

Digital Image Processing

Lecture # 2 **Fundamentals**

BRIGHTNESS ADAPTATION AND DISCRIMINATION

- The human visual system can perceive approximately 10^{10} different light intensity levels
- However, at any one time we can only discriminate between a much smaller number – *brightness adaptation*

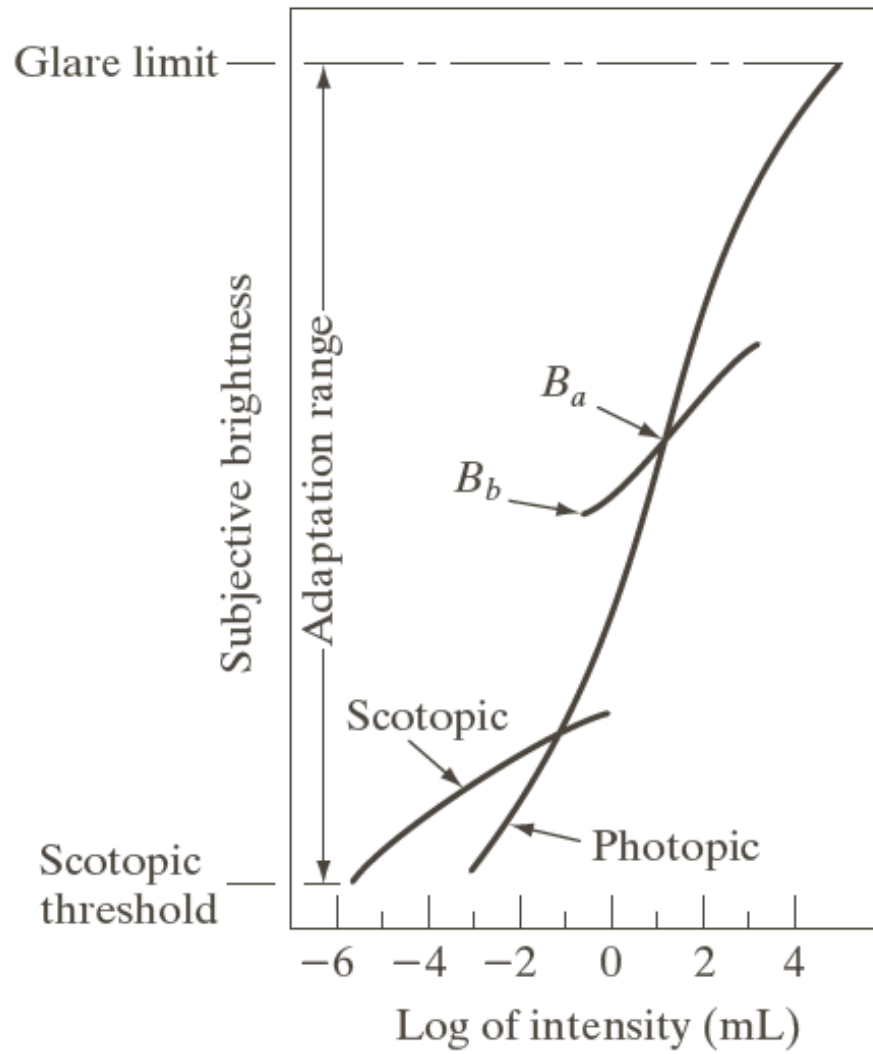
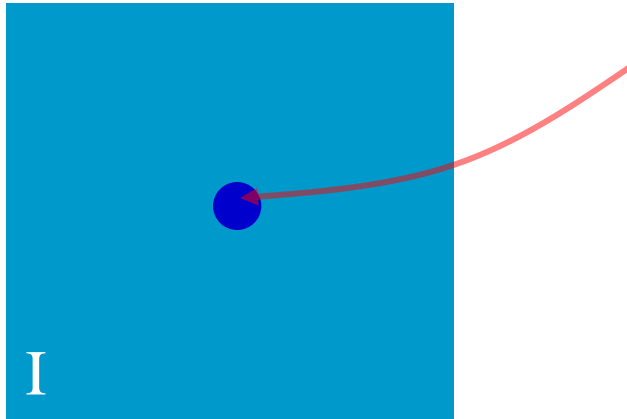


FIGURE 2.4
 Range of subjective brightness sensations showing a particular adaptation level.

CONTRAST SENSITIVITY



Weber's ratio: $\Delta I_c / I$

Good brightness discrimination

$\Rightarrow \Delta I_c / I$ is small.

Bad brightness discrimination

$\Rightarrow \Delta I_c / I$ is large.

- The ability of the eye to discrimination b/w changes in brightness at any specific adaptation level is of considerable interest.
- I is uniformly illuminated on a flat area large enough to occupy the entire field of view.
- ΔI_c is the change in the object brightness required to just distinguish the object from the background

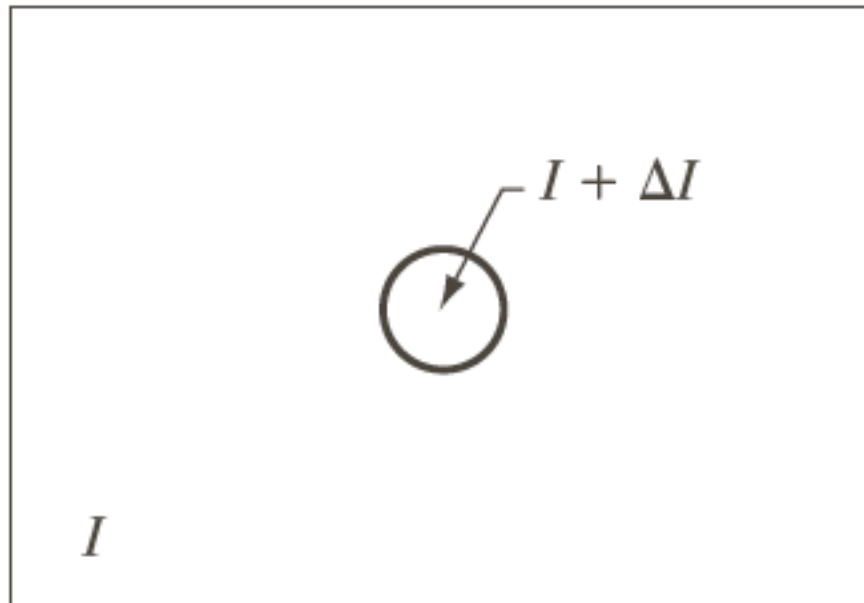


FIGURE 2.5 Basic experimental setup used to characterize brightness discrimination.

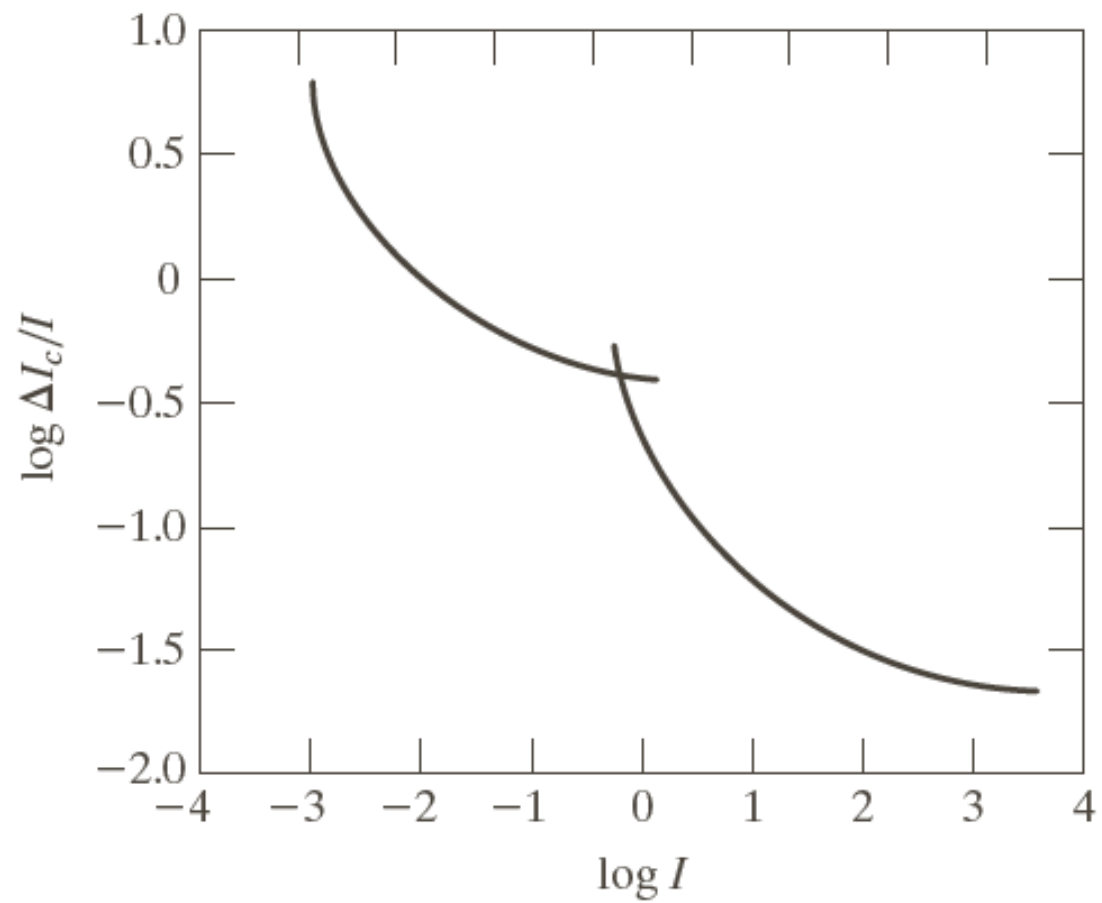
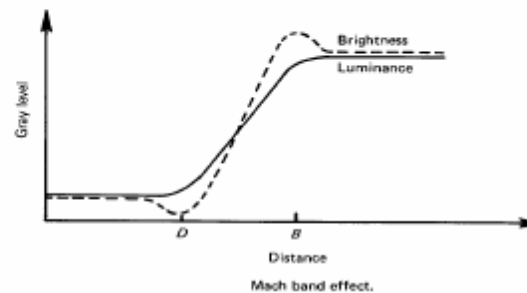
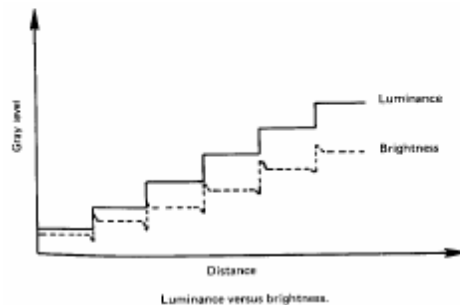
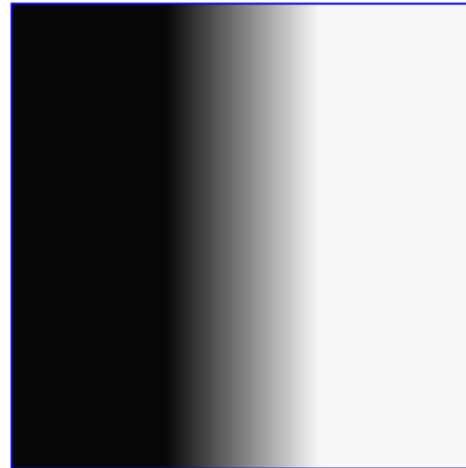
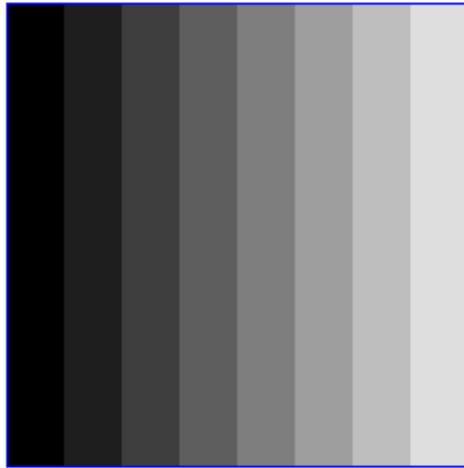


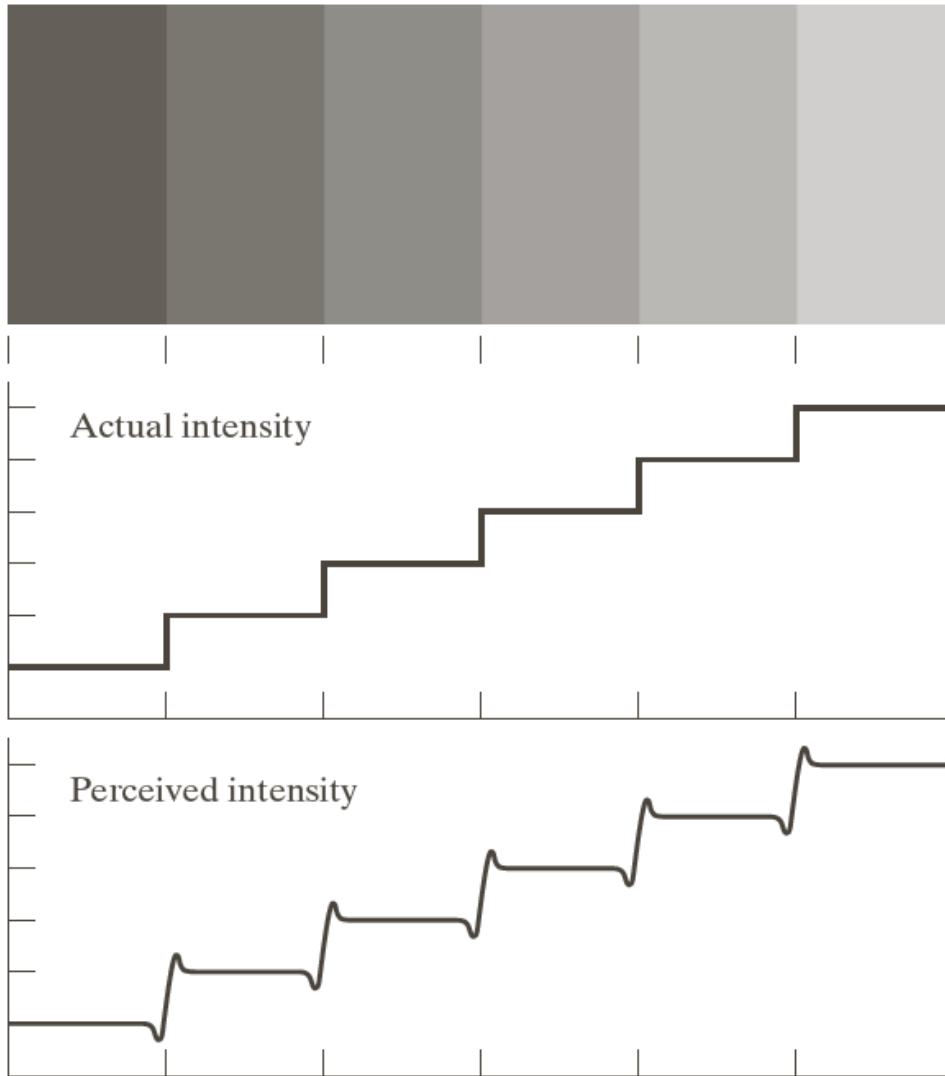
FIGURE 2.6
Typical Weber
ratio as a function
of intensity.

MACH BANDS

- Perceived brightness depends on **surroundings** as well as luminance



The intensity of the stripes is constant but we actually perceive a brightness pattern which is strongly scalloped near the boundaries.



a
b
c

FIGURE 2.7

Illustration of the Mach band effect. Perceived intensity is not a simple function of actual intensity.

Simultaneous Contrast

- Perceived brightness depends on **surroundings** as well as luminance



a b c

FIGURE 2.8 Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

a b
c d

FIGURE 2.9 Some well-known optical illusions.

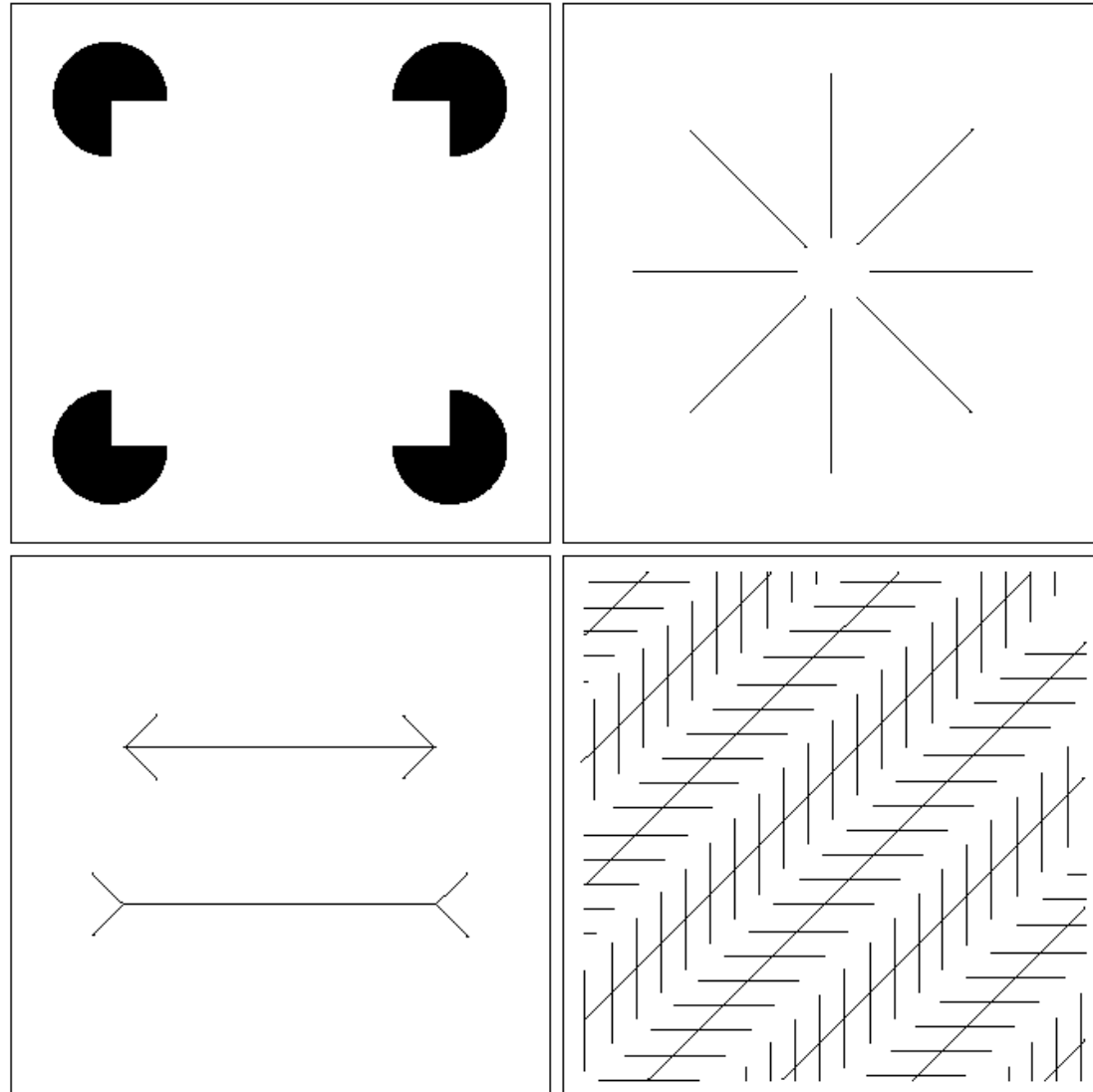


IMAGE FORMATION MODEL

- Image refers to a 2d light-intensity function, $f(x, y)$
- The amplitude of f at spatial coordinates (x, y) gives the intensity (brightness) of the image at that point.
- Light is a form of energy thus $f(x, y)$ must be nonzero and finite.

$$0 < f(x, y) < \infty.$$

IMAGE FORMATION MODEL

- The function $f(x, y)$ may be characterized by two components:
 - The amount of source light incident on the scene being viewed \Rightarrow illumination.
 - The amount of light reflected by the objects in the scene \Rightarrow reflectance.

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

$$0 < i(x, y) < \infty$$

$$0 < r(x, y) < 1.$$

GRAY LEVEL

- WE CALL THE INTENSITY OF A MONOCHROME IMAGE f AT COORDINATE (x, y) THE GRAY LEVEL (L) OF THE IMAGE AT THAT POINT.
- Thus, l lies in the range

$$L_{\min} \leq l \leq L_{\max}$$

- L_{\min} is positive and L_{\max} is finite.
- Gray scale = $[L_{\min}, L_{\max}]$
- Common practice, shift the interval to $[0, L]$: 0 = black, $L-1$ = white

Digital Image Representation

- ◆ Image Size

- Number of bits required to store an image

$$b = M \times N \times k$$

- Image having 2^k intensity levels
 - k – bit image
 - 256 intensity levels – 8 bit image

Image Size

TABLE 2.1

Number of storage bits for various values of N and k .

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





a b
c d

FIGURE 2.20 Typical effects of reducing spatial resolution. Images shown at: (a) 1250 dpi, (b) 300 dpi, (c) 150 dpi, and (d) 72 dpi. The thin black borders were added for clarity. They are not part of the data.

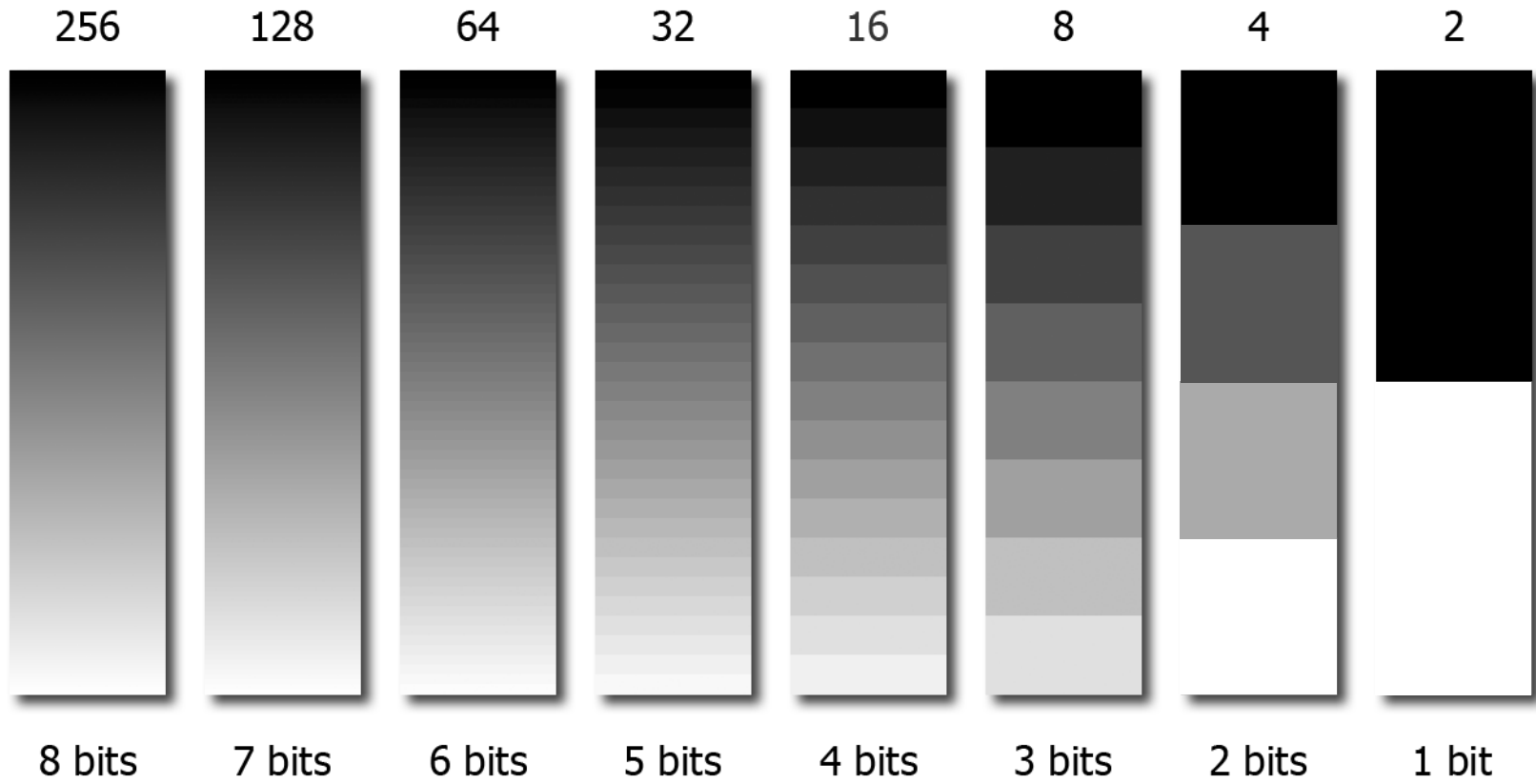
Intensity Level Resolution

- ◆ *Intensity level resolution* refers to the number of intensity levels used to represent the image
 - The more intensity levels used, the finer the level of detail in an image
 - Intensity level resolution is usually given in terms of the number of bits used to store each intensity level

Intensity Level Resolution

Number of Bits	Number of Intensity Levels	Examples
1	2	0, 1
2	4	00, 01, 10, 11
4	16	0000, 0101, 1111
8	256	00110011, 01010101
16	65,536	1010101010101010

Intensity Level Resolution



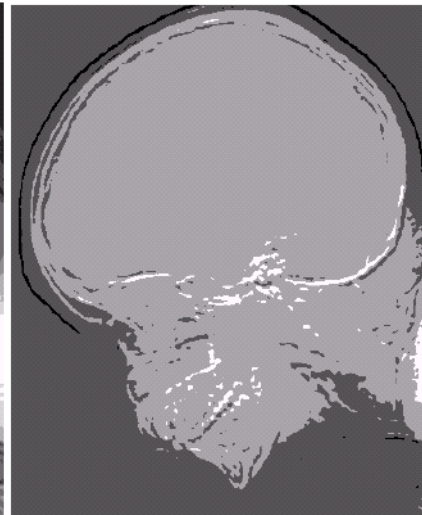
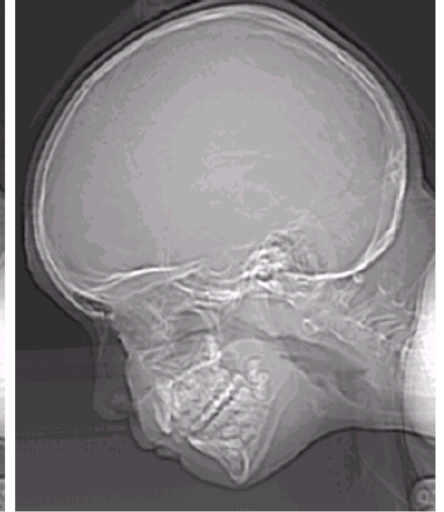
Intensity Level Resolution

256 grey levels (8 bits per pixel)

128 grey levels (7 bpp)

64 grey levels (6 bpp)

32 grey levels (5 bpp)



16 grey levels (4 bpp)

8 grey levels (3 bpp)

4 grey levels (2 bpp)

2 grey levels (1 bpp)

Resolution: How much is enough?

- ◆ How many samples and gray levels are required for a good approximation?
 - Quality of an image depends on number of pixels and gray-level number
 - The more these parameters are increased, the closer the digitized array approximates the original image
 - But: Storage & processing requirements increase rapidly as a function of N , M , and k

Resolution: How much is enough?

- ◆ Depends on what is in the image and what you would like to do with it



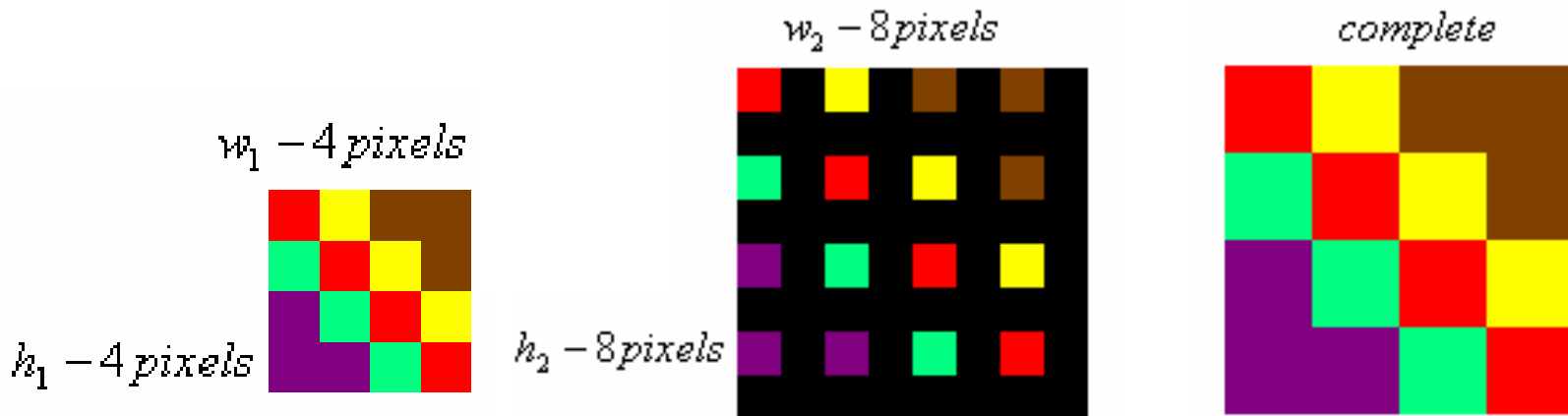
Enlarging an Image

- ◆ Pixel replication

[1 2 3 4 5]

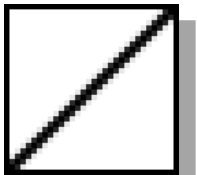
[1 1 2 2 3 3 4 4 5 5] (One step)

[1 1 1 2 2 2 3 3 3 4 4 4 5 5 5] (Two step)

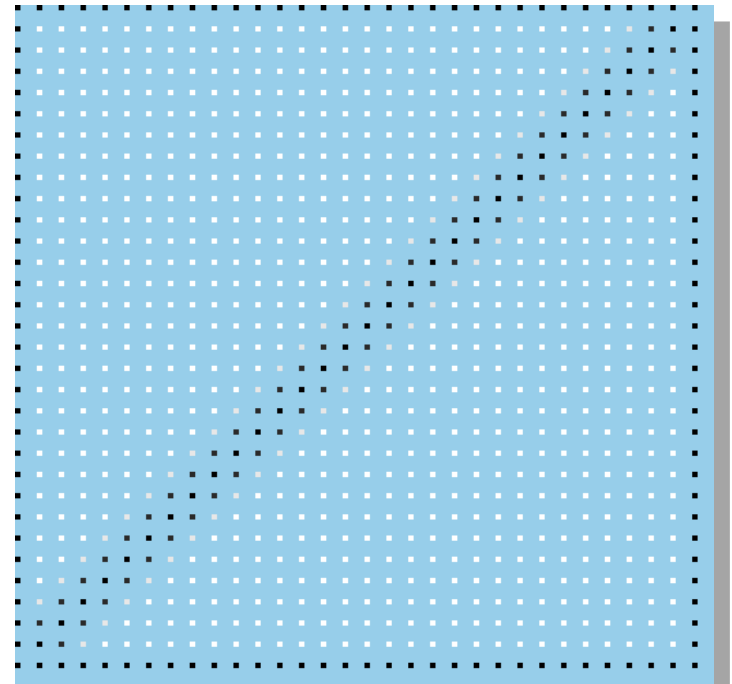


Enlarging an Image

Example:
zoom this
image 4x to
get this
image.

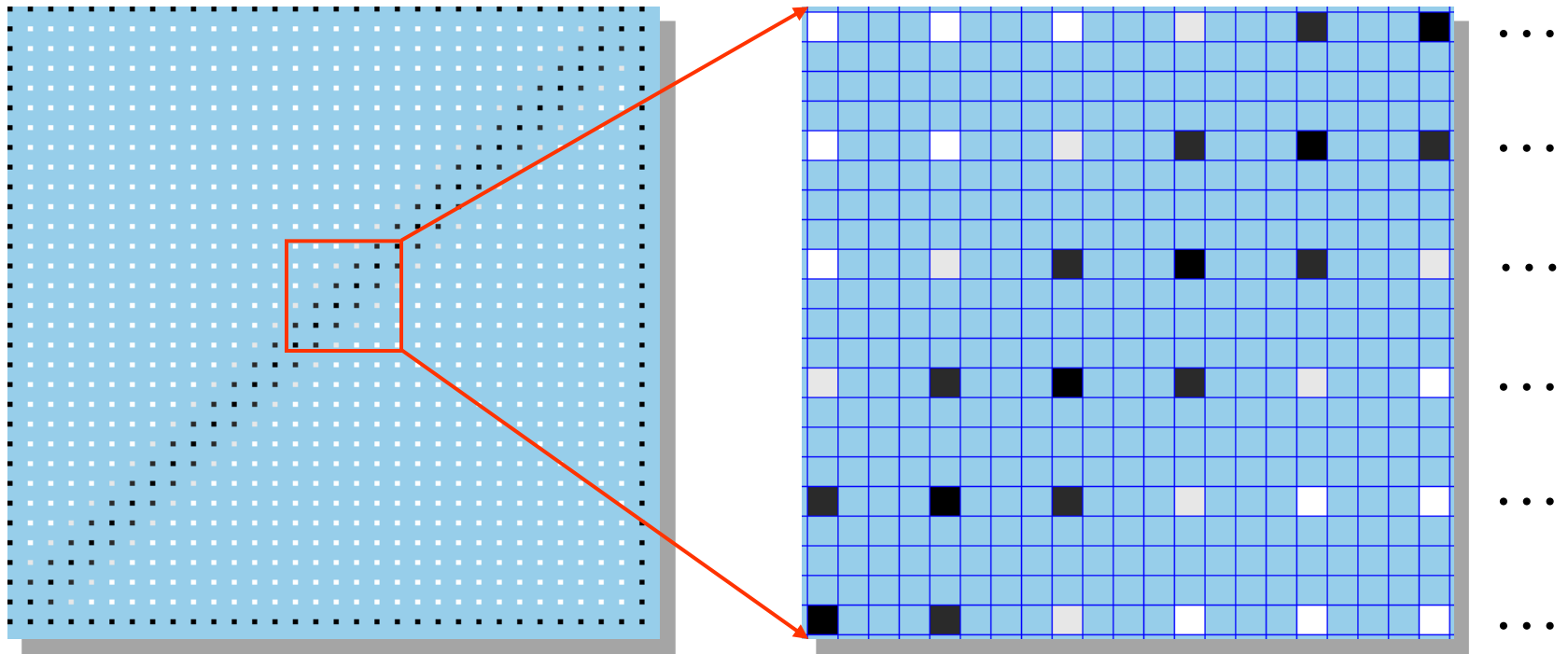


Start with a blank image 4 times the linear dimensions of the original.



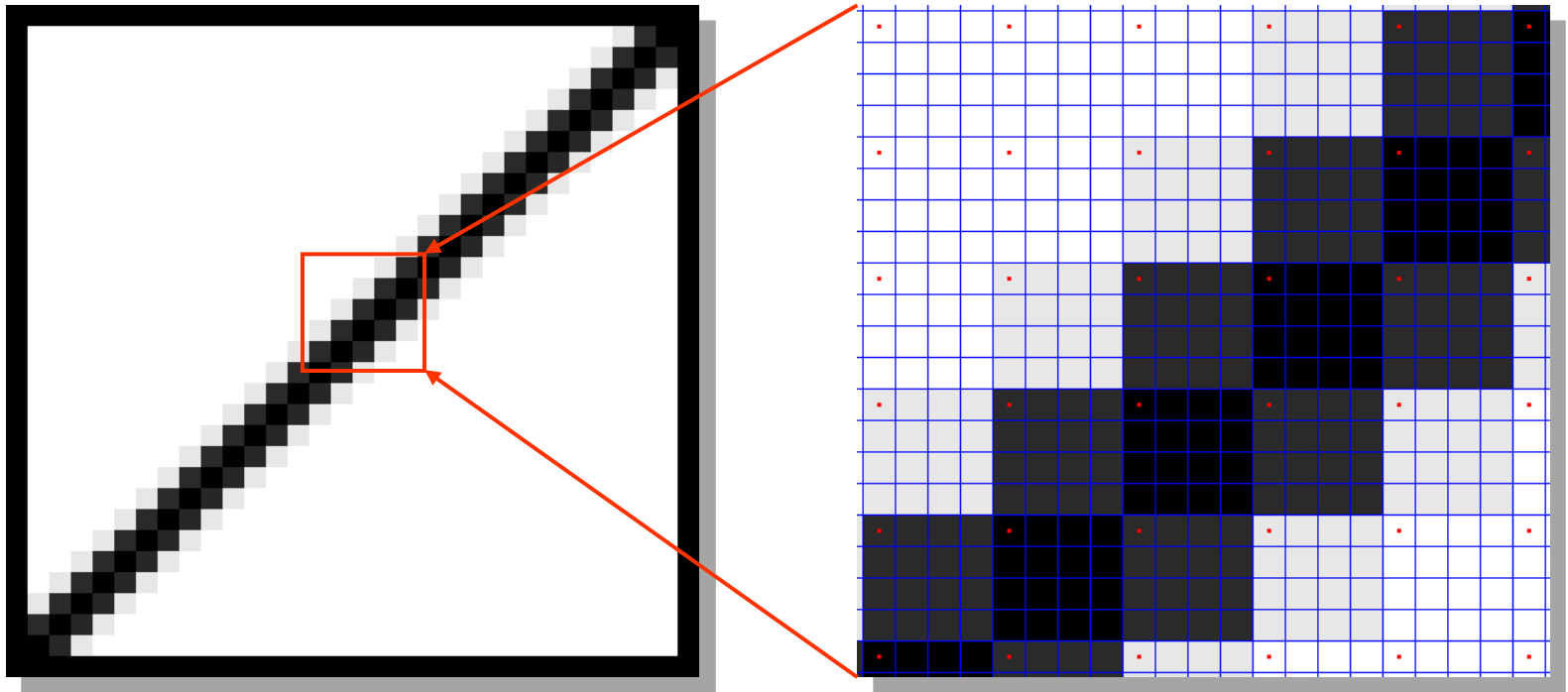
Fill in every 4th pixel in every 4th row with the original pixel values.

Enlarging an Image



Detail showing every 4th pixel in every 4th row with the original pixel values.

Enlarging an Image



Replicate the values

Image Interpolation

- ◆ Nearest neighbour interpolation
 - Simple but produces undesired artefacts
- ◆ Bilinear Interpolation
 - Contribution from 4 neighbors
- ◆ Bicubic Interpolation
 - Contribution from 16 neighbors

Interpolation: Comparison

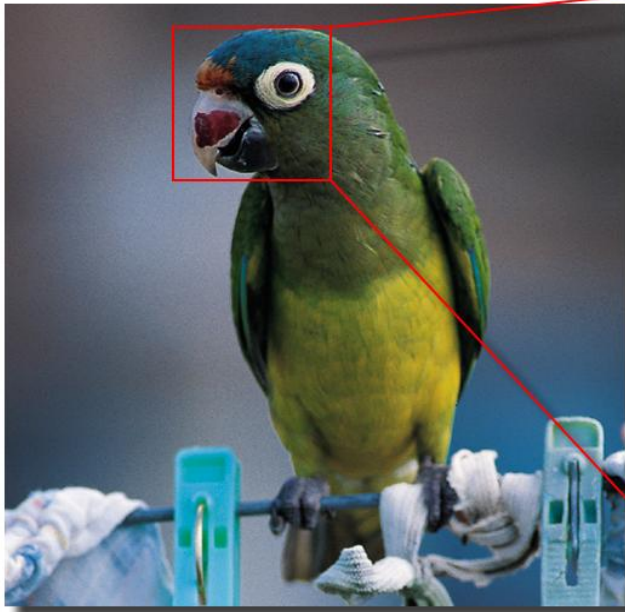


We'll enlarge this image by a factor of 4 ...

... via bilinear interpolation and compare it to a nearest neighbor enlargement.

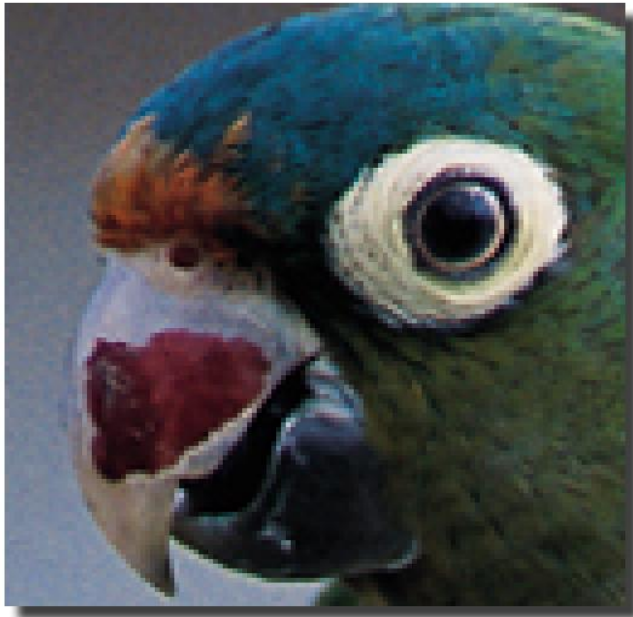
Interpolation: Comparison

Original
Image

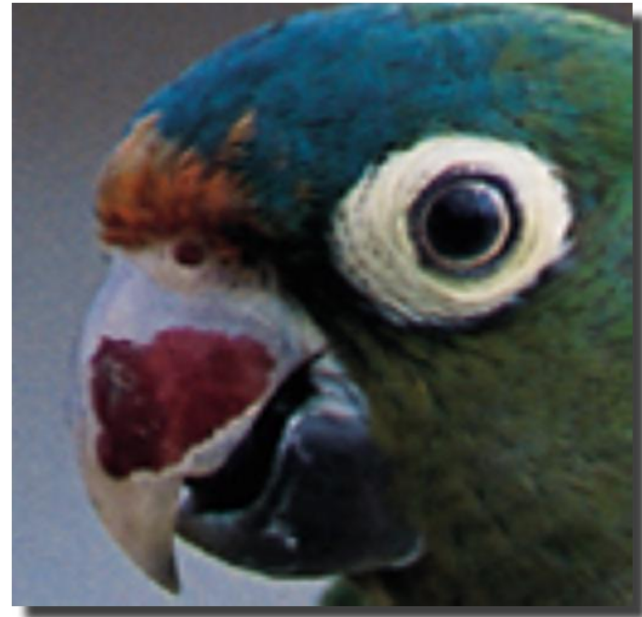


To better see what happens, we'll look at the parrot's eye.

Interpolation: Comparison

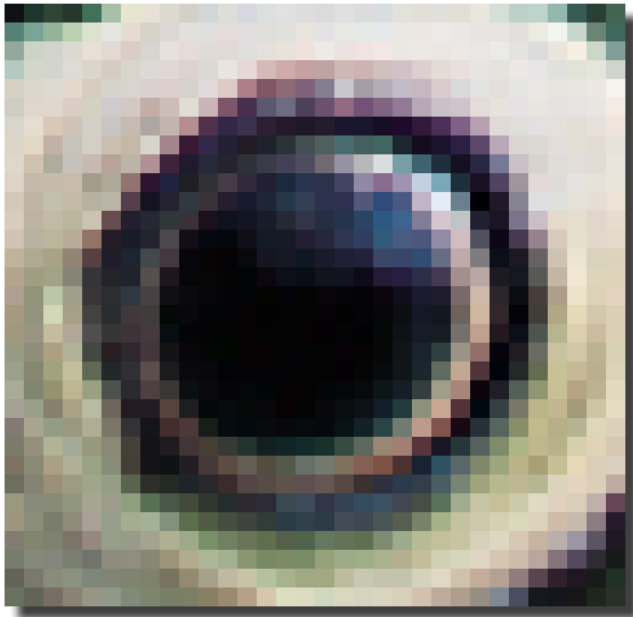


Pixel replication



Bilinear interpolation

Interpolation: Comparison



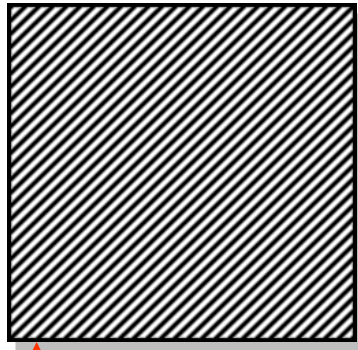
Pixel replication



Bilinear interpolation

Reducing an Image

- ◆ Pixel Decimation

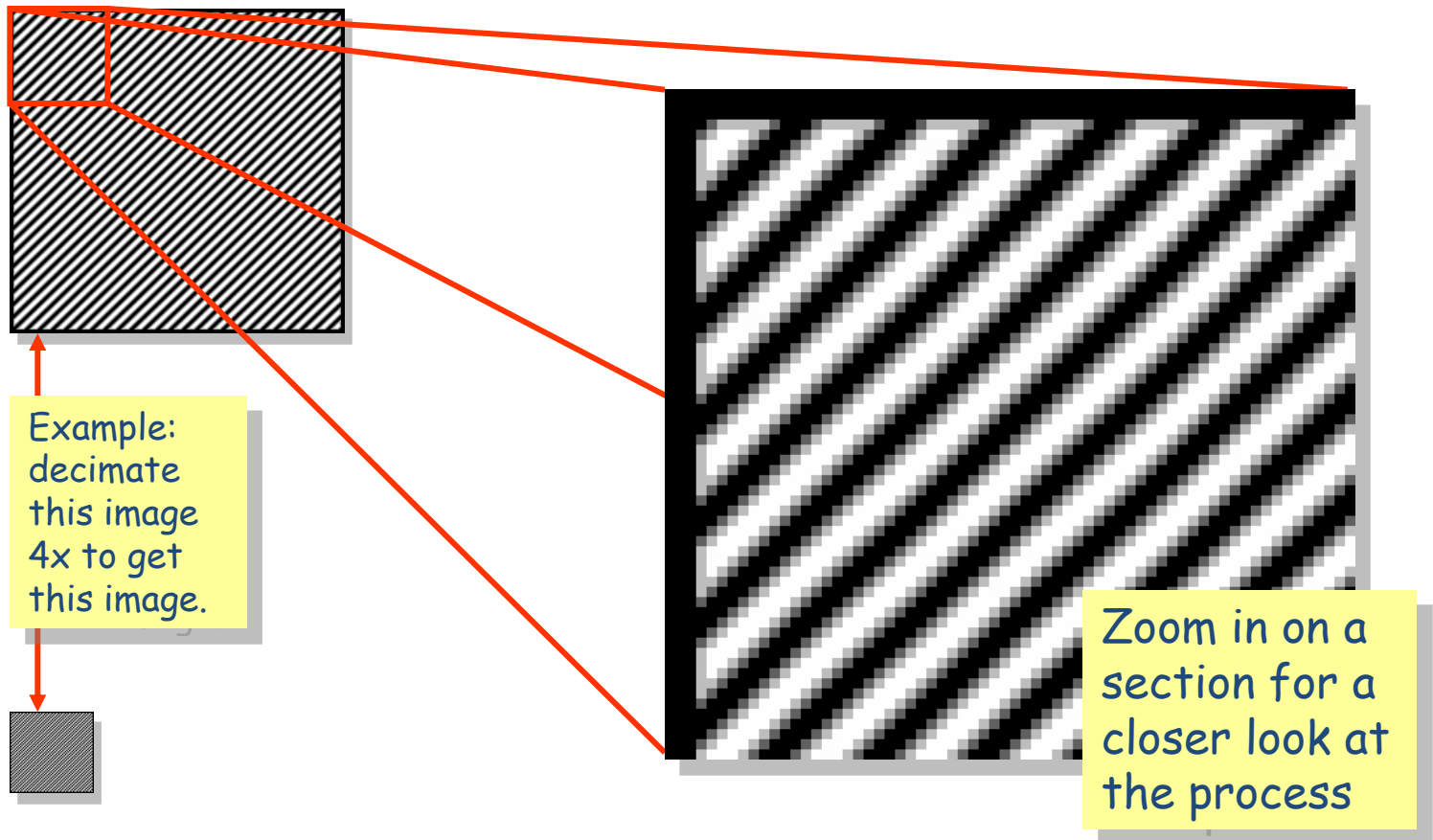


Example:
decimate
this image
4x to get
this image.

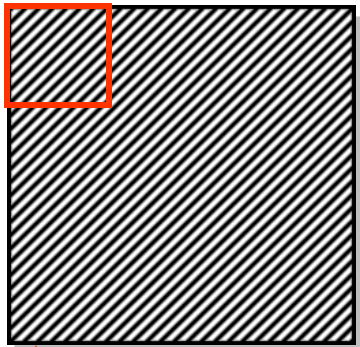


Decimation by
a factor of n :
take every n th
pixel in every
 n th row

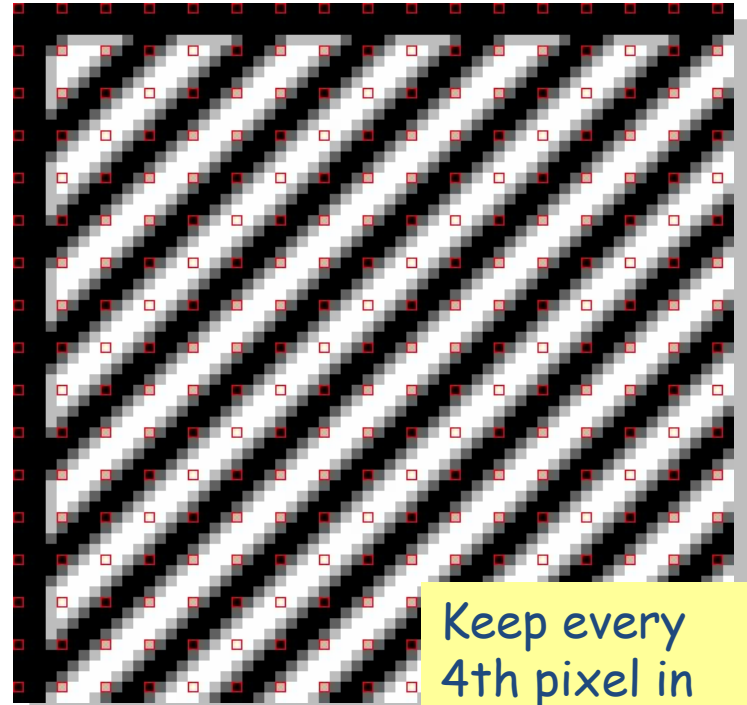
Reducing an Image



Reducing an Image

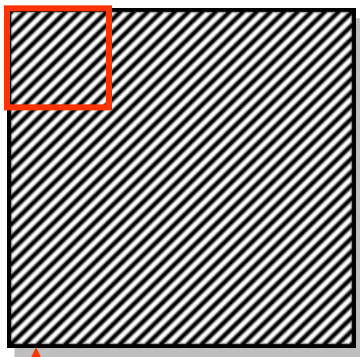


Example:
decimate
this image
4x to get
this image.

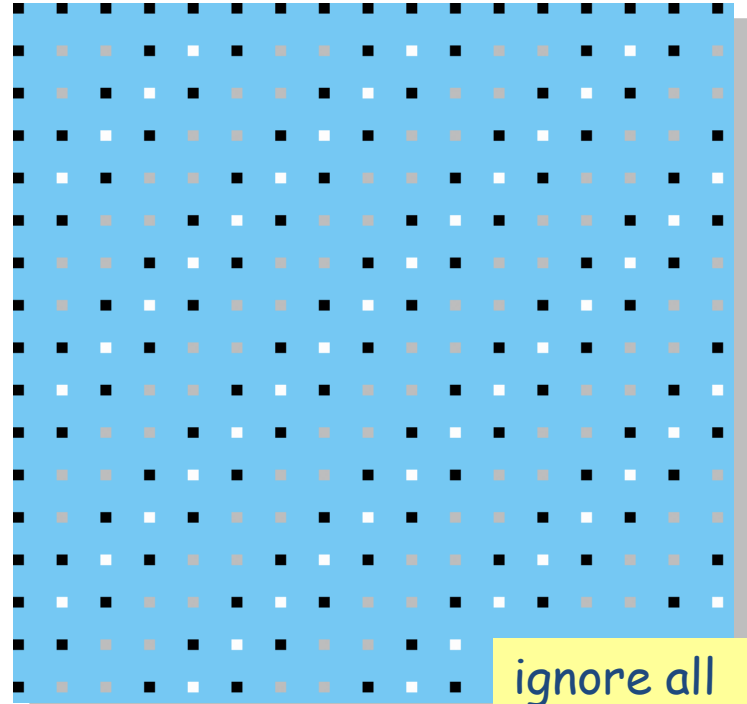
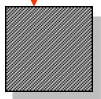


Keep every
4th pixel in
every 4th row

Reducing an Image

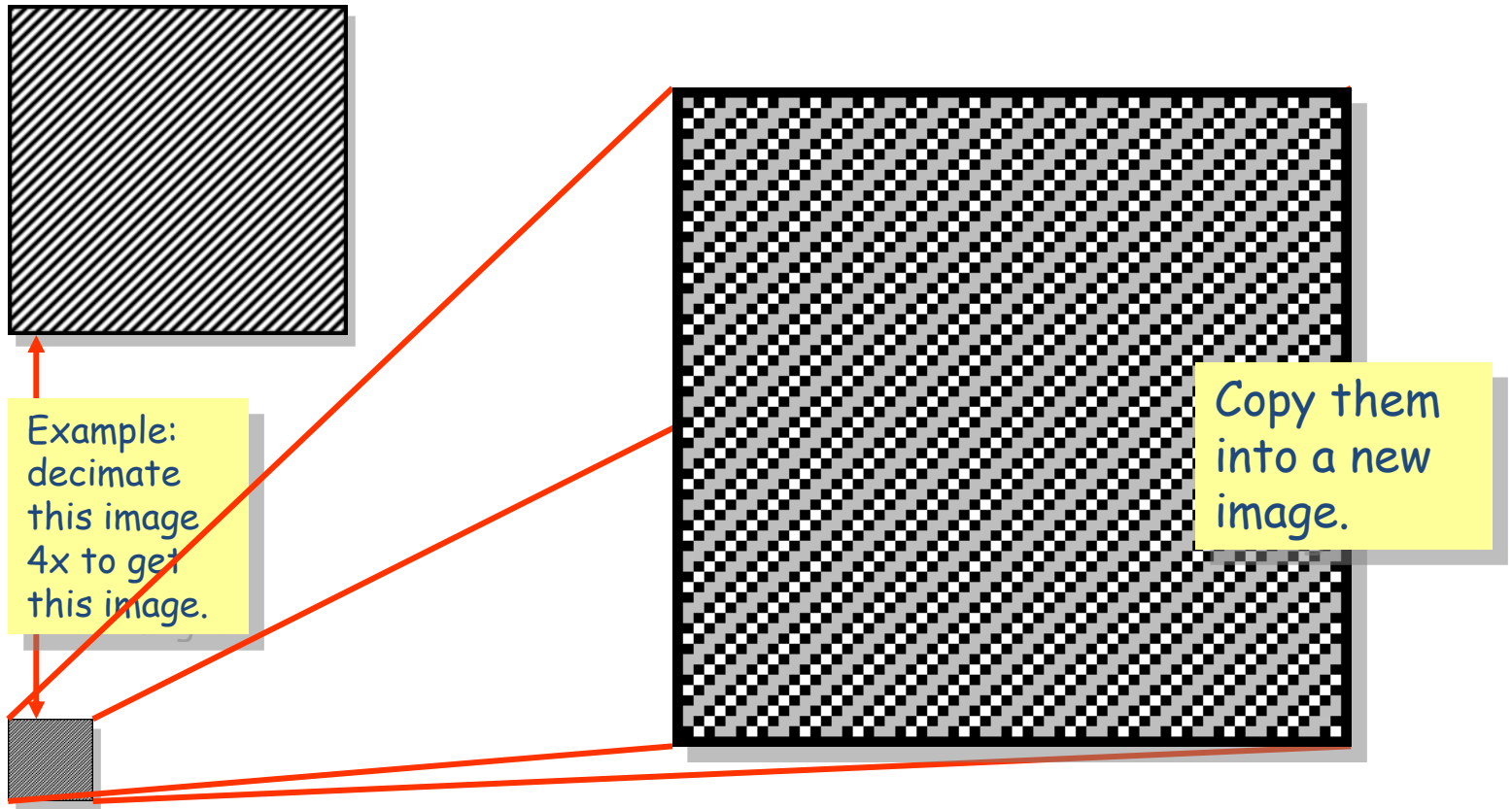


Example:
decimate
this image
4x to get
this image.



ignore all
the others

Reducing an Image



Readings from Book (3rd Edn.)

- 2.1.3 Brightness Adaptation
- 2.4 Image Sampling & Quantization
- 2.6 (Reading Assignment)



Acknowledgements

- ◆ Digital Image Processing”, Rafael C. Gonzalez & Richard E. Woods, Addison-Wesley, 2009
- ◆ Machine Vision: Automated Visual Inspection and Robot Vision”, David Vernon, Prentice Hall, 1991