Image Digitalization

Content

- Digital image representation
- Sampling
  - Spatial resolution
  - Interpolation
- Quantization
  - Intensity resolution
  - Dithering

Analog to digital

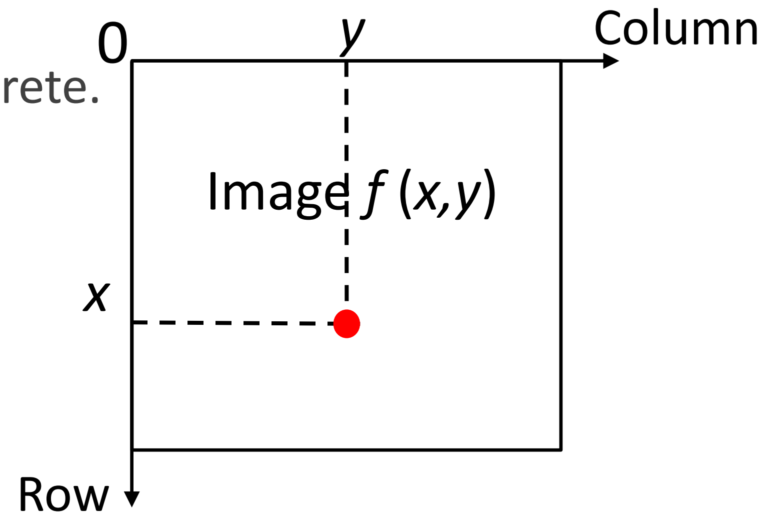
Colour in the real world and how human perceive it → Input of colour images to PC via scanner or camera → Conversion to digital rep. for storage, transmission, display & printing

Image

A monochrome image can be represented as

- a **2-dimensional** function $f(x,y)$.
- where x and y are spatial coordinates and the amplitude of f at any pair of coordinates (x,y) is called the intensity or grey level of the image at that point (x,y).

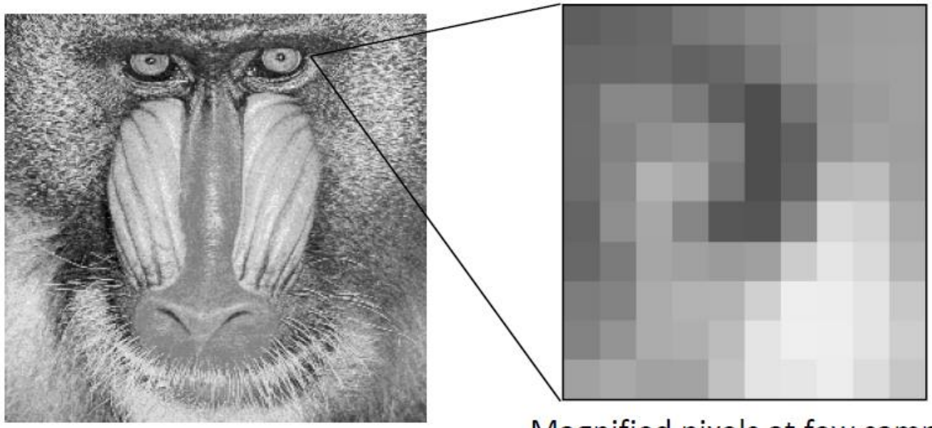
Digital image - f, x and y are all finite, discrete.



Digital monochrome image

Pixel - the basic unit of a digital image

10x10 pixel



Magnified pixels at few sampling positions

94	100	104	119	125	136	143	153	157	158
103	104	106	98	103	119	141	155	159	160
109	136	136	123	95	78	117	149	155	160
110	130	144	149	129	78	97	151	161	158
109	137	178	167	119	78	101	185	188	161
100	143	167	134	87	85	134	216	209	172
104	123	166	161	155	160	205	229	218	181
125	131	172	179	180	208	238	237	228	200
131	148	172	175	188	228	239	238	228	206
161	169	162	163	193	228	230	237	220	199

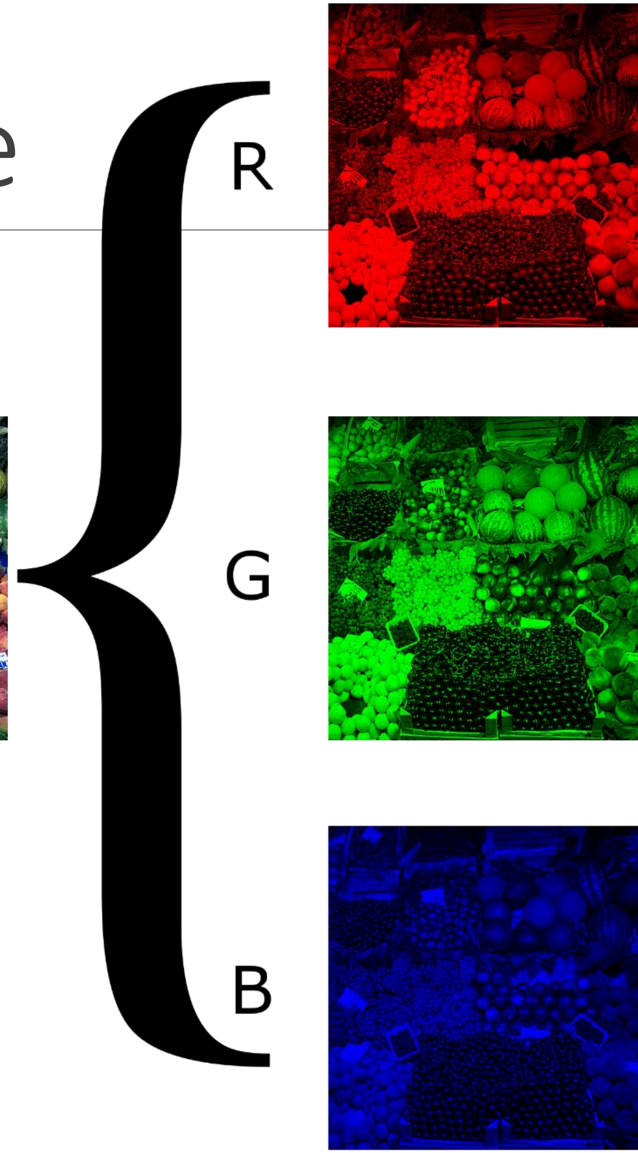
Corresponding array

Digital colour image

A colour image can be represented with its three components.

Each component represented as a monochrome image.

- -e.g. in RGB colour system, a colour image consists of three individual R G B component image.



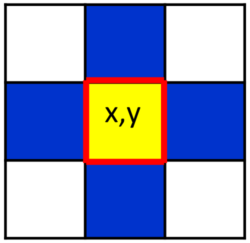
Relationship between pixels

Depending on the neighbourhood definition, a pixel has 4 or 8 neighbours

– 4-neihgborhood:

(x-1, y), (x,y-1), (x,y+1),(x+1,y)

each neighbour shares *a single edge* with the pixel.



– 8-neighbourhood:

(x-1, y), (x,y-1), (x,y+1),(x+1,y)

(x-1,y-1), (x-1 y+1), (x+1,y-1),(x+1,y+1)

each neighbour shares *an edge or a corner* with the pixel.

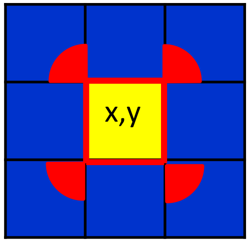


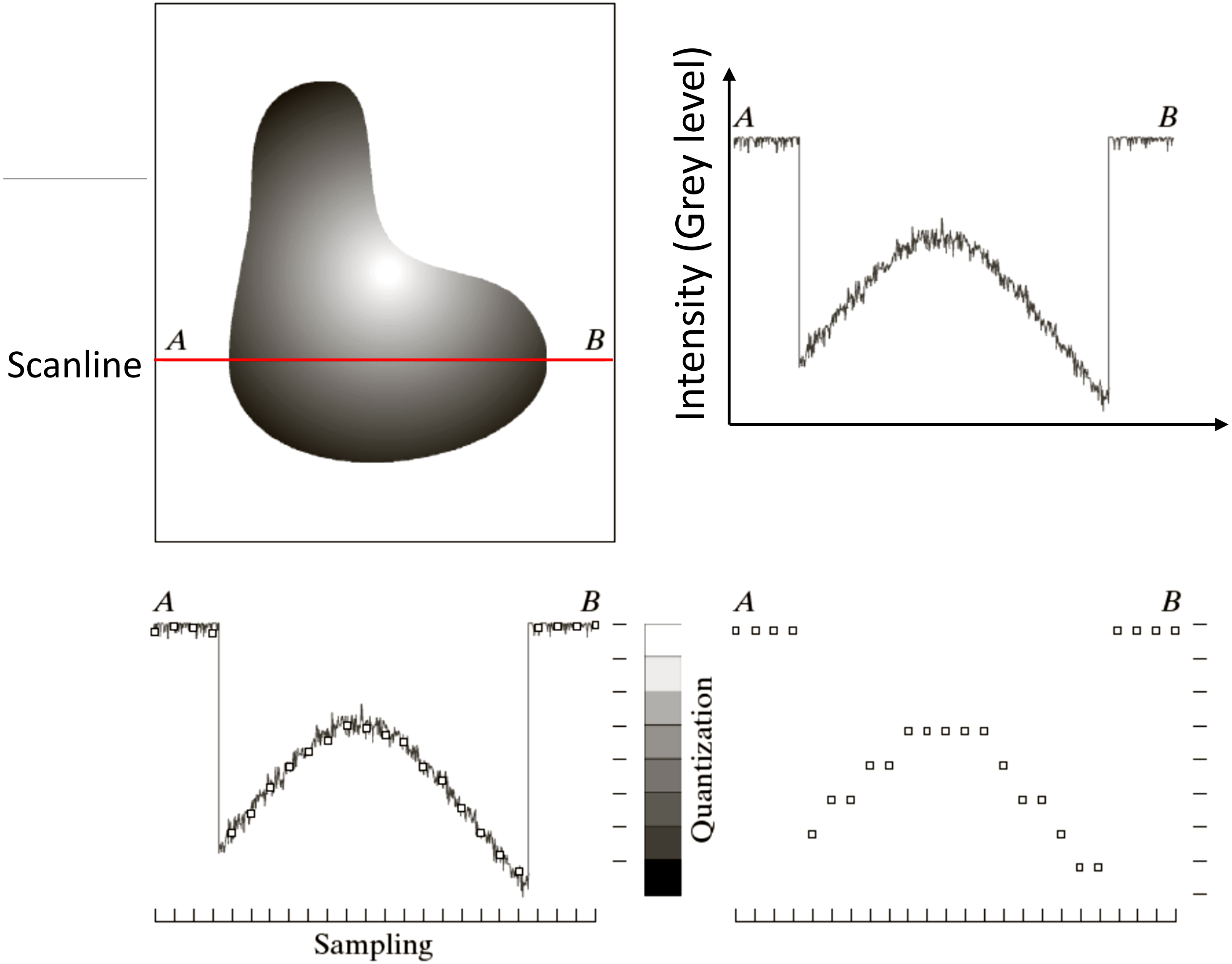
Image digitalization

- Why?
  - Microphones and video cameras produce analogue signals. (continuous-valued voltages)
  - To get audio or video into a computer, we must digitalize it by converting it into a stream of bits.
  - Digital form is easy to process, maintain and transmit...

Image digitalization

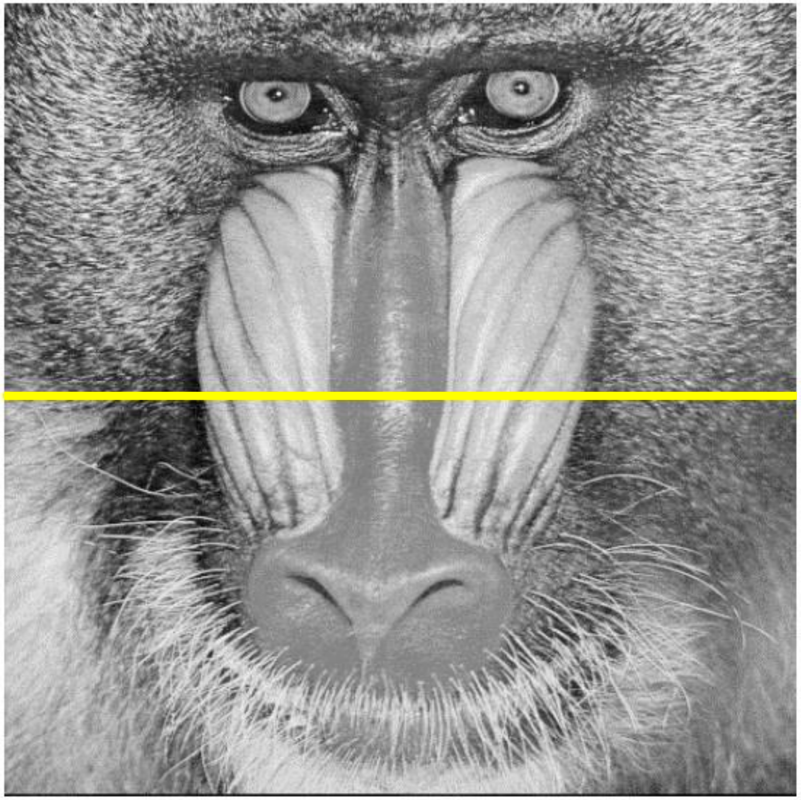
Converting the continuous 2D signal in a digital image by sampling per **scanlines.**

For each scanlines: digitalizing the coordinate values is called **sampling**, digitalizing the amplitude values is **quantization.**


Scanline
A
B
Intensity (Grey level)
A
B
A
B
Quantization
Sampling
A
B

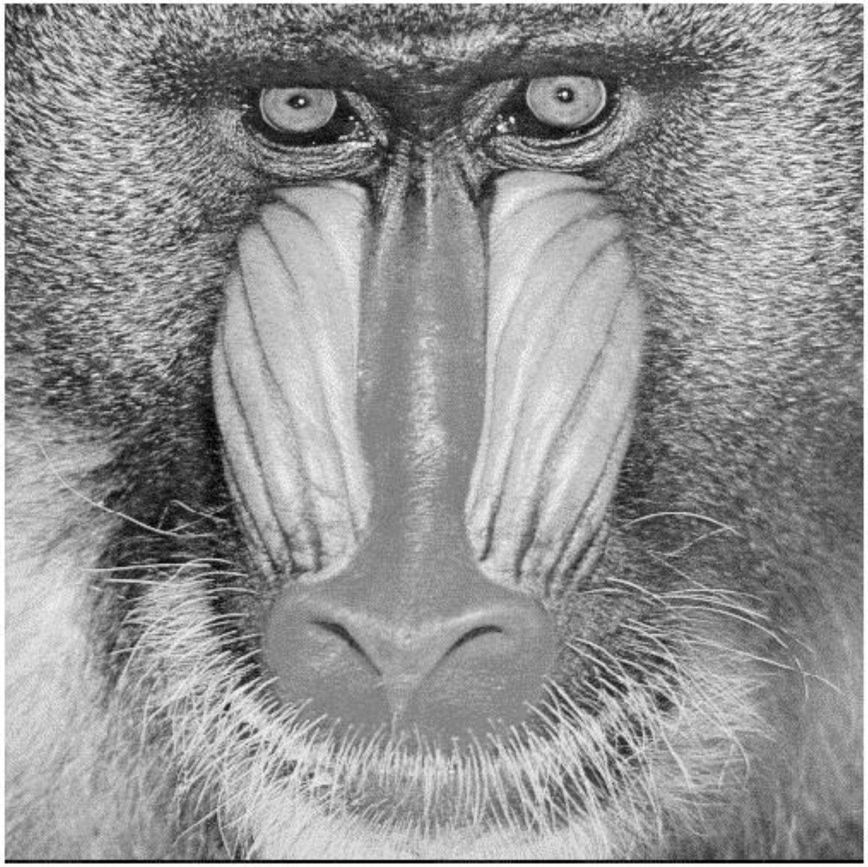
Sampling

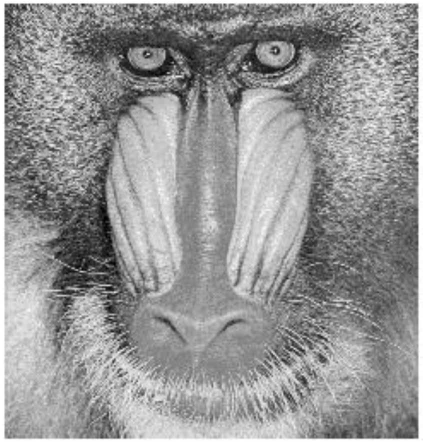
- The intensity value changes continuously in all directions on an analogue image.
- Here shows the continuous intensity value curve of a horizontal scanline.



The intensity value curve

512





256

128

64

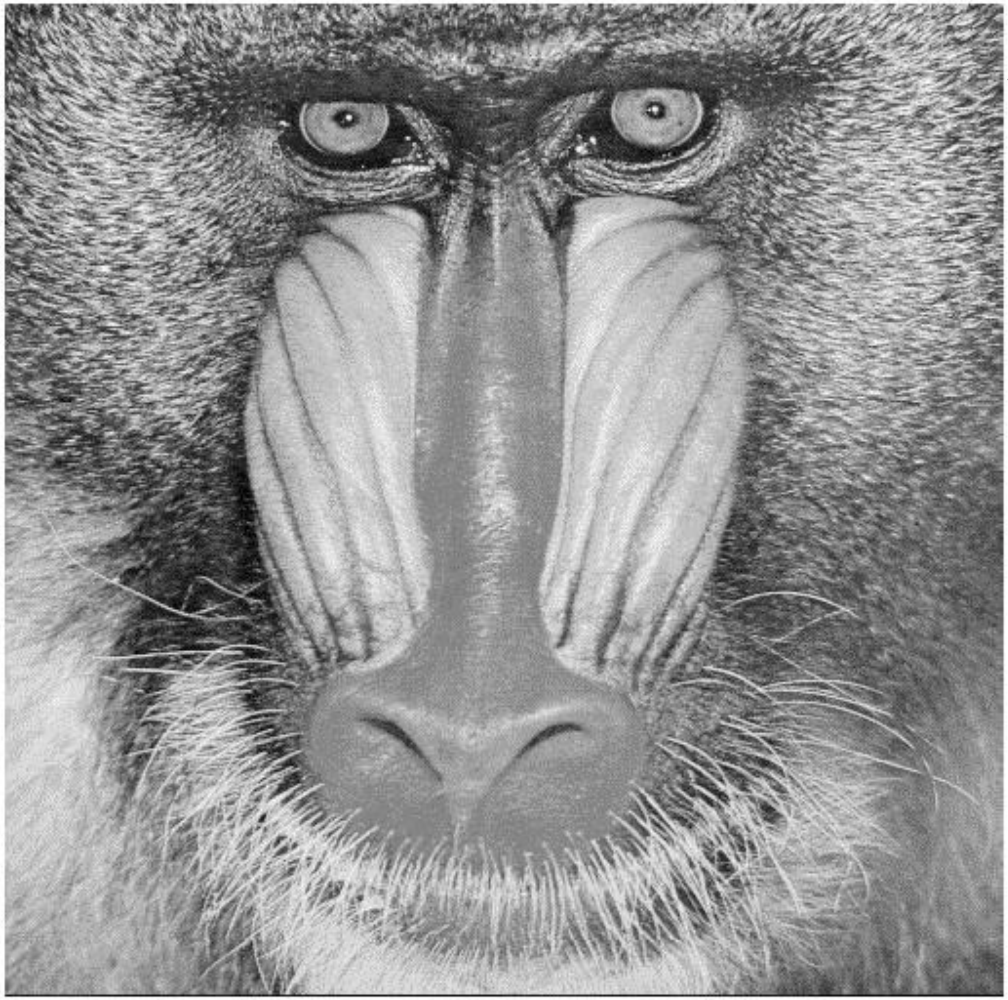
32

* Sampled images display with the same spatial resolution.

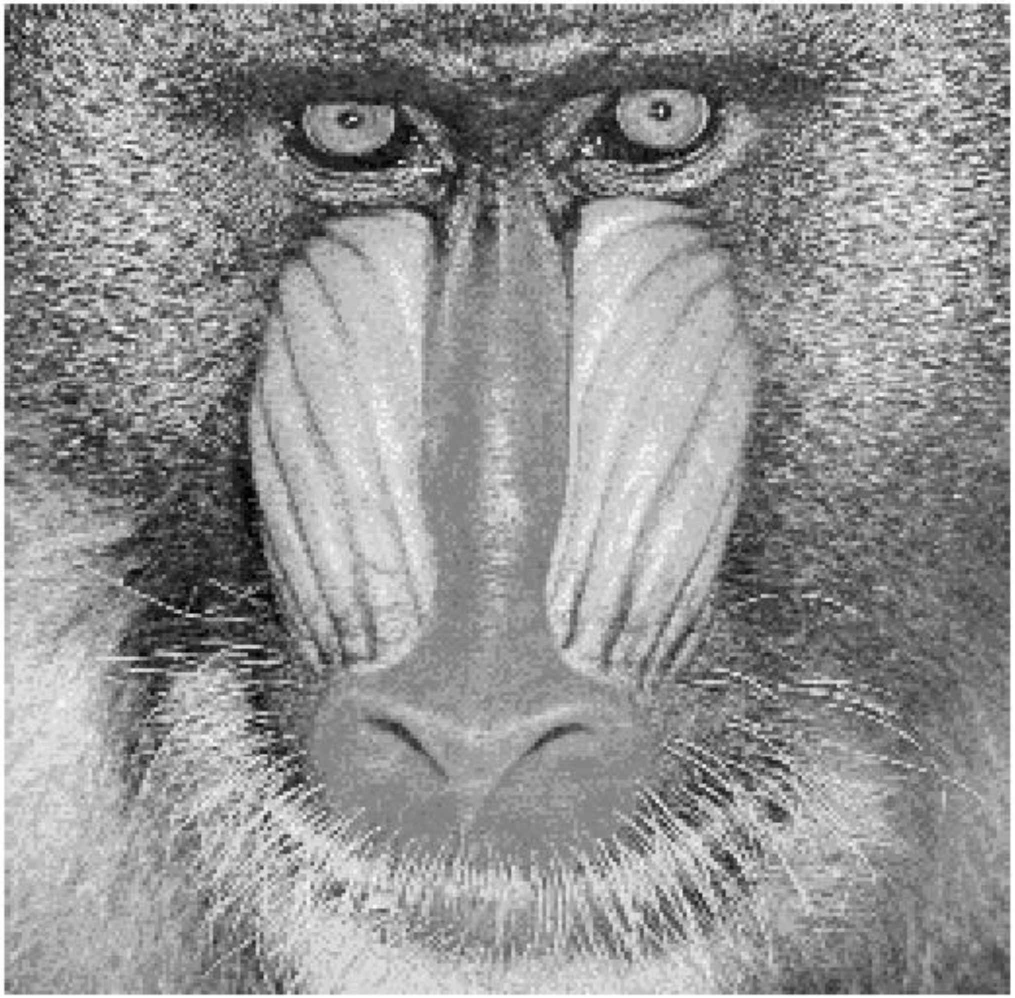
Unit: samples/row and column

Spatial resolution

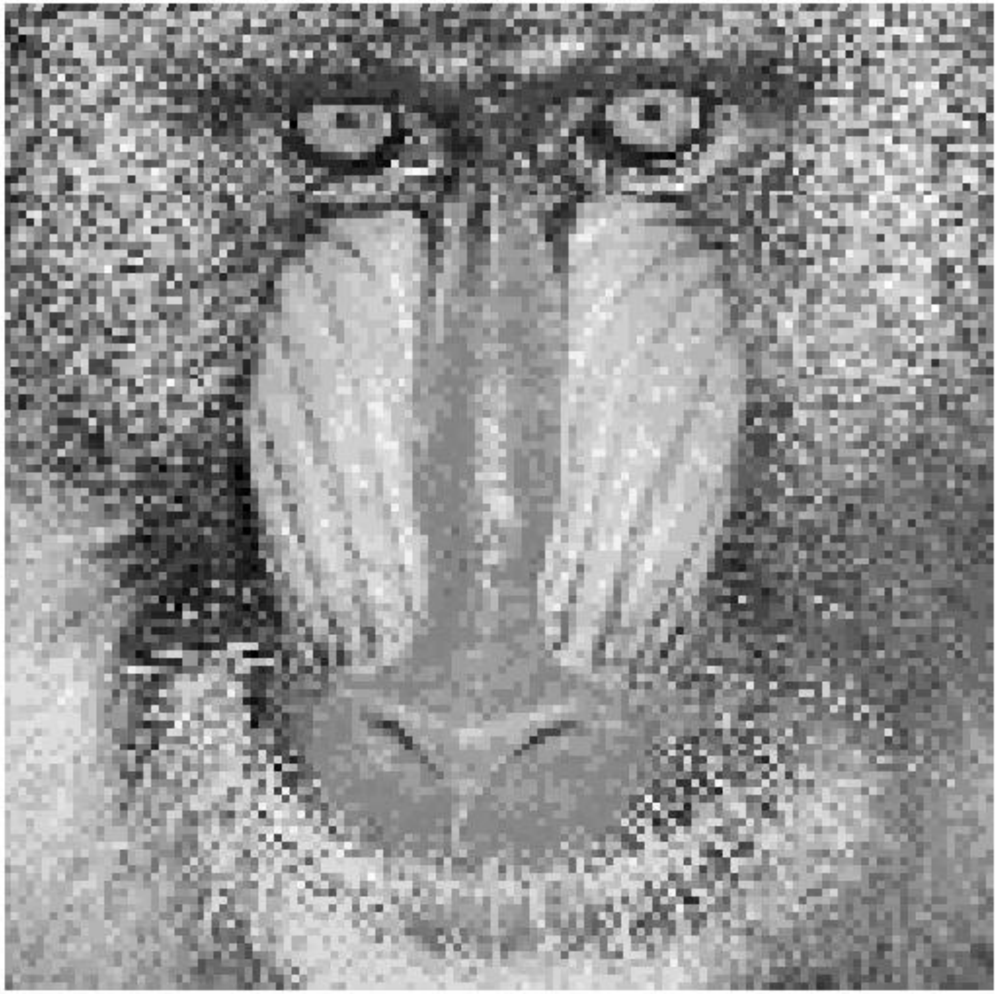
- Spatial Resolution is the capability of the sensor to observe or measure the smallest object clearly with distinct boundaries.
- Spatial Resolution depends upon the size of the pixel.
  - the smaller the size of the pixel, the higher the resolution will be and the clearer the object in the image will be.
- Measure spatial resolution
  1. pixels per inch(ppi) or pixels per square inch
  2. pixel number in a row X pixel number in a column
  3. Megapixels-the total number of pixels divided by 1 million



512

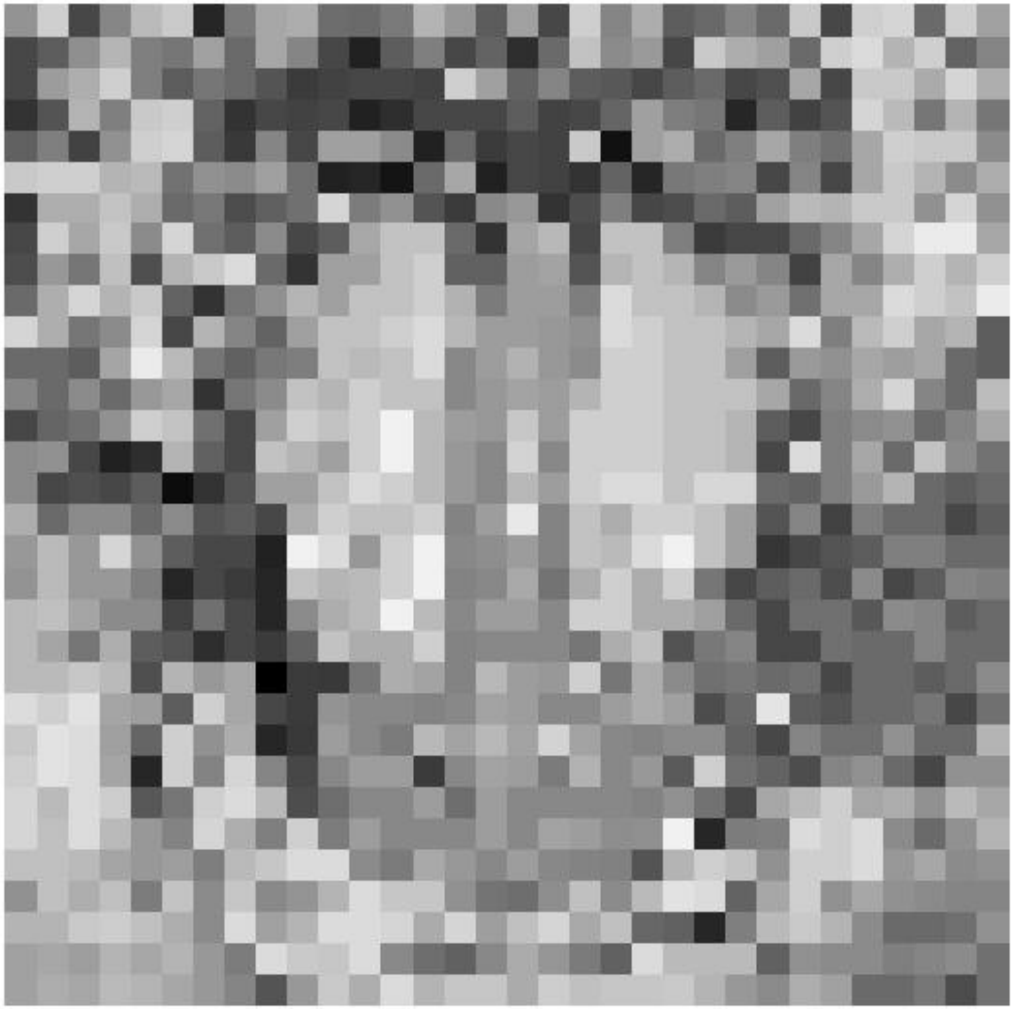


256



128

64



32

Sampling

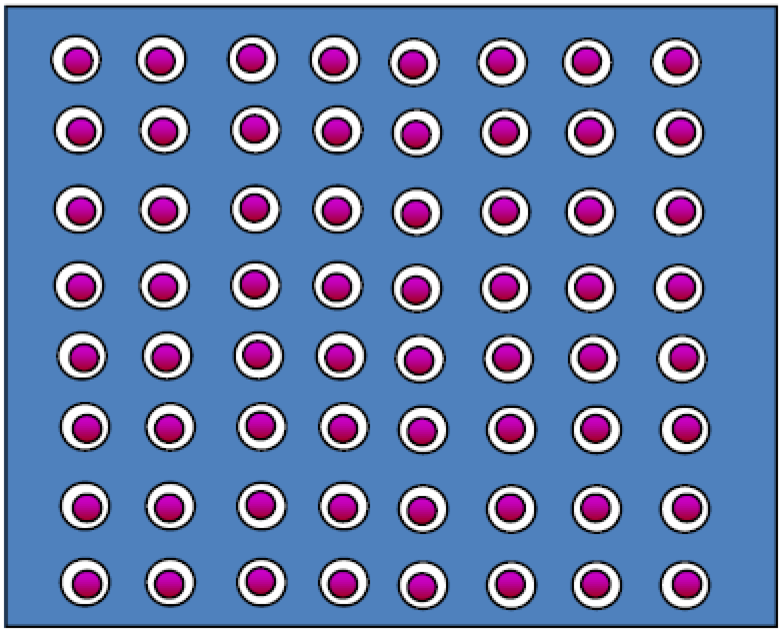
- Uniform
  - same sampling frequency everywhere
- Adaptive
  - higher sampling frequency in areas with greater details
  - compression strategy

Sampling

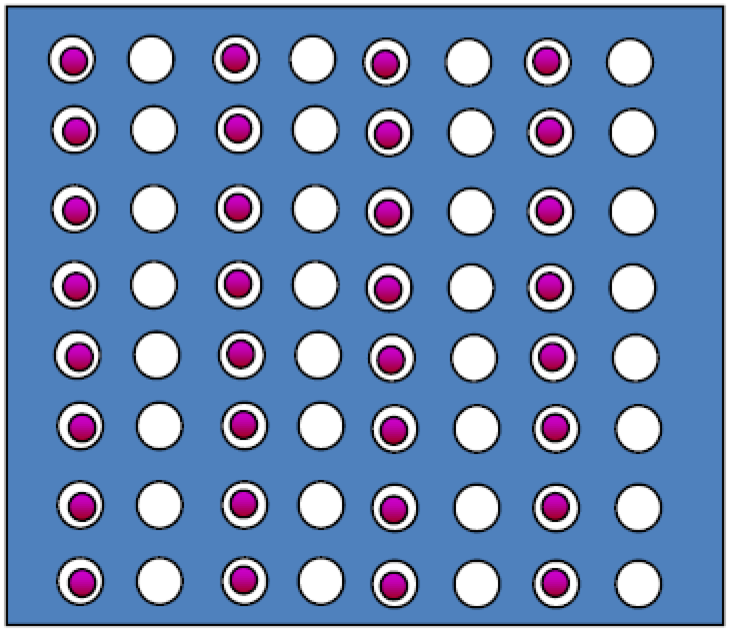
- Zooming
  - Can be seen as up-sampling
  - *Creation of new pixel locations*
  - Assignment of grey levels to those locations
- Shrinking
  - Can be seen as sub-sampling

Sub-sampling

Pixels are removed according to a given pattern.

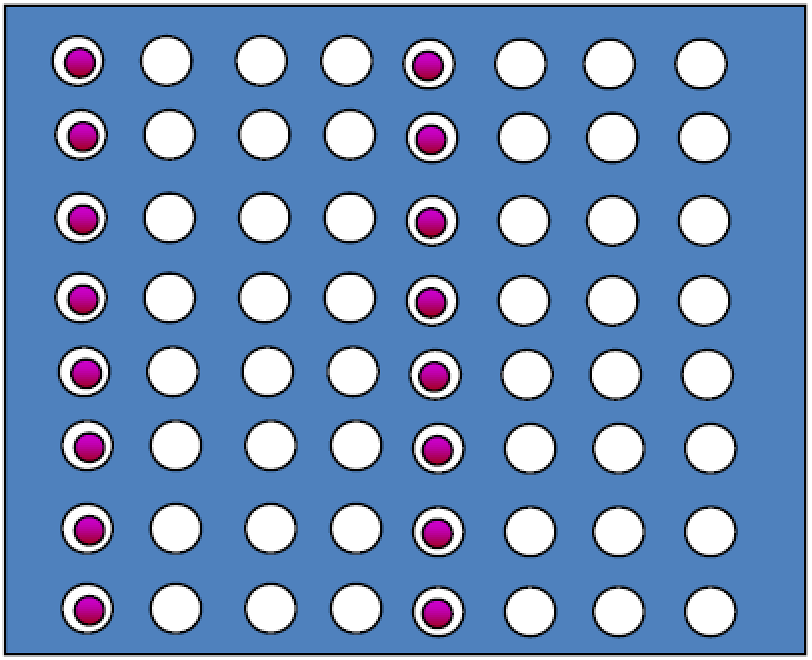


original sampling

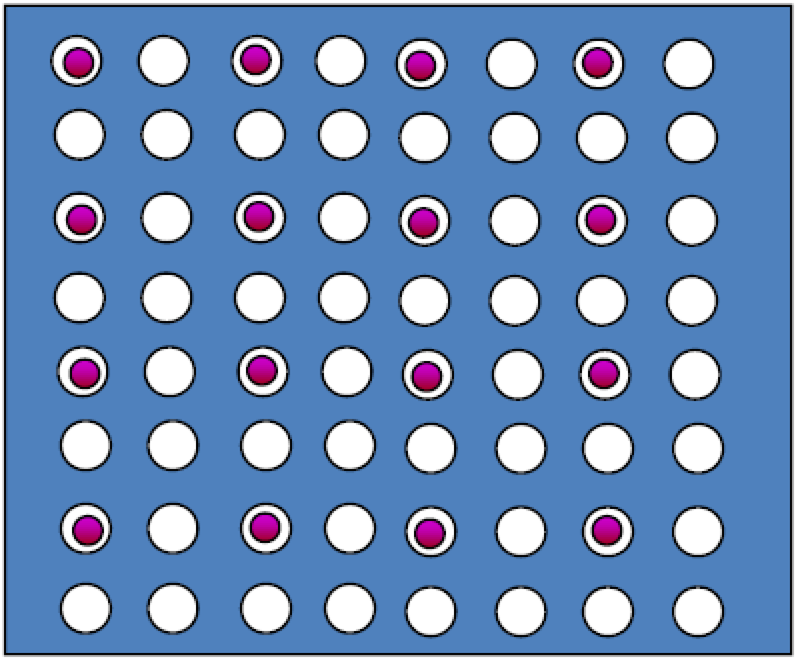


2:1 subsampling

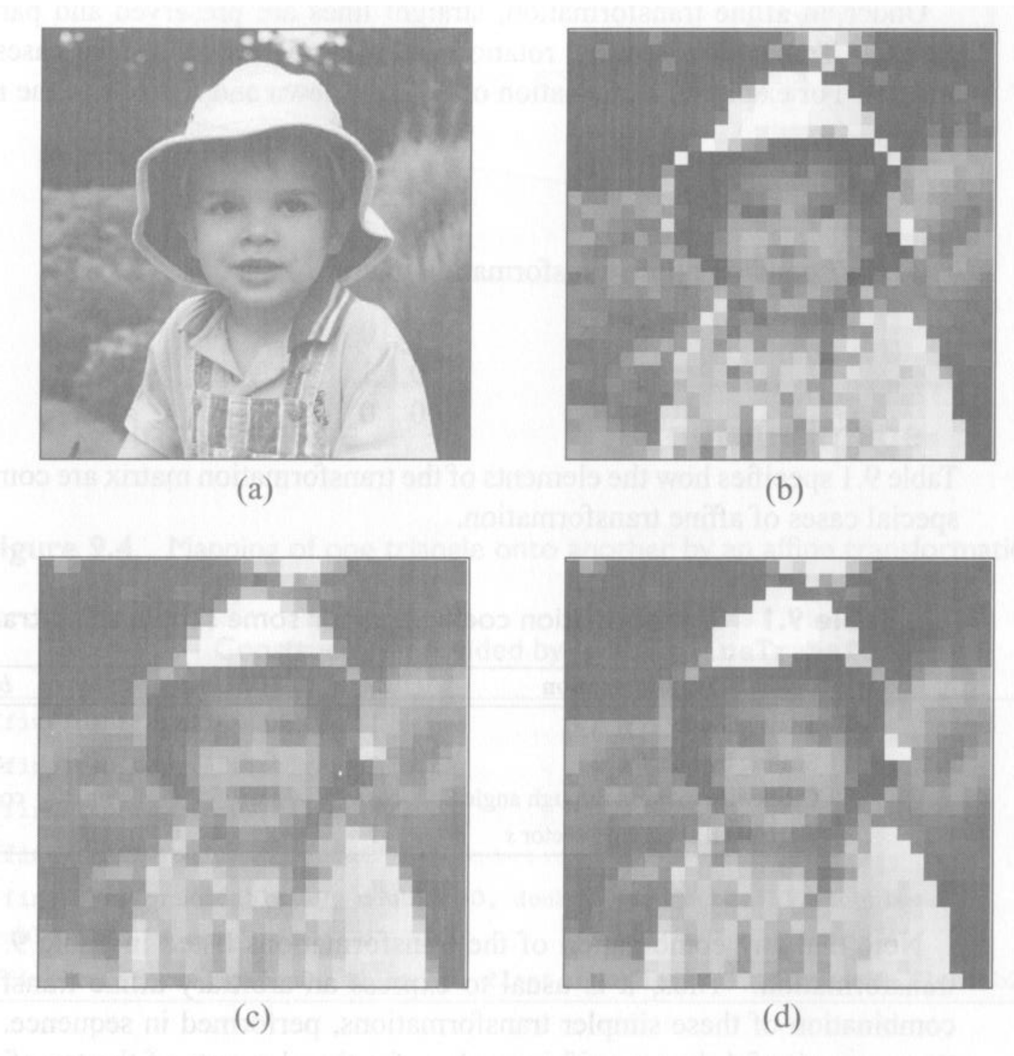
Sub-sampling



4:1 subsampling



4:1 subsampling

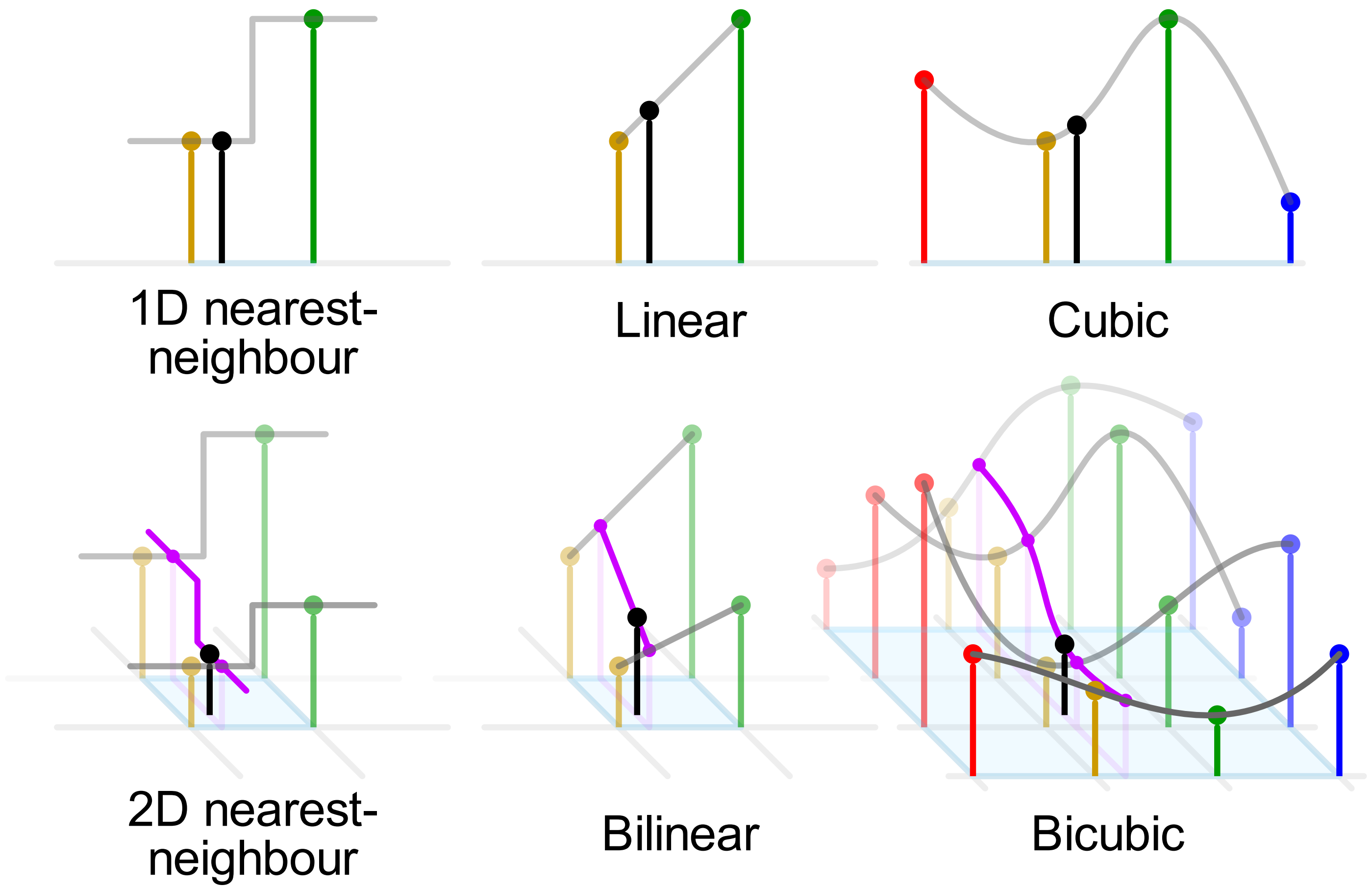


(a)original image
(b)sub-sampling
(c)mean of *n* x *n* block
(d)median of *n* x *n* block

Up-sampling

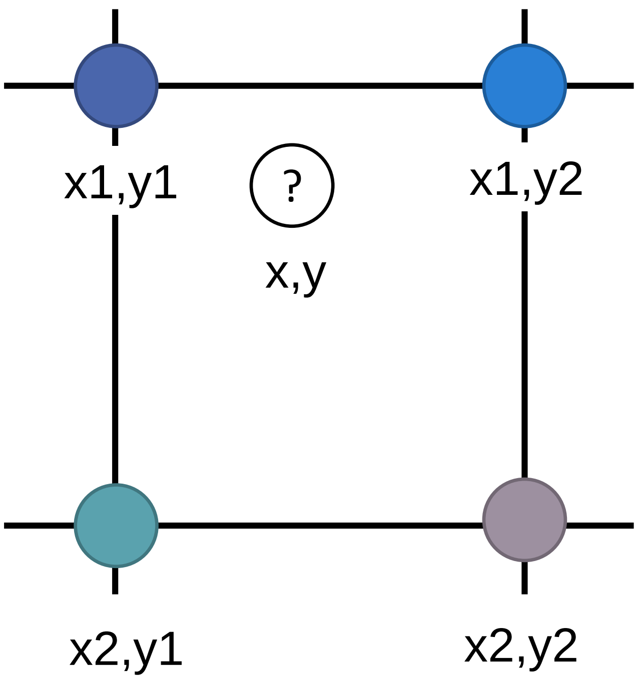
- Objective
  – to increase the spatial resolution
- Procedure is called **interpolation**
  – Interpolation is the process of using known data to estimate values at unknown locations.
  – Interpolation is used in zooming shrinking, rotating and geometric corrections.
- Methods
  – Nearest neighbour
  – Bilinear
  – Bicubic

Interpolation methods



Nearest Neighbour

Assumes 4 pixels on an image *f* are known, how to get the intensity of the interpolated pixel *f(x, y)* ?



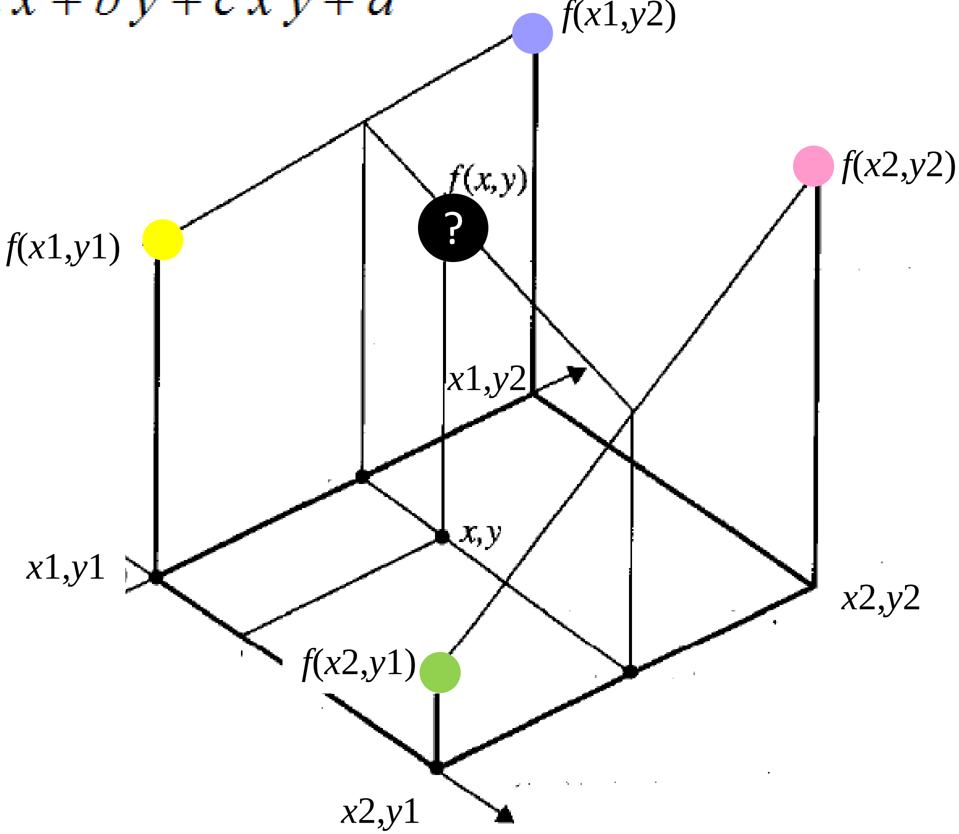
1. find the nearest neighbour whose distance is minimum to *f(x,y).*

$$\text{Distance} = \sqrt{(x - x_{nb})^2 + (y - y_{nb})^2}$$

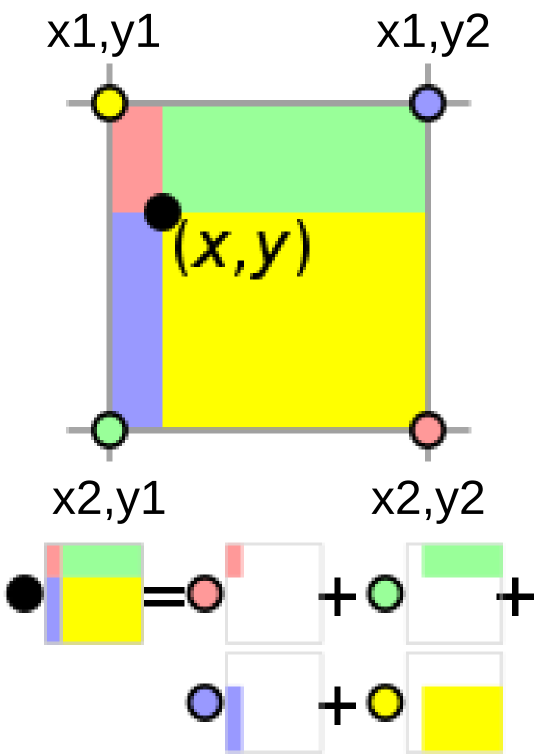
2. assign the intensity of that neighbour to the new pixel.

Bilinear interpolation

$$f(x,y) = ax + by + cxy + d$$



Bilinear interpolation



- Geometric visualisation

The value at the black spot *f(x,y)* is the sum of the value at each coloured spot multiplied by the area of the rectangle of the same colour, divided by the total area of all four rectangles.

Bilinear interpolation

Caculate the value of $f(x, y)$

given the value of the four neighbours $f(x_1, y_1), f(x_1, y_2), f(x_2, y_1), f(x_2, y_2)$

1.

$$f(x, y_1) \approx \frac{x_2 - x}{x_2 - x_1} f(x_1, y_1) + \frac{x - x_1}{x_2 - x_1} f(x_2, y_1)$$

$$f(x, y_2) \approx \frac{x_2 - x}{x_2 - x_1} f(x_1, y_2) + \frac{x - x_1}{x_2 - x_1} f(x_2, y_2)$$

2.

$$f(x, y) \approx \frac{y_2 - y}{y_2 - y_1} f(x, y_1) + \frac{y - y_1}{y_2 - y_1} f(x, y_2)$$

Quantization

- Usually mapping continuous colours from black to white into discrete integers from 0-255. (8-bit quantization)
  - 0 is pure black and 255 is pure white.
  - Quantized values (256 integers) are called grey levels.

0	207	207	255
130	0	255	52
130	255	0	52
255	111	111	0

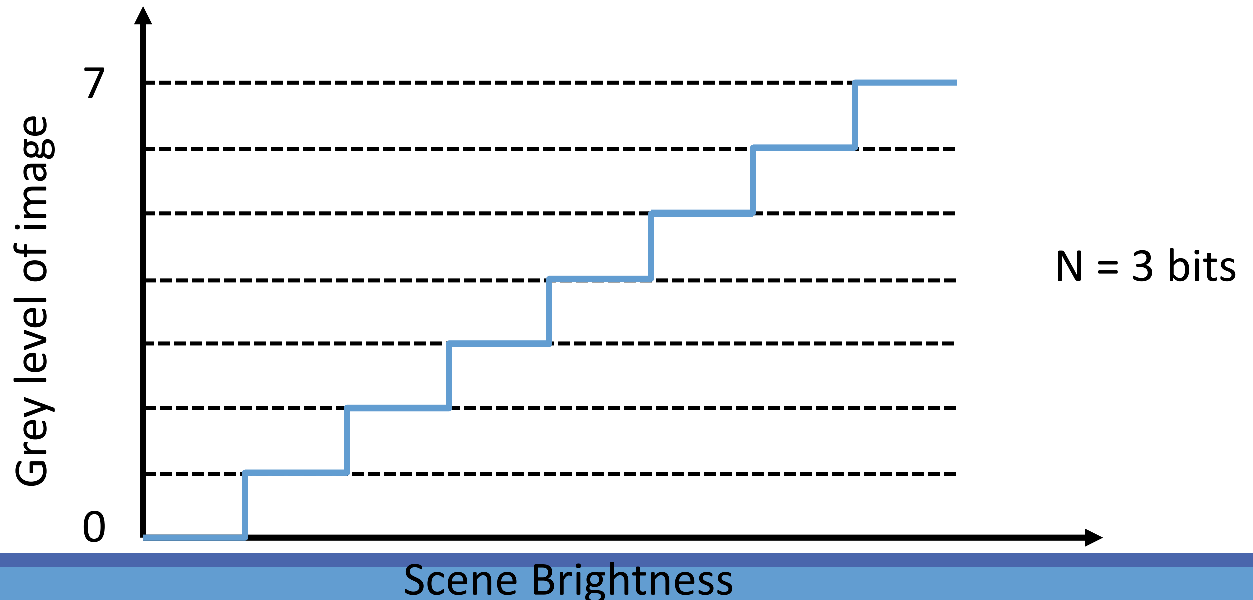
Image

Intensity resolution

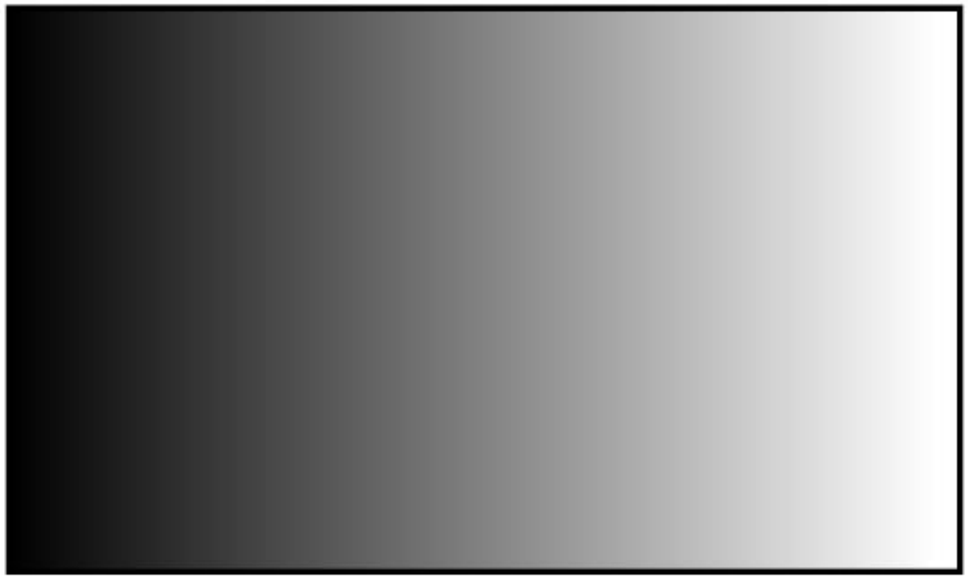
Intensity resolution

- refers to how accurately a pixel's grey level represents the brightness of the corresponding point in the original scene.

- during quantization, the brightness sampled at each point in the continuous-tone image is replaced by an integer value.



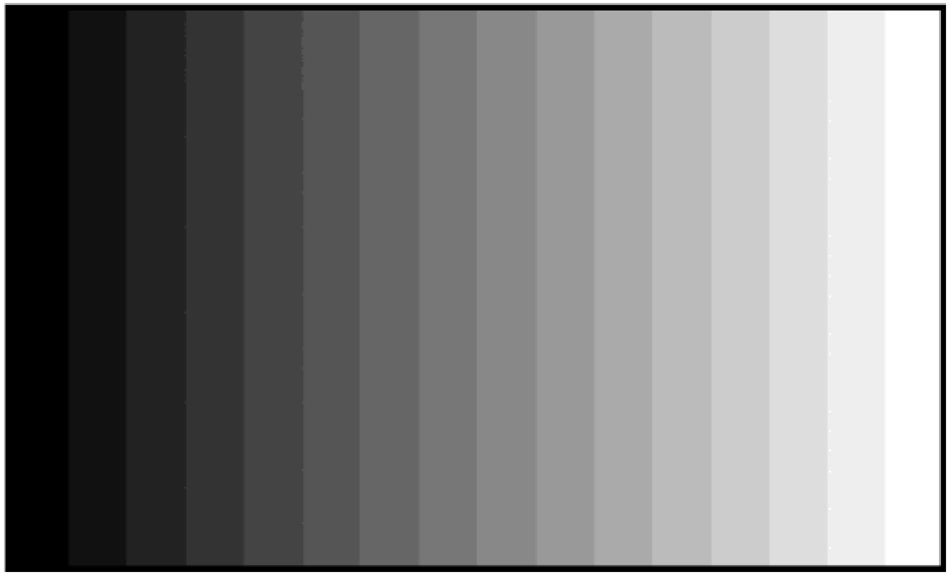
Intensity resolution



Digital image quantized with 8 bits (256 gray levels)

Note that the image appears continuous

Intensity resolution



The same image quantized with only 4 bits (16 gray levels)

Now the image brightness appears discontinuous

Intensity resolution

Intensity resolution

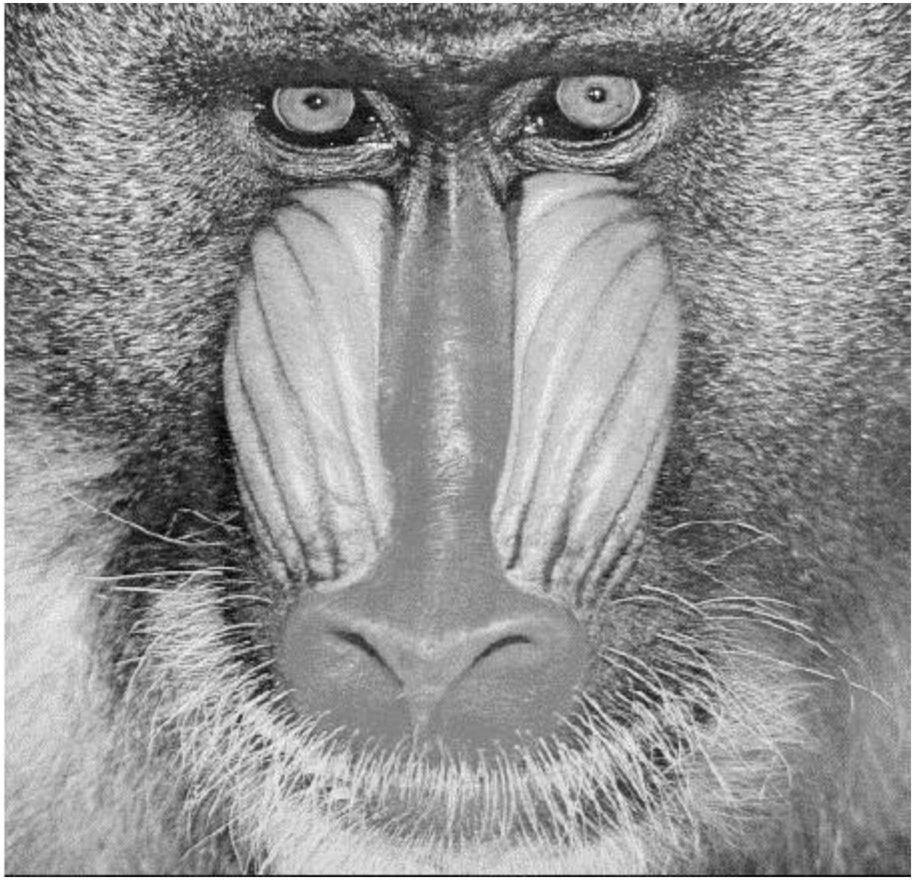
- Depends on the number of bits used to represent the grey level.
  - ➢ The more bits to represent the grey level → The better intensity resolution
- With fewer bits, we cannot accurately represent the gradual intensity variations in the original scene because a wider range of intensities in the original scene is mapped into a single grey level.
  - ➢ Think about binary image

Common quantization levels

Number of bits (N)	Number of quantization levels (grey levels) (2^N)	Remarks
1	2	Binary image
8	256	1 byte, very common
16	65,536	Common in research
24	16,777,216	Common in colour image (i.e. 3x8 for RGB)

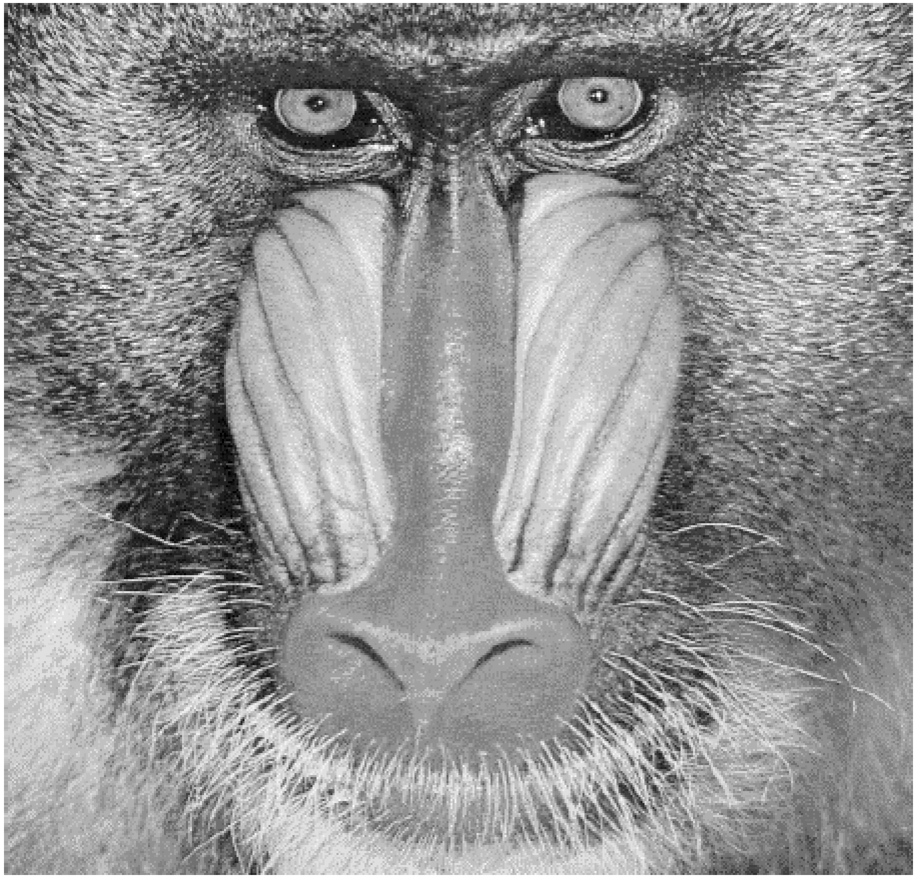
Grey-level quantization

256 levels



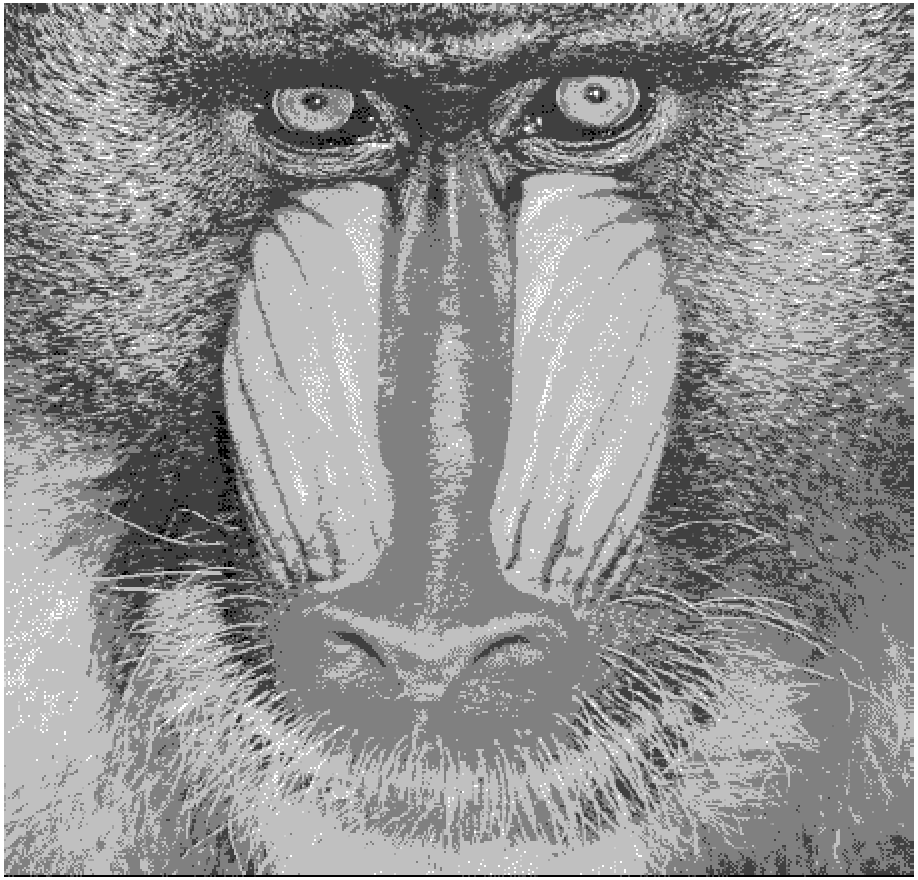
Grey-level quantization

32 levels



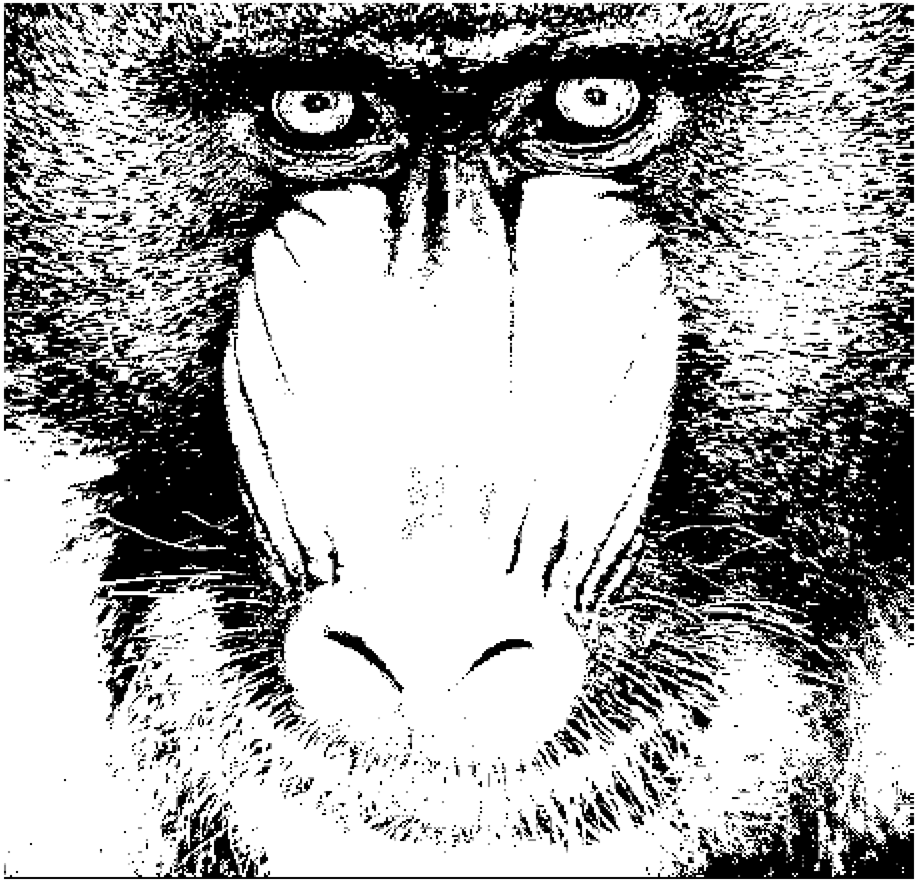
Grey-level quantization

8 levels



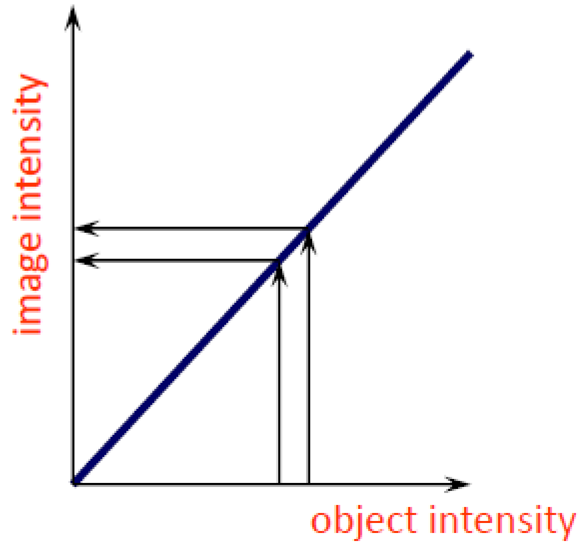
Grey-level quantization

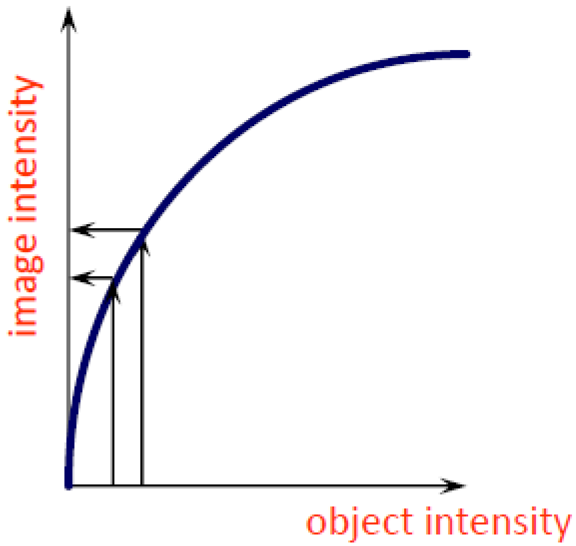
2 levels



Quantization methods

- Uniform or linear
  - intensity of object is linearly mapped to grey levels of image
- Logarithmic
  - higher intensity resolution in darker areas (the human eye is logarithmic)



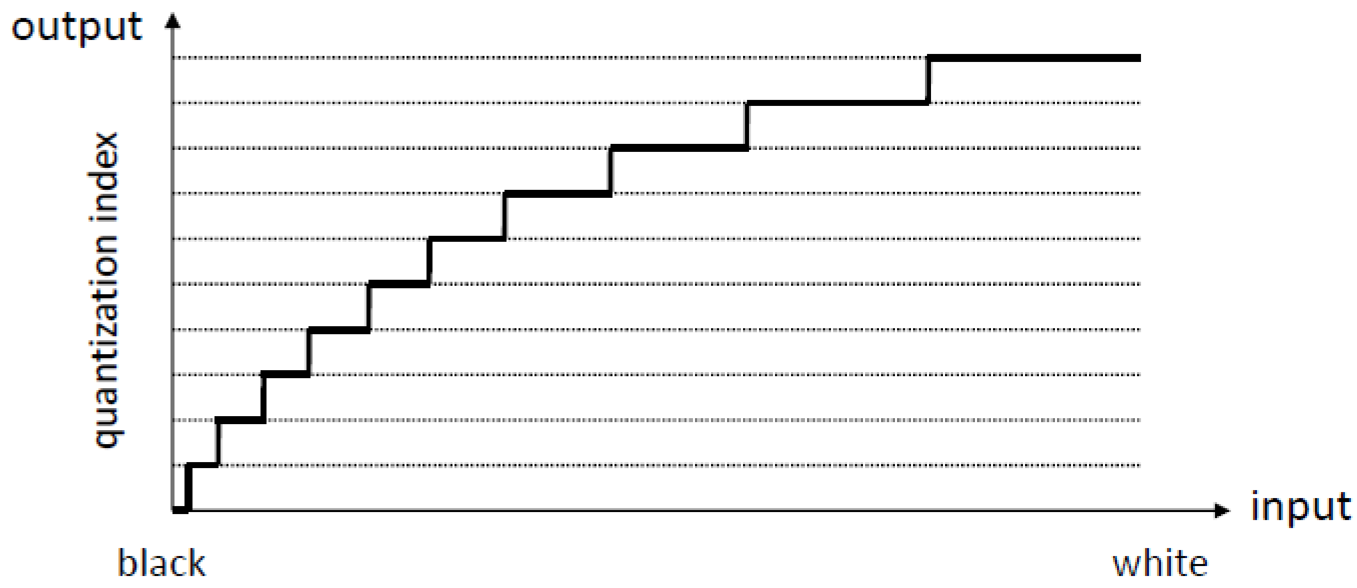


Non-uniform quantization

Non-uniform quantization

– Better choice when probability density of a signal is not uniform

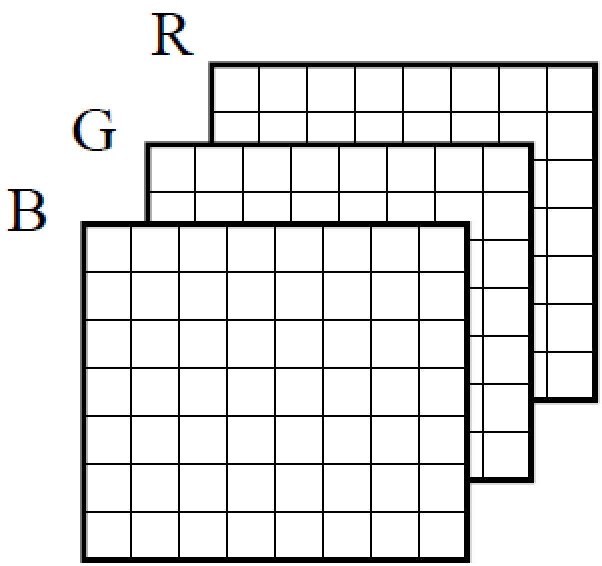
– Allow to consider the characteristics of the human vision system



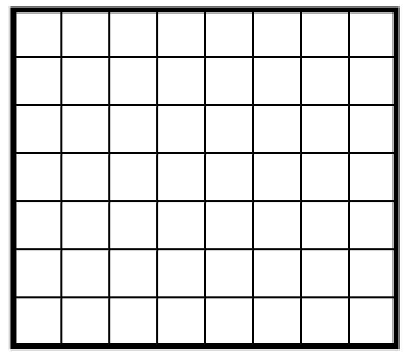
Quantizing colour images

- Each component can be quantized separately.
- Some colour components can be
  - Quantized with different steps.
  - Sampled with different steps.
- Quantization of a colour image with a Look-Up Table (LUT)

Look-up table (LUT)



True colours

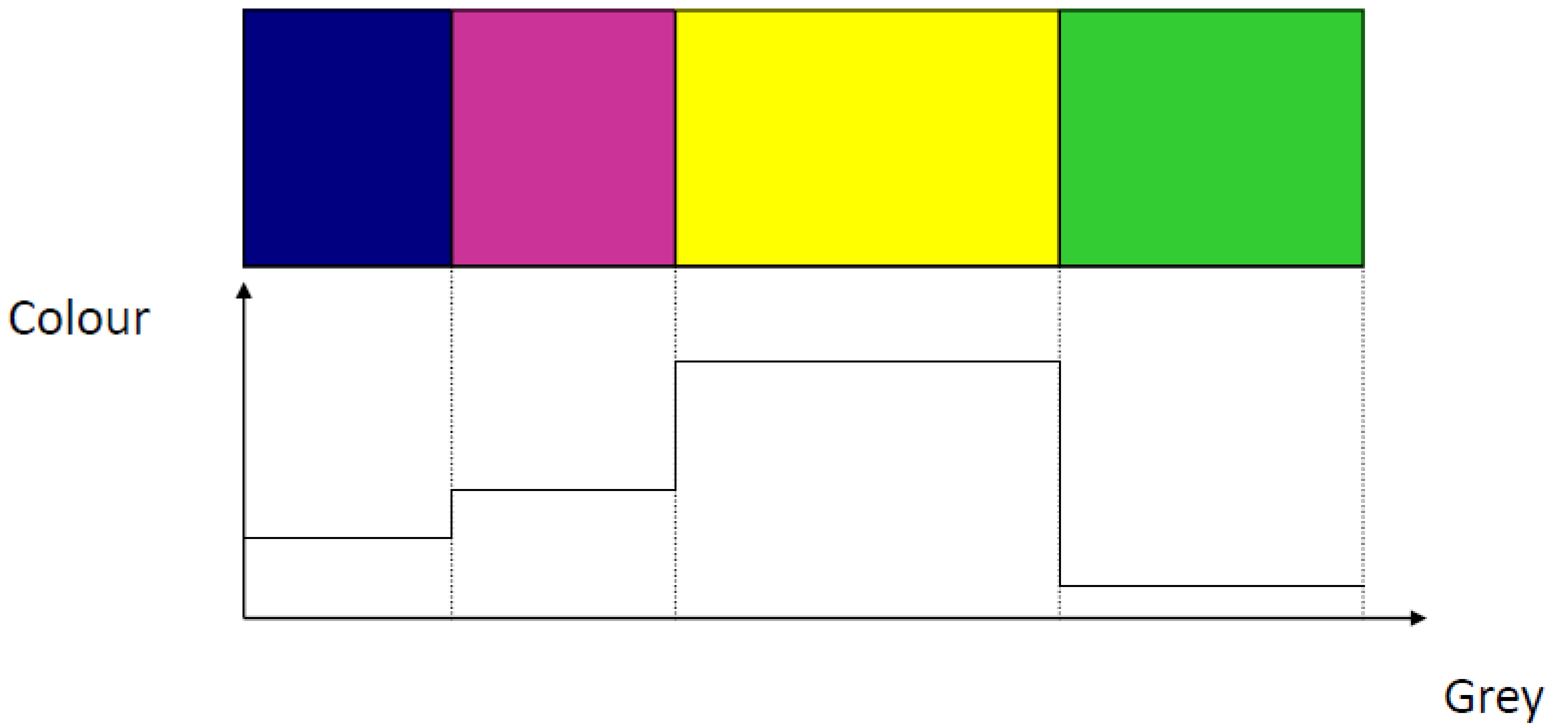


value	R	G	B
0	10	10	10
1	10	20	30
2	30	100	20
...	...	...	...

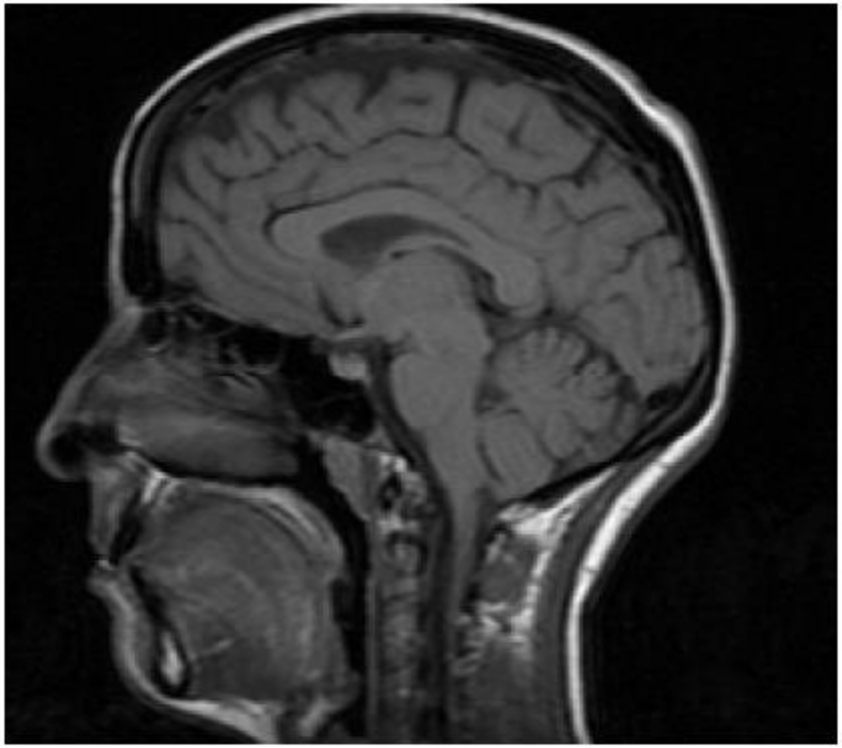
Look-up table

False colour images

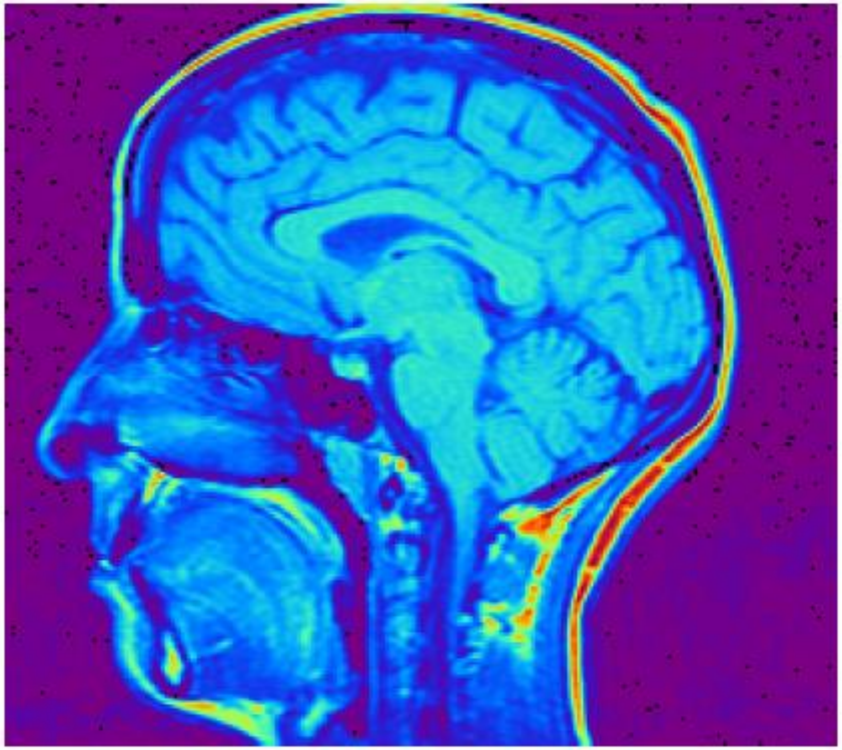
A special look-up table ...



Example



original image



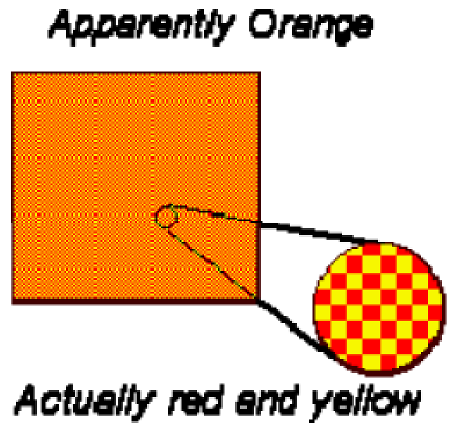
false colour image

Dithering and halftoning

used to render images and graphics with more apparent colours than are actually displayable.

When the HVS is confronted with large regions of high-frequency colour changes. they tend to blend the individual colours into uniform colour field.

Use this property of perception to represent colours that cannot be directly represented



Dithering

A process of juxtaposing pixels of two colours to create the illusion that a third colour is present

– largely used in printed media (newsprint, laser printers)

Original full-color photograph

Dithered to 256 colors

Dithering

HVS can discern **~100** brightness levels

– depends on hue and ambient lighting (e.g., we can see more distinct shades of green than blue)

True-colour displays

- – **256** colours available for each primary
- – usually adequate under normal indoor lighting (when the nonlinearities of the display are properly compensated for)
- – usually no need to dither a true-colour display

High-colour displays

- – only 32 shades of each primary
- – HVS sees **contours** between two colours that vary by only one level
    - HVS even amplifies the variation!
    - This apparent amplification of contours is called **Mach-banding**
- – need dithering

Q&A