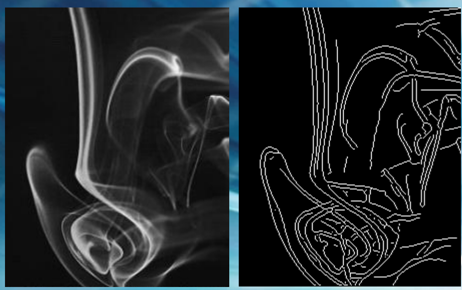
Introduction to Digital Image Processing with MATLAB® Asia Edition
McAndrew‧Wang‧Tseng



Chapter 9: Image Segmentation

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9.1 Introduction

- **Segmentation** refers to the operation of partitioning an image into component parts or into separate objects
- In this chapter, we will investigate two very important topics: **thresholding** and **edge detection**

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9.2 Thresholding

- **9.2.1 Single thresholding**

$$\text{A pixel becomes } \begin{cases} \text{white if its gray level is} > T, \\ \text{black if its gray level is} \leq T. \end{cases}$$

```
>> r=imread('rice.tif');
>> imshow(r),figure,imshow(r>110)
```

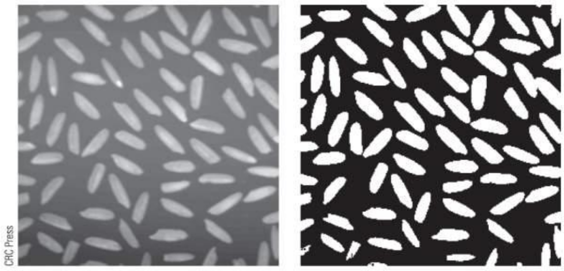

FIGURE 9.1 *Thresholded image of rice grains.*

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FIGURE 9.2

```
>> b=imread('bacteria.tif');
>> imshow(b),figure,imshow(b>100)
```

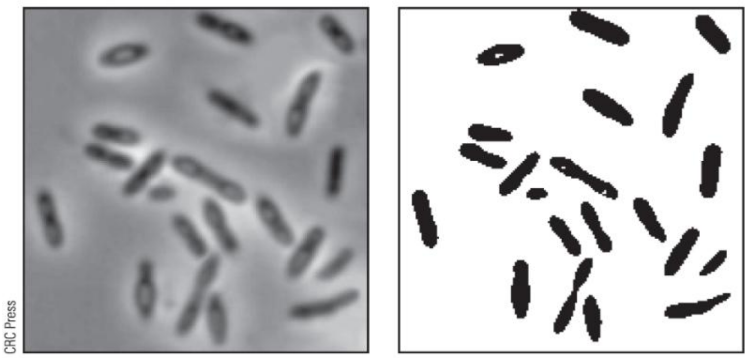

FIGURE 9.2 *Thresholded image of bacteria.*

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9.2 Thresholding

- MATLAB has the `im2bw` function, which thresholds an image of **any data type**, using the general syntax

```
im2bw(image,level)
```

e.g.

```
>> im2bw(r,0.43);
>> im2bw(b,0.39);
```

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FIGURE 9.3

- Showing hidden aspects of an image

```
>> p=imread('paper1.tif');
>> imshow(p),figure,imshow(p>241)
```

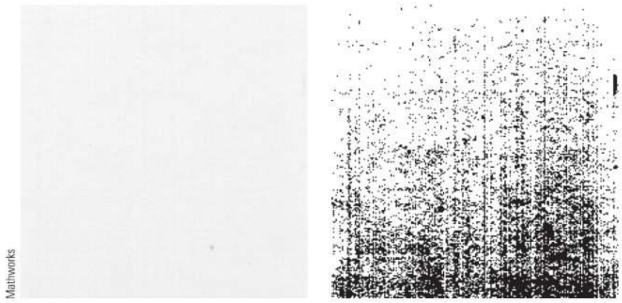

FIGURE 9.3 *The paper image and result after thresholding.*

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9.2.2 Double Thresholding

a pixel becomes $\begin{cases} \text{white if its gray level is between } T_1 \text{ and } T_2, \\ \text{black if its gray level is otherwise.} \end{cases}$

```
>> [x,map]=imread('spine.tif');
>> s=ind2gray(x,map);
>> imshow(s),figure,imshow(s>115 & s<125)
```

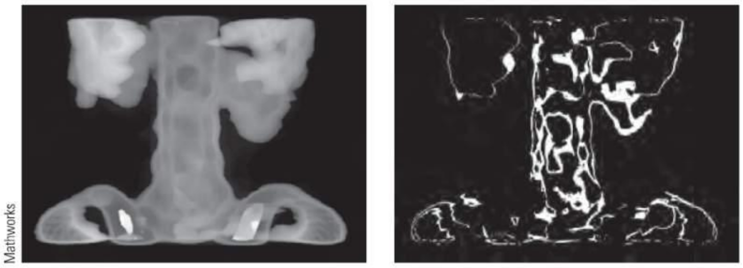

FIGURE 9.4 *The image* `spine.tif` *as the result after double thresholding.*

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9.3 Applications of Thresholdng

- Remove a varying background from text or a drawing

```
>> r=rand(256)*128+127;
>> t=imread('text.tif');
>> tr=uint8(r.*double(not(t)));
>> imshow(tr)
```

```
>> imshow(tr>100)
```

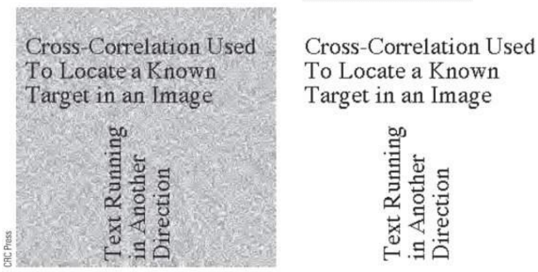

FIGURE 9.5 *Text on a varying background and thresholding.*

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9.4 Choosing an Appropriate Thresholding Value

```
>> n=imread('nodules1.tif');
>> imshow(n);
>> n1=im2bw(n,0.35);
>> n2=im2bw(n,0.75);
>> figure,imshow(n1),figure,imshow(n2)
```

n: Original image n1: Threshold too low n2: Threshold too high

FIGURE 9.6 *Attempts at thresholding.*

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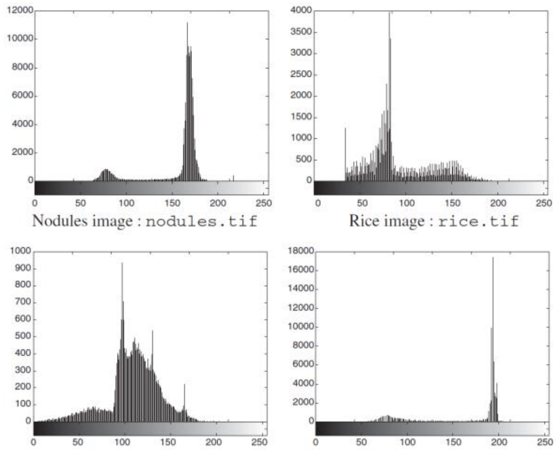
FIGURE 9.7



Nodules image : nodules.tif Rice image : rice.tif

Bacteria image : bacteria.tif Coins image : eight.tif

FIGURE 9.7 *Histograms.*

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FIGURE 9.8

- Describe the image histogram as a probability distribution

$$p_i = n_i/N$$

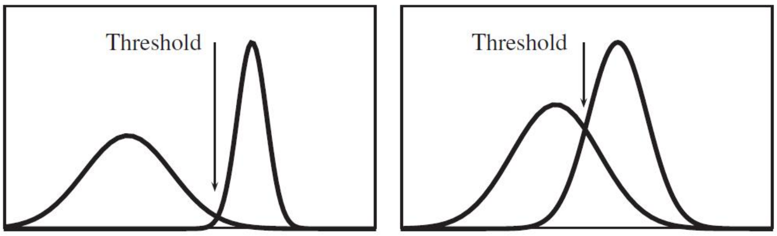

FIGURE 9.8 *Splitting up a histogram for thresholding.*

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9.4 Choosing an Appropriate Thresholding Value

$$\omega(k) = \sum_{i=0}^{k} p_i$$

$$\mu(k) = \sum_{i=k+1}^{L-1} p_i,$$

$$\omega(k) + \mu(k) = \sum_{i=0}^{L-1} p_i = 1$$

- We would like to find k to maximize the difference between $\omega(k)$ and $\mu(k)$

Define the image average as $\mu_T = \sum_{i=0}^{L-1} i p_i,$

then find a k, which maximizes $\dfrac{(\mu_T \omega(k) - \mu(k))^2}{\omega(k)\mu(k)}$

(Otsu's method, MATLAB function `graythresh`)

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9.4 Choosing an Appropriate Thresholding Value

```
>> tn=graythresh(n)

tn =

    0.5804

>> r=imread('rice.tif');
>> tr=graythresh(r)

tr =

    0.4902

>> b=imread('bacteria.tif');
>> tb=graythresh(b)

tb =

    0.3765

>> e=imread('eight.tif');
>> te=graythresh(e)

te =

    0.6490
```

```
>> imshow(im2bw(n,tn))
>> figure,imshow(im2bw(r,tr))
>> figure,imshow(im2bw(b,tb))
>> figure,imshow(im2bw(e,te))
```


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FIGURE 9.9

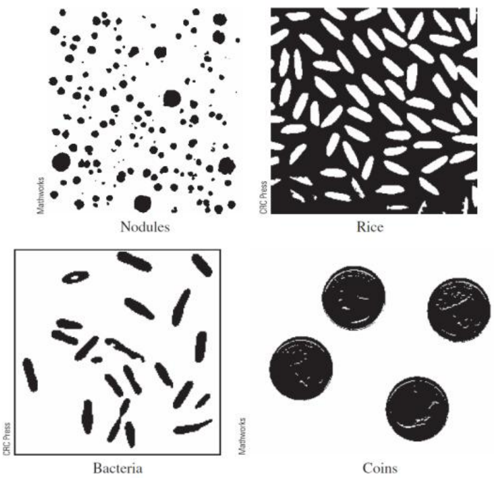

FIGURE 9.9 *Thresholding with values from* graythresh.

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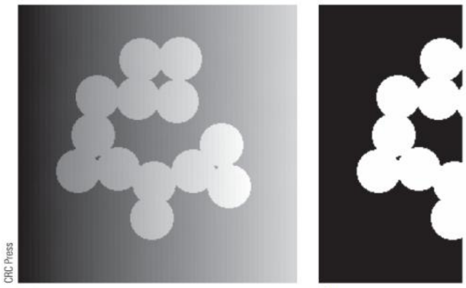
9.5 Adaptive Thresholding

```
>> c=imread('circles.tif');
>> x=ones(256,1)*[1:256];
>> c2=double(c).*(x/2+50)+(1-double(c)).*x/2;
>> c3=uint8(255*mat2gray(c2));
```



(a) (b)

```
>> t=graythresh(c3)

t =

    0.4196

>> ct=im2bw(c3,t);
```

FIGURE 9.10 *An attempt at thresholding. (a) Circles image:* c3. *(b) Thresholding attempt:* ct.

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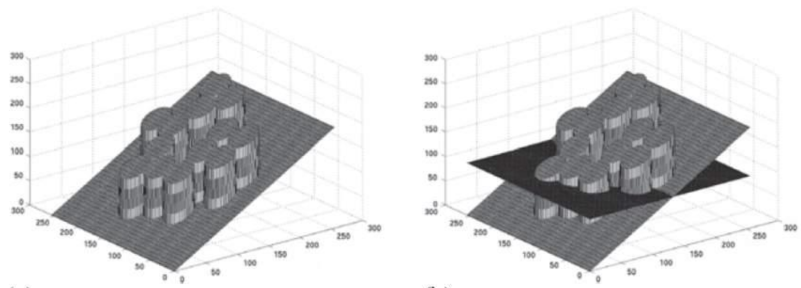
FIGURE 9.11



(a) (b)

FIGURE 9.11 *An attempt at thresholding—functional version. (a) The image as a function. (b) Thresholding attempt.*

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9.5 Adaptive Thresholding

```
>> p1=c3(:,1:64);
>> p2=c3(:,65:128);
>> p3=c3(:,129:192);
>> p4=c3(:,193:256);
```

```
>> g1=im2bw(p1,graythresh(p1));
>> g2=im2bw(p2,graythresh(p2));
>> g3=im2bw(p3,graythresh(p3));
>> g4=im2bw(p4,graythresh(p4));
```

```
>> imshow([g1 g2 g3 g4])
```

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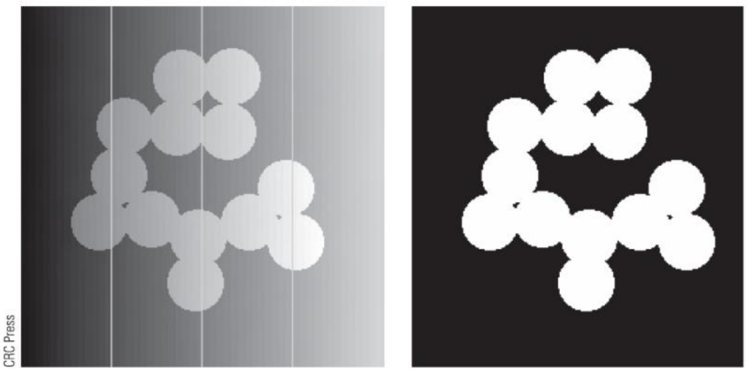
FIGURE 9.12



(a) (b)

FIGURE 9.12 *Adaptive thresholding. (a) Cutting up the image. (b) Thresholding each part separately.*

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9.6 Edge Detection

- The general MATLAB command for finding edges is

```
edge(image,'method',parameters. . .)
```

51	52	53	59
54	52	53	62
50	52	53	68
55	52	53	55

(a)

50	53	155	160
51	53	160	170
52	53	167	190
51	53	162	155

(b)

FIGURE 9.13 *Blocks of pixels.*

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9.7 Derivatives and Edges

- **9.7.1 Fundamental Definitions**

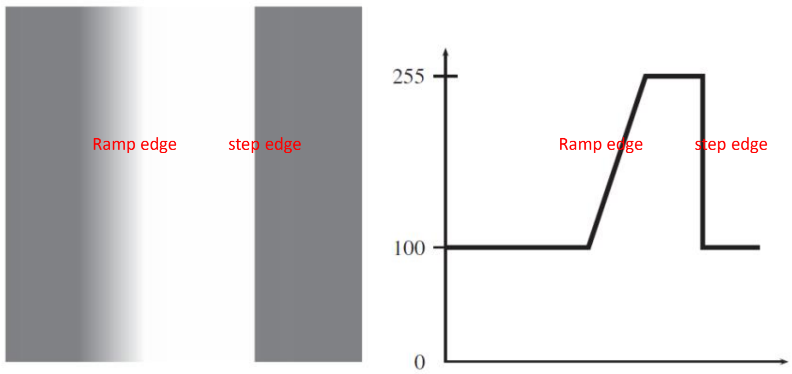

FIGURE 9.14 *Edges and their profiles.*

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FIGURE 9.15

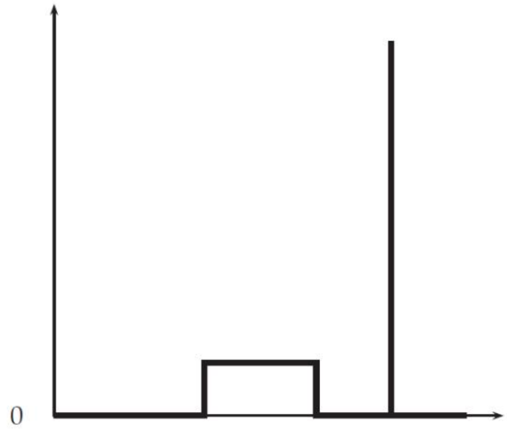

FIGURE 9.15 *The derivative of the edge profile.*

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9.7.2 Some Edge Detection Filters

- **Prewitt filters**

$$P_x = \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} \qquad P_y = \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

```
>> ic=imread('ic.tif');
```

```
>> px=[-1 0 1;-1 0 1;-1 0 1];
>> icx=filter2(px,ic);
>> figure,imshow(icx/255)
```


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FIGURE 9.16 & 17

```
>> py=px';
>> icy=filter2(py,ic);
>> figure,imshow(icy/255)
```

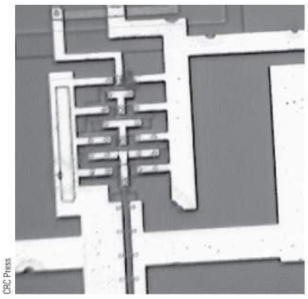
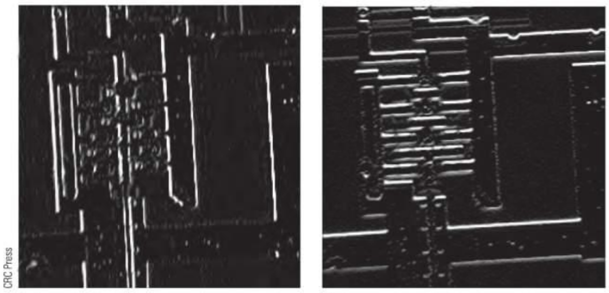


FIGURE 9.16 *An integrated circuit.*



(a) (b)

FIGURE 9.17 *The circuit after filtering with the Prewitt filters.*

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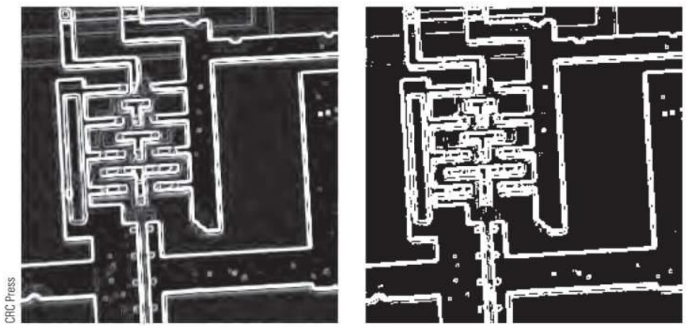
FIGURE 9.18

```
>> edge_p=sqrt(icx.^2+icy.^2);
>> figure,imshow(edge_p/255)
```

```
>> edge_t=im2bw(edge_p/255,0.3);
```



(a) (b)

FIGURE 9.18 *All the edges of the circuit.*

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FIGURE 9.19

```
>> edge_p=edge(ic,'prewitt');
```

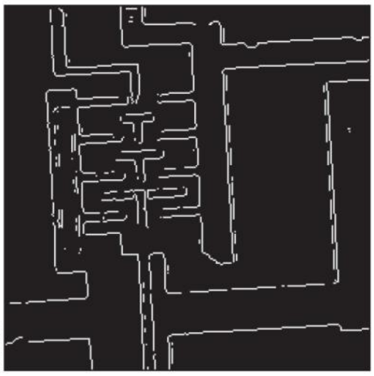

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FIGURE 9.19 *The* `prewitt` *option of* `edge`.

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9.7.2 Some Edge Detection Filters

- **Roberts cross-gradient filters**

$$\begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{bmatrix} \text{ and } \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

- **Sobel filters**

$$\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \text{ and } \begin{bmatrix} -1 & -2 & 1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix}$$

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FIGURE 9.20

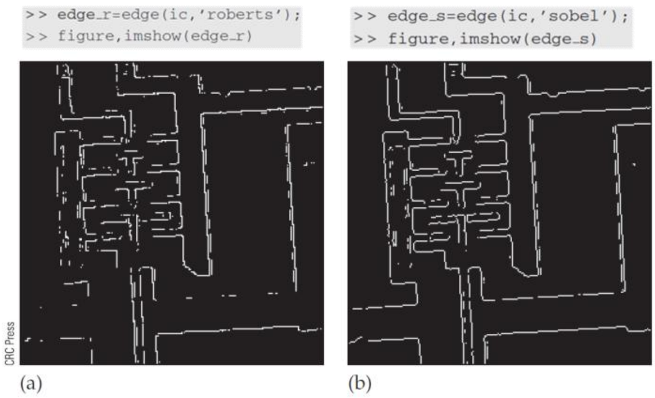

FIGURE 9.20 *Results of the Roberts and Sobel filters. (a) Roberts edge detection. (b) Sobel edge detection.*

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9.8 Second Derivatives

- **9.8.1 The Laplacian**

$$\nabla^2 f = \frac{\partial^2 f}{\partial x^2} + \frac{\partial^2 f}{\partial y^2} \qquad \begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

✓ Isotropic filter

✓ Very sensitive to noise

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FIGURE 9.21

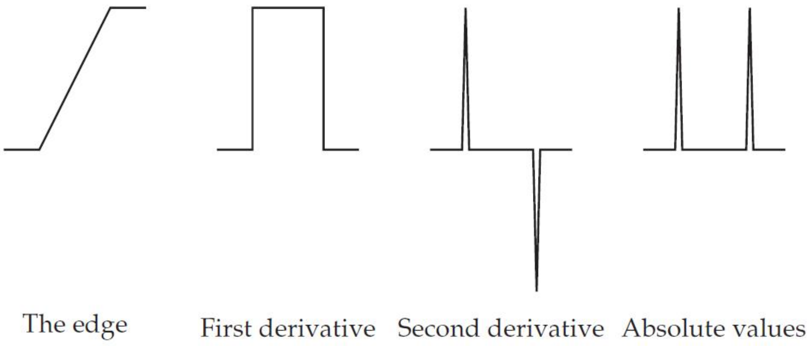

FIGURE 9.21 *Second derivatives of an edge function.*

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FIGURE 9.22

```
>> l=fspecial('laplacian',0);
>> ic_l=filter2(l,ic);
>> figure,imshow(mat2gray(ic_l))
```

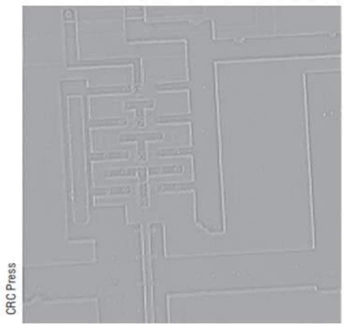

FIGURE 9.22 *Result after filtering with a discrete Laplacian.*

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9.8.2 Zero Crossing

- The position where the result of the filter **changes sign**
- e.g., consider the simple image given in Figure 9.23(a) and the result after filtering with a Laplacian mask in Figure 9.23(b)

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FIGURE 9.23

50	50	50	50	50	50	50	50	50	50
50	50	50	50	50	50	50	50	50	50
50	50	200	200	200	200	200	200	50	50
50	50	200	200	200	200	200	200	50	50
50	50	200	200	200	200	200	200	50	50
50	50	200	200	200	200	200	200	50	50
50	50	50	50	200	200	200	200	50	50
50	50	50	50	200	200	200	200	50	50
50	50	50	50	50	50	50	50	50	50
50	50	50	50	50	50	50	50	50	50

(a)

−100	−50	−50	−50	−50	−50	−50	−50	−50	−100
−50	0	150	150	150	150	150	150	0	−50
−50	150	−300	−150	−150	−150	−150	−300	150	−50
−50	150	−150	0	0	0	0	−150	150	−50
−50	150	−150	0	0	0	0	−150	150	−50
−50	150	−300	−150	0	0	0	−150	150	−50
−50	0	150	300	−150	0	0	−150	150	−50
−50	0	0	150	−300	−150	−150	−300	150	−50
−50	0	0	0	150	150	150	150	0	−50
−100	−50	−50	−50	−50	−50	−50	−50	−50	−100

(b)

FIGURE 9.23 *Locating zero crossings in an image. (a) A simple image. (b) After laplace filtering.*

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9.8.2 Zero Crossing

- We define the **zero crossings** in such a filtered image to be pixels that satisfy either of the following:
  - ✓ They have a negative gray value and are orthogonally adjacent to a pixel whose gray value is positive
  - ✓ They have a value of zero and are between negative- and positive-valued pixels

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FIGURE 9.24

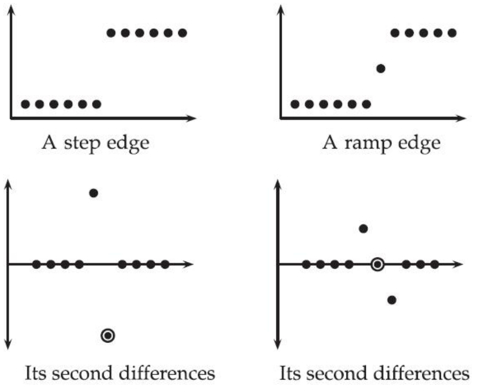

FIGURE 9.24 *Edges and second differences.*

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9.8.2 Zero Crossing

- **Marr-Hildreth** method
  - ✓ Smooth the image with a Gaussian filter
  - ✓ Convolve the result with a Laplacian filter
  - ✓ Find the zero crossings

```
>> fspecial('log',13,2)
```

```
>> edge(ic,'zerocross');
```


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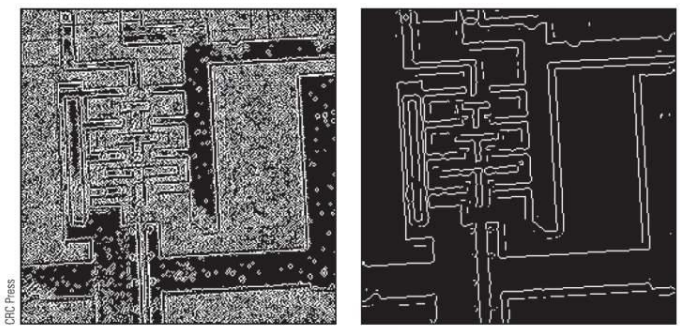
FIGURE 9.25

```
>> l=fspecial('laplace',0);
>> icz=edge(ic,'zerocross',1);
>> imshow(icz)
```

```
>> log=fspecial('log',13,2);
>> edge(ic,'zerocross',log);
```



(a) (b)

FIGURE 9.25 *Edge detection using zero crossings. (a) Zero crossings. (b) Using an LoG filter first.*

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9.9 The Canny Edge Detector

- ✓ Take our image x
- ✓ Create a one-dimensional Gaussian filter g
- ✓ Create a one-dimensional filter dg corresponding to the expression given in

$$\left(-\frac{x}{\sigma^2}\right)e^{-\frac{x^2}{2\sigma^2}}$$

- ✓ 4. Convolve g with dg to obtain gdg
- ✓ 5. Apply gdg to x producing x1
- ✓ 6. Apply gdg' to x producing x2

We can now form an edge image with $\mathrm{xe} = \sqrt{\mathrm{x1}^2 + \mathrm{x2}^2}$

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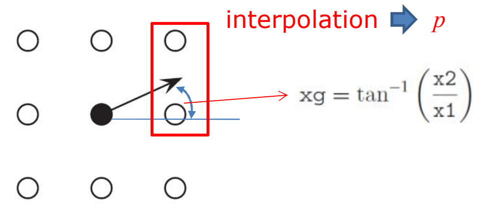
FIGURE 9.26

- ✓ **Non-maximum suppression**



The edge direction at a pixel

FIGURE 9.26 *Nonmaximum suppression in the Canny edge detector.*

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FIGURE 9.27

Region	Degree	Pixel Location
1	0°	$y \le 0$ and $x > -y$
(1)	0°	$y \ge 0$ and $x < -y$
2	45°	$x > 0$ and $x \le -y$
(2)	45°	$x < 0$ and $x \ge -y$
3	90°	$x \le 0$ and $x > y$
(3)	90°	$x \ge 0$ and $x < y$
4	135°	$y < 0$ and $x \le y$
(4)	135°	$y > 0$ and $x \ge y$

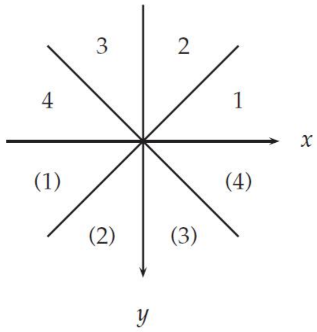

FIGURE 9.27 *Using pixel locations to quantize the gradient.*

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FIGURE 9.28

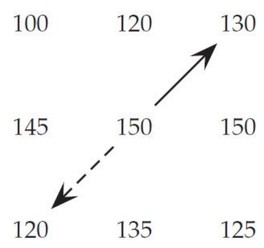

FIGURE 9.28 *Quantizing in non-maximum suppression.*

- ✓ **Hysteresis thresholding**

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FIGURE 9.29

```
>> [icc,t]=edge(ic,'canny');
>> t

t =

    0.0500    0.1250

>> imshow(icc)
```

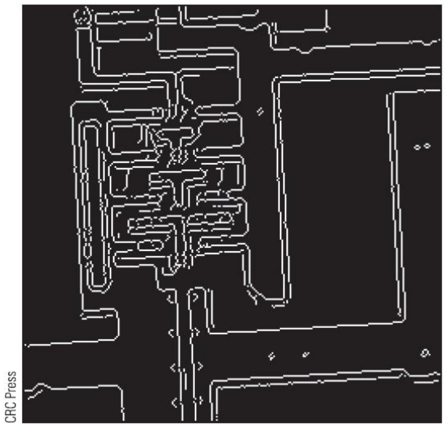

FIGURE 9.29 *Canny edge detection.*

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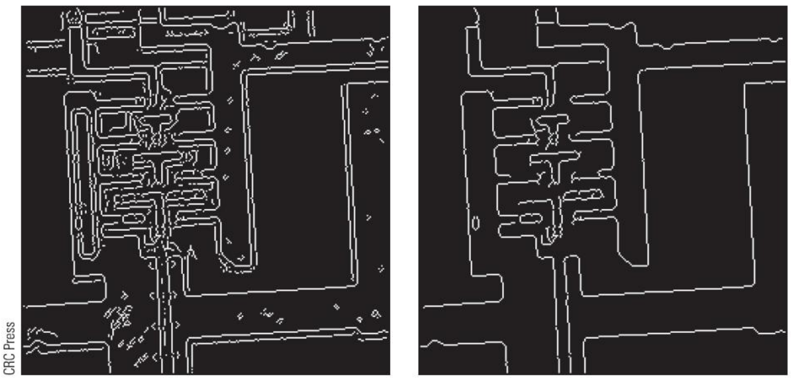
FIGURE 9.30



`edge(ic,'canny',[0,0.05])` `edge(ic,'canny',[0.01,0.5])`

FIGURE 9.30 *Canny edge detection with different thresholds.*

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9.10 The Hough Transform

$$y = ax + b$$

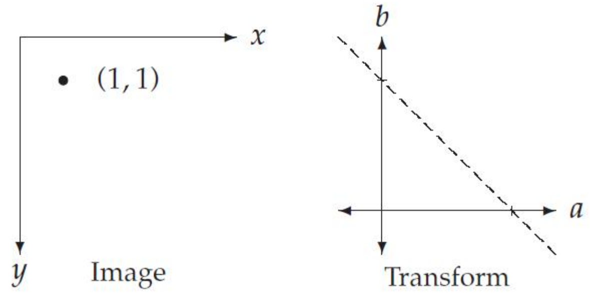

FIGURE 9.31 *A point in an image and its corresponding line in the transform.*

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FIGURE 9.32

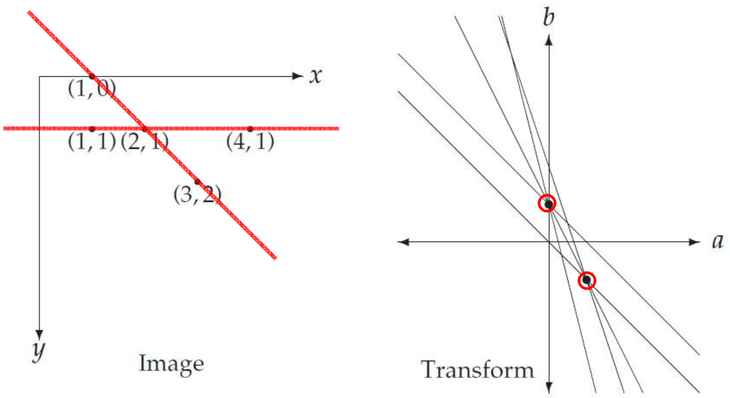

FIGURE 9.32 *An image and its corresponding lines in the transform.*

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FIGURE 9.33

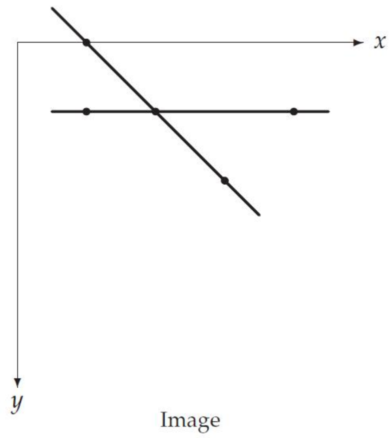

FIGURE 9.33 *Lines found by the Hough transform.*

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9.10 The Hough Transform

- We cannot express a vertical line in the form $y = mx+c$, because m represents the gradient and a vertical line has infinite gradient
- Any line can be described in terms of the two parameters r and θ
  - ✓ r is the perpendicular distance from the line to the origin
  - ✓ θ is the angle of the line's perpendicular to the x axis

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FIGURE 9.34

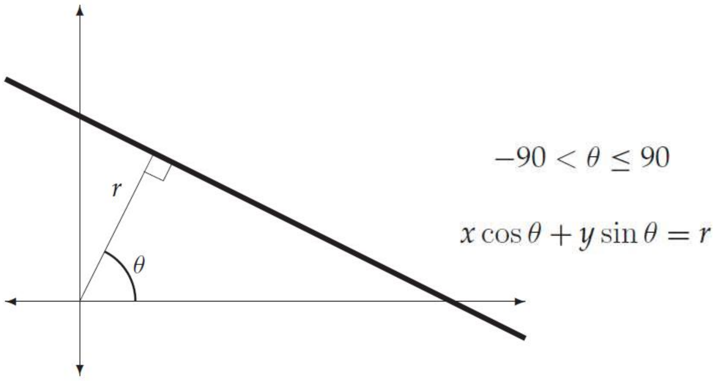

FIGURE 9.34 *A line and its parameters.*

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FIGURE 9.35

- If we discretize θ to use only four values: -45°, 0°, 45°, 90°

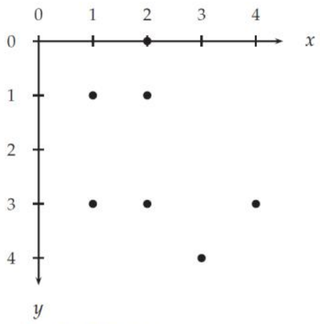

FIGURE 9.35 *A small image.*

(x, y)	$-45°$	$0°$	$45°$	$90°$
(2, 0)	1.4	2	1.4	0
(1, 1)	0	1	1.4	1
(2, 1)	0.7	2	2.1	1
(1, 3)	−1.4	1	2.8	3
(2, 3)	−0.7	2	3.5	3
(4, 3)	0.7	4	4.9	3
(3, 4)	−0.7	3	4.9	4

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9.10 The Hough Transform

- The accumulator array contains the number of times each value of (r, θ) appears in the above table

	-1.4	-0.7	0	0.7	1	1.4	2	2.1	2.8	3	3.5	4	4.9
-45°	1	2	1	2		1							
0°					2		3			1		1	
45°						2		1	1		1		2
90°			1		2					3		2	

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FIGURE 9.36

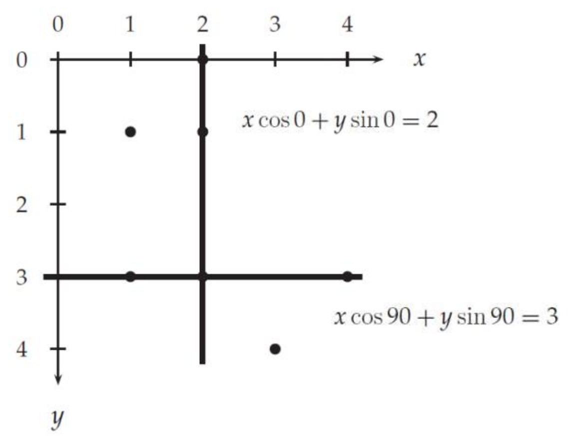

FIGURE 9.36 *Lines found by the Hough transform.*

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9.11 Implementing the Hough Transform in MATLAB

- ✓ Decide on a discrete set of values of θ and r to use
- ✓ Calculate for each foreground pixel (x, y) in the image the values of $r = x\cos\theta + y\sin\theta$ for all of our chosen values of θ
- ✓ Create an accumulator array whose sizes are the numbers of angles θ and values r in our chosen discretizations from Step 1, and
- ✓ Step through all of our r values, updating the accumulator array as we go

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FIGURE 9.37

- **9.11.1 Discretizing r and θ**

```
>> angles = [-90:180]*pi/180;
```

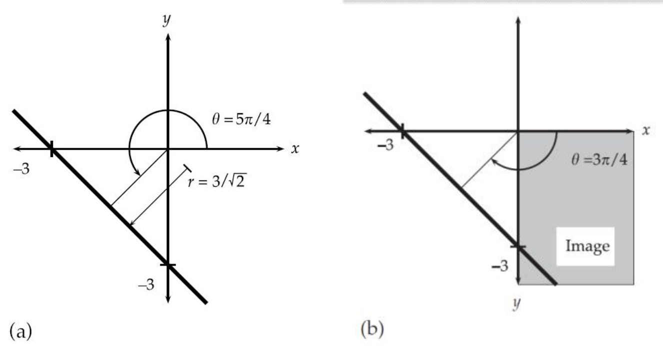

FIGURE 9.37 *A line parameterized with r and θ. (a) Using ordinary Cartesian axes. (b) Using matrix axes.*

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9.11 Implementing the Hough Transform in MATLAB

9.11.2 Calculating the r Values

✓ If im is a **binary image**

We can create a binary edge image by use of the `edge` function

```
>> [x,y]=find(im);
```

```
>> r=floor(x*cos(angles)+y*sin(angles));
```

9.11.3 Forming the Accumulator Array

```
>> rmax=max(r(find(r>0)));
>> acc=zeros(rmax+1,270);
```

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9.11 Implementing the Hough Transform in MATLAB

- **9.11.4 Updating the Accumulator Array**

```
function res=hough2(image)

%
% HOUGH2(IMAGE) creates the Hough transform corresponding to the image IMAGE
%

if ~isbw(image)
  edges=edge(image,'canny');
else
  edges=image;
end;
[x,y]=find(edges);
angles=[-90:180]*pi/180;
r=floor(x*cos(angles)+y*sin(angles));
rmax=max(r(find(r>0)));
acc=zeros(rmax+1,270);
for i=1:length(x),
  for j=1:270,
    if r(i,j)>=0
      acc(r(i,j)+1,j)=acc(r(i,j)+1,j)+1;
    end;
  end;
end;
res=acc;
```

FIGURE 9.38 *A simple MATLAB function for implementing the Hough transform.*

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FIGURE 9.39

```
>> c=imread('cameraman.tif');
>> hc=hough2(c);
```

```
>> imshow(mat2gray(hc)*1.5)
```

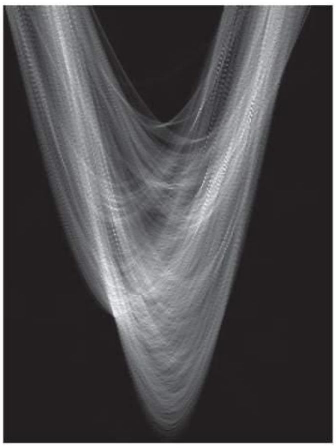

FIGURE 9.39 *The result of a Hough Transform.*

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FIGURE 9.40

```
>> max(hc(:))

ans =

    91
```

```
>> [r,theta]=find(hc==91)

r =

   138


theta =

   181
```

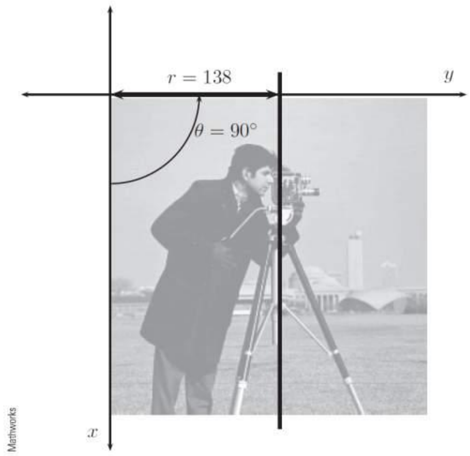

FIGURE 9.40 *A line from the Hough Transform.*

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FIGURE 9.41

```
function houghline(image,r,theta)
%
% Draws a line at perpendicular distance R from the upper left corner of the
% current figure, with perpendicular angle THETA to the left vertical axis.
% THETA is assumed to be in degrees.
%
[x,y]=size(image);
angle=pi*(181-theta)/180;
X=[1:x];
if sin(angle)==0
  line([r r],[0,y],'Color','black')
else
  line([0,y],[r/sin(angle),(r-y*cos(angle))/sin(angle)],'Color','black')
end;
```

FIGURE 9.41 *A simple MATLAB function for drawing lines on an image.*

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FIGURE 9.42

(a) (b)

FIGURE 9.42 *The* `houghline` *function in action.*

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