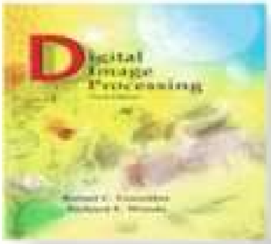

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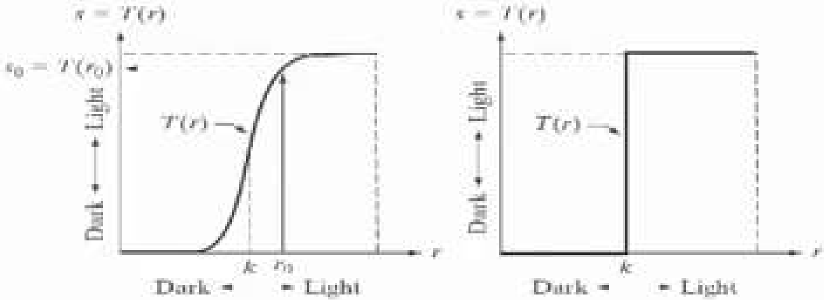
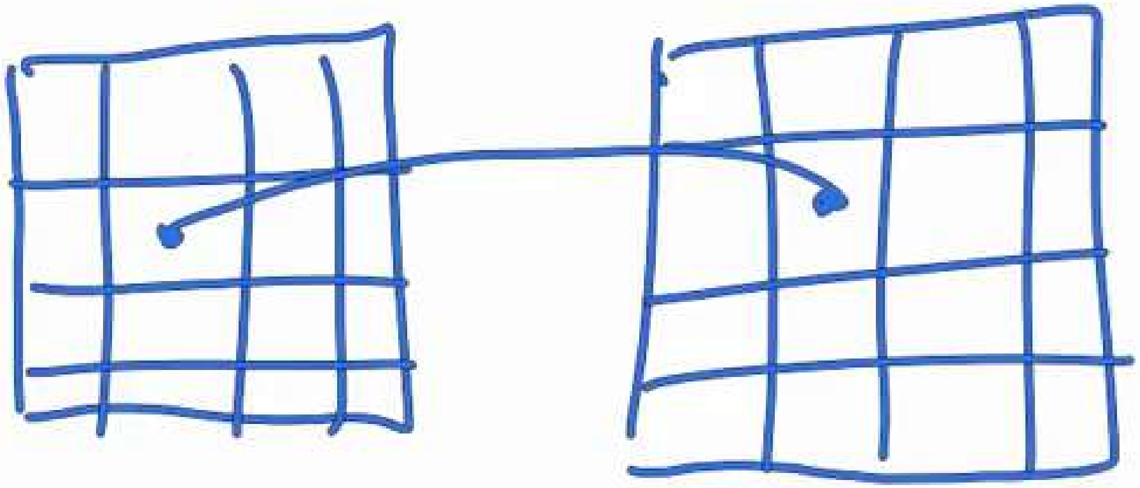
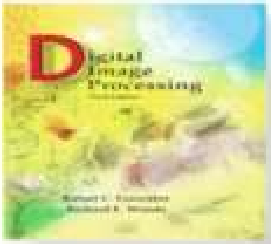


a b

FIGURE 3.2 Intensity transformation functions. (a) Contrast-stretching function. (b) Thresholding function.





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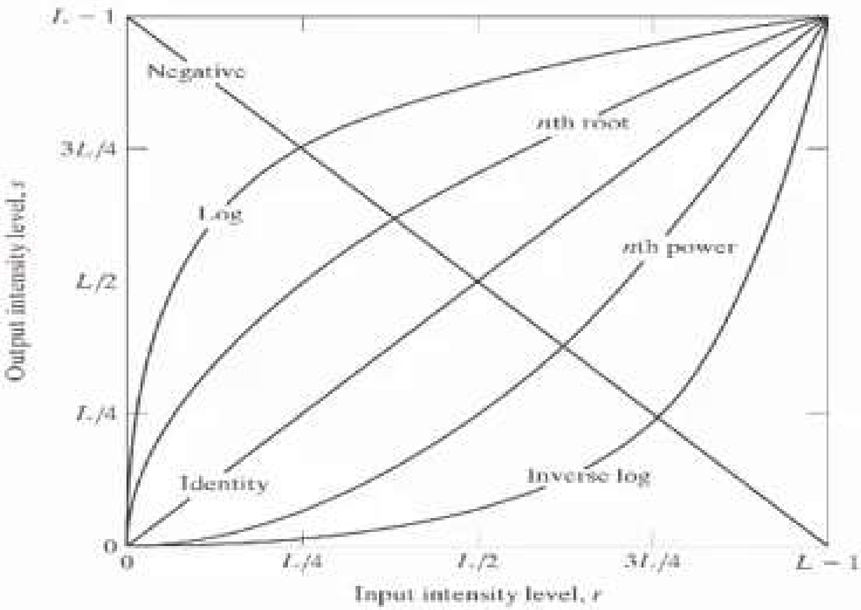


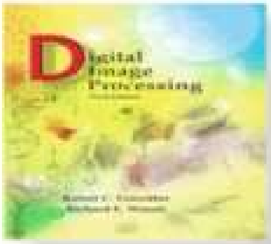
$$s = r$$

$$s = c\log(r+1)$$

$$[0 \,..\, L]$$

$$s = f(r)$$

$$s = L - r$$



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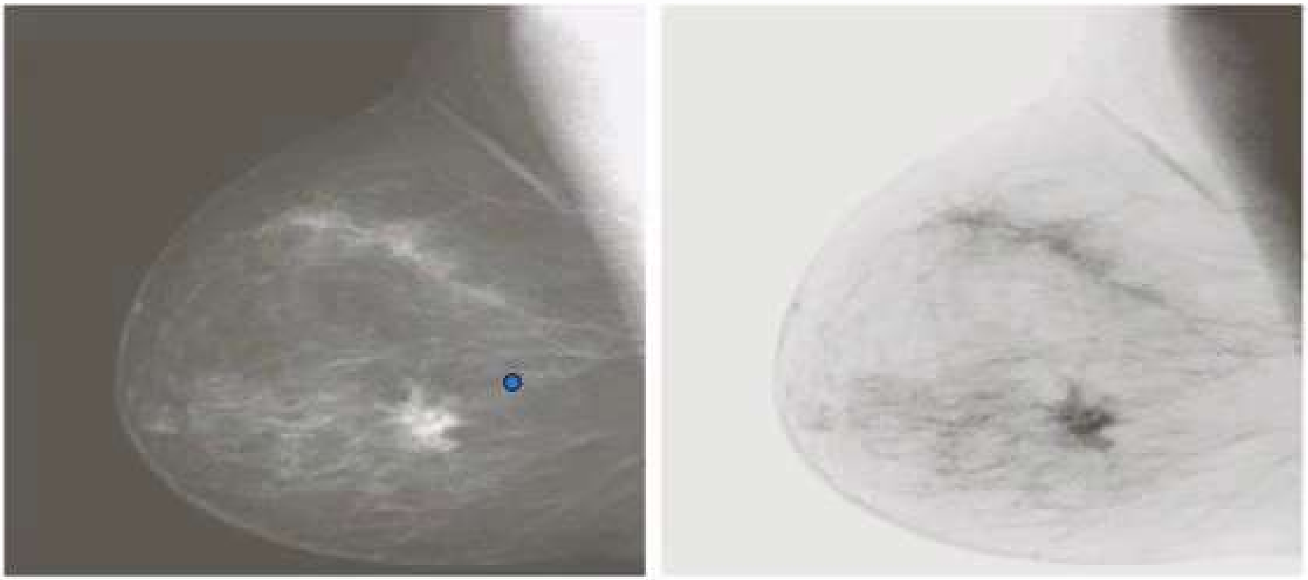

a b

FIGURE 3.4
(a) Original digital mammogram.
(b) Negative image obtained using the negative transformation in Eq. (3.2-1).
(Courtesy of G.E. Medical Systems.)

$$s = L - r$$

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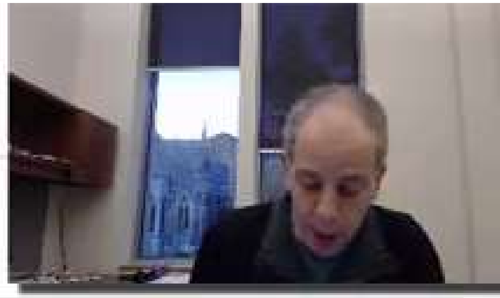


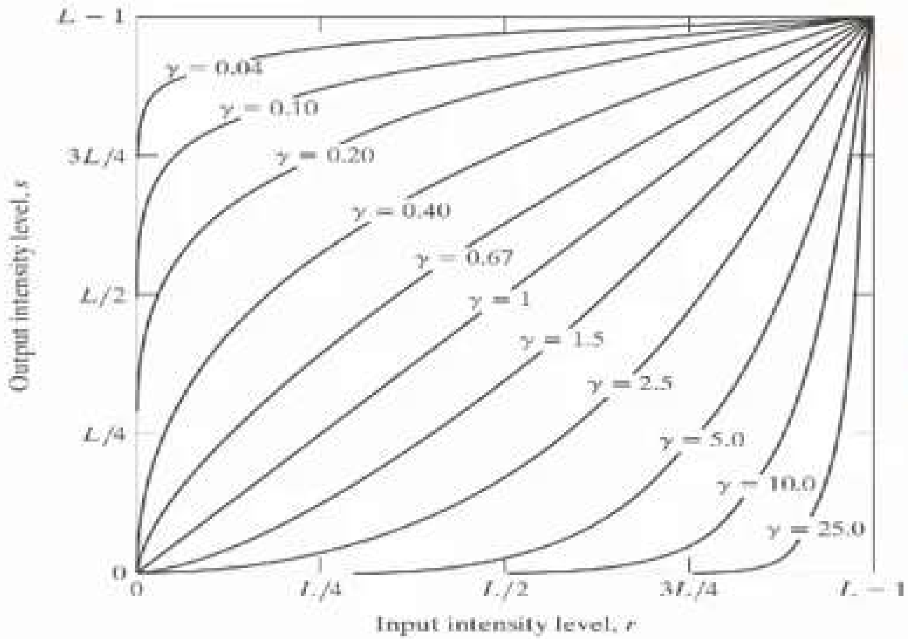
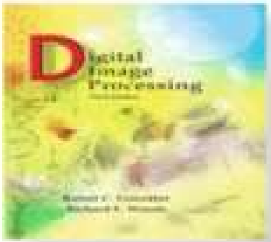


FIGURE 3.6 Plots of the equation $s = cr^{\gamma}$ for various values of γ ($c = 1$ in all cases). All curves were scaled to fit in the range shown.

$$s = c r^{\gamma}$$



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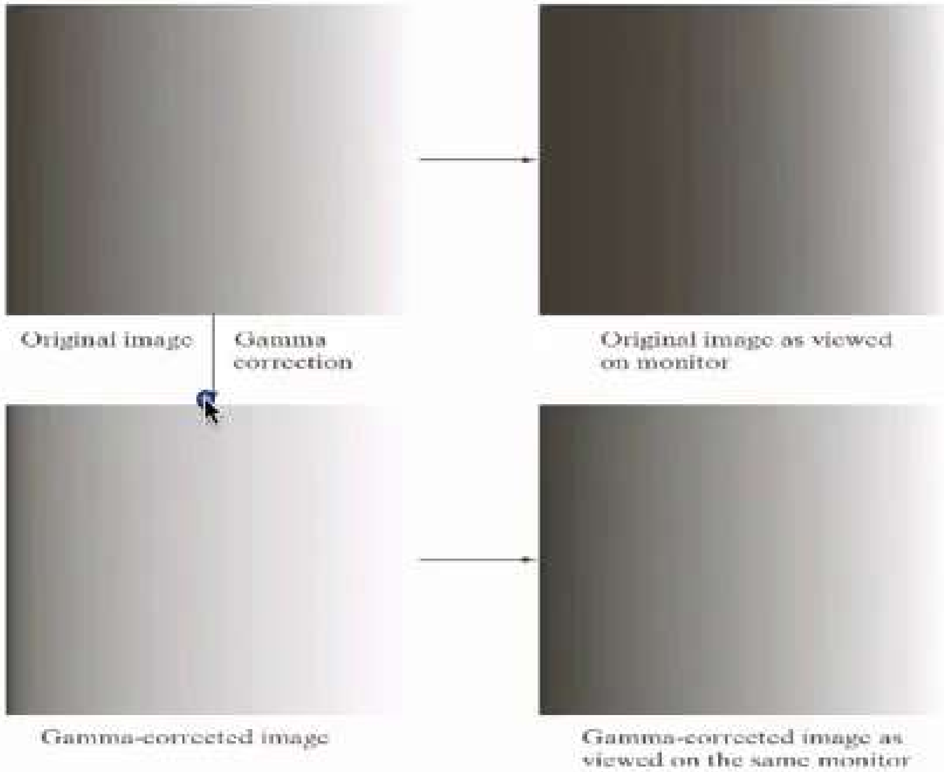

a b
c d

FIGURE 3.7 (a) Intensity ramp image. (b) Image as viewed on a simulated monitor with a gamma of 2.5. (c) Gamma-corrected image. (d) Corrected image as viewed on the same monitor. Compare (d) and (a).

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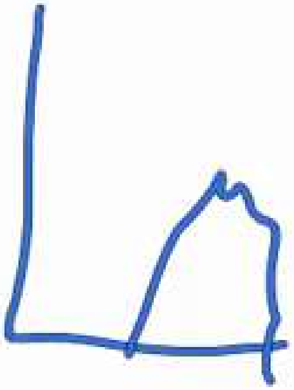

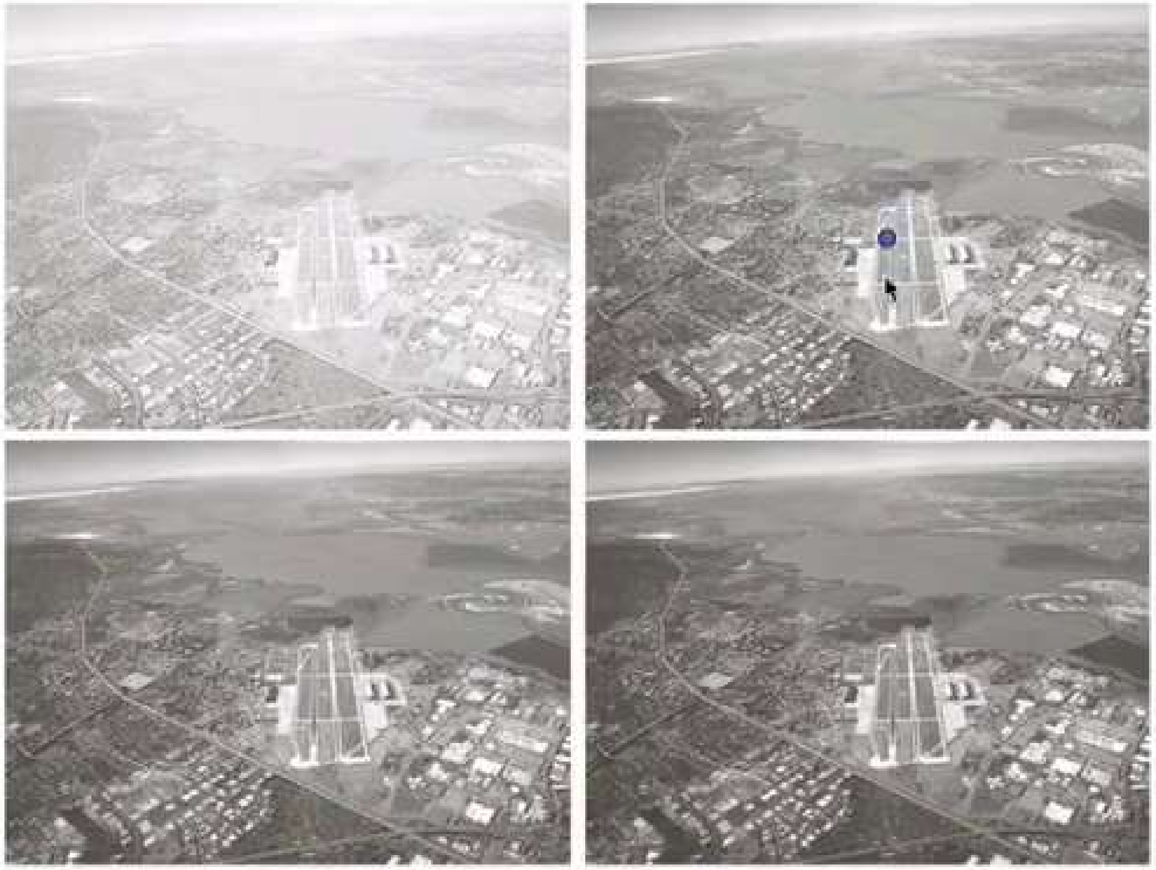

a b
c d

FIGURE 3.9 (a) Aerial image. (b)–(d) Results of applying the transformation in Eq. (3.2-3) with $c = 1$ and $\gamma = 3.0, 4.0$, and 5.0, respectively. (Original image for this example courtesy of NASA.)

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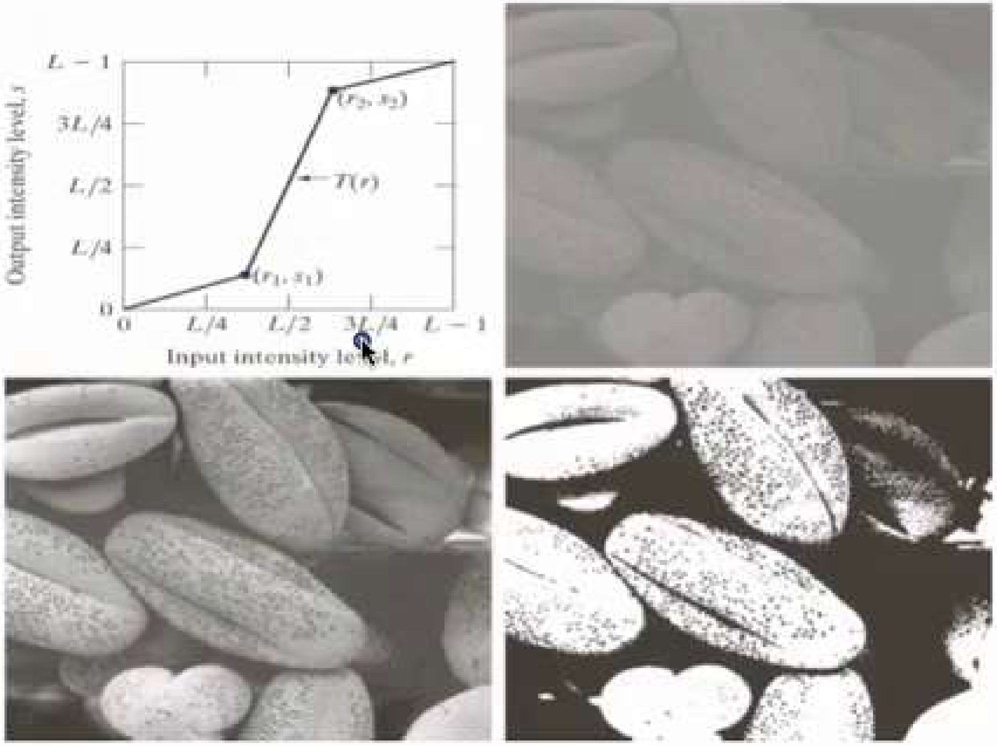

a b
c d

FIGURE 3.10 Contrast stretching. (a) Form of transformation function. (b) A low-contrast image. (c) Result of contrast stretching. (d) Result of thresholding. (Original image courtesy of Dr. Roger Heady, Research School of Biological Sciences, Australian National University, Canberra, Australia.)

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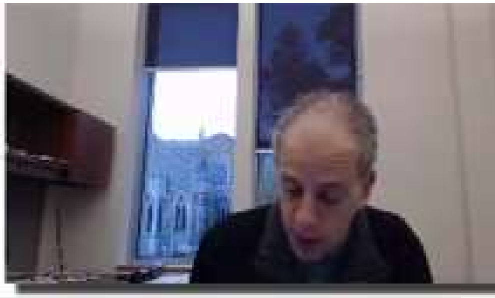
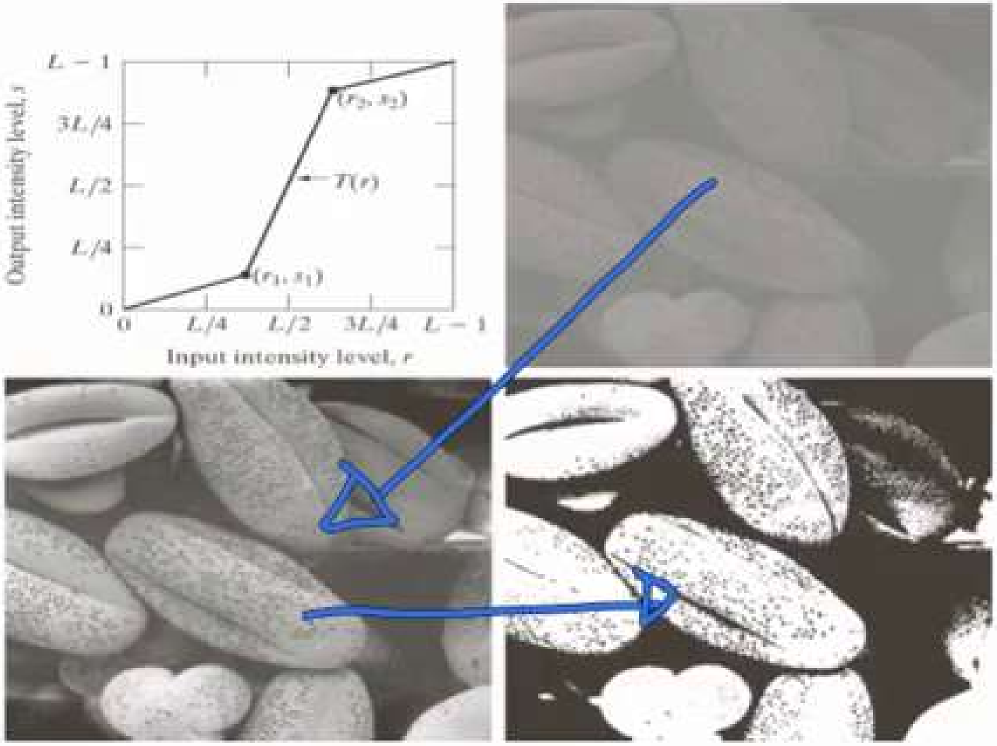
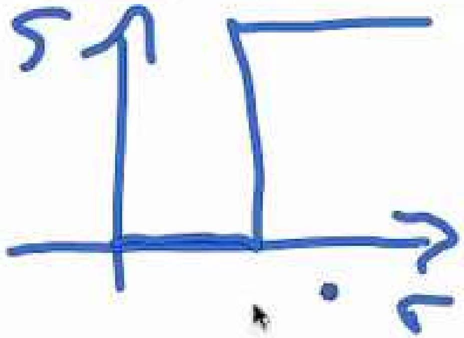
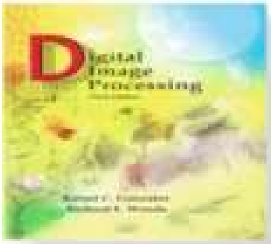


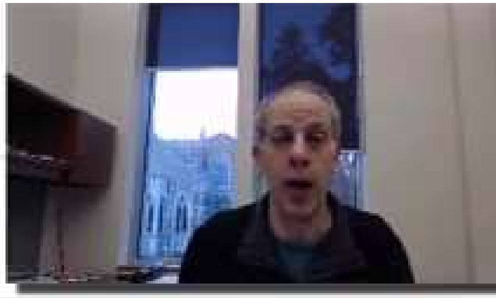


a b
c d

FIGURE 3.10 Contrast stretching. (a) Form of transformation function. (b) A low-contrast image. (c) Result of contrast stretching. (d) Result of thresholding. (Original image courtesy of Dr. Roger Heady, Research School of Biological Sciences, Australian National University, Canberra, Australia.)







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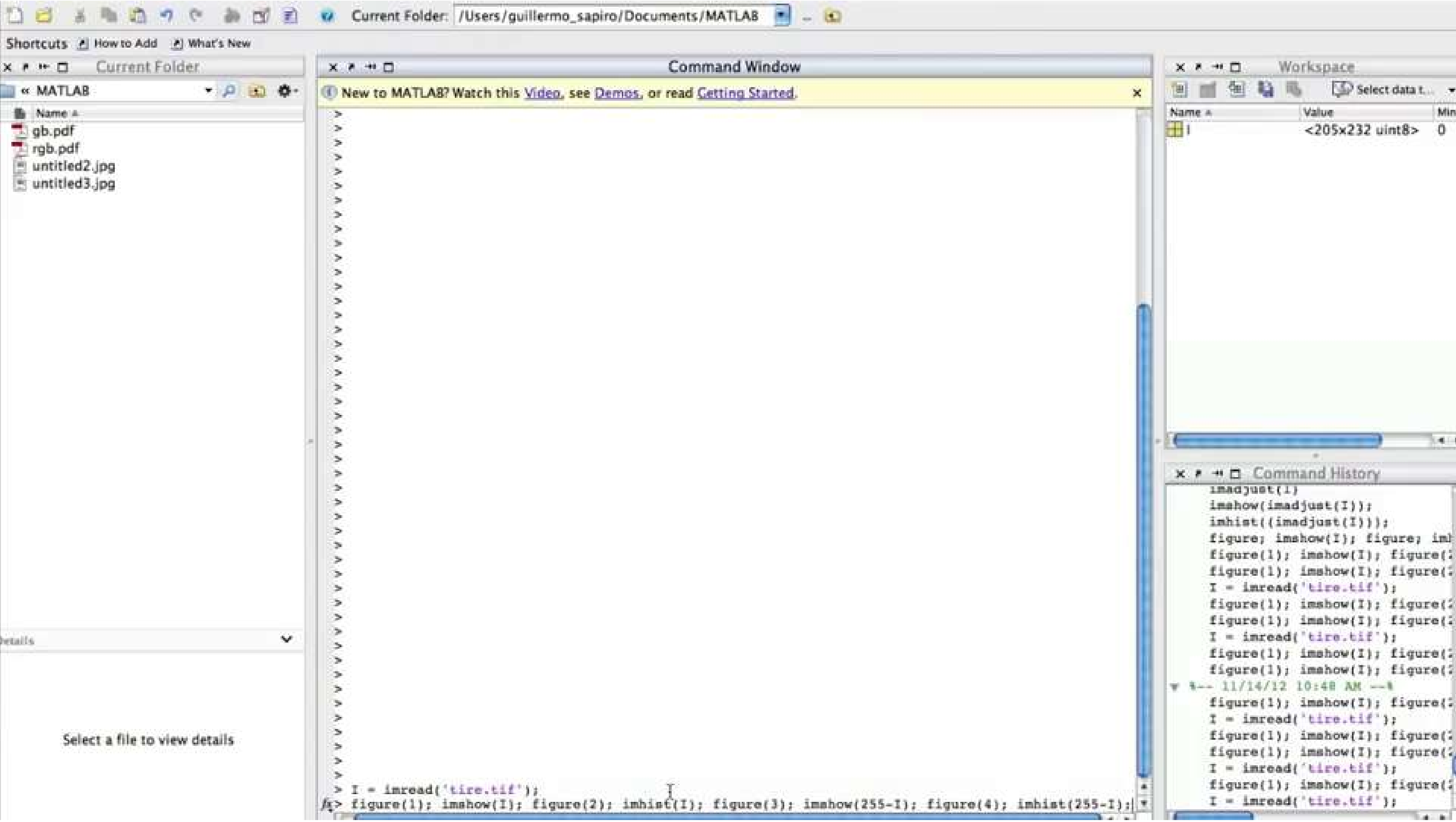
a b c

FIGURE 3.12 (a) Aortic angiogram. (b) Result of using a slicing transformation of the type illustrated in Fig. 3.11(a), with the range of intensities of interest selected in the upper end of the gray scale. (c) Result of using the transformation in Fig. 3.11(b), with the selected area set to black, so that grays in the area of the blood vessels and kidneys were preserved. (Original image courtesy of Dr. Thomas R. Gest, University of Michigan Medical School.)


Current Folder: /Users/guillermo_sapiro/Documents/MATLAB
Shortcuts
How to Add
What's New
Current Folder
MATLAB
Name
gb.pdf
rgb.pdf
untitled2.jpg
untitled3.jpg
Details
Select a file to view details
Command Window
New to MATLAB? Watch this Video, see Demos, or read Getting Started.
> I = imread('tire.tif');
> figure(1); imshow(I); figure(2); imhist(I); figure(3); imshow(255-I); figure(4); imhist(255-I);
Workspace
Select data t...
Name
Value
I
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0
Command History
imshow(imadjust(I));
imhist((imadjust(I)));
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figure(1); imshow(I); figure(
I = imread('tire.tif');
%-- 11/14/12 10:48 AM --%

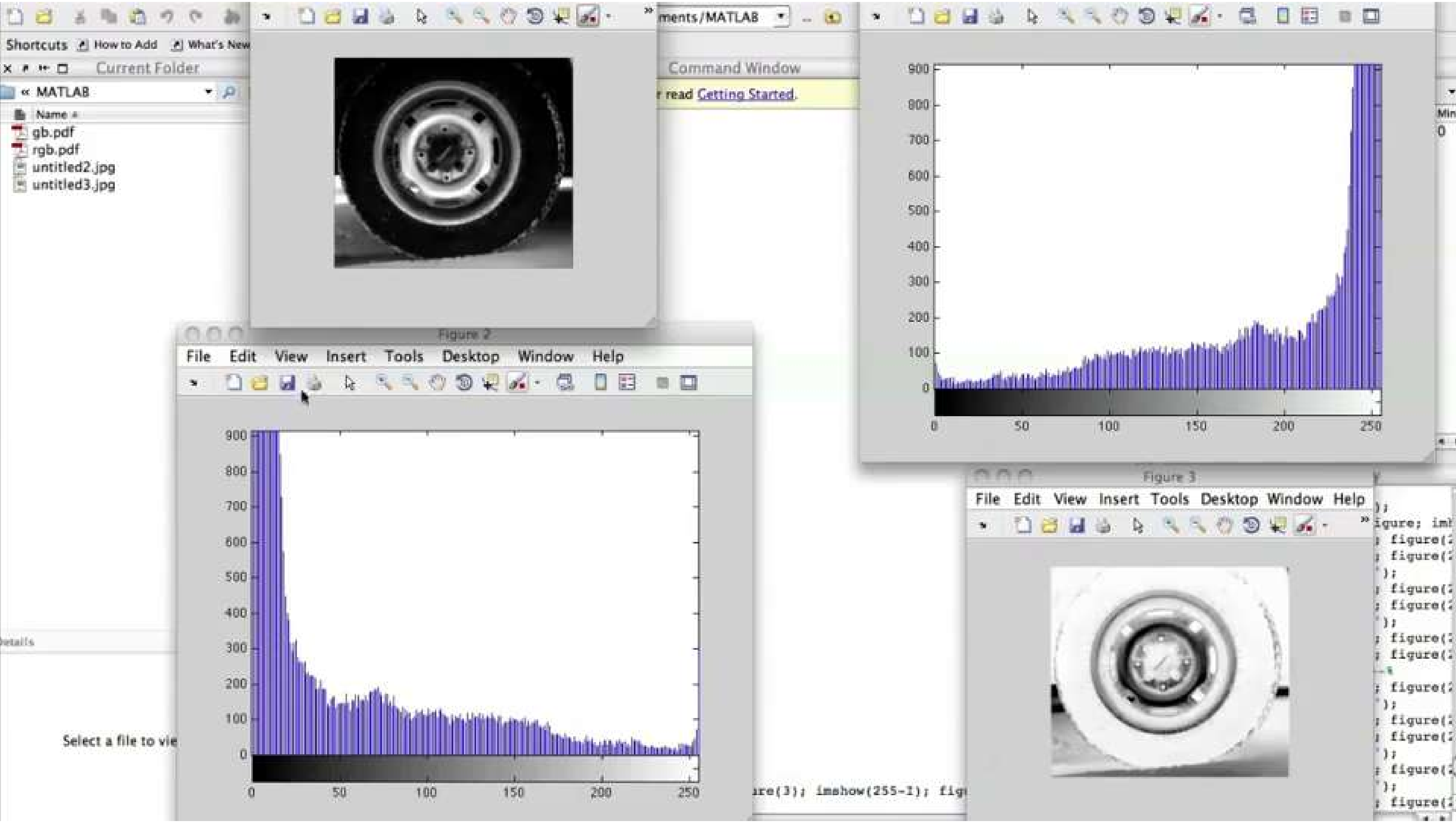
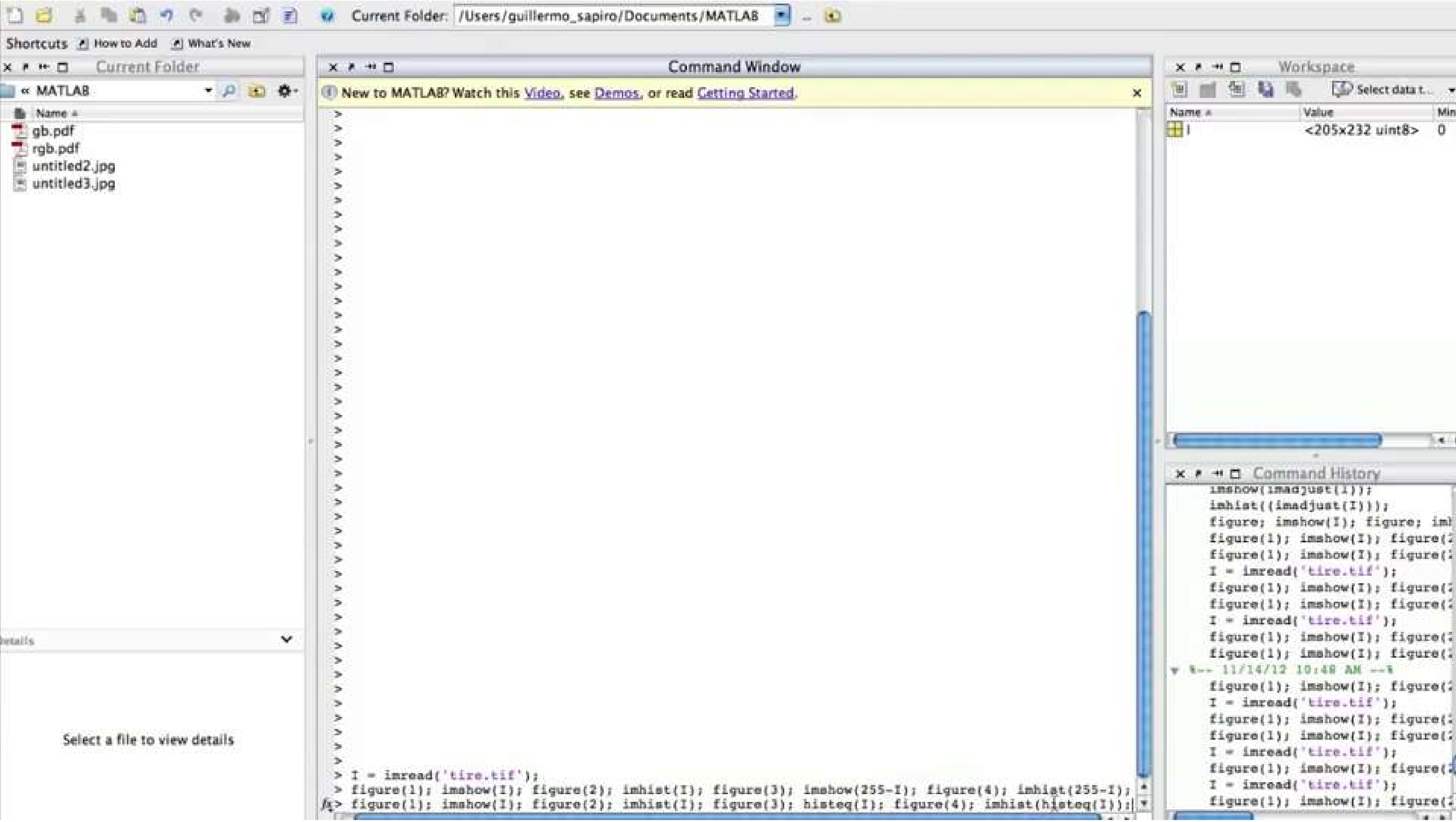


Figure 2
File Edit View Insert Tools Desktop Window Help
Figure 3
Command Window
Current Folder
MATLAB
gb.pdf
rgb.pdf
untitled2.jpg
untitled3.jpg
Select a file to vie


Current Folder: /Users/guillermo_sapiro/Documents/MATLAB
Shortcuts
How to Add
What's New
Current Folder
MATLAB
Name
gb.pdf
rgb.pdf
untitled2.jpg
untitled3.jpg
Select a file to view details
Command Window
New to MATLAB? Watch this Video, see Demos, or read Getting Started.
> I = imread('tire.tif');
> figure(1); imshow(I); figure(2); imhist(I); figure(3); imshow(255-I); figure(4); imhist(255-I);
> figure(1); imshow(I); figure(2); imhist(I); figure(3); histeq(I); figure(4); imhist(histeq(I));
Workspace
Name
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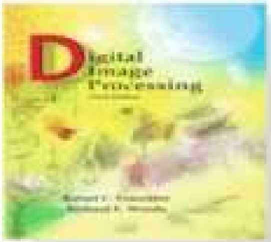
Command History
imhist((imadjust(I)));
I = imread('tire.tif');
%-- 11/14/12 10:48 AM --%



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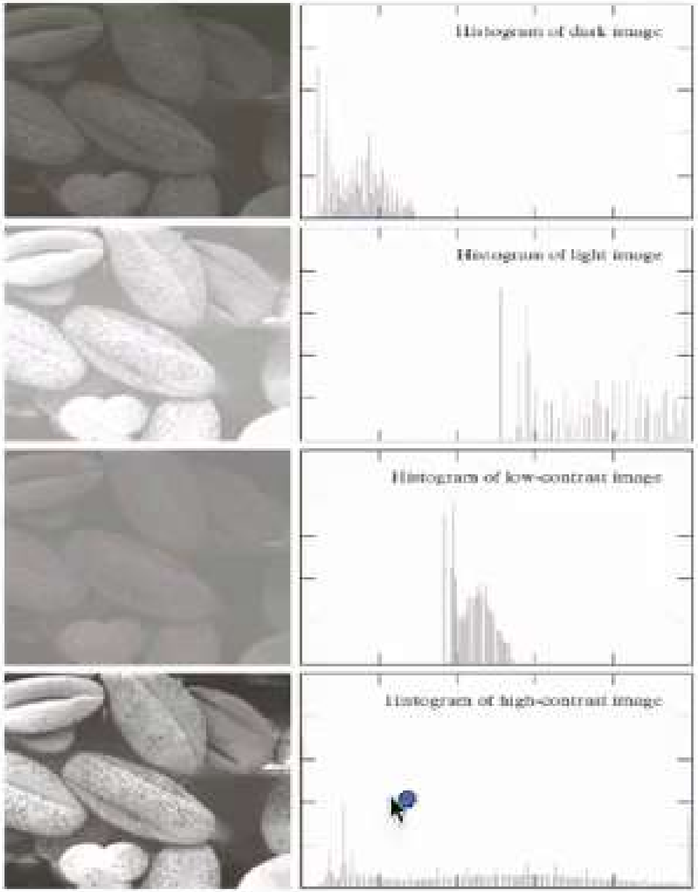
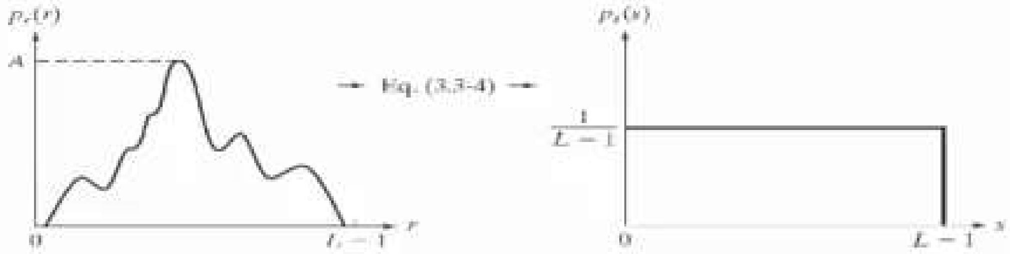


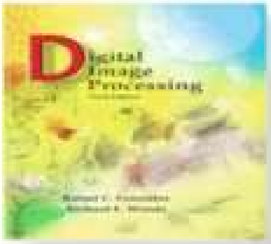
FIGURE 3.16 Four basic image types: dark, light, low contrast, high contrast, and their corresponding histograms.

Histogram Equalization



a b

FIGURE 3.18 (a) An arbitrary PDF. (b) Result of applying the transformation in Eq. (3.3-4) to all intensity levels, r. The resulting intensities, s, have a uniform PDF, independently of the form of the PDF of the r's.



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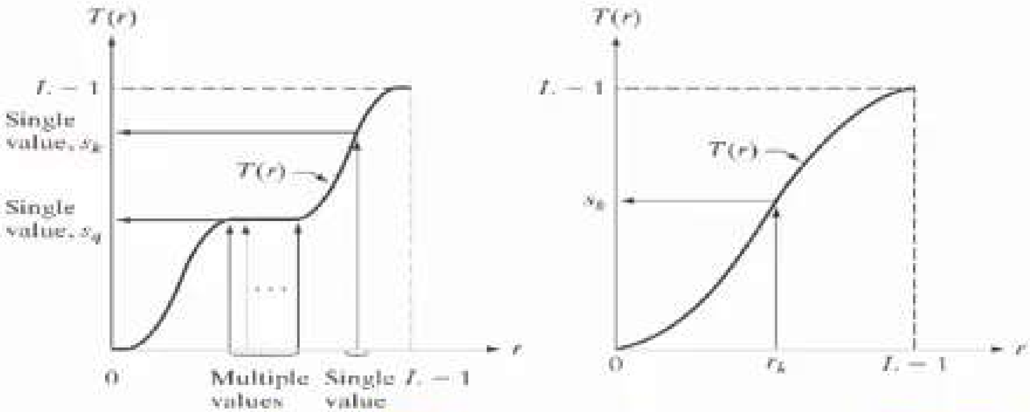
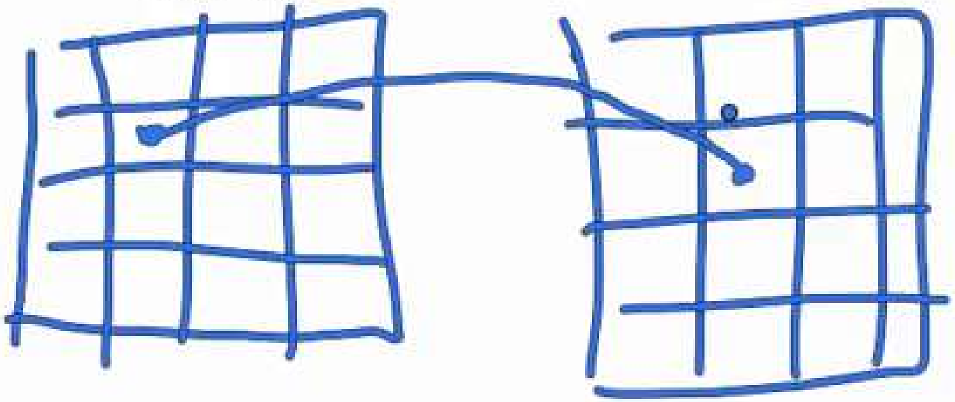


a b

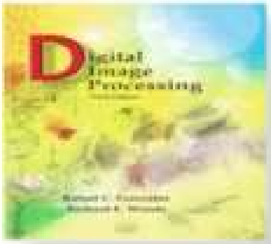
FIGURE 3.17 (a) Monotonically increasing function, showing how multiple values can map to a single value. (b) Strictly monotonically increasing function. This is a one-to-one mapping, both ways.



$$s = T(r) \qquad p_s(s) = p_r(r)\left|\frac{dr}{ds}\right|$$

$$s = T(r) = (L-1)\int^{r} p_r(w)\,dw$$

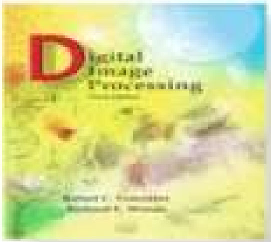
$$\frac{ds}{dr} = \frac{dT(r)}{dr} = \frac{d(L-1)\int_0^{r} p_r(w)\,dw}{dr}$$



$$p_s(s) = p_r(r)\left|\frac{dr}{ds}\right| =$$

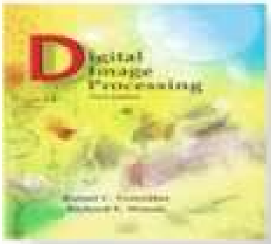
$$= p_r(r)\left|\frac{1}{(L-1)\,p_r(r)}\right| = \frac{1}{L-1}$$

$$s = T(r) = (L-1)\int_0^r p_r(w)\,dw$$



r_k	n_k	$p_r(r_k) = n_k/MN$
$r_0 = 0$	790	0.19
$r_1 = 1$	1023	0.25
$r_2 = 2$	850	0.21
$r_3 = 3$	656	0.16
$r_4 = 4$	329	0.08
$r_5 = 5$	245	0.06
$r_6 = 6$	122	0.03
$r_7 = 7$	81	0.02

TABLE 3.1 Intensity distribution and histogram values for a 3-bit, 64×64 digital image.



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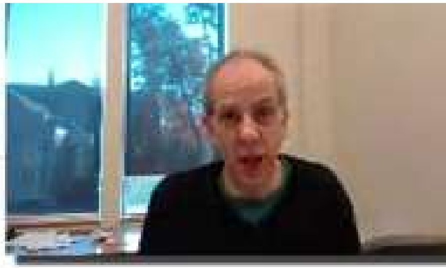

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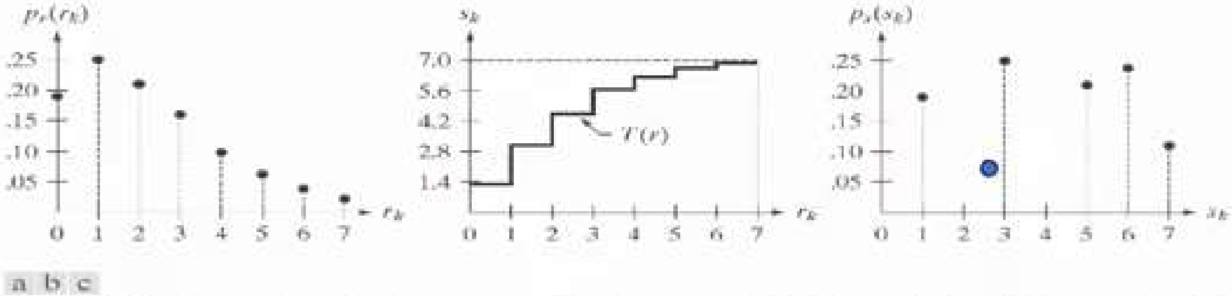

FIGURE 3.19 Illustration of histogram equalization of a 3-bit (8 intensity levels) image. (a) Original histogram. (b) Transformation function. (c) Equalized histogram.

$$\int_0^r p_r(w)\,dw$$

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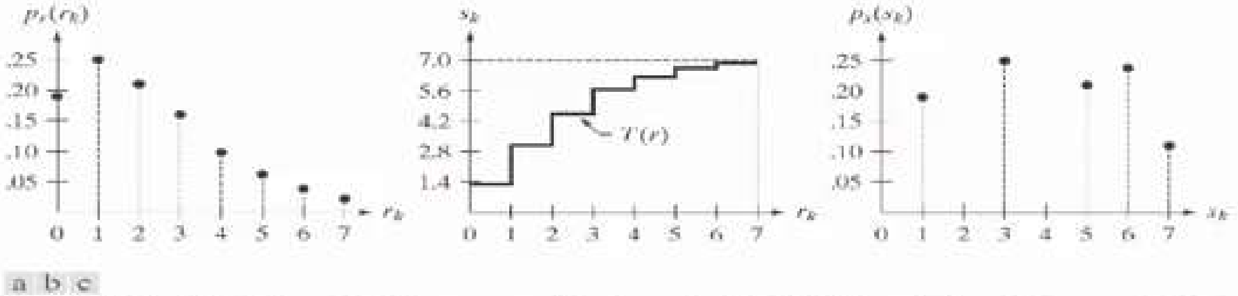
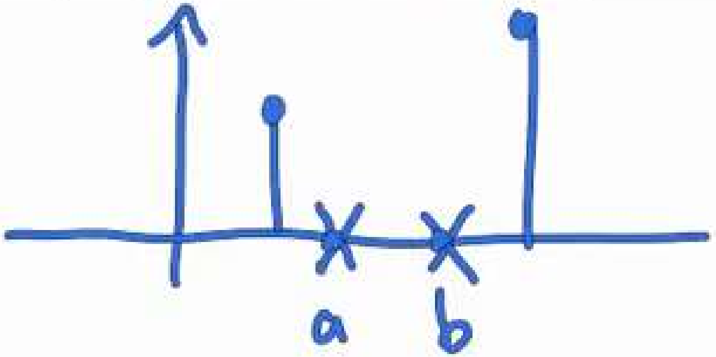
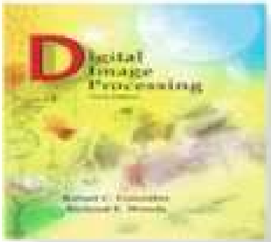


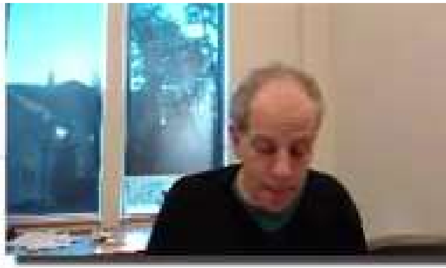
FIGURE 3.19 Illustration of histogram equalization of a 3-bit (8 intensity levels) image. (a) Original histogram. (b) Transformation function. (c) Equalized histogram.



$$T(a) \overset{?}{\substack{= \\ < \\ >}} T(b)$$

$$T(a) = T(b)$$





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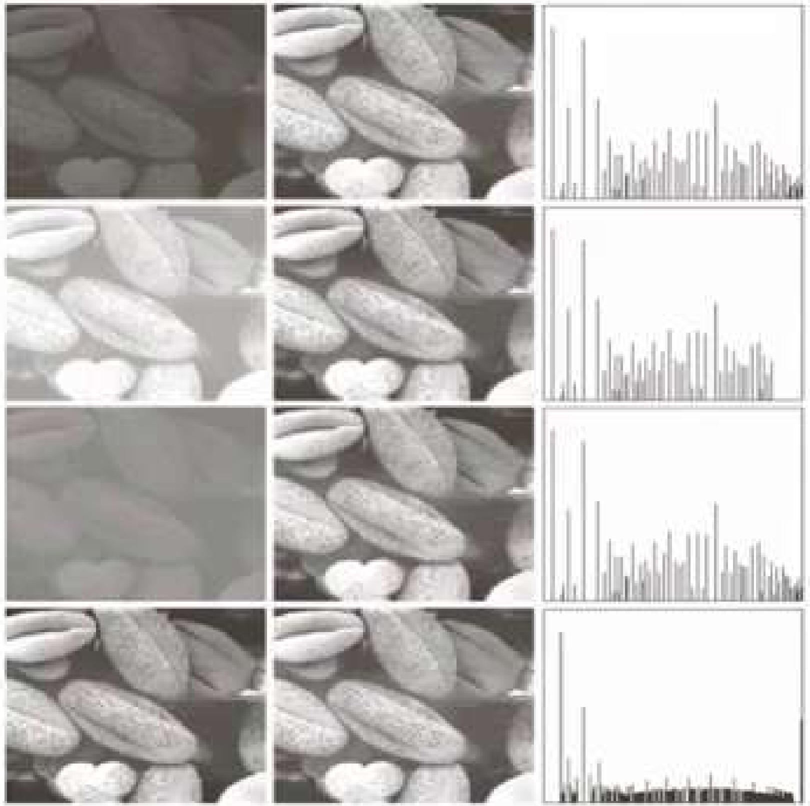


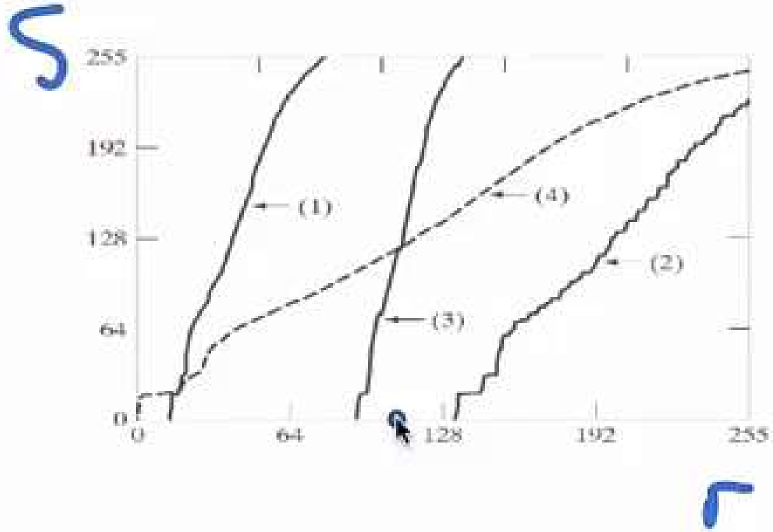
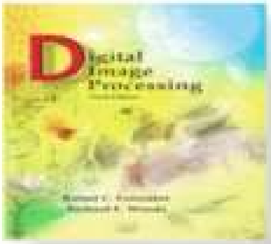
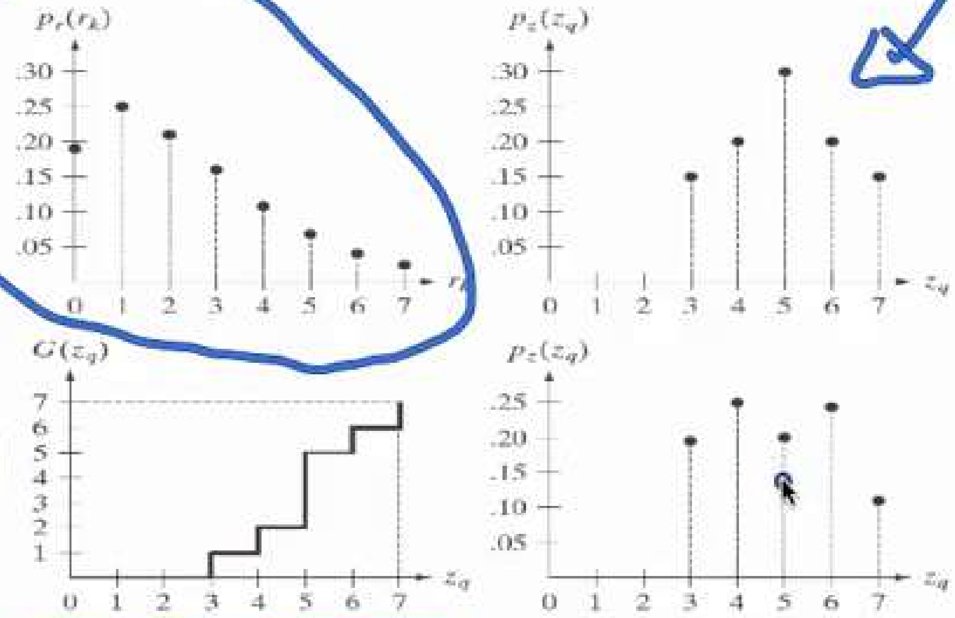


FIGURE 3.20 Left column: images from Fig. 3.16. Center column: corresponding histogram-equalized images. Right column: histograms of the images in the center column.



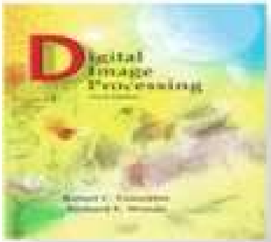
Histogram Matching

T(r)



a b
c d

FIGURE 3.22 (a) Histogram of a 3-bit image. (b) Specified histogram. (c) Transformation function obtained from the specified histogram. (d) Result of performing histogram specification. Compare (b) and (d).



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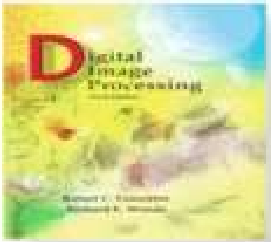
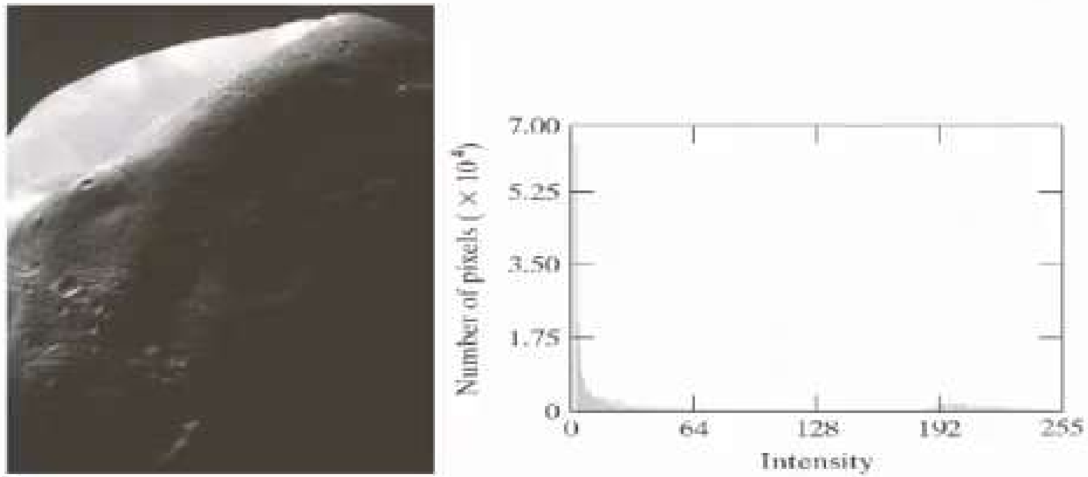
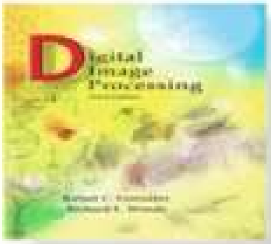
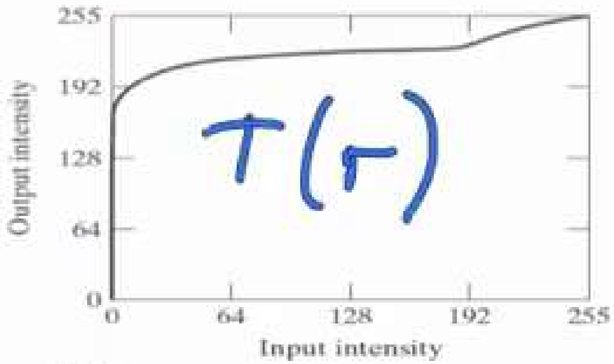




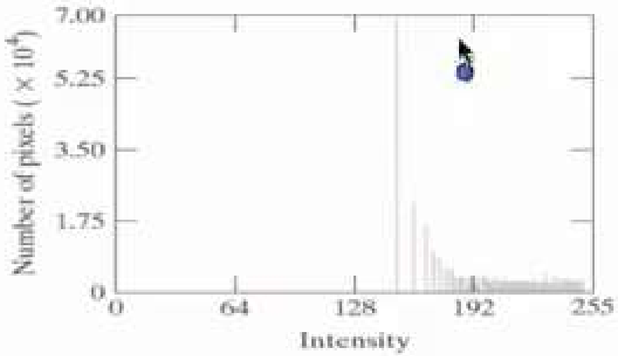
a b

FIGURE 3.23 (a) Image of the Mars moon Phobos taken by NASA's *Mars Global Surveyor.* (b) Histogram. (Original image courtesy of NASA.)

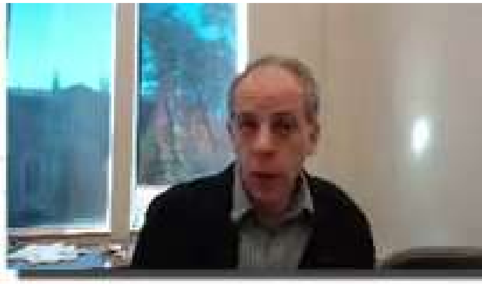




255
192
128
64
0
Output intensity
0
64
128
192
255
Input intensity
T(r)



7.00
5.25
3.50
1.75
0
Number of pixels (× 10^4)
0
64
128
192
255
Intensity



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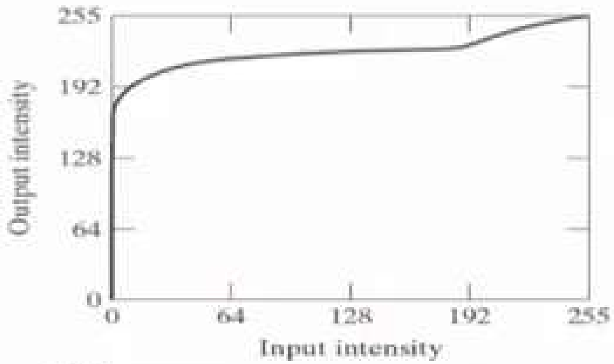
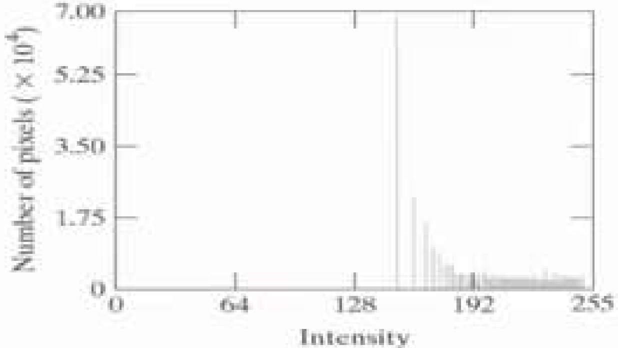
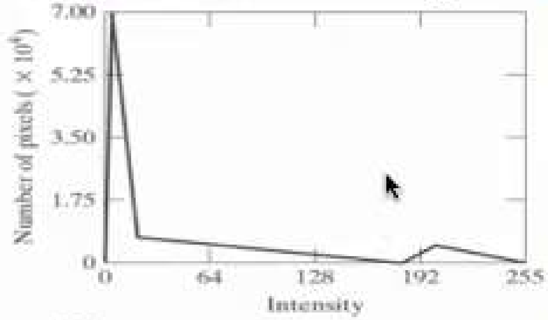
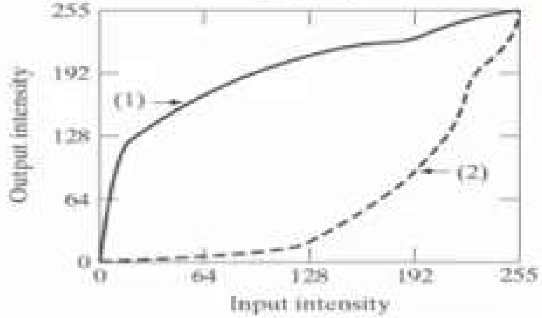
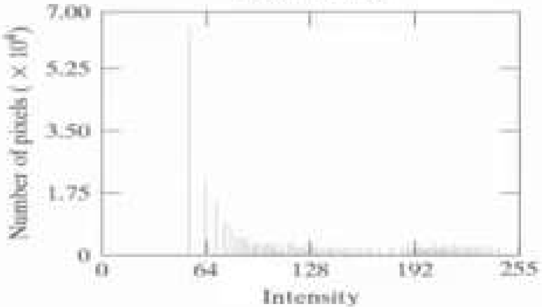
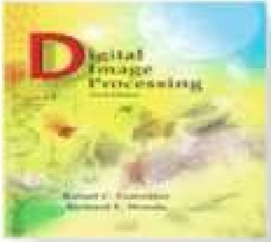








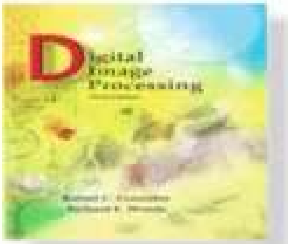




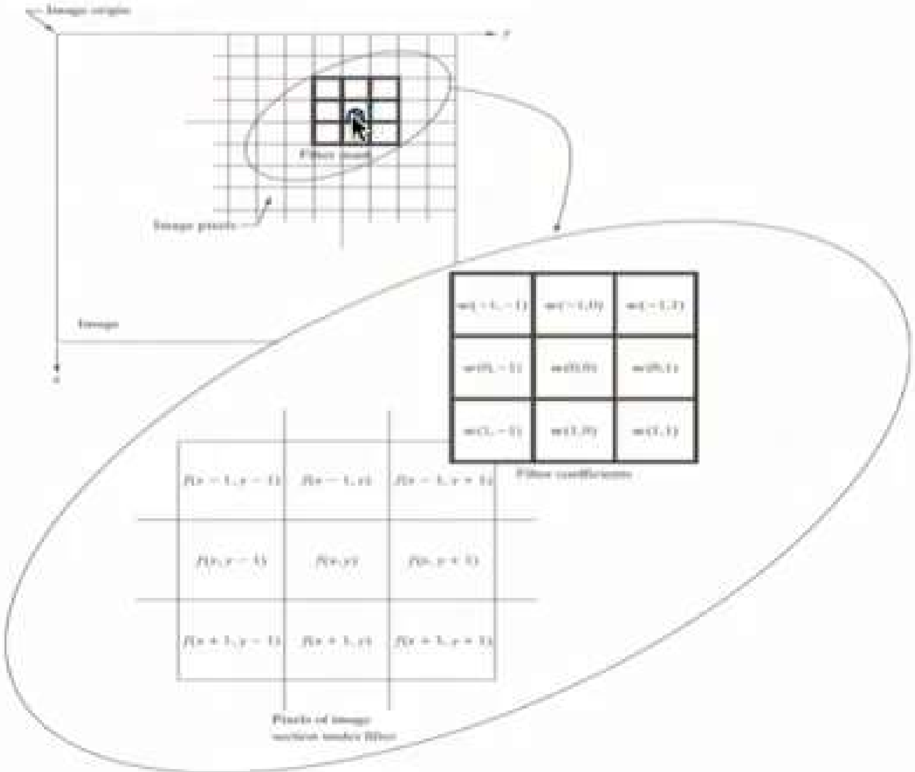
Chapter 3
Intensity Transformations & Spatial Filtering

a b c

FIGURE 3.27 (a) SEM image of a tungsten filament magnified approximately 130×. (b) Result of global histogram equalization. (c) Image enhanced using local histogram statistics. (Original image courtesy of Mr. Michael Shaffer, Department of Geological Sciences, University of Oregon, Eugene.)

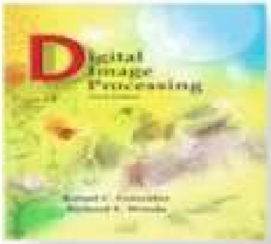


Chapter 3
Intensity Transformations & Spatial Filtering



w_1	w_2	w_3
w_4	w_5	w_6
w_7	w_8	w_9

FIGURE 3.28 The mechanics of linear spatial filtering using a 3 × 3 filter mask. The form chosen to denote the coordinates of the filter mask coefficients simplifies writing expressions for linear filtering.



a b

$$\frac{1}{9} \times \begin{array}{|c|c|c|} \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array} \qquad \frac{1}{16} \times \begin{array}{|c|c|c|} \hline 1 & 2 & 1 \\ \hline 2 & 4 & 2 \\ \hline 1 & 2 & 1 \\ \hline \end{array}$$

FIGURE 3.32 Two 3×3 smoothing (averaging) filter masks. The constant multiplier in front of each mask is equal to 1 divided by the sum of the values of its coefficients, as is required to compute an average.

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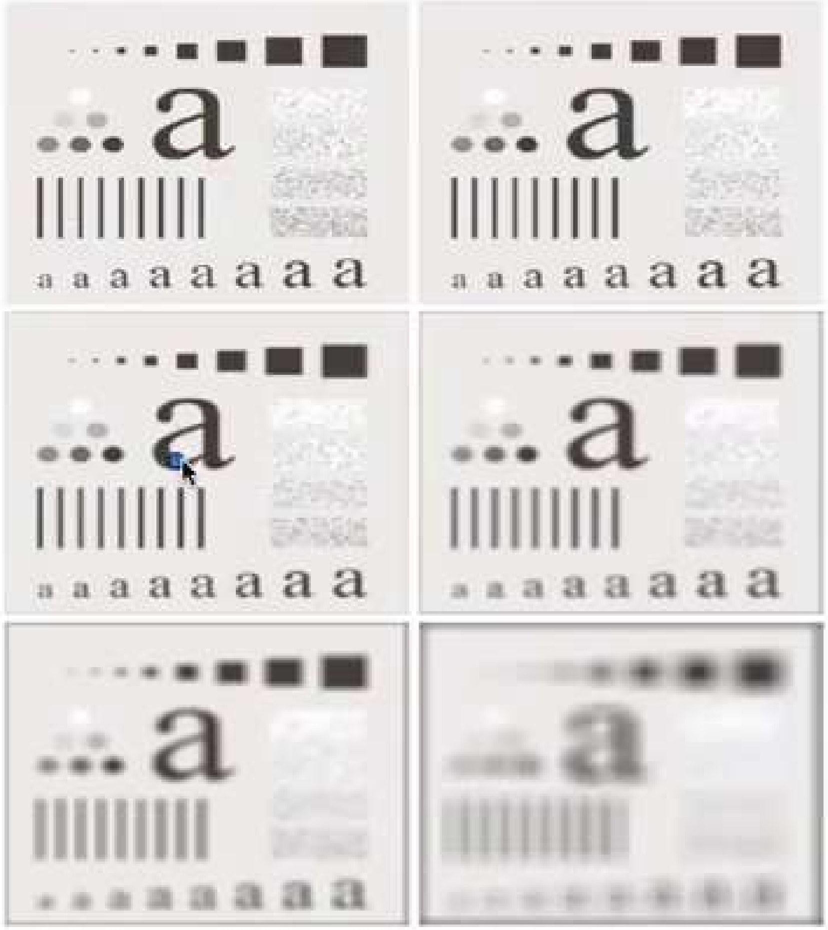
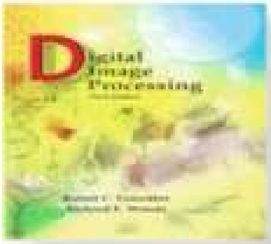
FIGURE 3.33 (a) Original image, of size 500×500 pixels. (b)–(f) Results of smoothing with square averaging filter masks of sizes $m = 3, 5, 9, 15$, and 35, respectively. The black squares at the top are of sizes 3, 5, 9, 15, 25, 35, 45, and 55 pixels, respectively; their borders are 25 pixels apart. The letters at the bottom range in size from 10 to 24 points, in increments of 2 points; the large letter at the top is 60 points. The vertical bars are 5 pixels wide and 100 pixels high; their separation is 20 pixels. The diameter of the circles is 25 pixels, and their borders are 15 pixels apart; their intensity levels range from 0% to 100% black in increments of 20%. The background of the image is 10% black. The noisy rectangles are of size 50×120 pixels.

a b
c d
e f





Chapter 3
Intensity Transformations & Spatial Filtering

a b c

FIGURE 3.34 (a) Image of size 528×485 pixels from the Hubble Space Telescope. (b) Image filtered with a 15×15 averaging mask. (c) Result of thresholding (b). (Original image courtesy of NASA.)

Averaging, Gaussian Filtering, Heat Flow

1, 2, 3 $\qquad a$

$$(a-1)^2 + (a-2)^2 + (a-3)^2$$

No

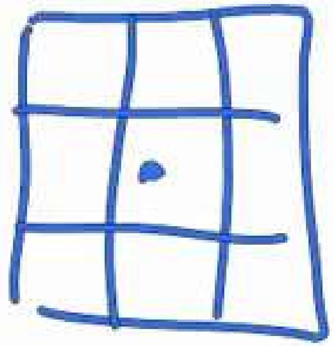
Yes - 0

Yes - 2

Yes - 4

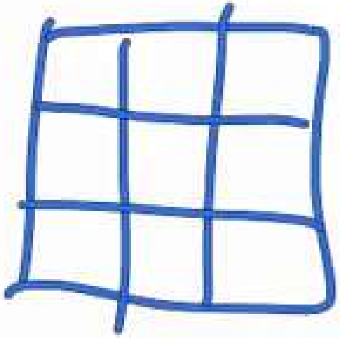
Averaging, Gaussian Filtering, Heat Flow

$$N = \sum_i (\overset{a_i}{a} - a_i)^2$$

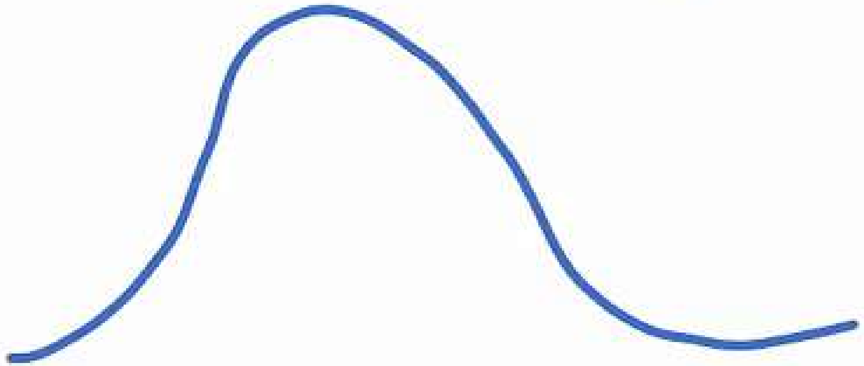


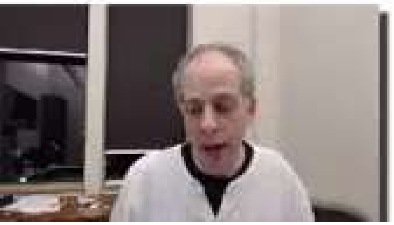
$$a = \overline{a_i}$$

Averaging, Gaussian Filtering, Heat Flow

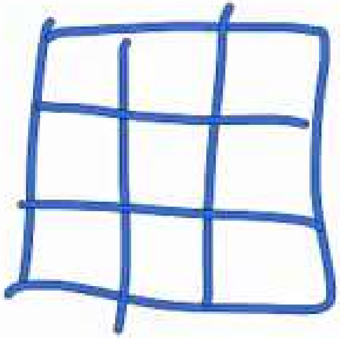


$$f(x,y,\sigma) = f(x,y) * G(0,\sigma)$$



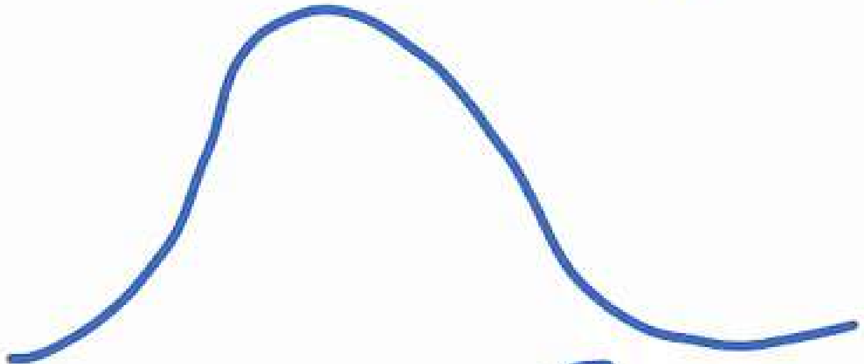


Averaging, Gaussian Filtering, Heat Flow



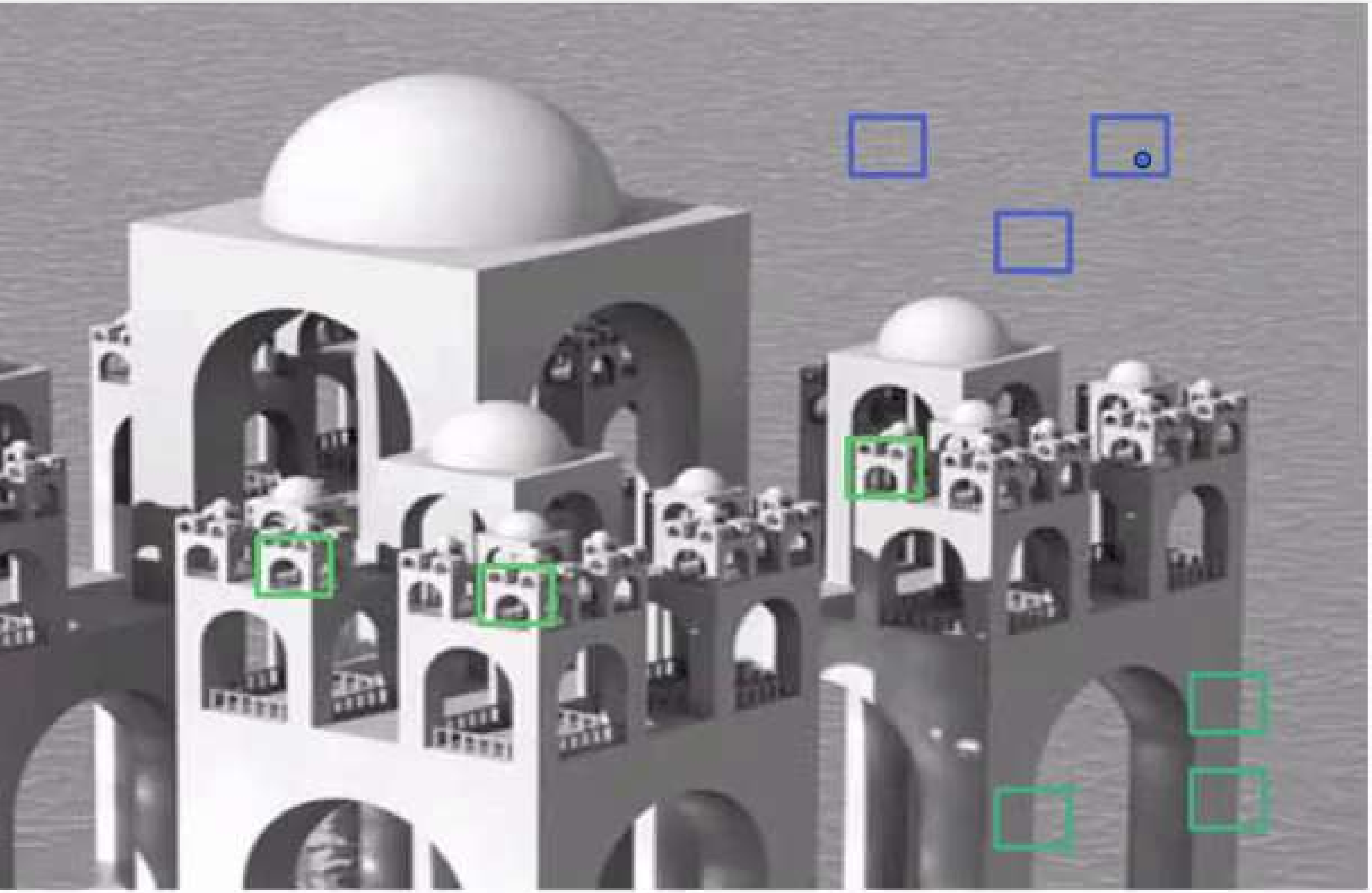
$$f(x,y,\sigma) = f(x,y) * G(0,\sigma)$$

$$\Updownarrow$$

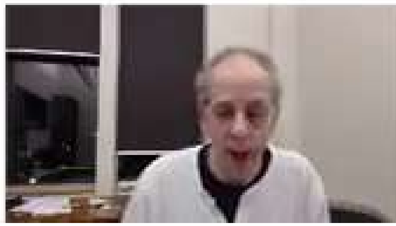


$$\frac{\partial f}{\partial t} = \Delta f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2}$$

Non Local Means/Average



Credits: Glasner et al. – Buades et al.



demo.ipol.im/demo/bcm_non_local_means_denoising/result?key=D7B0F397B350FA1730C849EF38F46FA7

The algorithm result is displayed hereafter. It ran in 5.82s.
You can run again this algorithm with new data.

Run again?: new input | different parameter or subimage

Results (sigma: 25)

- Noisy
- Denoised
- Original
- Difference

demo.ipol.im/demo/bcm_non_local_means_denoising/result?key=D7B0F397B350FA1730C849EF38F46FA7

The algorithm result is displayed hereafter. It ran in 5.82s.
You can run again this algorithm with new data.

Run again?: new input | different parameter or subimage

Results (sigma: 25)

- Noisy
- Denoised
- Original
- Difference

demo.ipol.im/demo/bcm_non_local_means_denoising/result?key=D7B0F397B350FA1730C849EF38F46FA7

The algorithm result is displayed hereafter. It ran in 5.82s.
You can run again this algorithm with new data.

Run again?: new input | different parameter or subimage

Results (sigma: 25)

- Noisy
- Denoised
- Original
- Difference

demo.ipol.im/demo/bcm_non_local_means_denoising/result?key=D7B0F397B350FA1730C849EF38F46FA7

The algorithm result is displayed hereafter. It ran in 5.82s.
You can run again this algorithm with new data.

Run again?: new input | different parameter or subimage

Results (sigma: 25)

- Noisy
- Denoised
- Original
- Difference

demo.ipol.im/demo/bcm_non_local_means_denoising/result?key=5ABA2A4448E8980B01B51837F6486422

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Please cite this article if you publish results obtained with this online demo.

The algorithm result is displayed hereafter. It ran in 16.33s.
You can run again this algorithm with new data.

Run again?: ⇨ new input ⇨ different parameter or subimage

Results (sigma: 35)

- Noisy
- Denoised
- Original
- Difference

demo.ipol.im/demo/bcm_non_local_means_denoising/result?key=5A8A2A4448E8980B01851837F6486422

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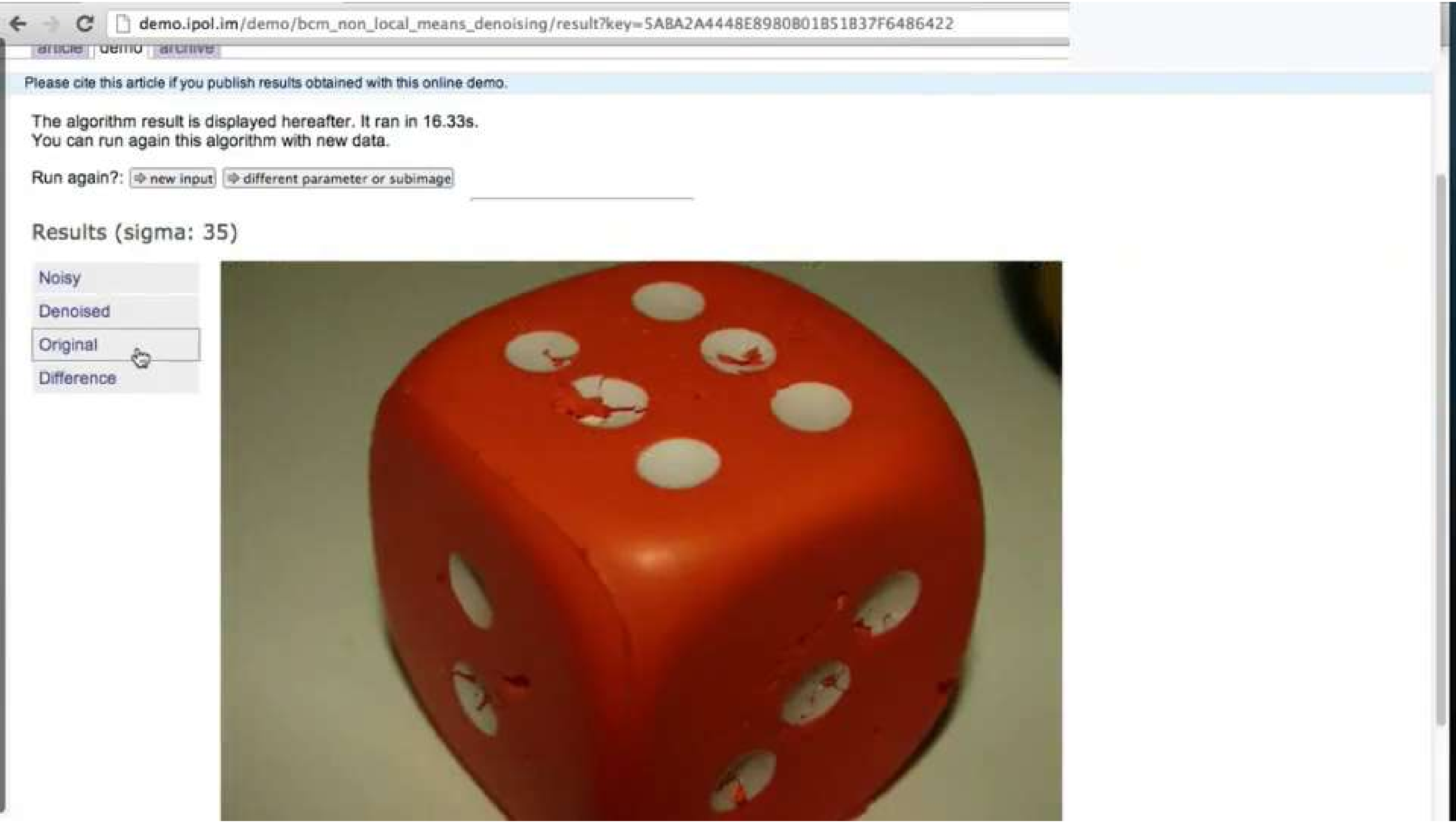
Please cite this article if you publish results obtained with this online demo.

The algorithm result is displayed hereafter. It ran in 16.33s.
You can run again this algorithm with new data.

Run again?: [new input] [different parameter or subimage]

Results (sigma: 35)

- Noisy
- Denoised
- Original
- Difference


demo.ipol.im/demo/bcm_non_local_means_denoising/result?key=5ABA2A4448E8980B01B51837F6486422
article
demo
archive
Please cite this article if you publish results obtained with this online demo.
The algorithm result is displayed hereafter. It ran in 16.33s.
You can run again this algorithm with new data.
Run again?: new input different parameter or subimage
Results (sigma: 35)
Noisy
Denoised
Original
Difference


demo.ipol.im/demo/bcm_non_local_means_denoising/result?key=5ABA2A4448E8980B01B51837F6486422
article
demo
archive
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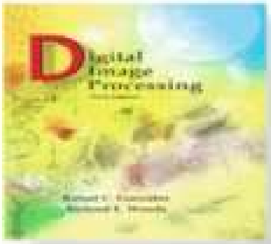
The algorithm result is displayed hereafter. It ran in 16.33s.
You can run again this algorithm with new data.
Run again?: new input
different parameter or subimage
Results (sigma: 35)
Noisy
Denoised
Original
Difference



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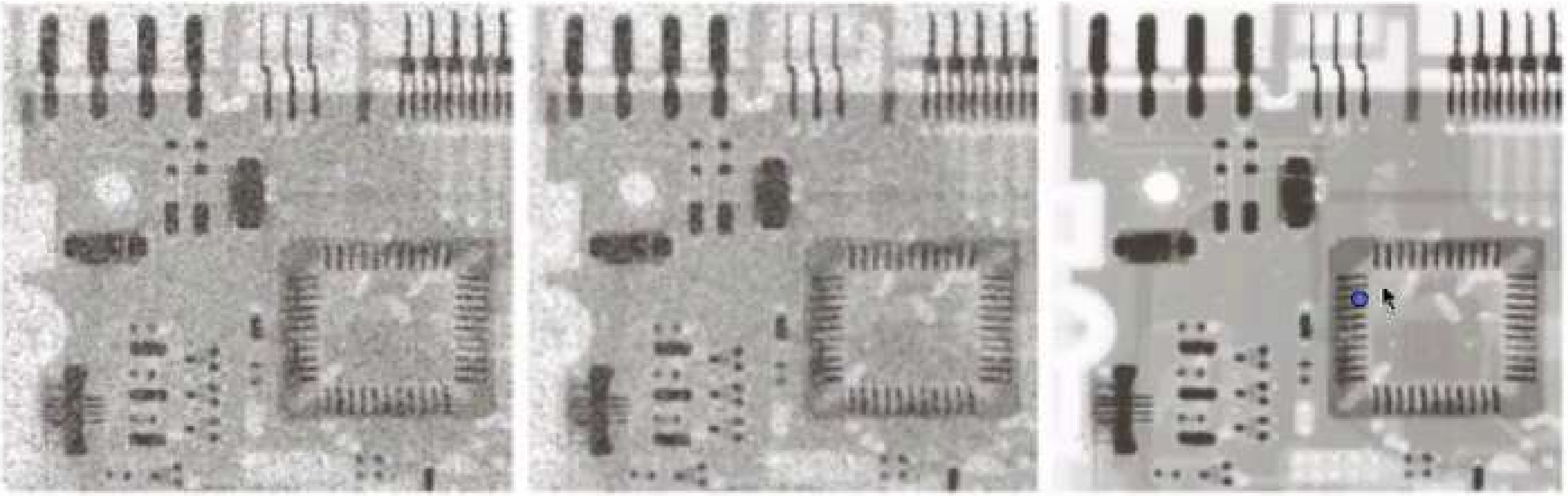
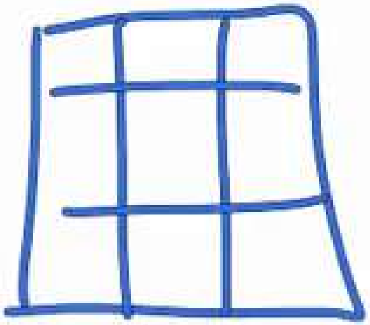
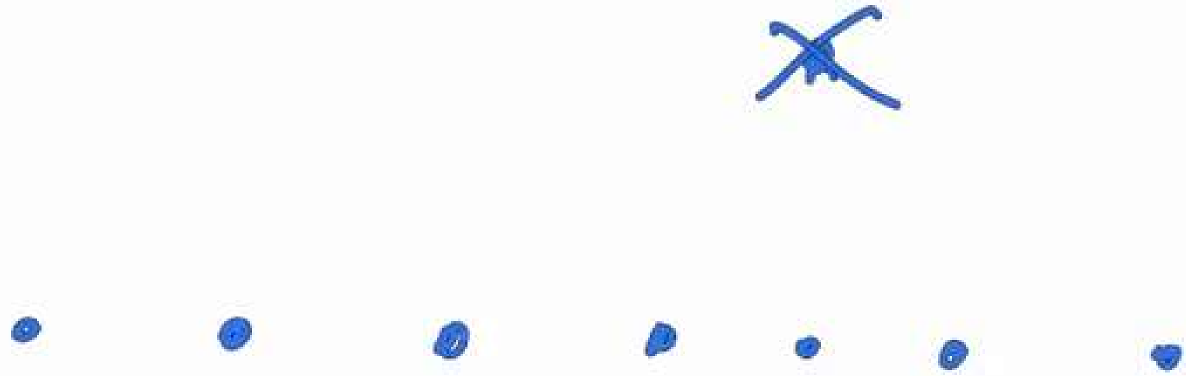


a b c

FIGURE 3.35 (a) X-ray image of circuit board corrupted by salt-and-pepper noise. (b) Noise reduction with a 3 × 3 averaging mask. (c) Noise reduction with a 3 × 3 median filter. (Original image courtesy of Mr. Joseph E. Pascente, Lixi, Inc.)





$$\sum_i (a-a_i)^2 \qquad \sum f(a-a_i)$$

Mean

$$\sum |a-a_i|$$

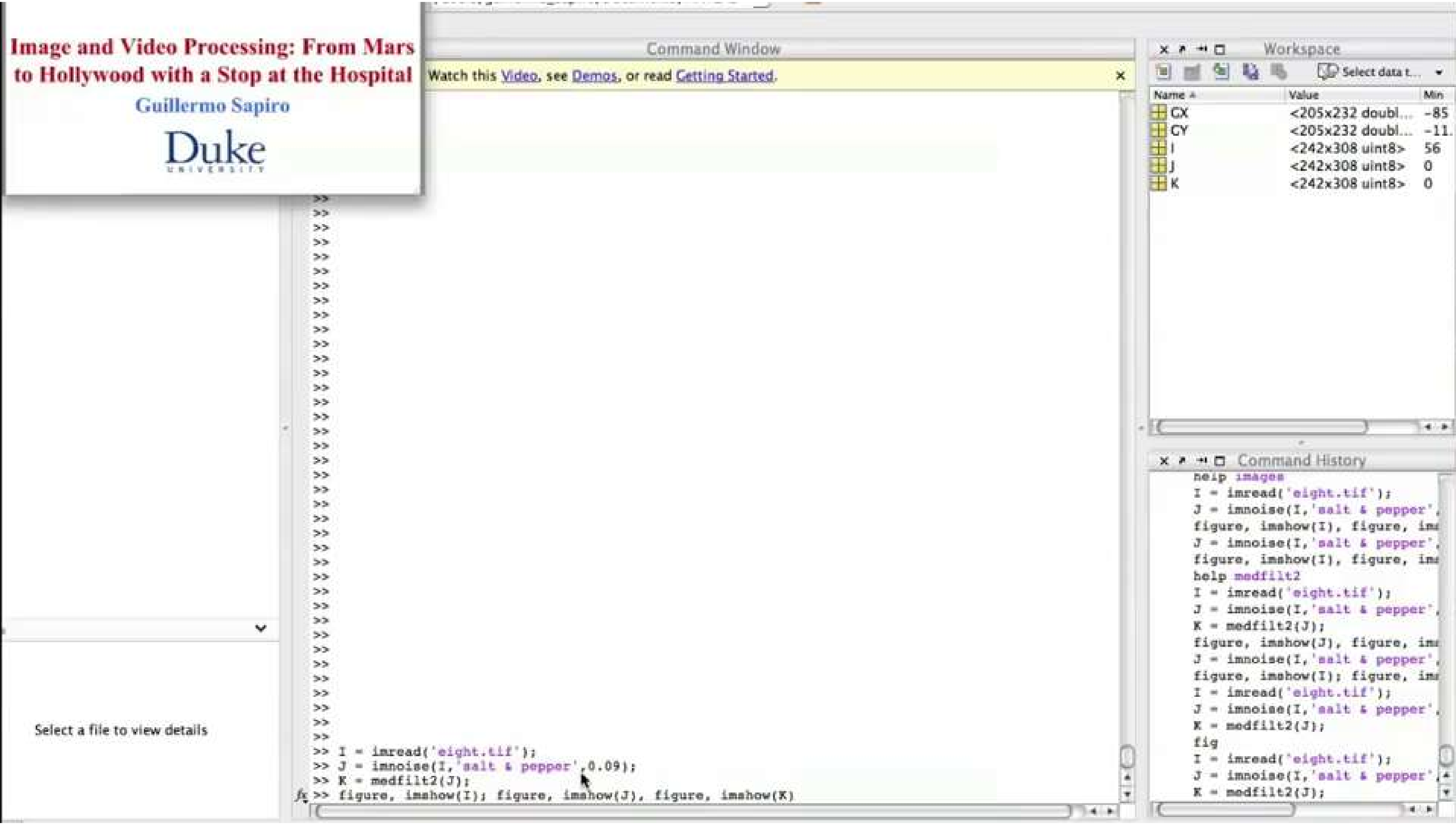


Image and Video Processing: From Mars to Hollywood with a Stop at the Hospital
Guillermo Sapiro
Duke University
Command Window
Watch this Video, see Demos, or read Getting Started.
>> I = imread('eight.tif');
>> J = imnoise(I,'salt & pepper',0.09);
>> K = medfilt2(J);
>> figure, imshow(I); figure, imshow(J), figure, imshow(K)
Select a file to view details
Workspace
Name
Value
Min
GX <205x232 doubl... -85
GY <205x232 doubl... -11.
I <242x308 uint8> 56
J <242x308 uint8> 0
K <242x308 uint8> 0
Command History
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J = imnoise(I,'salt & pepper',
figure, imshow(I), figure, ims
help medfilt2
K = medfilt2(J);
fig

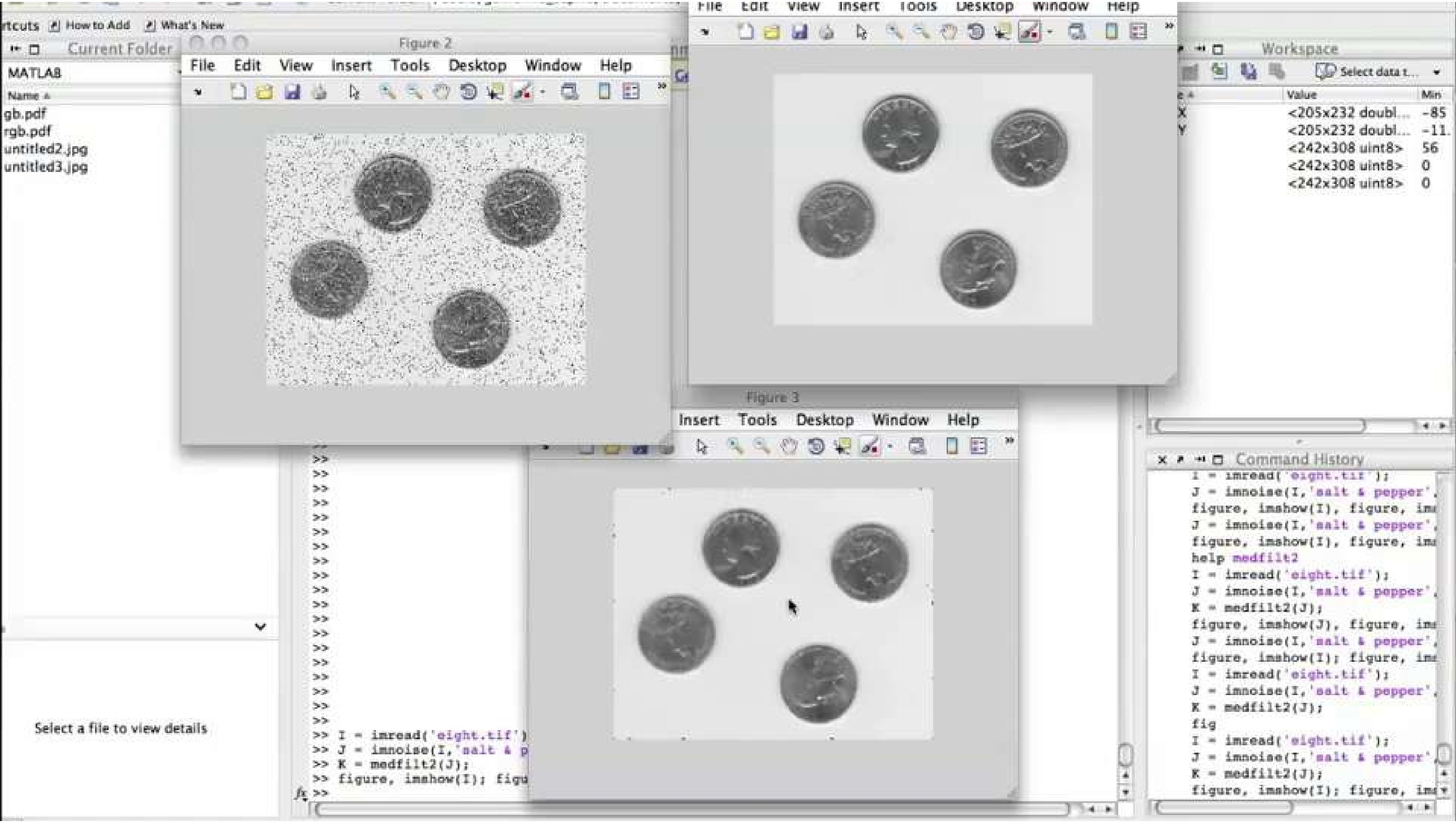
Figure 2
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Figure 3
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untitled2.jpg
untitled3.jpg
Select a file to view details
Workspace
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Value
Min
<205x232 doubl... -85
<205x232 doubl... -11.
<242x308 uint8> 56
<242x308 uint8> 0
<242x308 uint8> 0
>> I = imread('eight.tif')
>> J = imnoise(I,'salt & p
>> K = medfilt2(J);
>> figure, imshow(I); figu
Command History
J = imnoise(I,'salt & pepper',
figure, imshow(I), figure, im
J = imnoise(I,'salt & pepper',
figure, imshow(I), figure, im
help medfilt2
I = imread('eight.tif');
J = imnoise(I,'salt & pepper',
K = medfilt2(J);
figure, imshow(J), figure, im
J = imnoise(I,'salt & pepper',
figure, imshow(I); figure, im
I = imread('eight.tif');
J = imnoise(I,'salt & pepper',
K = medfilt2(J);
fig
I = imread('eight.tif');
J = imnoise(I,'salt & pepper',
K = medfilt2(J);
figure, imshow(I); figure, im

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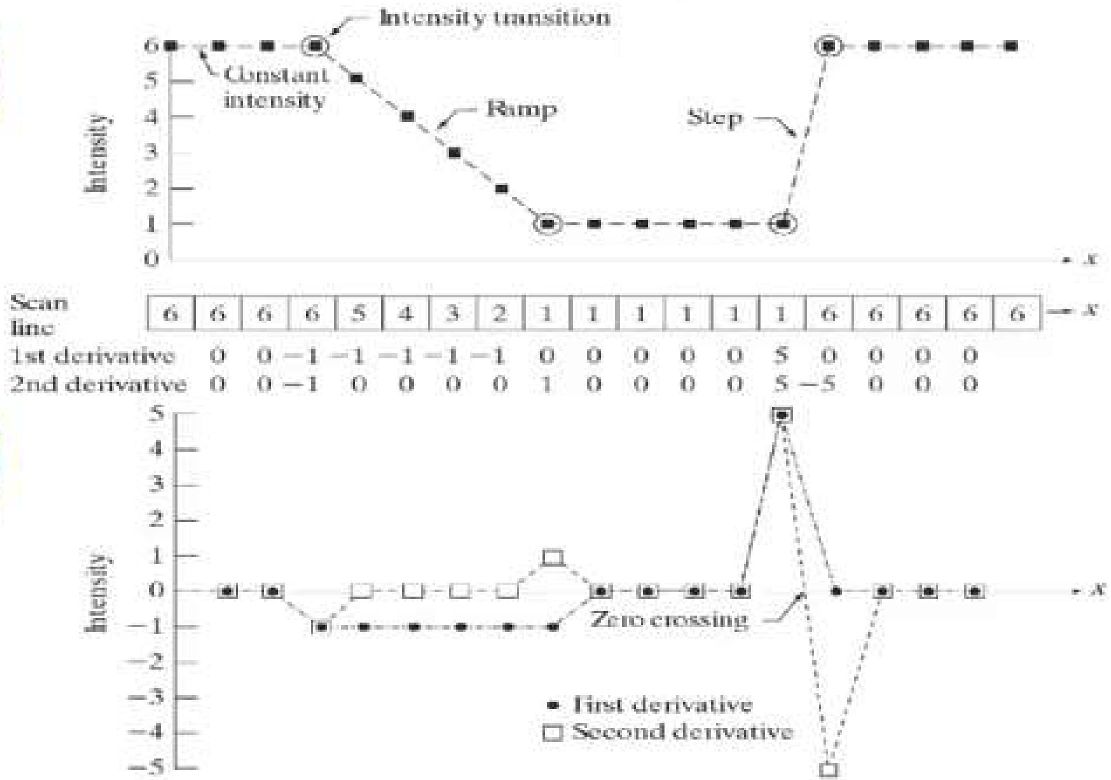
Intensity Transformations & Spatial Filtering

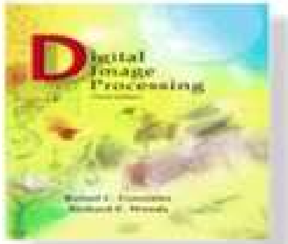
$$\frac{\partial f}{\partial x} \cong f(x+1) - f(x)$$

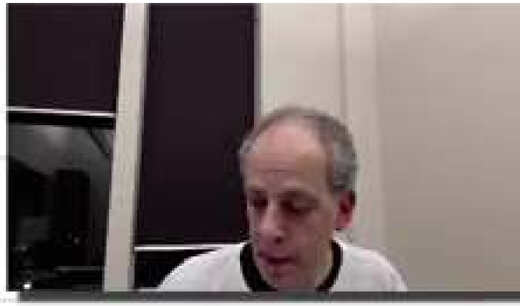
$$\begin{array}{|c|c|c|}\hline 0 & 0 & 0 \\ \hline 0 & -1 & 1 \\ \hline 0 & 0 & 0 \\ \hline \end{array}$$

$$\frac{\partial^2 f}{\partial x^2} = f(x+1) + f(x-1) - 2f(x)$$

$$\begin{array}{|c|c|c|}\hline 0 & 0 & 0 \\ \hline 1 & -2 & 1 \\ \hline 0 & 0 & 0 \\ \hline \end{array}$$







$$\frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} = \Delta f$$

$$= f(x+1) + f(x-1) - 2f(x)$$

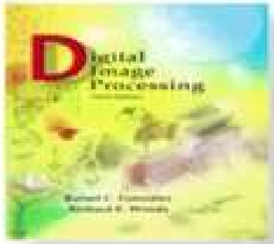
$$f(y+1) + f(y-1) - 2f(y)$$

0	1	0
1	−4	1
0	1	0

1	1	1
1	−8	1
1	1	1

0	−1	0
−1	4	−1
0	−1	0

−1	−1	−1
−1	8	−1
−1	−1	−1

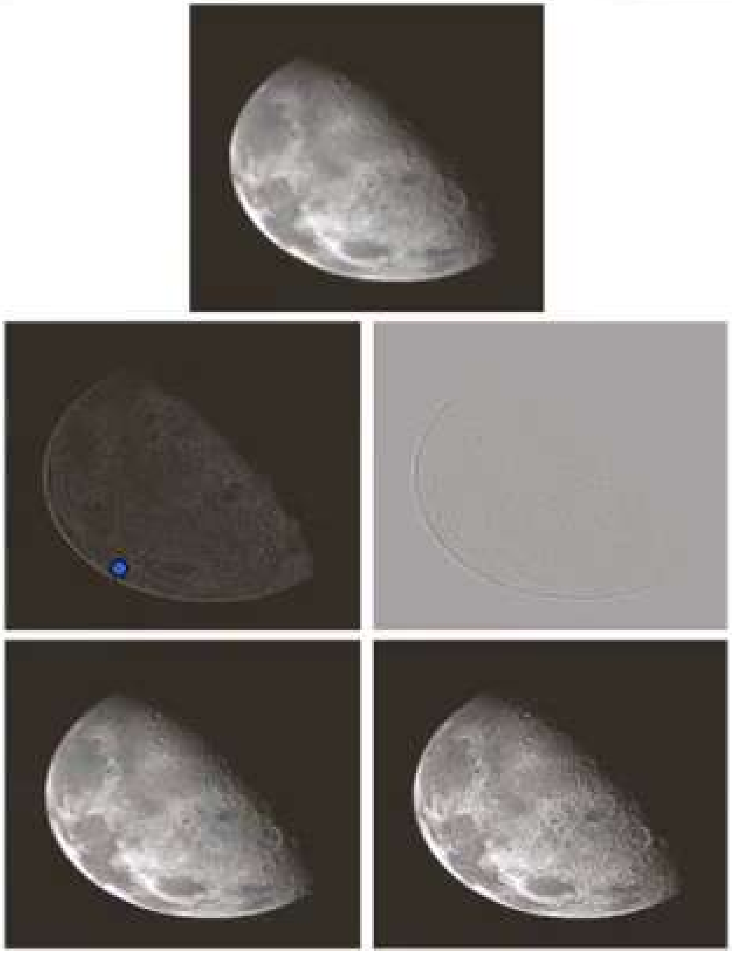


0	1	0
1	−4	1
0	1	0

1	1	1
1	−8	1
1	1	1

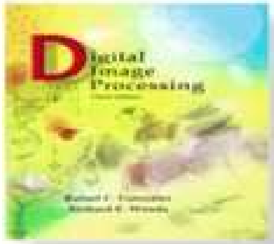
0	−1	0
−1	4	−1
0	−1	0

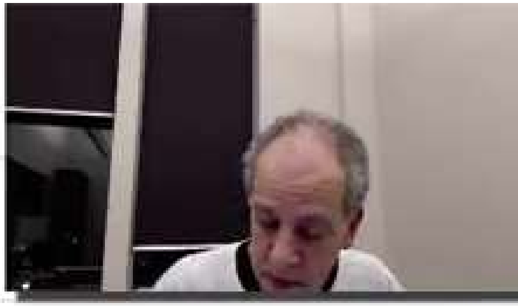
−1	−1	−1
−1	8	−1
−1	−1	−1

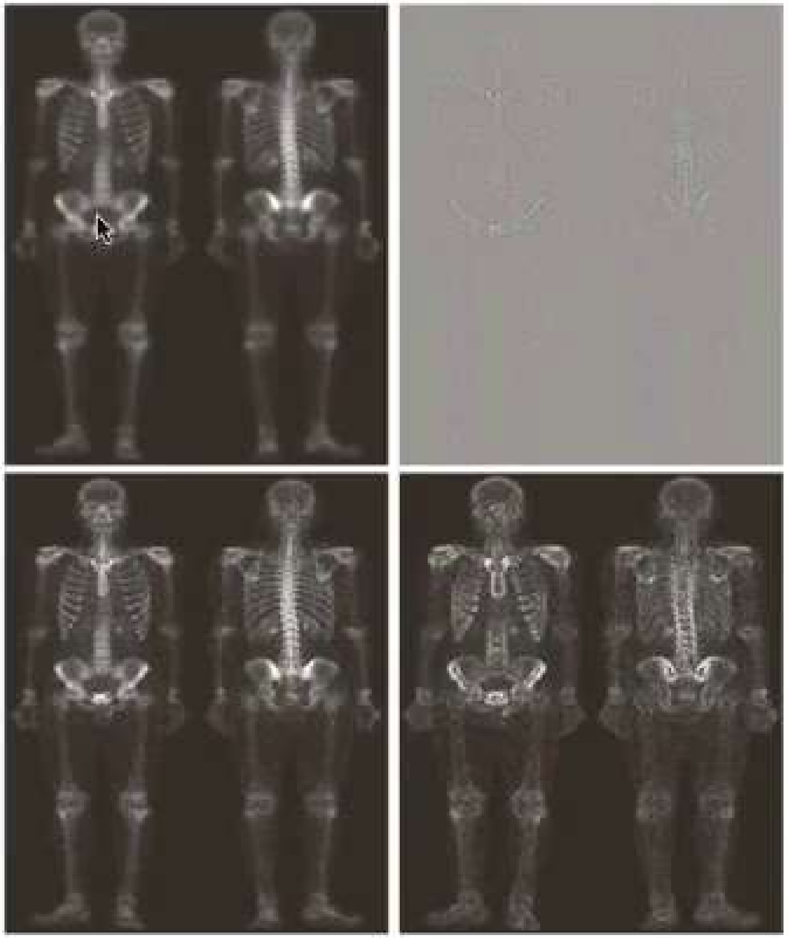


a
b c
d e

FIGURE 3.38 (a) Blurred image of the North Pole of the moon. (b) Laplacian without scaling. (c) Laplacian with scaling. (d) Image sharpened using the mask in Fig. 3.37(a). (e) Result of using the mask in Fig. 3.37(b). (Original image courtesy of NASA.)

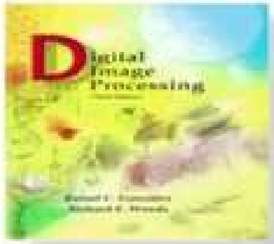






a b
c d

FIGURE 3.43 (a) Image of whole body bone scan. (b) Laplacian of (a). (c) Sharpened image obtained by adding (a) and (b). (d) Sobel gradient of (a).



Digital Image Processing, 3rd ed.

Gonzalez & Woods

www.ImageProcessingPlace.com

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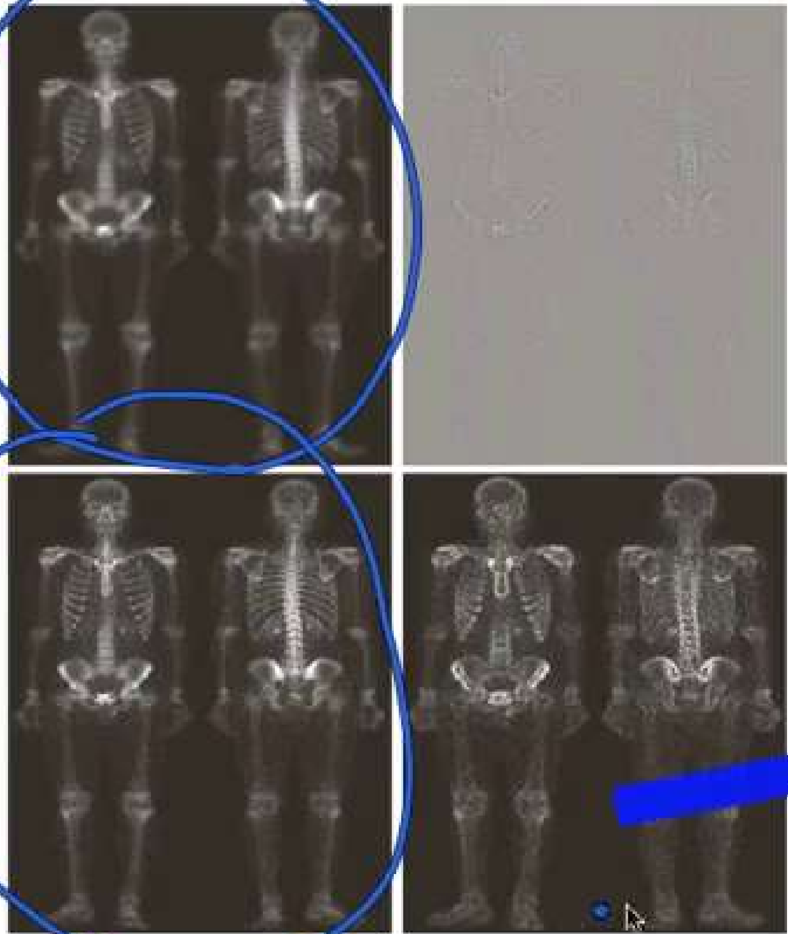
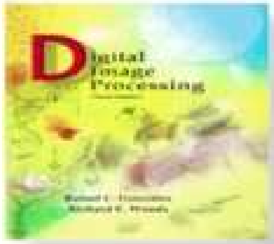


FIGURE 3.43 (a) Image of whole body bone scan. (b) Laplacian of (a). (c) Sharpened image obtained by adding (a) and (b). (d) Sobel gradient of (a).

Sobel Edges



Chapter 3
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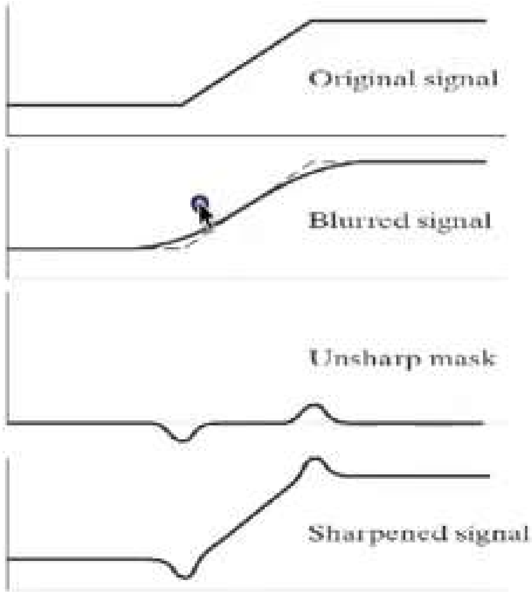
Unsharp

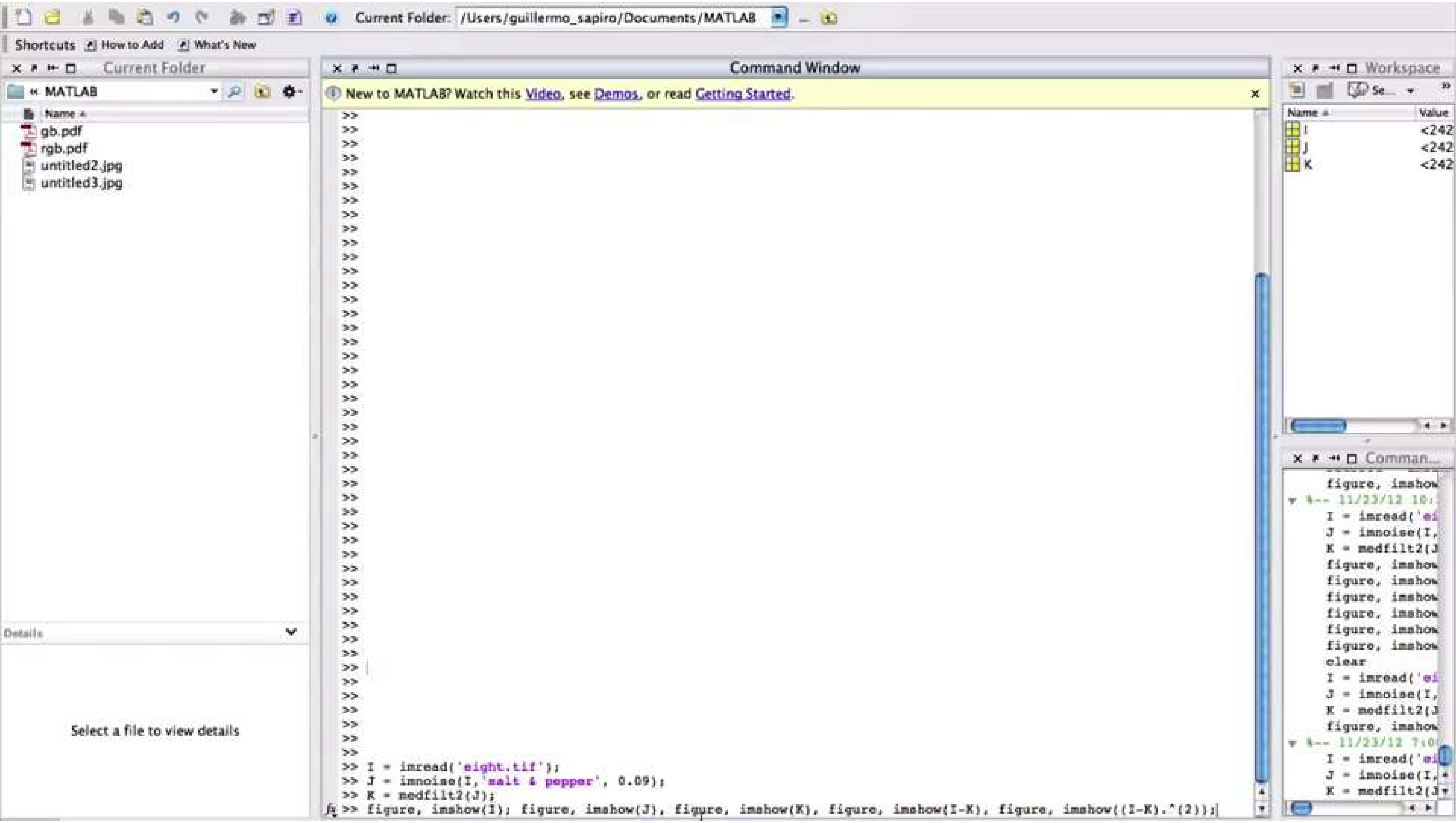
$$\frac{1}{9}\begin{bmatrix}1 & 1 & 1\\ 1 & 1 & 1\\ 1 & 1 & 1\end{bmatrix}$$

$$\begin{bmatrix}0 & 0 & 0\\ 0 & 1 & 0\\ 0 & 0 & 0\end{bmatrix}$$



a
b
c
d

FIGURE 3.39 1-D illustration of the mechanics of unsharp masking. (a) Original signal. (b) Blurred signal with original shown dashed for reference. (c) Unsharp mask. (d) Sharpened signal, obtained by adding (c) to (a).


Current Folder: /Users/guillermo_sapiro/Documents/MATLAB
Shortcuts
How to Add
What's New
Current Folder
MATLAB
Name
gb.pdf
rgb.pdf
untitled2.jpg
untitled3.jpg
Details
Select a file to view details
Command Window
New to MATLAB? Watch this Video, see Demos, or read Getting Started.
>> I = imread('eight.tif');
>> J = imnoise(I,'salt & pepper', 0.09);
>> K = medfilt2(J);
>> figure, imshow(I); figure, imshow(J), figure, imshow(K), figure, imshow(I-K), figure, imshow((I-K).^(2));
Workspace
Name
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I
J
K
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clear

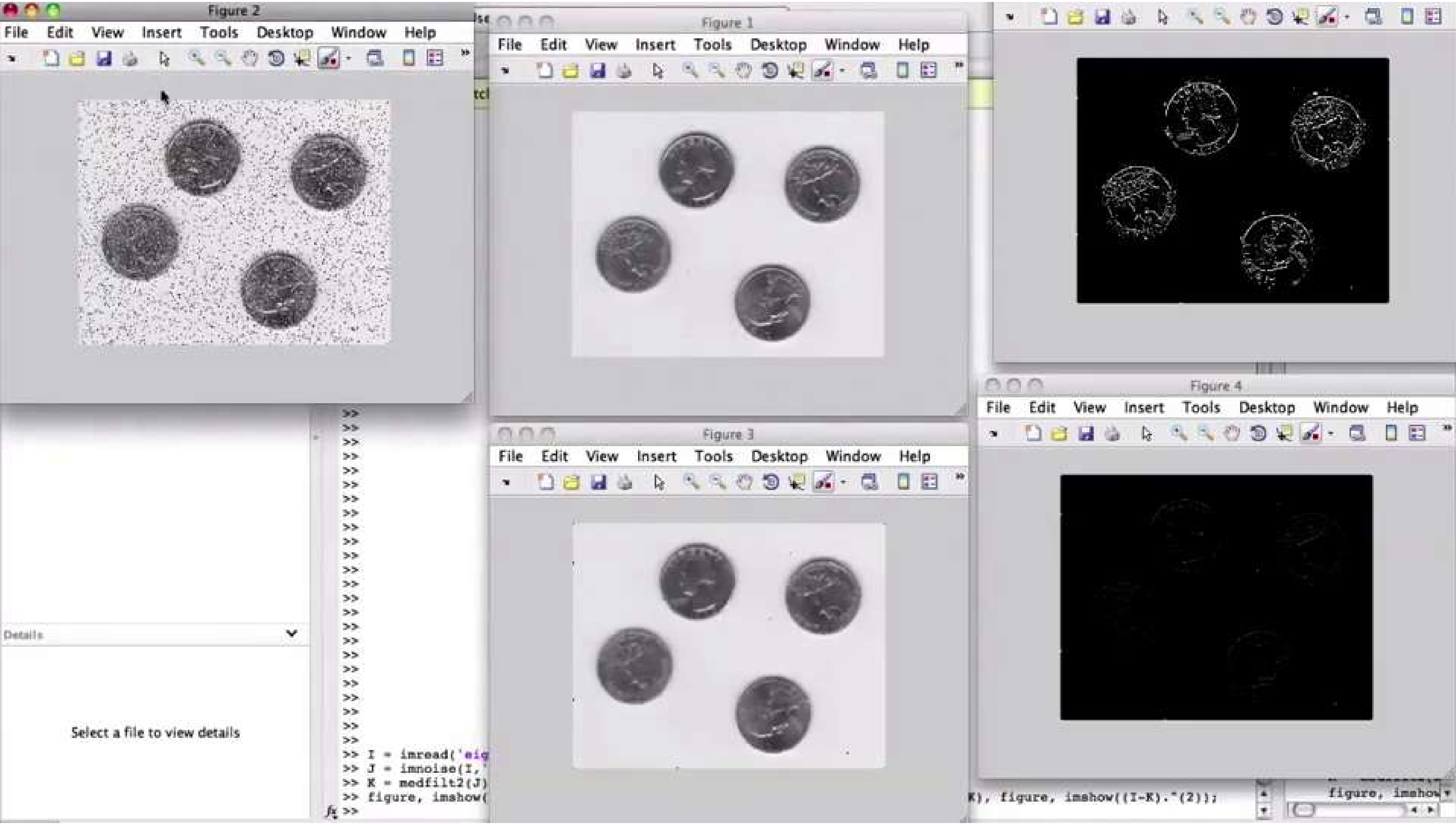
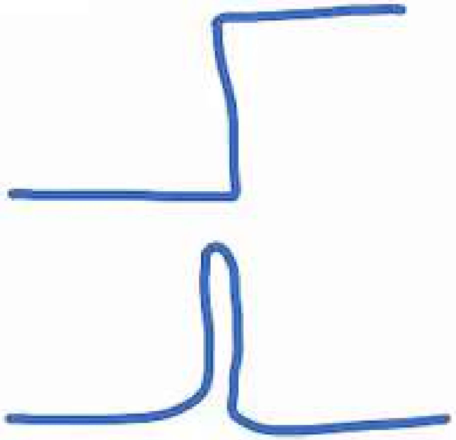
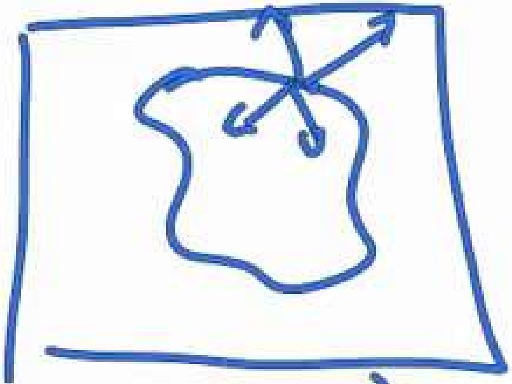


Figure 2
File Edit View Insert Tools Desktop Window Help
Figure 1
File Edit View Insert Tools Desktop Window Help
Figure 3
File Edit View Insert Tools Desktop Window Help
Figure 4
File Edit View Insert Tools Desktop Window Help
Details
Select a file to view details
>> I = imread('eig
>> J = imnoise(I,'
>> K = medfilt2(J)
>> figure, imshow(
K), figure, imshow((I-K).^(2));
figure, imshow

Edge Detection and Color Edge Detection

$$\nabla f(x,y) = \left(\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right)$$





$$|\nabla f| = \sqrt{\left(\frac{\partial f}{\partial x}\right)^2 + \left(\frac{\partial f}{\partial y}\right)^2}$$

$$(R, G, B)$$