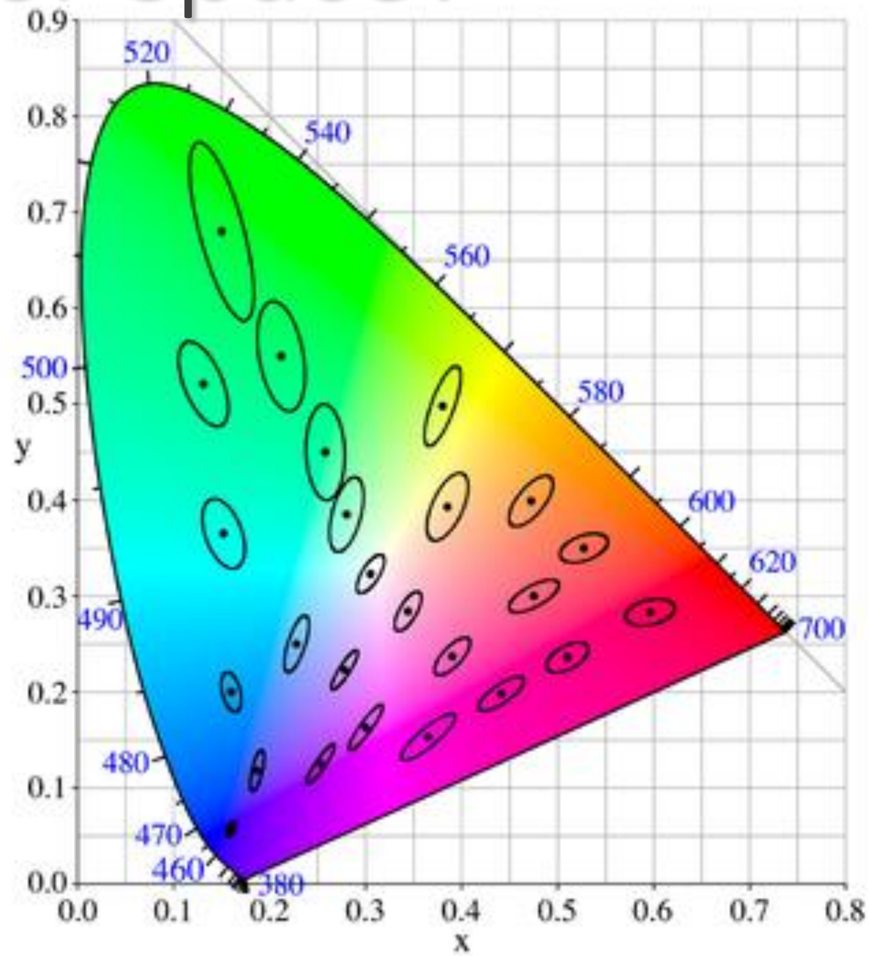


What about Color Space?

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

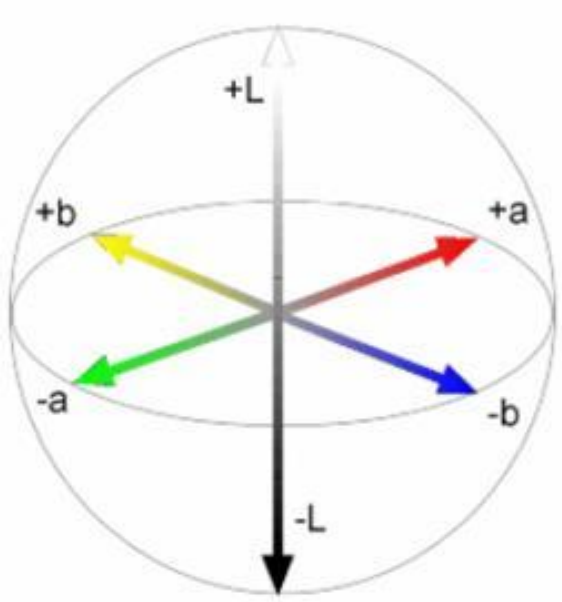


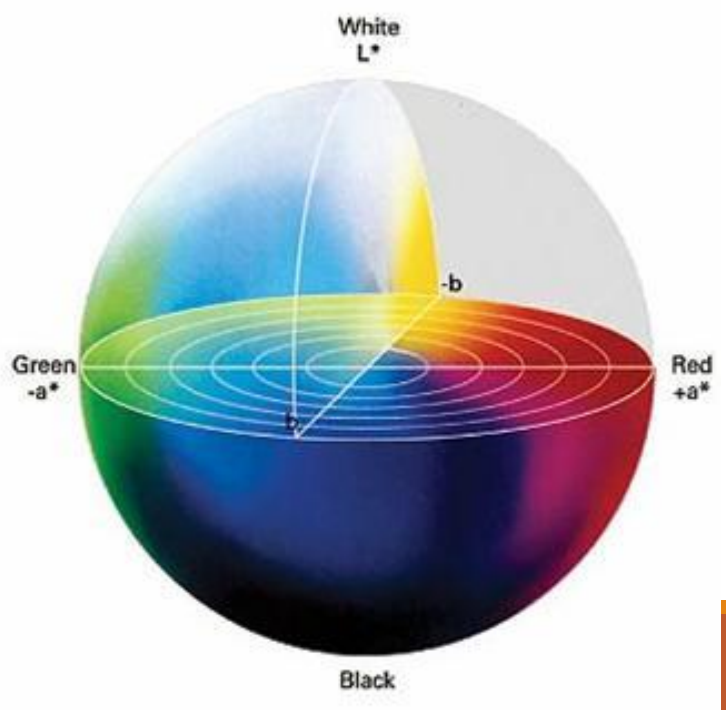
Perceptually Uniform Color Space

Most common: CIE-L*a*b* (CIELAB) color space.

L* represents luminance.

a* represents the difference between green and red, and b* represents the difference between yellow and blue.





Perceptually Uniform Color Space

XYZ to CIELAB conversion:

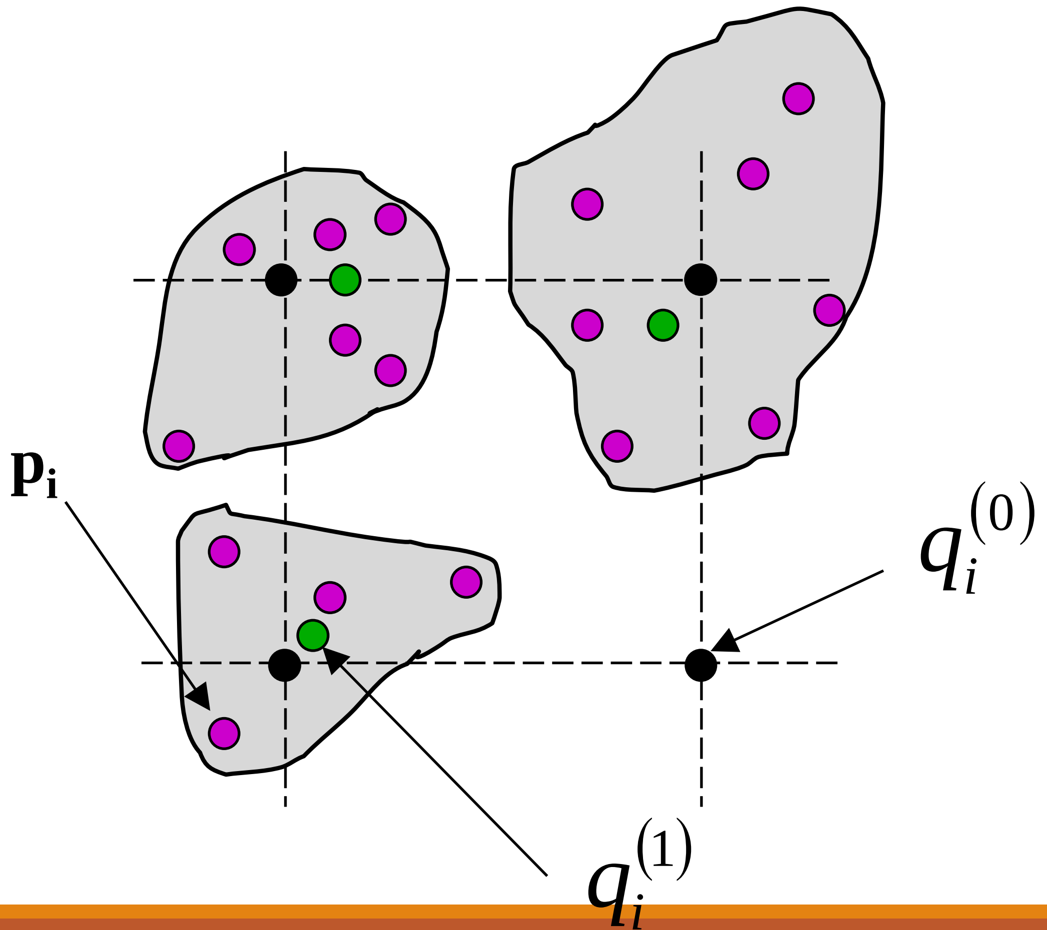
$$a^* = 500\left[\left(X/X_0\right)^{1/3} - \left(Y/Y_0\right)^{1/3}\right]$$

$$b^* = 200\left[\left(X/X_0\right)^{1/3} - \left(Z/Z_0\right)^{1/3}\right]$$

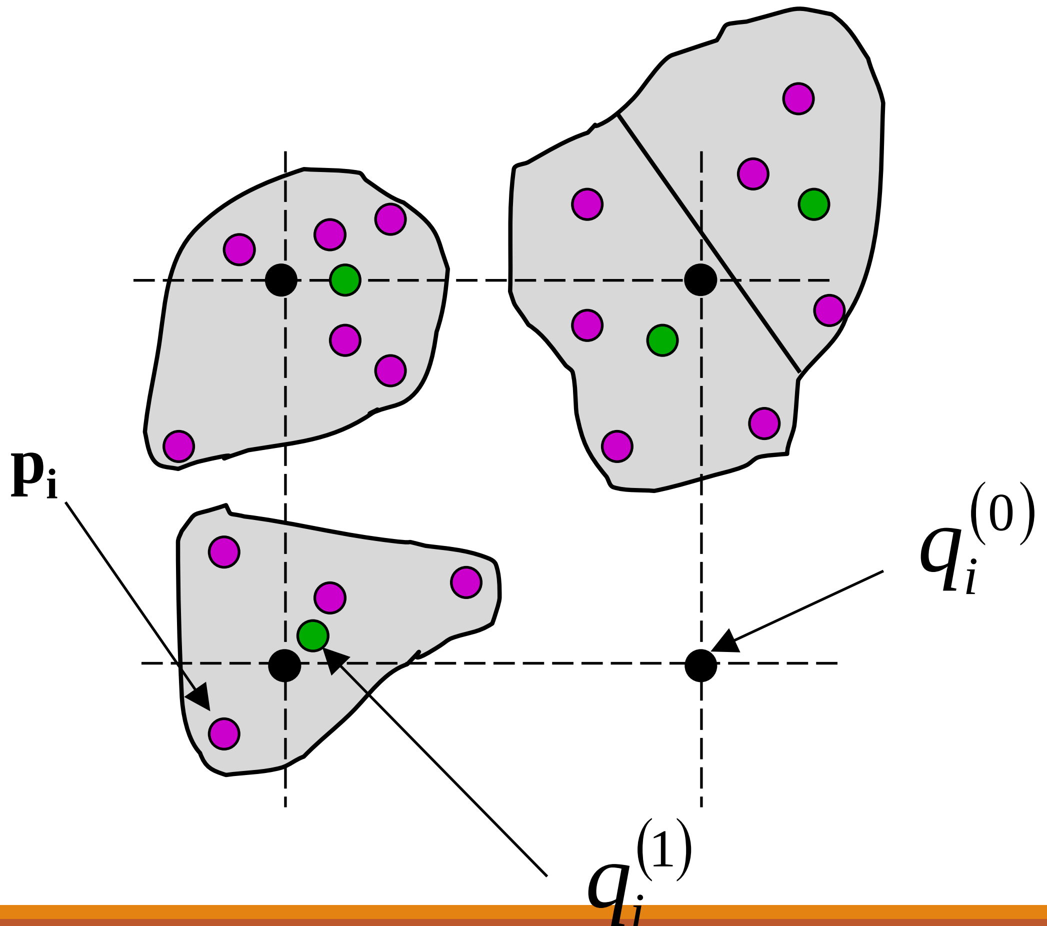
$$L^* = \begin{cases} 116\left(Y/Y_0\right)^{1/3} - 16 & for\, Y/Y_0 > 0.01 \\ 903\left(Y/Y_0\right) & otherwise \end{cases}$$

where (X_0, Y_0, Z_0) are the XYZ values of a reference white point

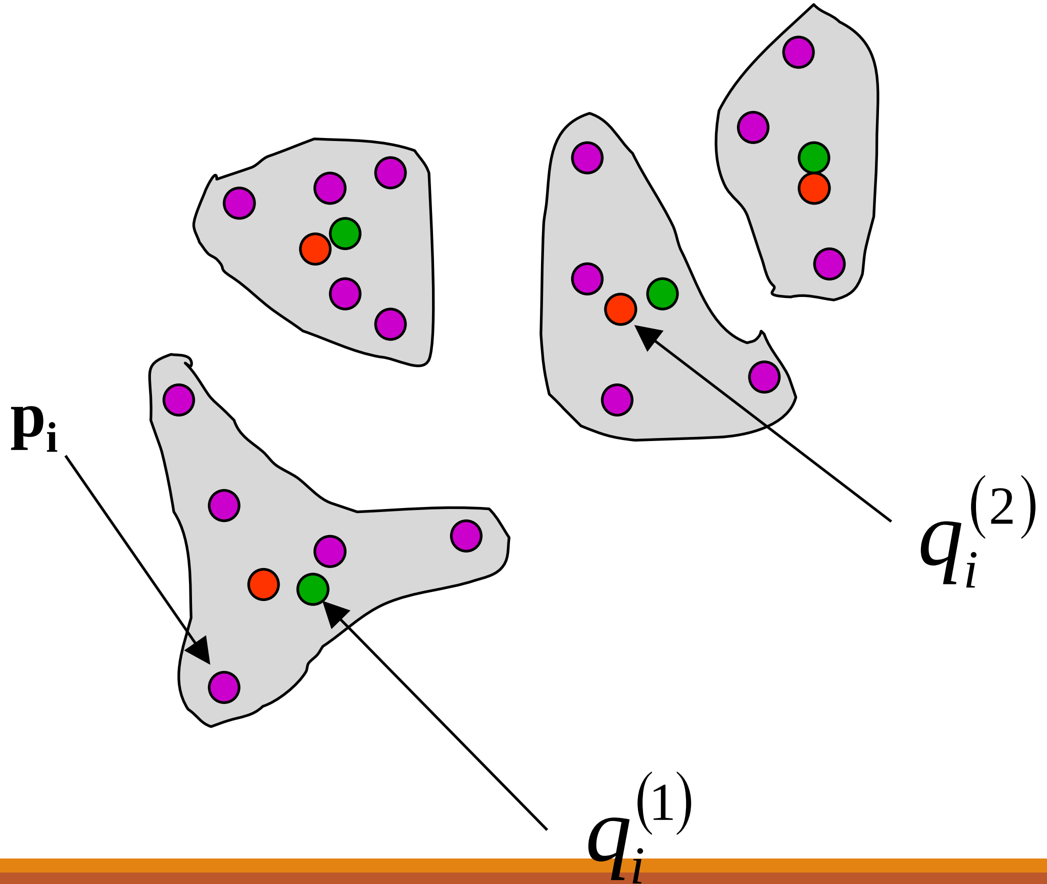
Generalized Lloyed Algorithm (GLA)



Generalized Lloyed Algorithm (GLA)



Generalized Lloyed Algorithm (GLA)



The GLA algorithms aims at minimizing the quantization error:

$$E = \sum_{i=1}^{K} \sum_{j \in C_i} \left(p_j - q_i\right)^2$$

Color_GLloyd(Image, K) {

  - Guess *K* cluster centre locations

  - Repeat until convergence {

    - For each data point finds out which centre it’s closest to

    - For each centre finds the centroid of the points it owns

    - Set a new set of cluster centre locations

    - optional: split clusters with high variance

  }

}

24 bit

More on Color Quantization

~~**Observation 1**: Distances and quantization errors measured in~~ RGB space, do not relate to human perception.

Solution: Apply quantization in perceptually uniform color space (such as CIELAB).

More on Color Quantization

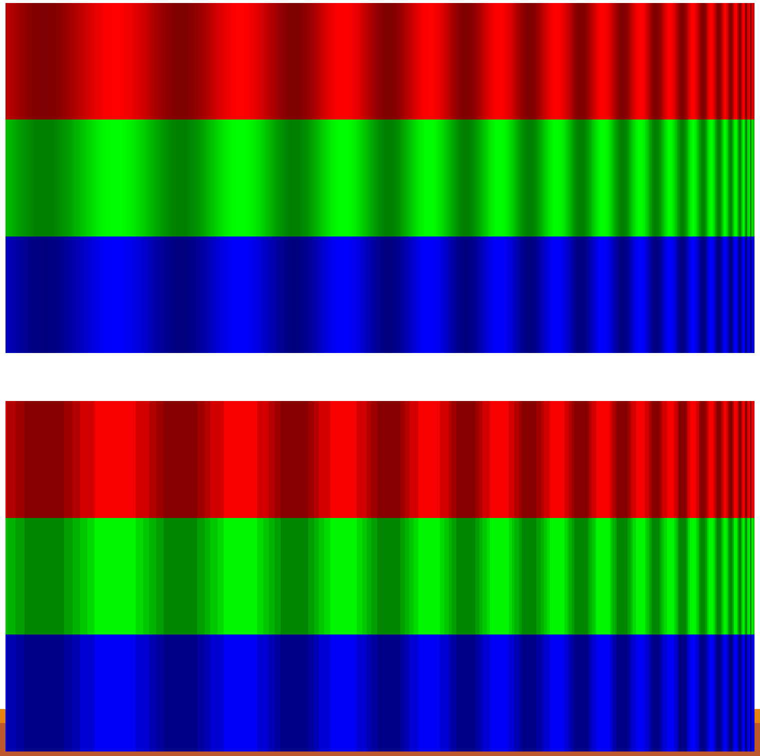
Original

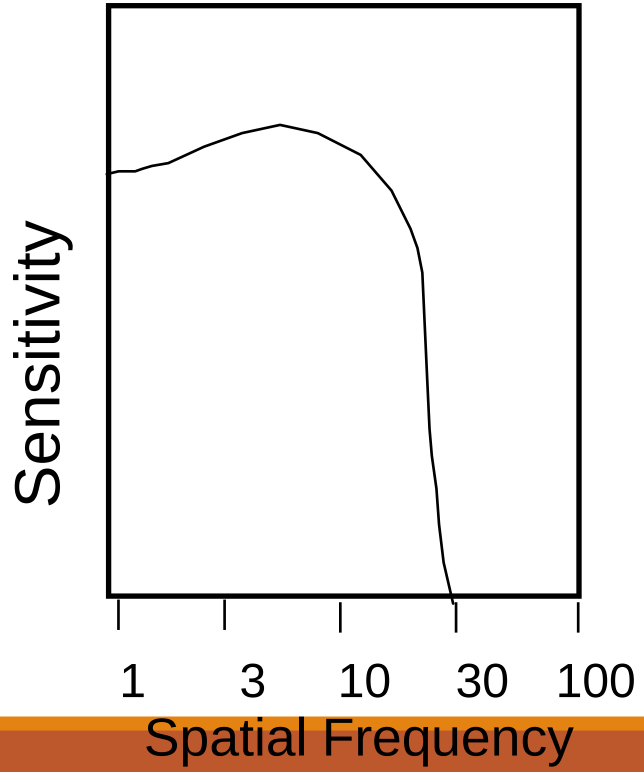
RGB Quantization

Lab Quantization

More on Color Quantization

Observation 2: Quantization errors are spatially dependent: we are more sensitive to errors at lower spatial frequencies.



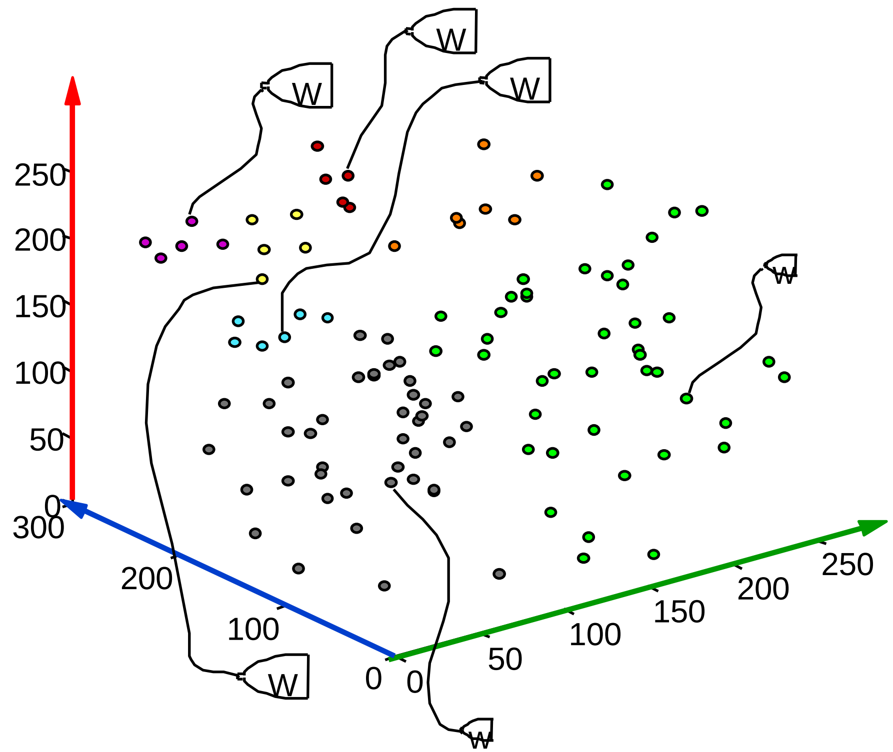


More on Color Quantization

Solution: Assign weight for each pixel color

Using this scheme we minimize:

$$E = \sum_{i=0}^{k-1} \sum_{j \in C_i} w_j \left(p_j - q_i\right)^2$$



Original

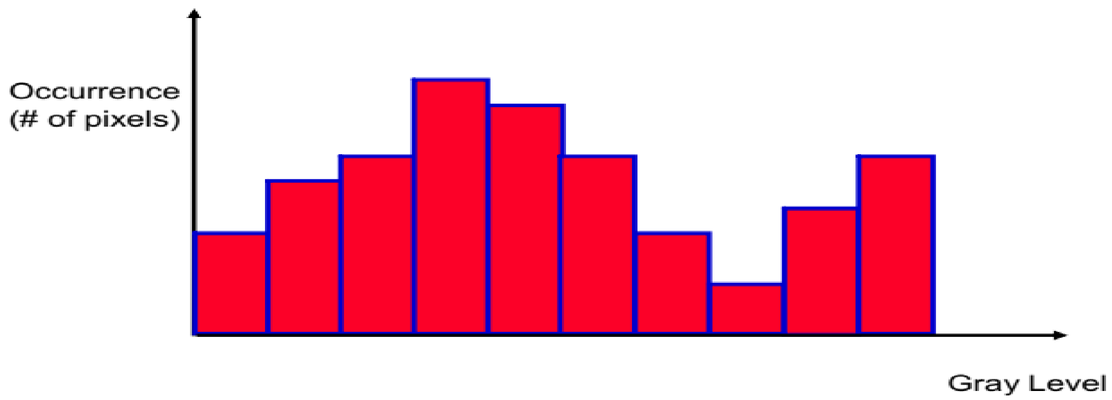
Standard quantization

Weighted quantization

Image Characteristic

- The contrast definition of the entire image is ambiguous.
- In general it is said that the image contrast is high if the image gray-levels fill the entire range.

Image Histogram



H(k) = #pixels with gray-level k

Normalized histogram:

$H_{norm}(k)=H(k)/N$

where N is the total number of pixels in the image.

THE END