Citra Digital, *Sampling*, dan *Quantization*

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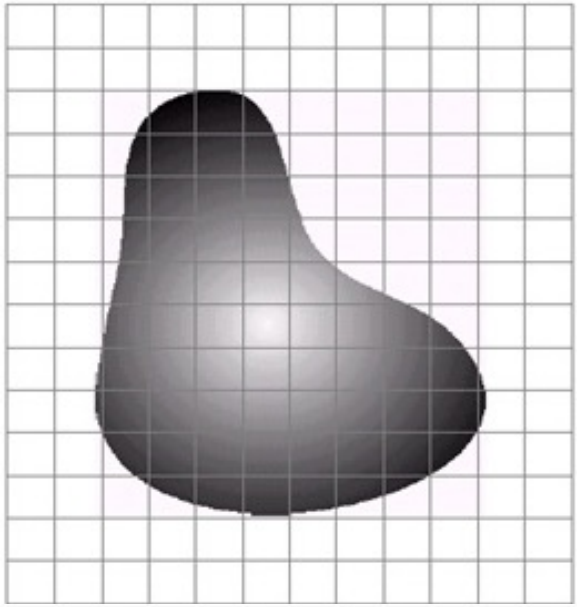
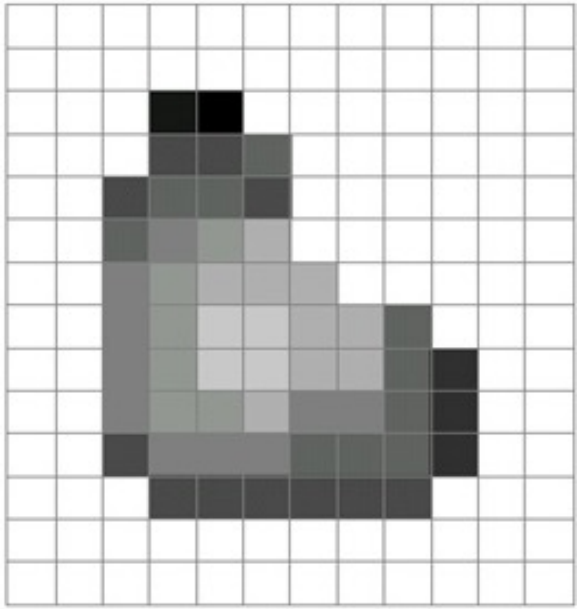




Inquiry :: [An inquiry is any process that has the aim of augmenting knowledge, resolving doubt, or solving a problem]

https://en.wikipedia.org/wiki/Inquiry

- **Apa itu citra digital ?**
- **Apa saja ruang lingkup bidang pengolahan citra digital ?**
- **Bagaimana sejarah dimulainya teknologi citra digital ?**
- **Bagaimana proses pembentukan citra digital ?**

img src:
https://www.123rf.com/

Apa itu citra digital ?

- Image/Citra :
  - fungsi dua dimensi *f(x,y)*
  - *x* dan *y* : koordinat spasial
  - *f* : nilai intensitas (*intensity*) atau derajat keabuan (*grey level*) dari citra pada posisi (x,y)
- Digital image/Citra digital :
  - nilai x, y, dan f : finit / kuantitas diskrit
  - sejumlah elemen yang terbatas, yang masing-masing memiliki lokasi dan nilai tertentu
  - *elements : picture elements, image elements, pels, and pixels*
- Digital image processing/Pengolahan citra digital :
  - Memproses/mengolah citra digital dengan menggunakan komputer digital

Image processing VS Image editing VS Computer graphics

- *Digital image editing :*
  - *sometimes referred to, digital imaging,*
  - *the manipulation of digital images using an existing software application such as Adobe Photoshop or Corel Paint*
- *Digital image processing :*
  - *the conception, design, development, and enhancement of digital imaging programs*
- *Computer graphics :*
  - *in contrast to digital image processing,*
  - *concentrates on the synthesis of digital images from geometrical descriptions such as three-dimensional (3D) object models*

Ruang lingkup pengolahan citra digital

- Vision : peran paling penting dalam sistem persepsi manusia
- Humans vision :
  - terbatas pada pita visual (*band*) dari spektrum gelombang elektromagnetik (EM)
- Imaging machines :
  - mencakup hampir seluruh spektrum EM, mulai dari sinar gamma hingga gelombang radio
- Mereka dapat beroperasi pada gambar yang dihasilkan oleh sumber yang tidak biasa dikaitkan dengan gambar oleh manusia. Ini termasuk ultrasound, mikroskop elektron, dan gambar yang dihasilkan komputer
- Pengolahan citra digital mencakup bidang aplikasi yang luas dan beragam
- Pengolahan citra digital digunakan dengan sukses di berbagai bidang dengan nilai sosial dan ekonomi yang luar biasa

Ruang lingkup pengolahan citra digital

- Saat lingkup pengolahan citra digital berakhir maka lingkup area lainnya, seperti image analysis dan computer vision dimulai
- Bagaimana mendefinisikan image processing ?
  - sebagai bidang kajian di mana input dan output dari prosesnya adalah citra digital ?
- Computer vision and AI :
  - Area image analysis (disebut juga image understanding) berada diantara image processing dan computer vision
- tidak ada batasan yang jelas dalam rangkaian dari pengolahan citra digital di satu ujung hingga computer vision di ujung lainnya

Paradigma

- Tiga jenis proses komputerisasi :
  - Low level :
    - Operasi-operasi primitif seperti image preprocessing untuk mengurangi noise, contrast enhancement, dan image sharpening
    - Input dan outputnya adalah citra digital
  - Mid level :
    - Meliputi task-task seperti segmentation (membagi sebuah citra digital menjadi area-area atau objek-objek), deskripsi objek-objek itu untuk menguranginya menjadi bentuk yang cocok untuk pemrosesan komputer, dan classification (recognition) dari objek-objek individual
    - Secara umum inputnya adalah citra digital, tetapi outputnya adalah atribut-atribut yang diekstrak dari citra digital tersebut (misalnya, edges, contours, dan identitas individual dari objek-objek).
  - High level
    - Meliputi “making sense” dari sekumpulan objek yang sudah dikenali, seperti pada image analysis, hingga di akhir task melakukan cognitive functions yang secara umum diasosiasikan dengan vision

Sejarah Pengolahan Citra Digital

- Industri surat kabar :
  - Gambar dikirim melalui kabel bawah laut antara London dan New York
- Bartlane cable picture transmission system :
  - Awal tahun 1920s
  - Mengurangi waktu pengiriman gambar menyeberangi Atlantik dari lebih dari satu minggu menjadi kurang dari tiga jam
- Specialized printing equipment :
  - Mengkodekan gambar untuk cable transmission dan menkonstruksinya kembali di titi penerima

Sejarah Pengolahan Citra Digital

- A digital picture produced in 1921 from a coded tape by a telegraph printer with special type faces.

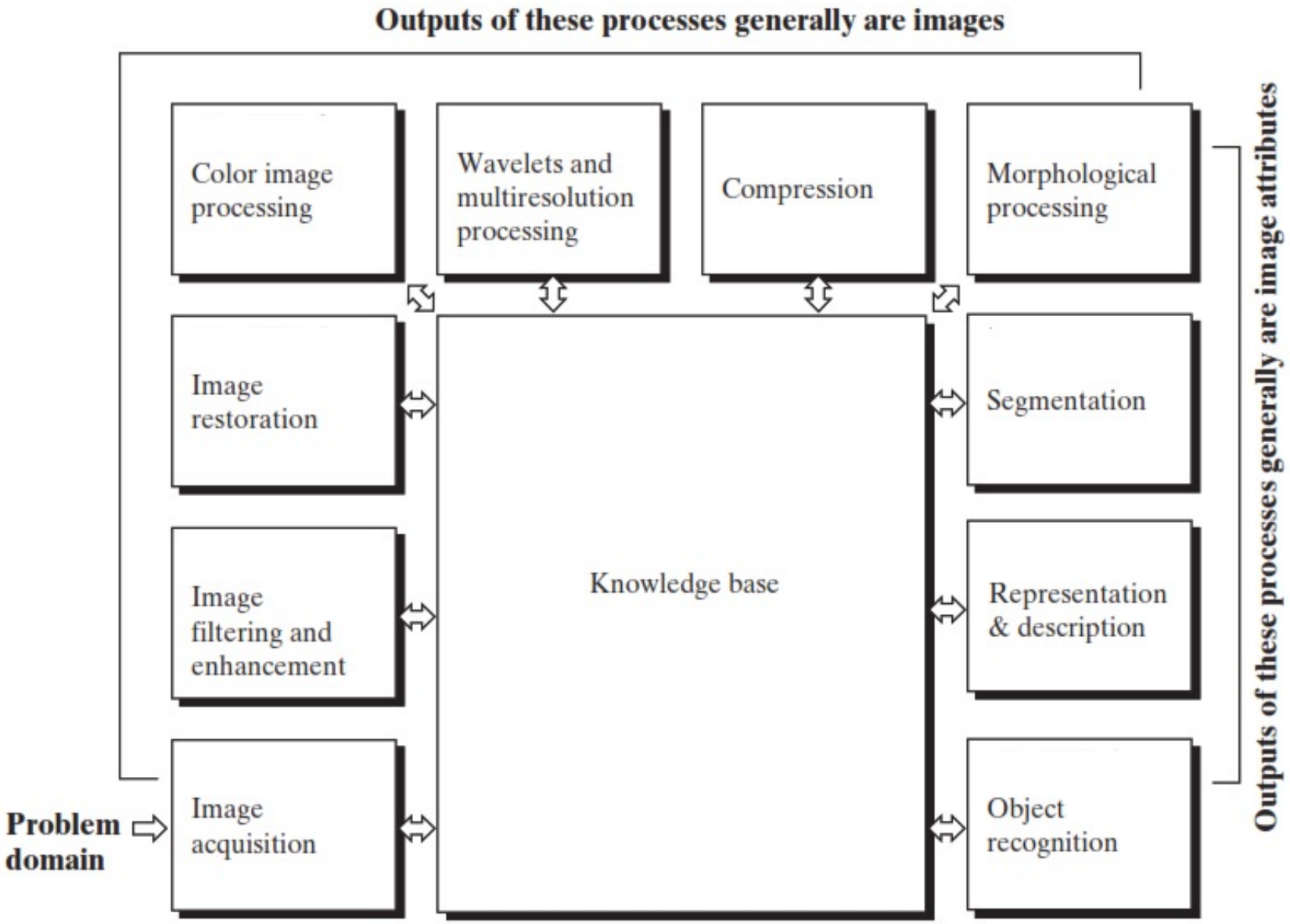
Sejarah Pengolahan Citra Digital

- The early Bartlane systems :
  - coding images dalam 5 levels of gray.
  - Naik menjadi 15 levels in 1929
- Unretouched cable picture of Generals Pershing and Foch, transmitted in 1929 from London to New York by 15-tone equipment.

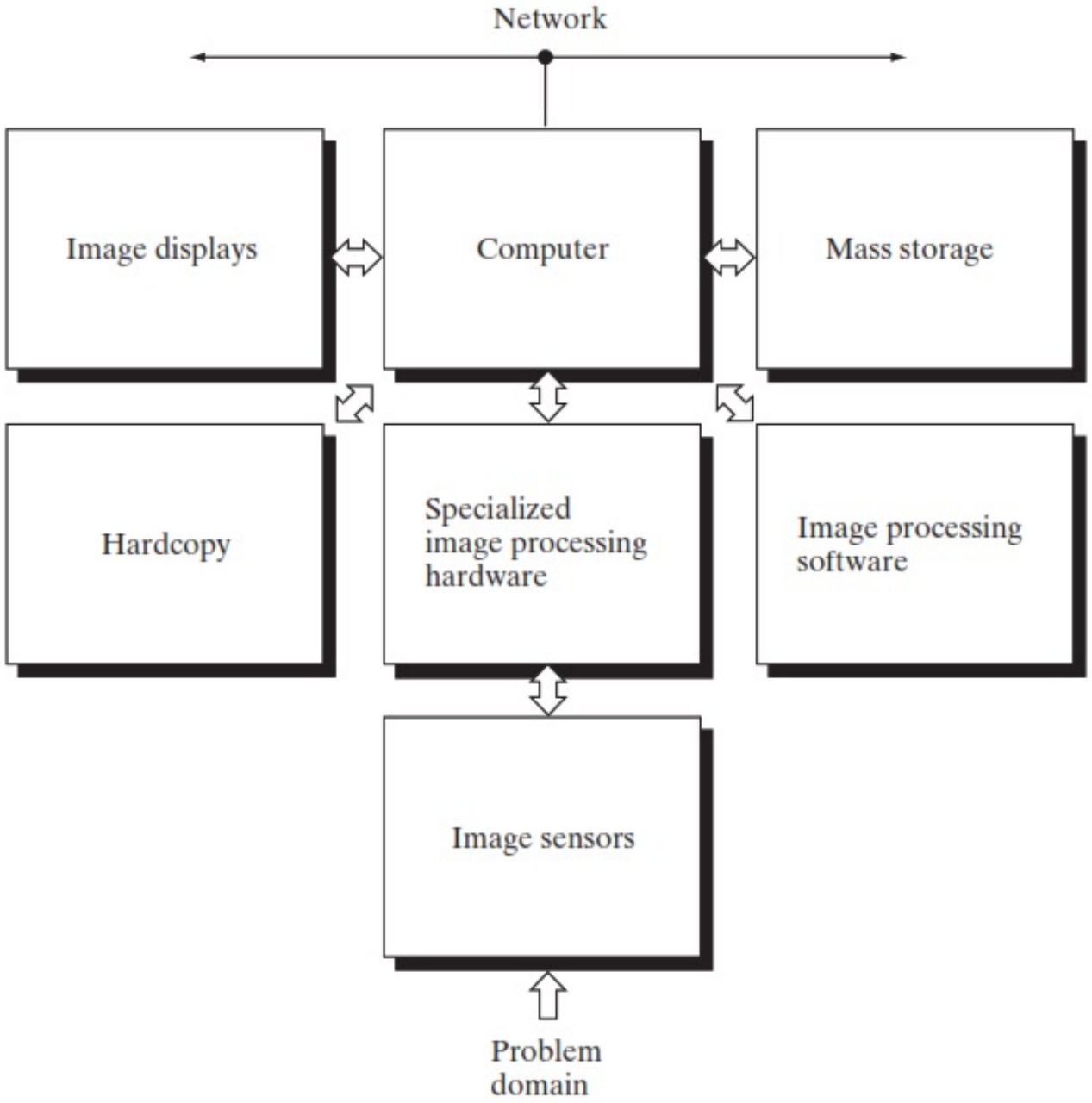
Sejarah Pengolahan Citra Digital

- NOTE :
  - Melibatkan citra digital tetapi tidak dianggap sebagai hasil pemrosesan citra digital dalam konteks definisi karena komputer tidak terlibat dalam pembuatannya
- Dengan demikian, sejarah pengolahan citra digital terkait erat dengan perkembangan komputer digital
- Faktanya :
  - citra digital membutuhkan begitu banyak penyimpanan dan daya komputasi sehingga kemajuan di bidang pemrosesan citra digital bergantung pada perkembangan komputer digital dan teknologi pendukung yang mencakup penyimpanan data, tampilan, dan transmisi

Fundamental Steps in Digital Image Processing



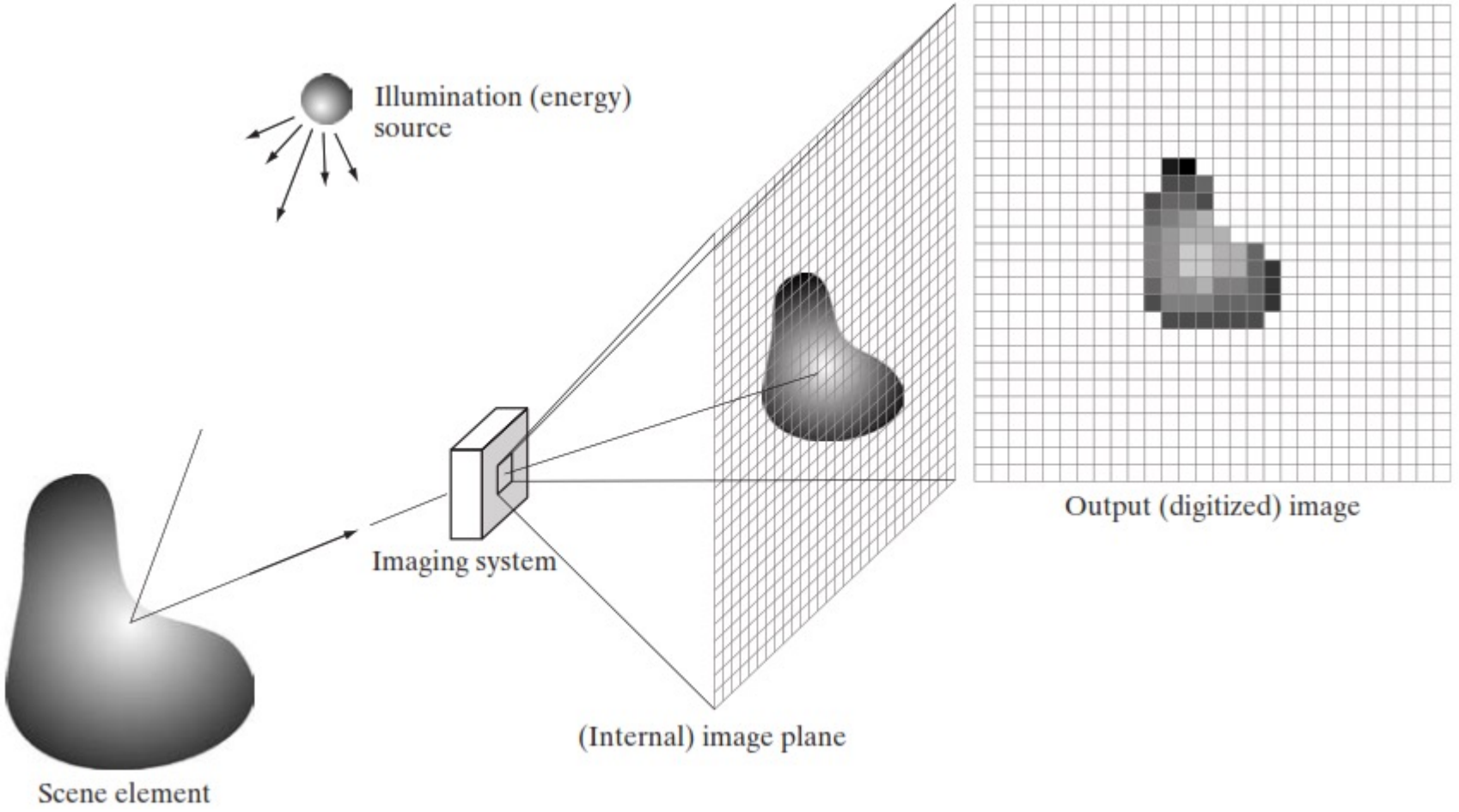
Komponen Sistem Pengolahan Citra Digital



Komponen Sistem Pengolahan Citra Digital

- Sensing, dua elemen diperlukan untuk memperoleh citra digital :
  - Perangkat fisik yang peka terhadap energi yang dipancarkan oleh objek yang ingin kita gambar
  - A digitizer : perangkat untuk mengubah output dari perangkat penginderaan fisik menjadi bentuk digital
- Contoh, pada video camera digital :
  - Sensors : menghasilkan keluaran listrik sebanding dengan intensitas cahaya
  - Digitizer : mengubah output ini menjadi data digital

A Simple Image Formation Model



A Simple Image Formation Model

- Nilai atau amplitudo dari fungsi *f* pada koordinat spasial (x,y) :
  - besaran skalar positif
  - physical meaning : ditentukan oleh sumber gambar
  - ketika gambar dihasilkan dari proses fisik, nilai intensitasnya sebanding dengan energi yang dipancarkan oleh sumber fisik (contoh, gelombang elektromagnetik)
- Fungsi *f* dapat dicirikan oleh dua komponen :
  - jumlah sumber yang menerangi objek di scene tempat objek yang sedang dilihat
  - jumlah iluminasi yang dipantulkan oleh objek dalam scene tersebut
  - Dua komponen ini disebut dengan : the illumination and reflectance components : i(x,y) dan r(x,y)

A Simple Image Formation Model

- Kedua fungsi bergabung sebagai dot product untuk membentuk
  - $f(x,y) = i(x,y)\, r(x,y)$
  - $0 < i(x,y) <$ *tak hingga*
  - $0 < r(x,y) < 1$
- Reflectance :
  - bounded by 0 (total absorption) and 1 (total reflectance).
- i(x,y) ditentukan oleh sumber iluminasi
- r(x,y) ditentukan oleh karakteristik objek yang dicitrakan
- Note :
  - model ini juga berlaku untuk citra yang terbentuk melalui transmisi iluminasi melalui media, seperti rontgen dada.
  - Dalam hal ini : fungsi *transmissivity* menggantikan fungsi *reflectivity*

Contoh tingkat illumination dan reflectance

- Illuminance :
  - Matahari :
    - Hari cerah : 90.000 lm/m2 di permukaan bumi
    - Hari berawan : 10.000 lm/m2
  - Saat malam cerah : bulan purnama : 0,1 lm/m2

- Reflectance :
  - Black velvet : 0,01
  - Stainless steel : 0,65
  - Flat-white wall paint : 0.80
  - Silver-plated metal : 0.90
  - Snow : 0.93

Gray (or intensity) scale

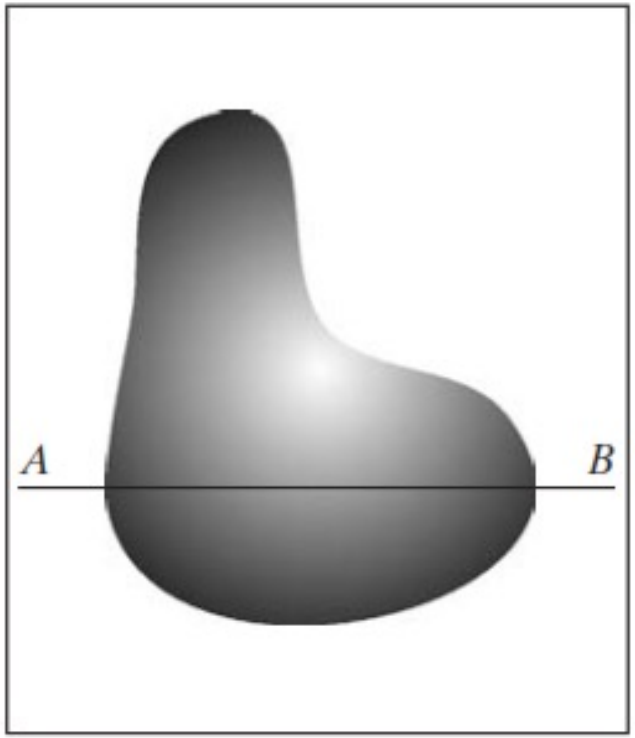
- Intensity (gray level) of a monochrome image at any coordinates (x_0,y_0) : $l = f(x_0,y_0)$
  - l lies in the range : $L_{min} <= l <= L_{max}$
  - L_{min} : positif, L_{max} : finite
  - $L_{min} = i_{min}\ r_{min}$
  - $L_{max} = i_{max}\ r_{max}$
- Interval $[L_{min},L_{max}]$: gray (or intensity) scale
- In practice : shift into the interval [0,L-1]
  - l = 0 : black
  - l = L-1 : white
  - All intermediate values : shades of gray from black to white

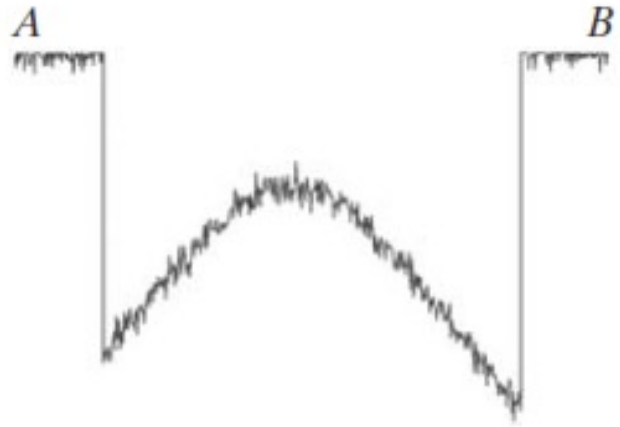
Konsep Dasar *Sampling* dan *Quantization*

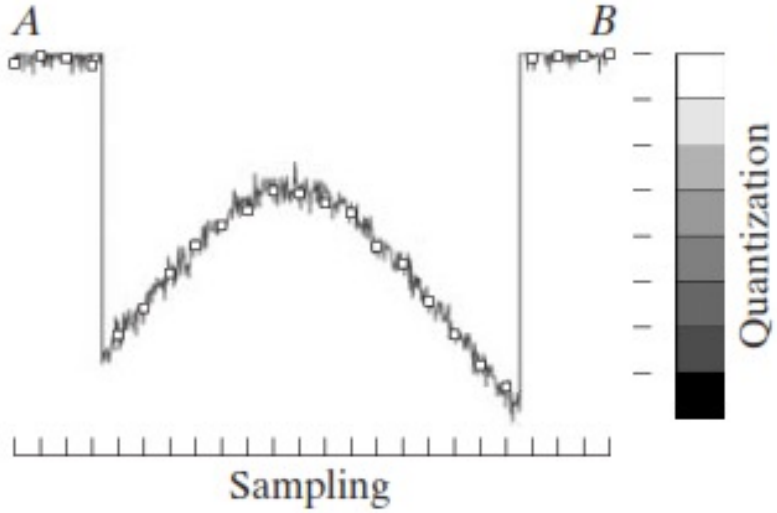
- Citra Natural : continuous
  - the x- and y-coordinates
  - in amplitude
- To convert it to digital form :
  - sample the function in both coordinates and in amplitude
  - Digitizing the coordinate values is called sampling
  - Digitizing the amplitude values is called quantization
- Selain jumlah level diskrit yang digunakan, akurasi yang dicapai dalam kuantisasi sangat bergantung pada kandungan noise dari sinyal sampel
- Kualitas citra digital ditentukan sebagian besar oleh jumlah sampel dan tingkat intensitas diskrit yang digunakan dalam pengambilan sampel dan kuantisasi.

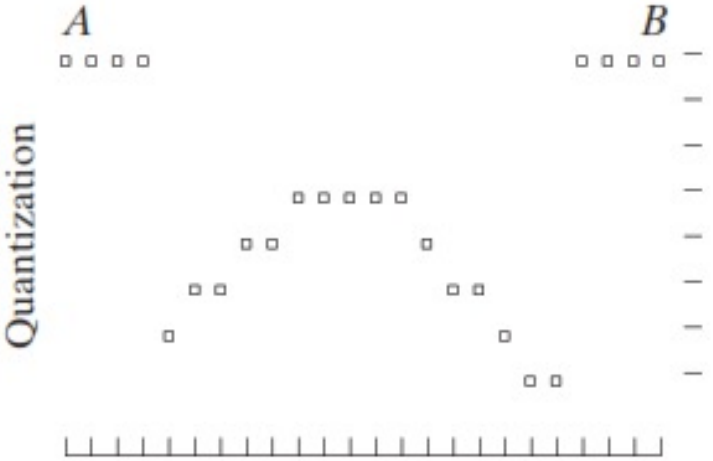
Konsep Dasar *Sampling* dan *Quantization*

- Perhatikan contoh :
- Fungsi 1 dimensi : plot amplitudo segment garis AB
- Random variations = image noise
- Spatial sample : vertical tick mark
- Intensity scale : 8 level diskrit
- 2 dimensi : line by line procedure

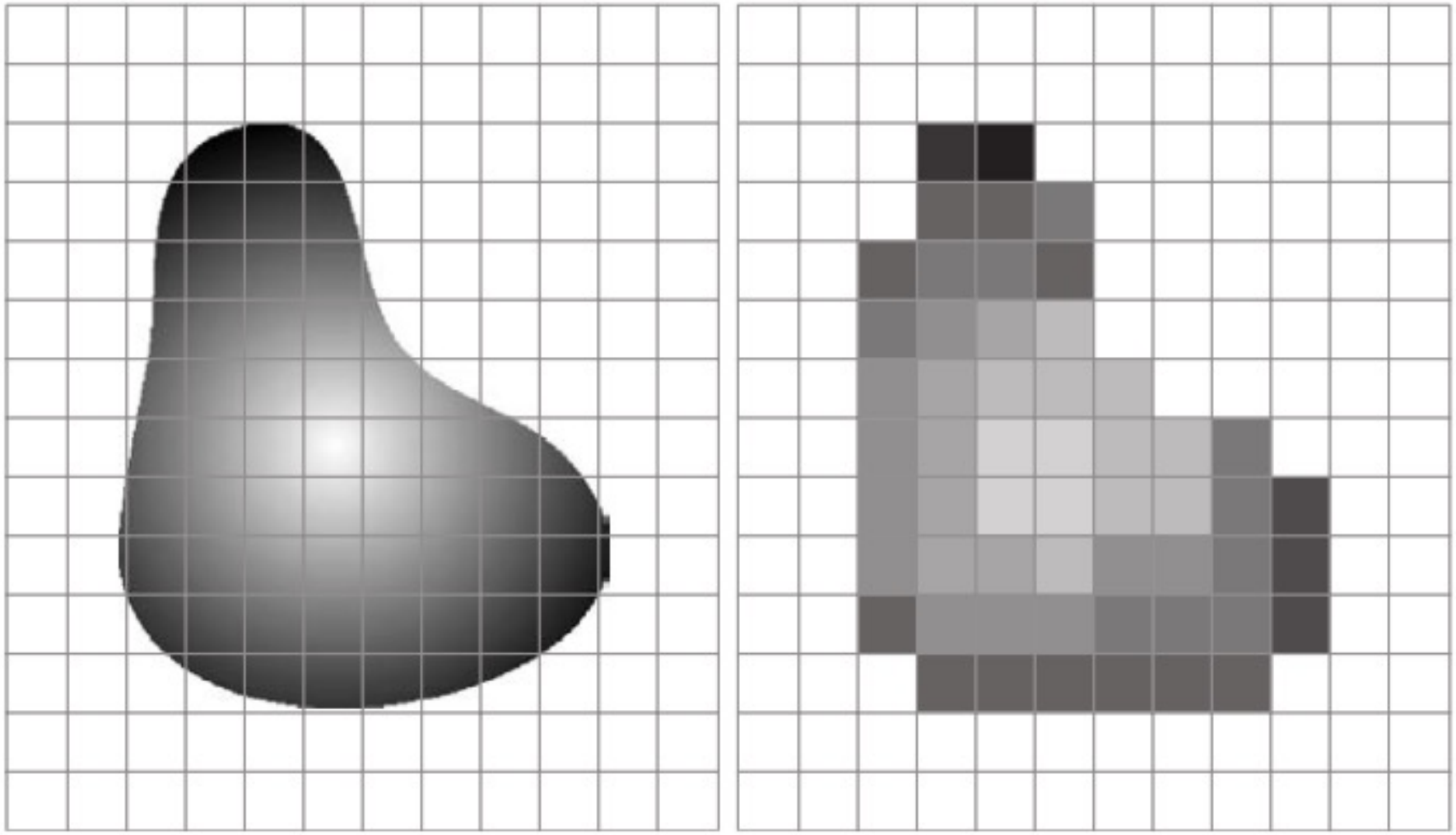








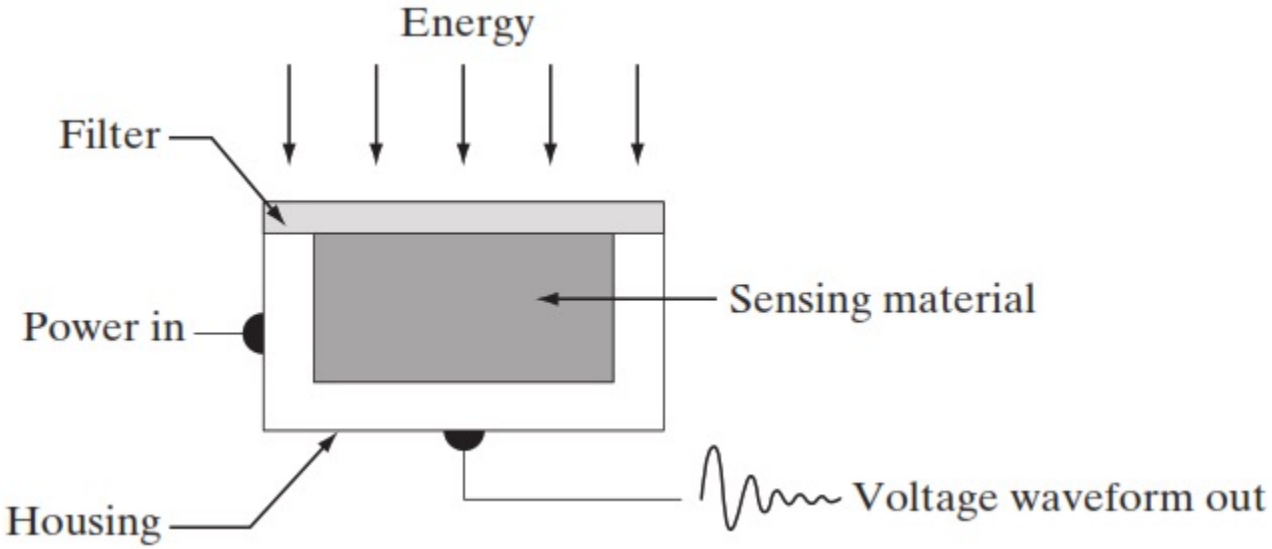
Konsep Dasar *Sampling* dan *Quantization*

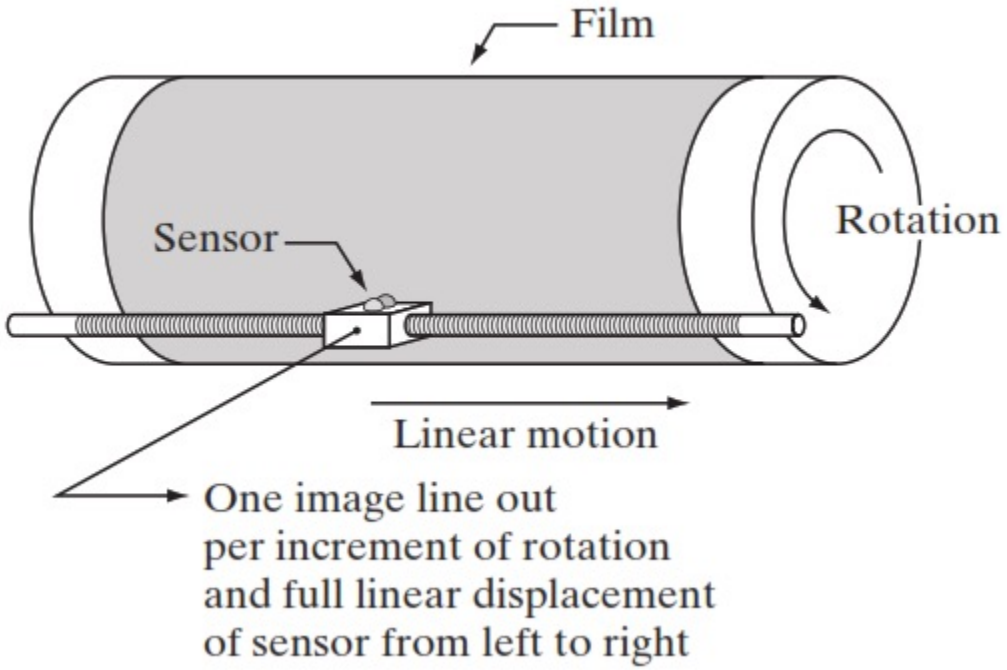


Sensor arrangement

- A single sensing element combined with mechanical motion
  - the output of the sensor is quantized in the manner described above.
  - However, spatial sampling is accomplished by selecting the number of individual mechanical increments at which we activate the sensor to collect data.
  - Mechanical motion can be made very exact so, in principle, there is almost no limit as to how fine we can sample an image using this approach.
  - In practice, limits on sampling accuracy are determined by other factors, such as the quality of the optical components of the system.

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





Sensor arrangement

- A sensing strip
  - the number of sensors in the strip establishes the sampling limitations in one image direction
  - Mechanical motion in the other direction can be controlled more accurately, but it makes little sense to try to achieve sampling density in one direction that exceeds the sampling limits established by the number of sensors in the other.
  - Quantization of the sensor outputs completes the process of generating a digital image.

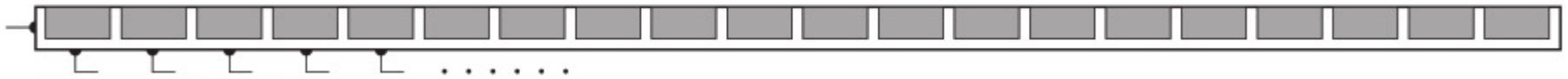
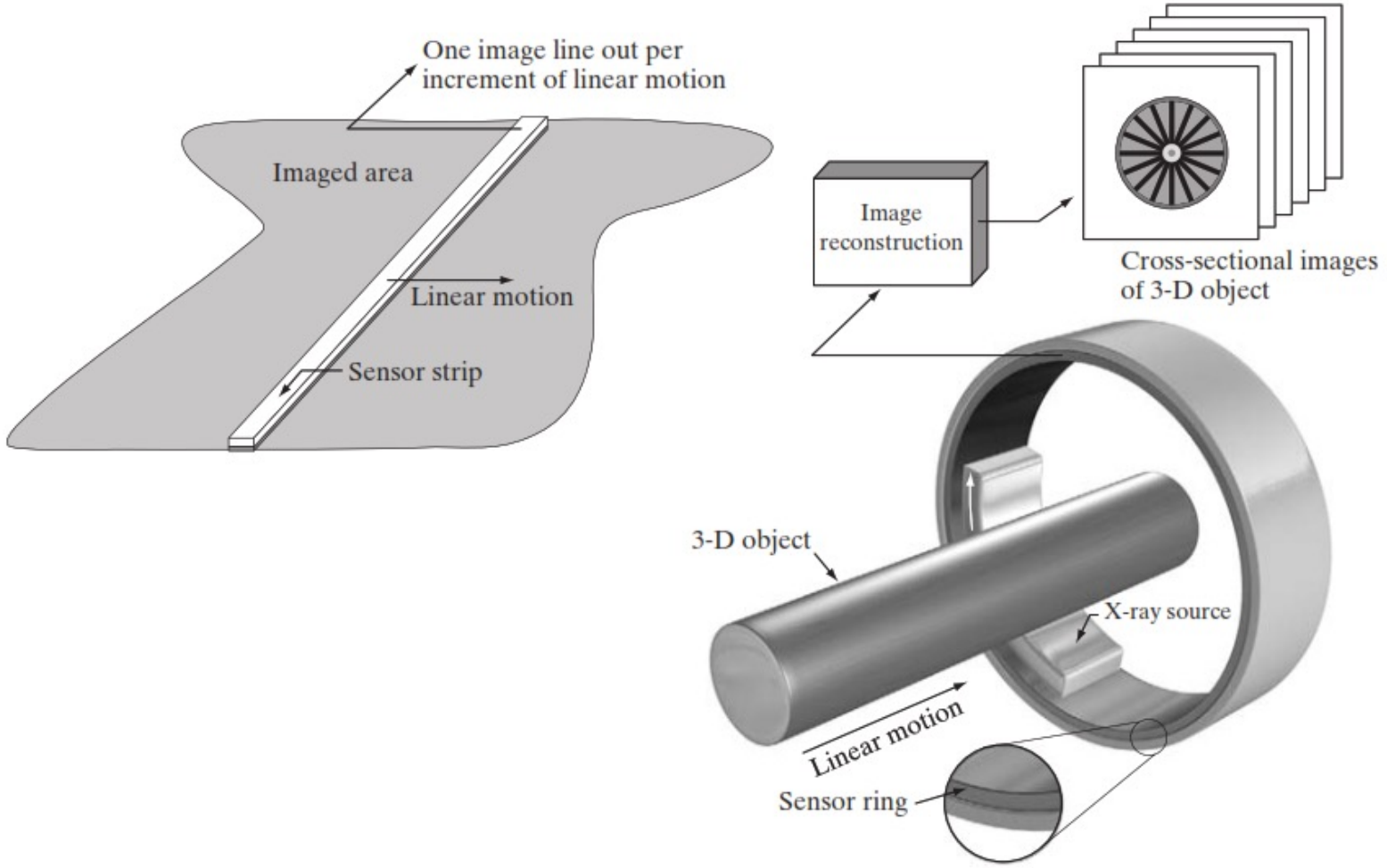
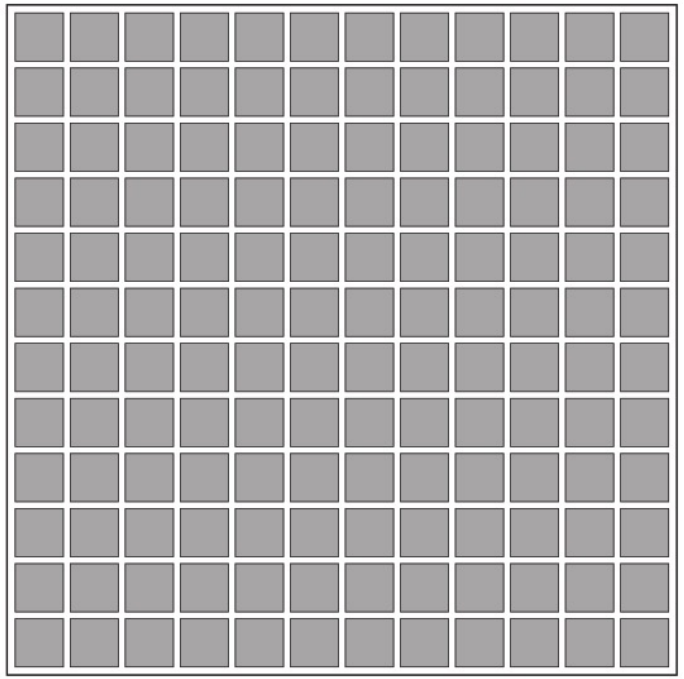


Image acquisition using a linear sensor strip and using a circular sensor strip

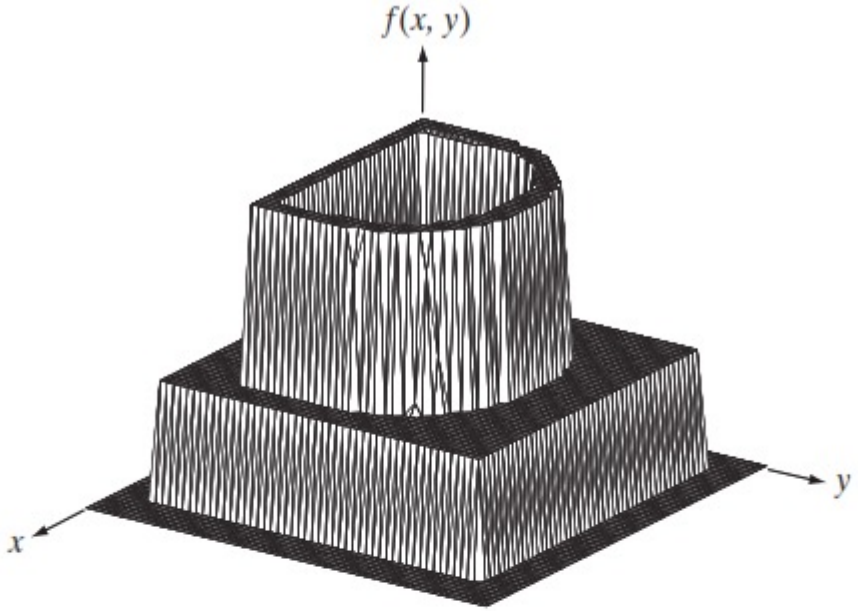


Sensor arrangement

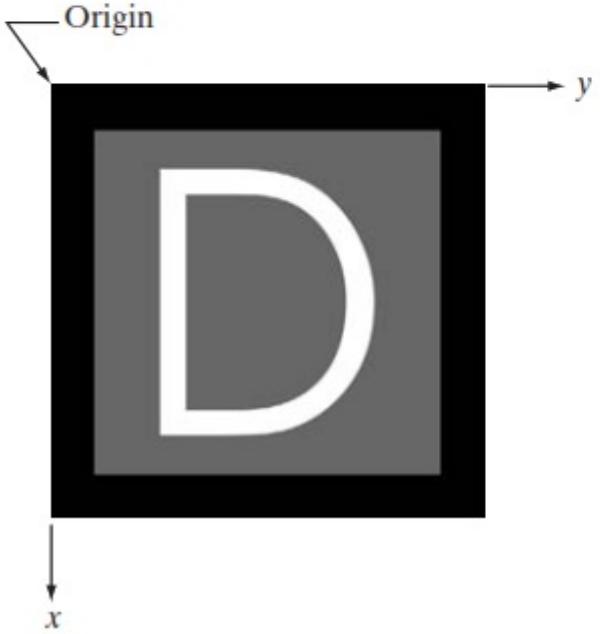
- A sensing array
  - there is no motion and the number of sensors in the array establishes the limits of sampling in both directions.
  - Quantization of the sensor outputs is as before.



Representing Digital Images



$$f(x, y) = \begin{bmatrix} f(0,0) & f(0,1) & \cdots & f(0, N-1) \\ f(1,0) & f(1,1) & \cdots & f(1, N-1) \\ \vdots & \vdots & & \vdots \\ f(M-1,0) & f(M-1,1) & \cdots & f(M-1, N-1) \end{bmatrix}$$



Representing Digital Images

- Digitization process : values for M, N, and for the number, L, of discrete intensity levels
- M and N : positive integers
- However, due to storage and quantizing hardware considerations :
  - $L = 2^k$
- Discrete levels :
  - equally spaced
  - integers in the interval [0,L-1]
- b : number of bits required to store a digitized image
  - $b = M \times N \times k$
- image as a “k-bit image.”
- Contoh :
  - Citra dengan 256 possible discrete intensity values : citra 8-bit

k-bit image

Number of storage bits for various values of N and k. L is the number of intensity levels.

N/k	1 ($L = 2$)	2 ($L = 4$)	3 ($L = 8$)	4 ($L = 16$)	5 ($L = 32$)	6 ($L = 64$)	7 ($L = 128$)	8 ($L = 256$)
32	1,024	2,048	3,072	4,096	5,120	6,144	7,168	8,192
64	4,096	8,192	12,288	16,384	20,480	24,576	28,672	32,768
128	16,384	32,768	49,152	65,536	81,920	98,304	114,688	131,072
256	65,536	131,072	196,608	262,144	327,680	393,216	458,752	524,288
512	262,144	524,288	786,432	1,048,576	1,310,720	1,572,864	1,835,008	2,097,152
1024	1,048,576	2,097,152	3,145,728	4,194,304	5,242,880	6,291,456	7,340,032	8,388,608
2048	4,194,304	8,388,608	12,582,912	16,777,216	20,971,520	25,165,824	29,369,128	33,554,432
4096	16,777,216	33,554,432	50,331,648	67,108,864	83,886,080	100,663,296	117,440,512	134,217,728
8192	67,108,864	134,217,728	201,326,592	268,435,456	335,544,320	402,653,184	469,762,048	536,870,912

Spatial Resolution

- Secara intuitif :
  - resolusi spasial adalah ukuran detail terkecil yang dapat dilihat dalam sebuah citra
- Secara kuantitatif :
  - resolusi spasial dapat dinyatakan dalam beberapa cara
    - dengan pasangan garis per satuan jarak
    - dengan titik (piksel) per satuan jarak
- Resolusi intensitas juga mengacu pada perubahan terkecil yang terlihat dalam tingkat intensitas

Contoh : Spatial and Intensity Resolution

- A chart with alternating black and white vertical lines
- each of width W units (W can be less than 1).
- The width of a line pair is thus 2W,
- there are 1/2W line pairs per unit distance.
- For example, if the width of a line is 0.1 mm, there are 5 line pairs per unit distance (mm).
- A widely used definition of image resolution is the largest number of discernible line pairs per unit distance (e.g., 100 line pairs per mm).
- Dots per unit distance is a measure of image resolution used commonly in the printing and publishing industry.
- In the U.S., this measure usually is expressed as dots per inch (dpi).
- To give you an idea of quality, newspapers are printed with a resolution of 75 dpi, magazines at 133 dpi, glossy brochures at 175 dpi, and the book page at which you are presently looking is printed at 2400 dpi.

Note : Spatial and Intensity Resolution

- to be meaningful, measures of spatial resolution must be stated with respect to spatial units.
- Image size by itself does not tell the complete story.
- To say that an image has, say, a resolution 1024 * 1024 pixels is not a meaningful statement without stating the spatial dimensions encompassed by the image.
- Size by itself is helpful only in making comparisons between imaging capabilities.
- For example, a digital camera with a 20-megapixel CCD imaging chip can be expected to have a higher capability to resolve detail than an 8-megapixel camera, assuming that both cameras are equipped with comparable lenses and the comparison images are taken at the same distance.

Intensity Resolution

- Intensity resolution similarly refers to the smallest discernible change in intensity level
- Based on hardware considerations, the number of intensity levels usually is an integer power of two
- The most common number is 8 bits, with 16 bits being used in some applications in which enhancement of specific intensity ranges is necessary. Intensity quantization using 32 bits is rare. Sometimes one finds systems that can digitize the intensity levels of an image using 10 or 12 bits, but these are the exception, rather than the rule

Contoh : Intensity Resolution

- Unlike spatial resolution, which must be based on a per unit of distance basis to be meaningful, it is common practice to refer to the number of bits used to quantize intensity as the intensity resolution. For example, it is common to say that an image whose intensity is quantized into 256 levels has 8 bits of intensity resolution.
- Because true discernible changes in intensity are influenced not only by noise and saturation values but also by the capabilities of human perception