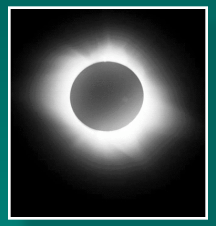
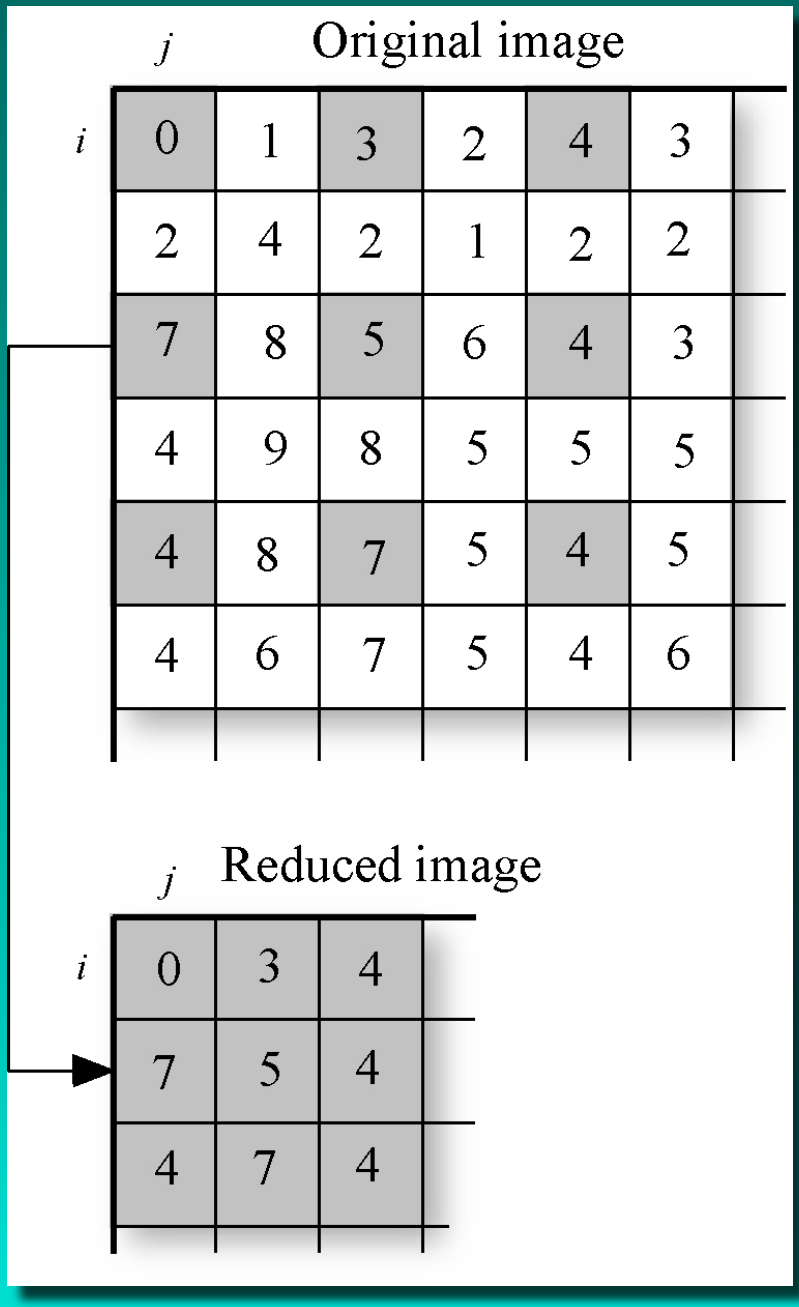


Image Enhancement

Reduction
Magnification
Spatial Profiles
Spectral Profiles
Ratioing
Contrast Stretching
Frequency Filtering
Edge Enhancement
Vegetation Indices
Texture

Jensen, 2011

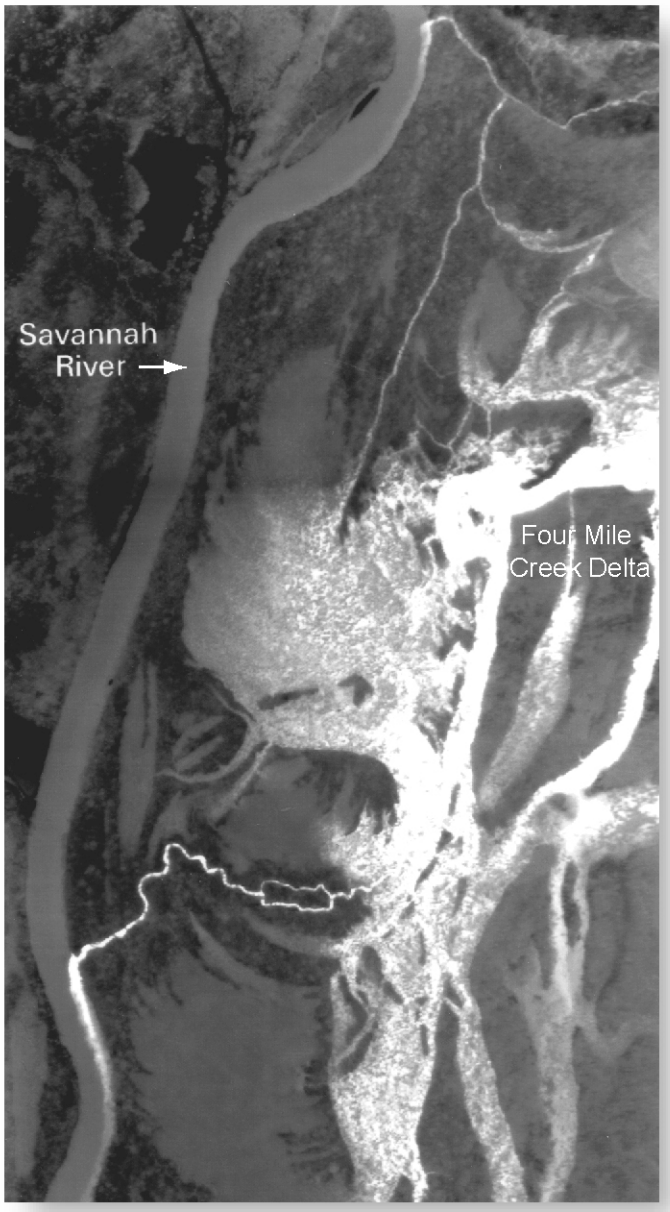
Integer Image Reduction



Jensen, 2011

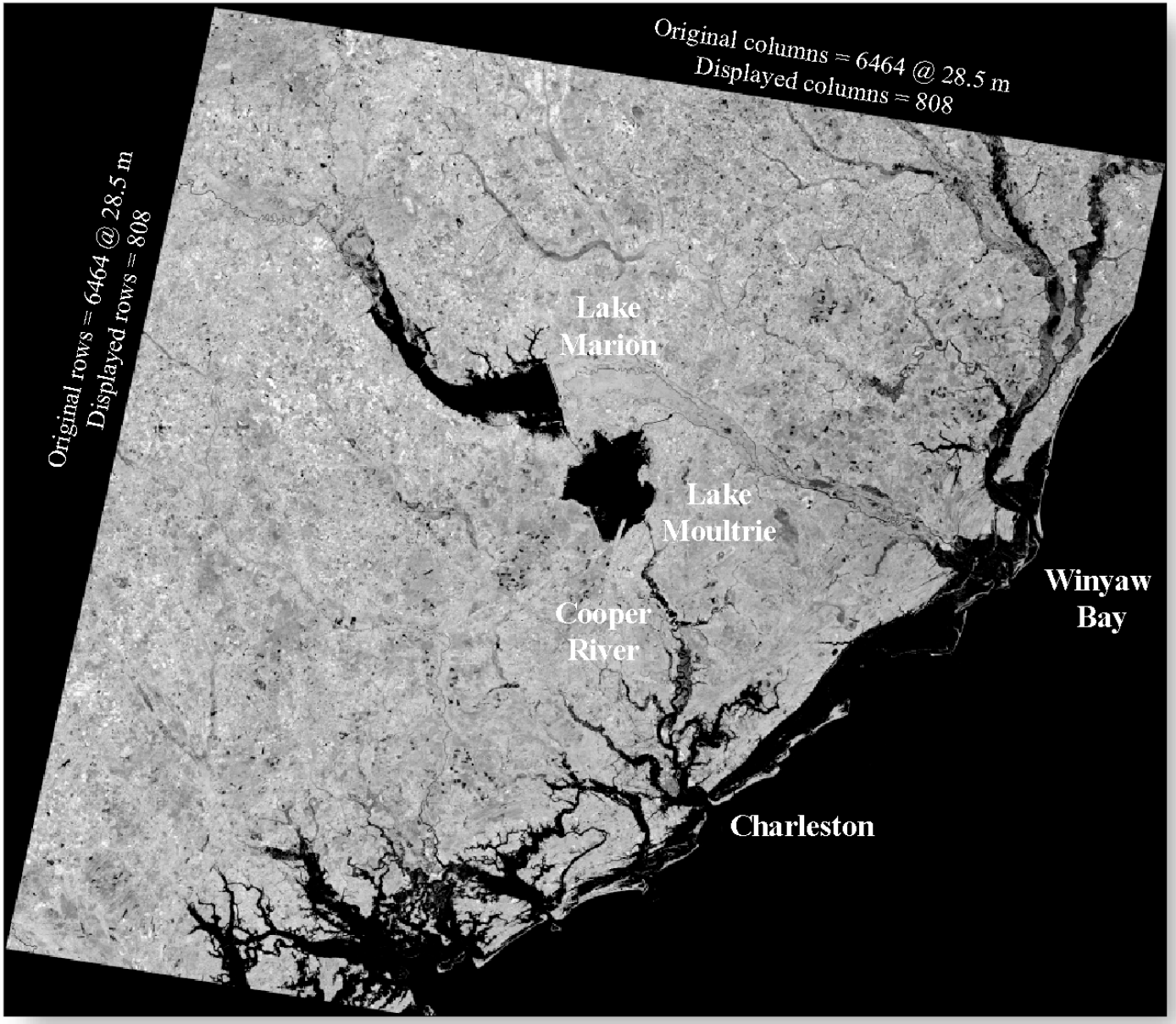
Integer Image Reduction

2x Reduction of Predawn Thermal Infrared Scanner Data



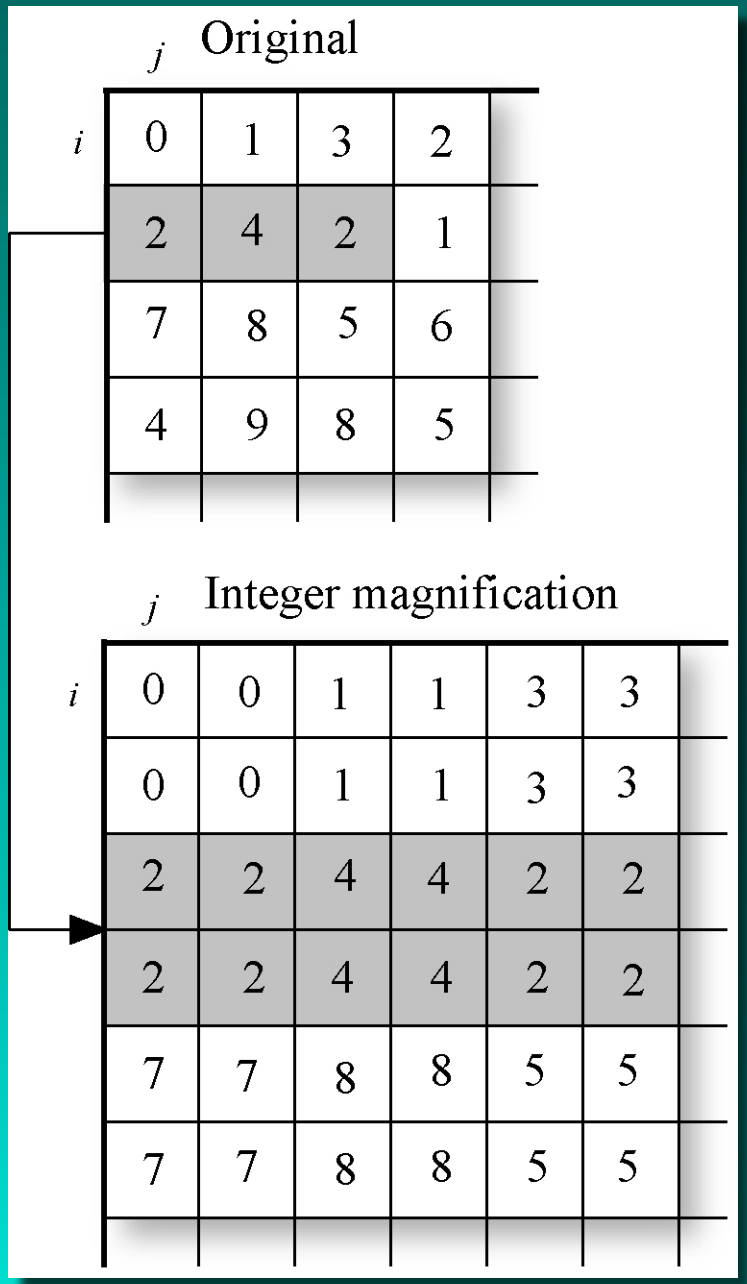
Jensen, 2011

8x Reduction of Landsat Enhanced Thematic Mapper Plus (ETM+) Imagery of Charleston, SC, Obtained on October 23, 1999 (Path 16, Row 37)



Jensen, 2011

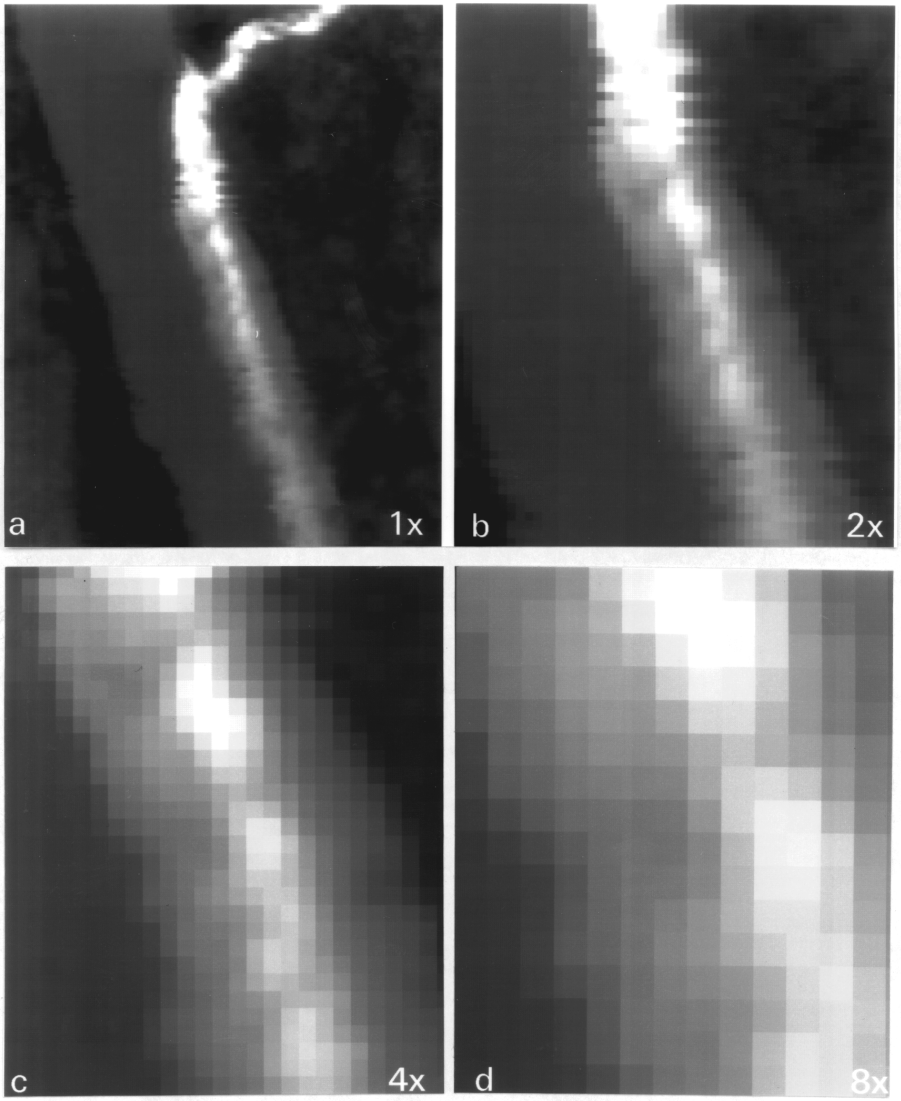
Integer Image Magnification



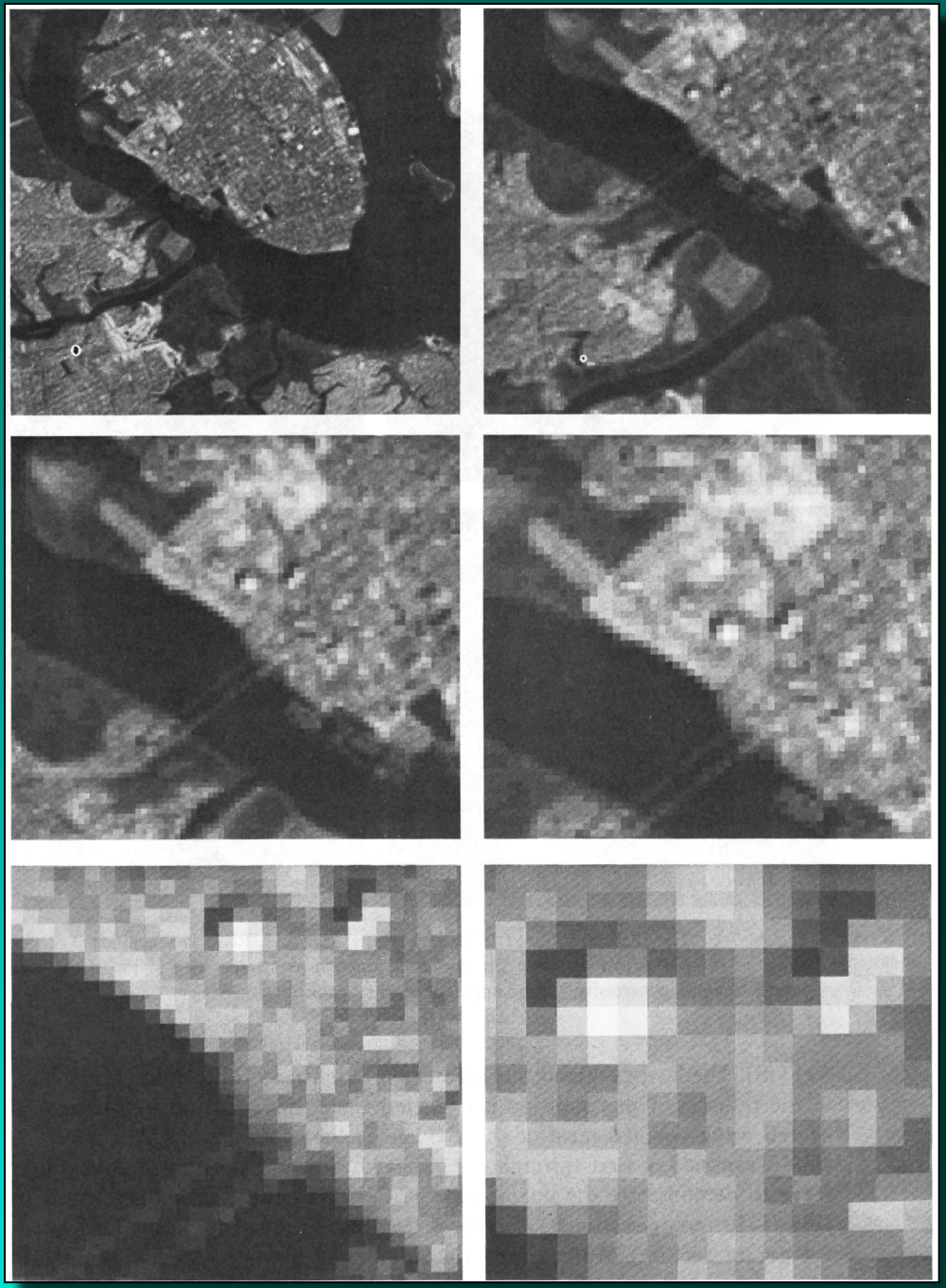
Jensen, 2011

Integer Image Magnification

Magnification of Predawn Thermal Infrared Data
of A Thermal Plume in the Savannah River



Jensen, 2011



Integer Image Magnification

Jensen, 2011

Band Ratioing

$$BV_{i,j,ratio} = \frac{BV_{i,j,k}}{BV_{i,j,l}}$$

where:

$BV_{i,j,k}$ is the original input brightness value in band k

$BV_{i,j,l}$ is the original input brightness value in band l

$BV_{i,j,ratio}$ is the ratio output brightness value

Jensen, 2011

Band Ratioing

Ratio values within the range 1/255 to 1 are assigned values between 1 and 128 by the function:

$$BV_{i,j,n} = Int\left(\left(BV_{i,j,r} \times 127\right) + 1\right)$$

Ratio values from 1 to 255 are assigned values within the range 128 to 255 by the function:

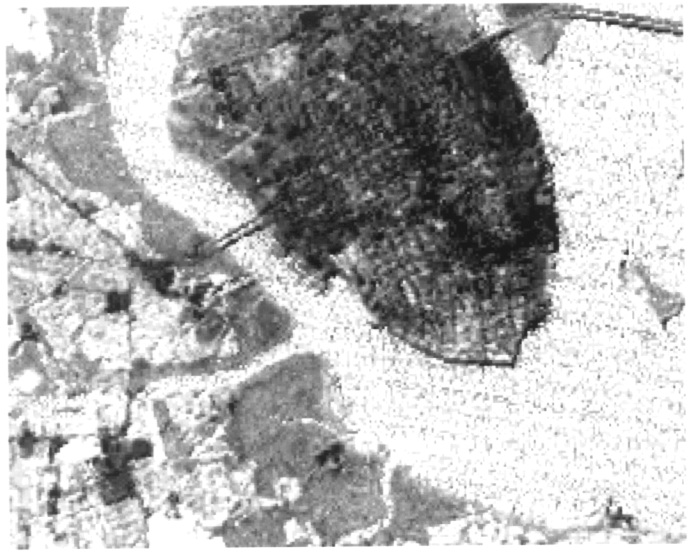
$$BV_{i,j,n} = Int\left(128 + \frac{BV_{i,j,r}}{2}\right)$$

Jensen, 2011

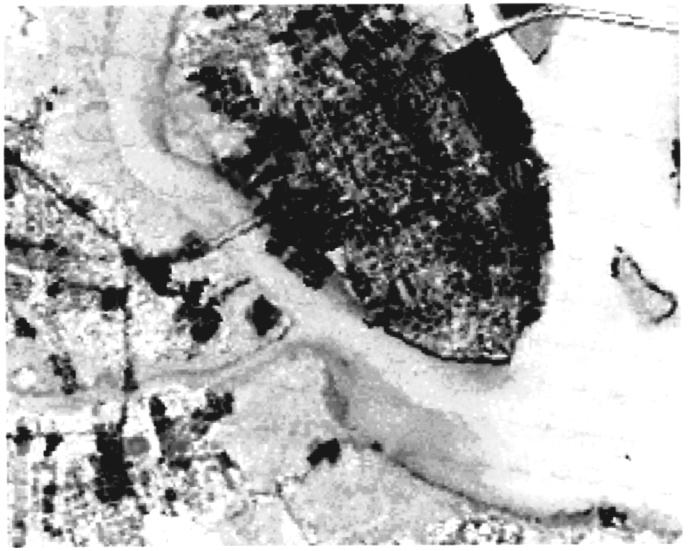
Band Ratioing of Charleston, SC Landsat Thematic Mapper Data

Ratio TM bands 3/4

Ratio TM bands 4/5



Ratio TM bands 4/7



Ratio TM bands 3/6

Jensen, 2011

Band Ratio Image

Landsat TM
Band 4 / Band 3

Jensen, 2011

Band Ratio

SPOT HRV
Band 3 / Pan

Jensen, 2011

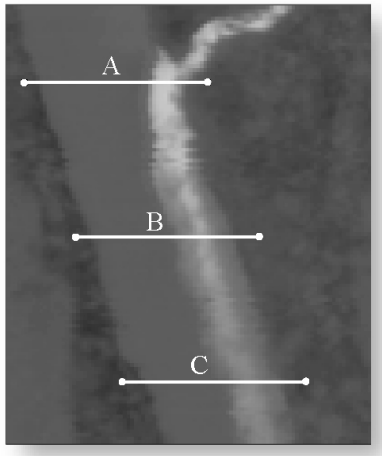
Band Ratio

HyMap Hyperspectral Data: Band 40 / Band 15

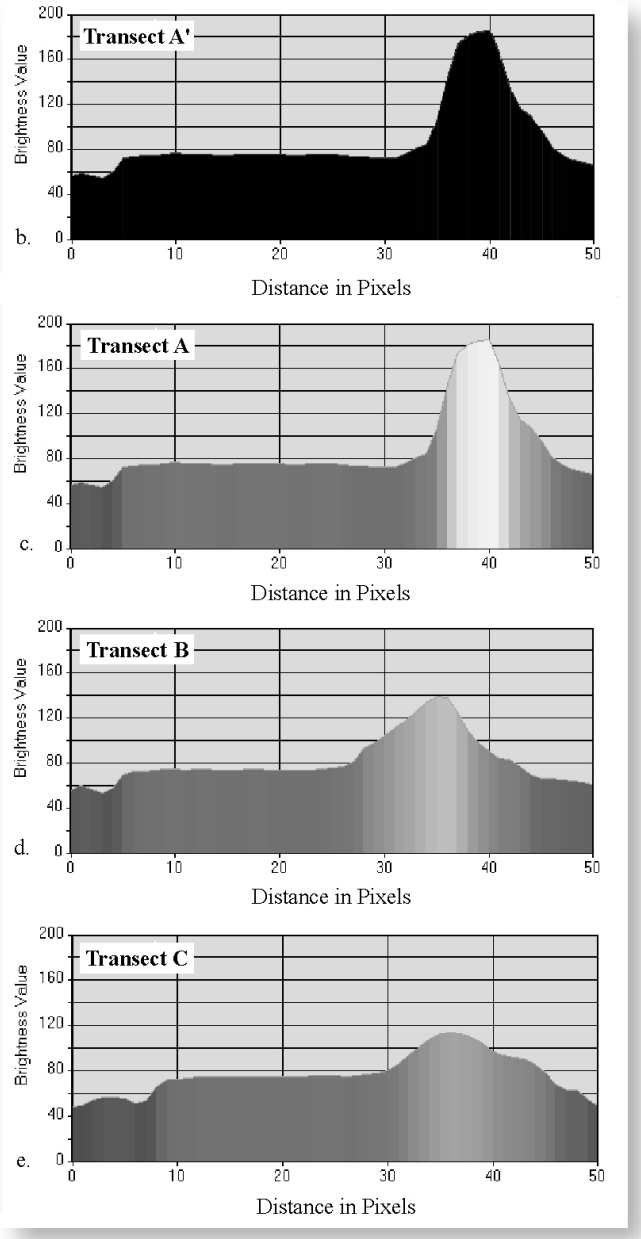
Jensen, 2011

Spatial Profile -Transect-

Spatial Profiles - Transects

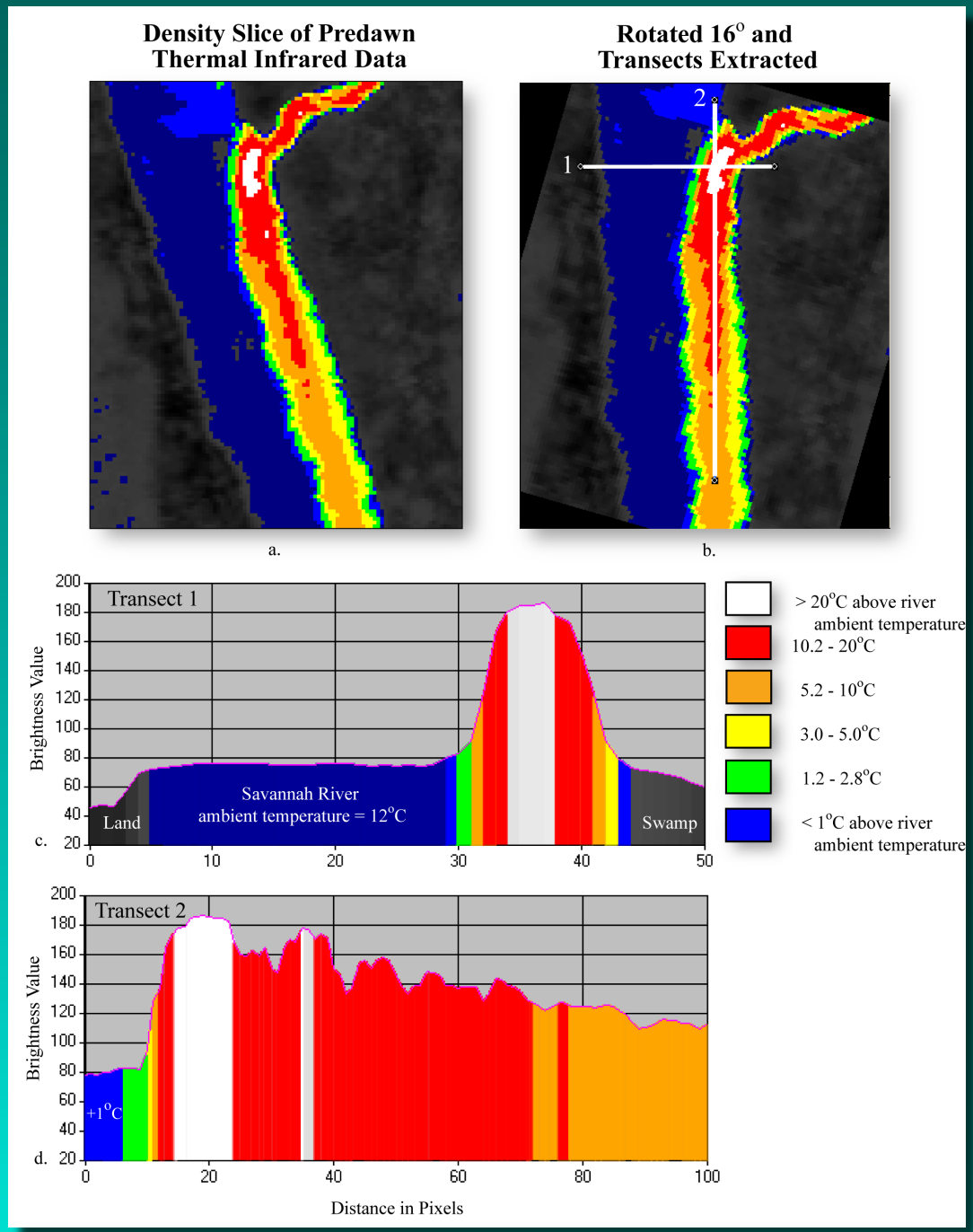


a. Predawn thermal infrared imagery.



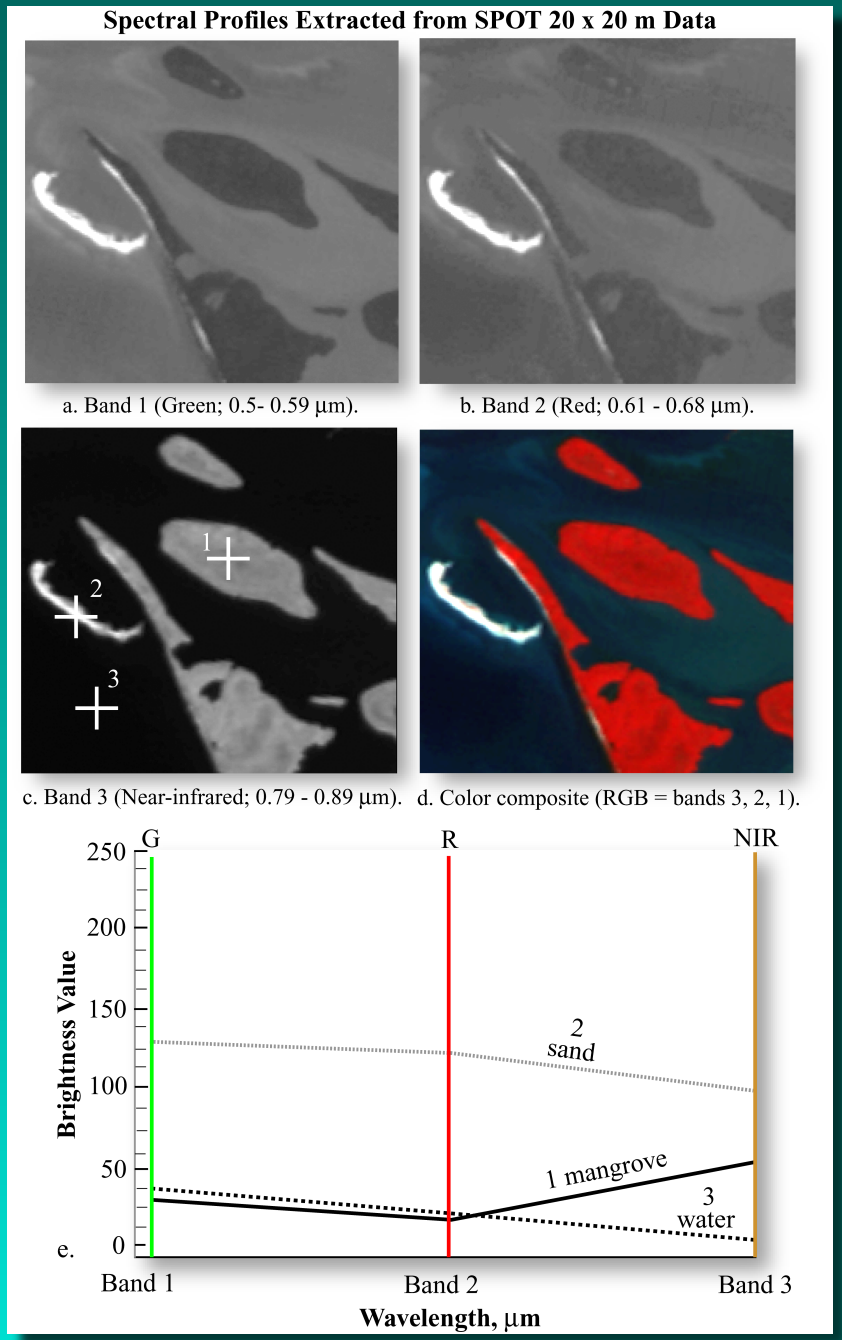
Jensen, 2011

Spatial Profile -Transect-



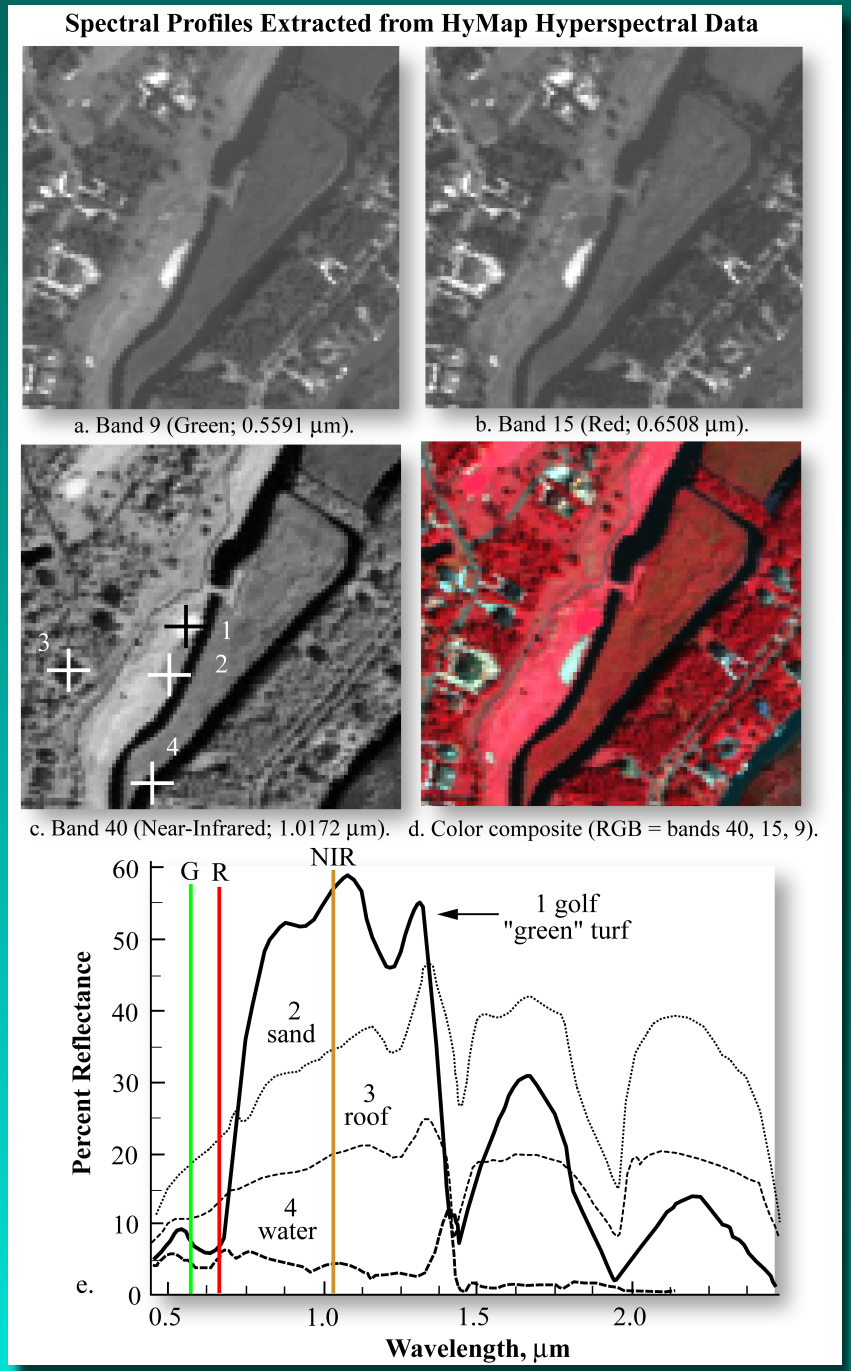
Jensen, 2011

Spectral Profile of SPOT 20 x 20 m Multispectral Data of Marco Island, Florida



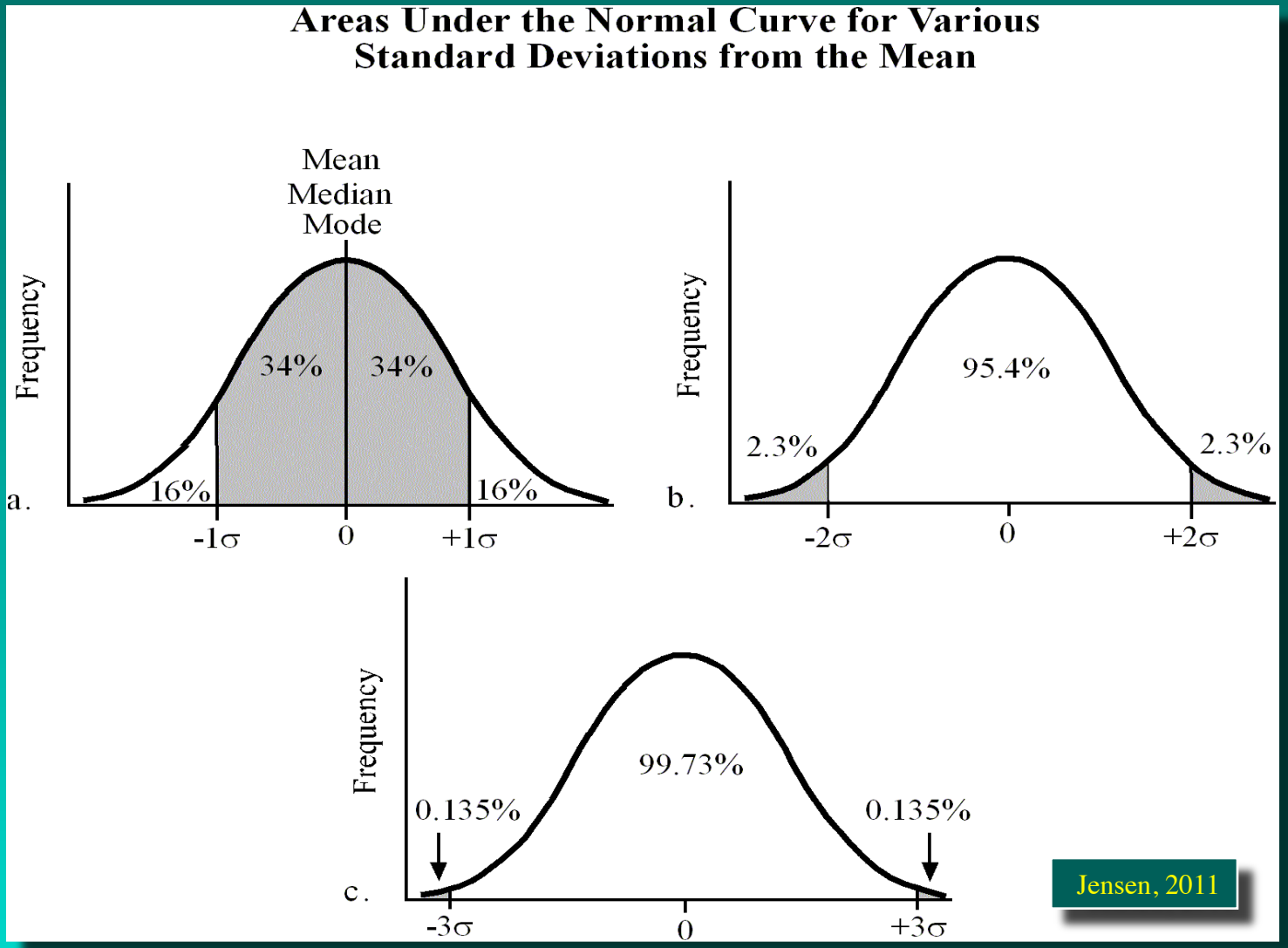
Jensen, 2011

Spectral Profile of HyMap 3 x 3 m Hyperspectral Data of Debordieu Colony near North Inlet, SC



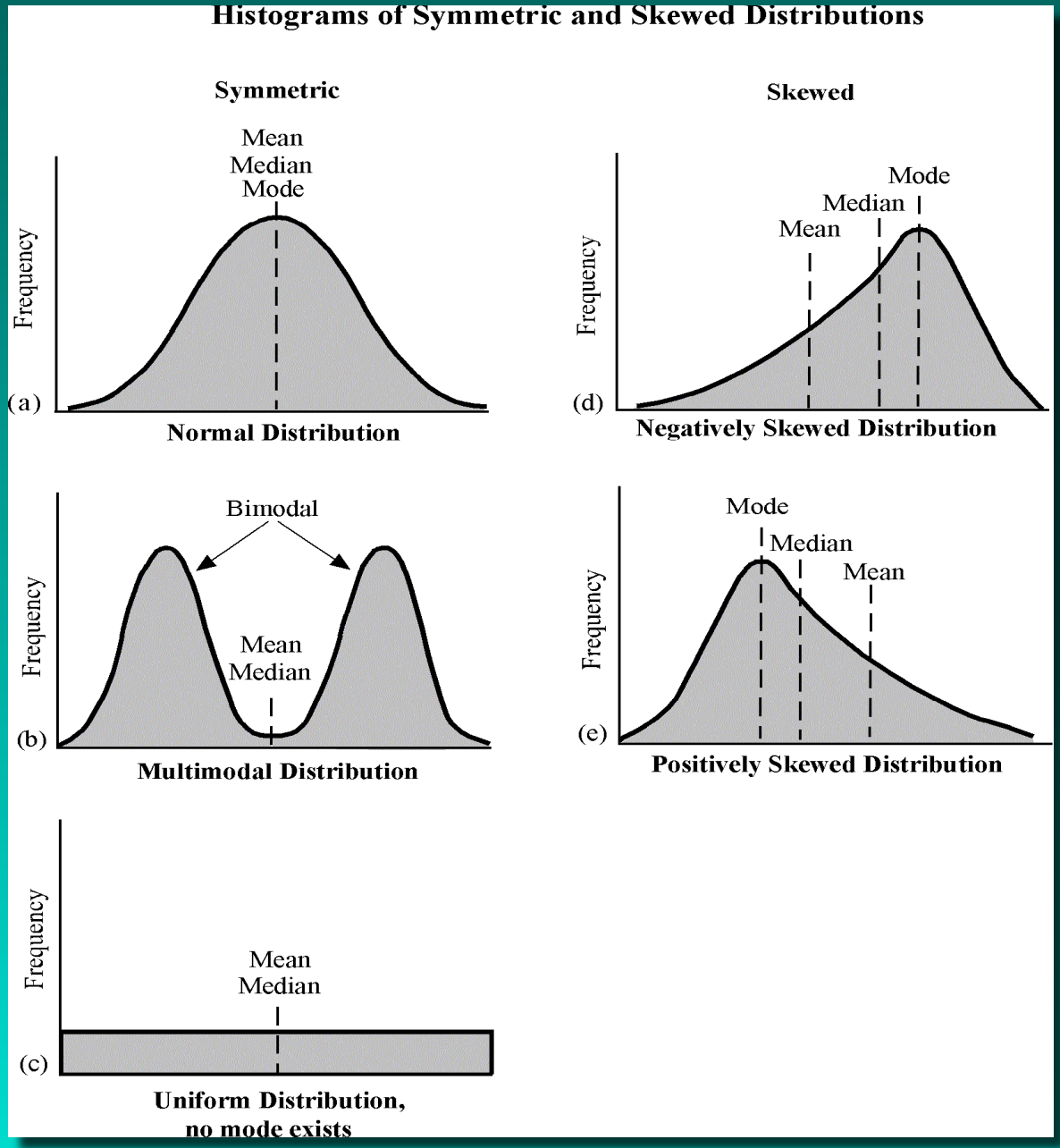
Jensen, 2011

Standard Deviation Contrast Stretch

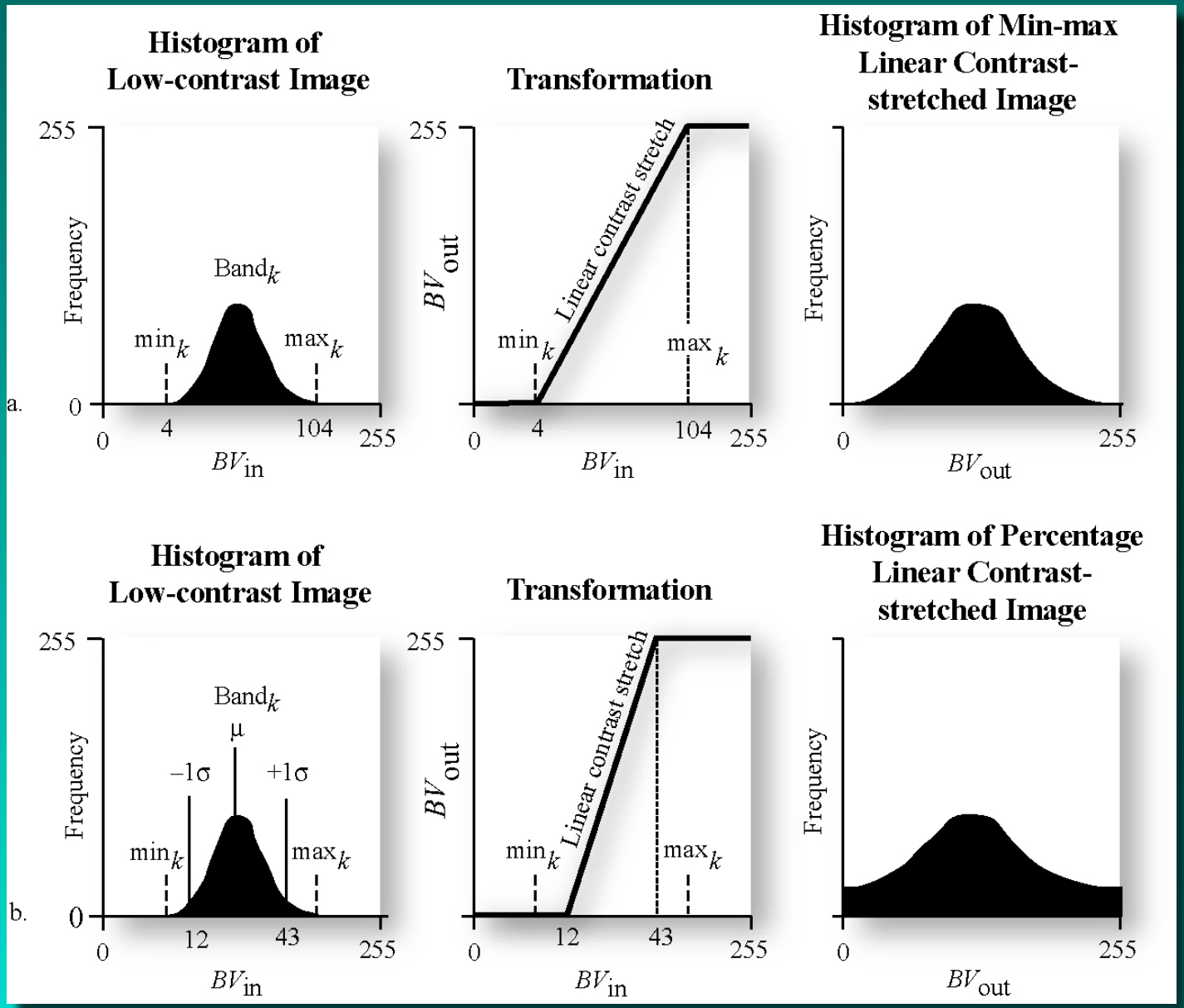


Jensen, 2011

Common Symmetric and Skewed Distributions in Remotely Sensed Data



Jensen, 2011



Min-Max Contrast Stretch

±1 Standard Deviation Contrast Stretch

Jensen, 2011

Linear Contrast Enhancement: Minimum- Maximum Contrast Stretch

$$BV_{out} = \left(\frac{BV_{in} - \min_k}{\max_k - \min_k} \right) quant_k$$

where:

- BV_{in} is the original input brightness value
- $quant_k$ is the range of the brightness values that can be displayed on the CRT (e.g., 255),
- min_k is the minimum value in the image,
- max_k is the maximum value in the image, and
- BV_{out} is the output brightness value

Jensen, 2011

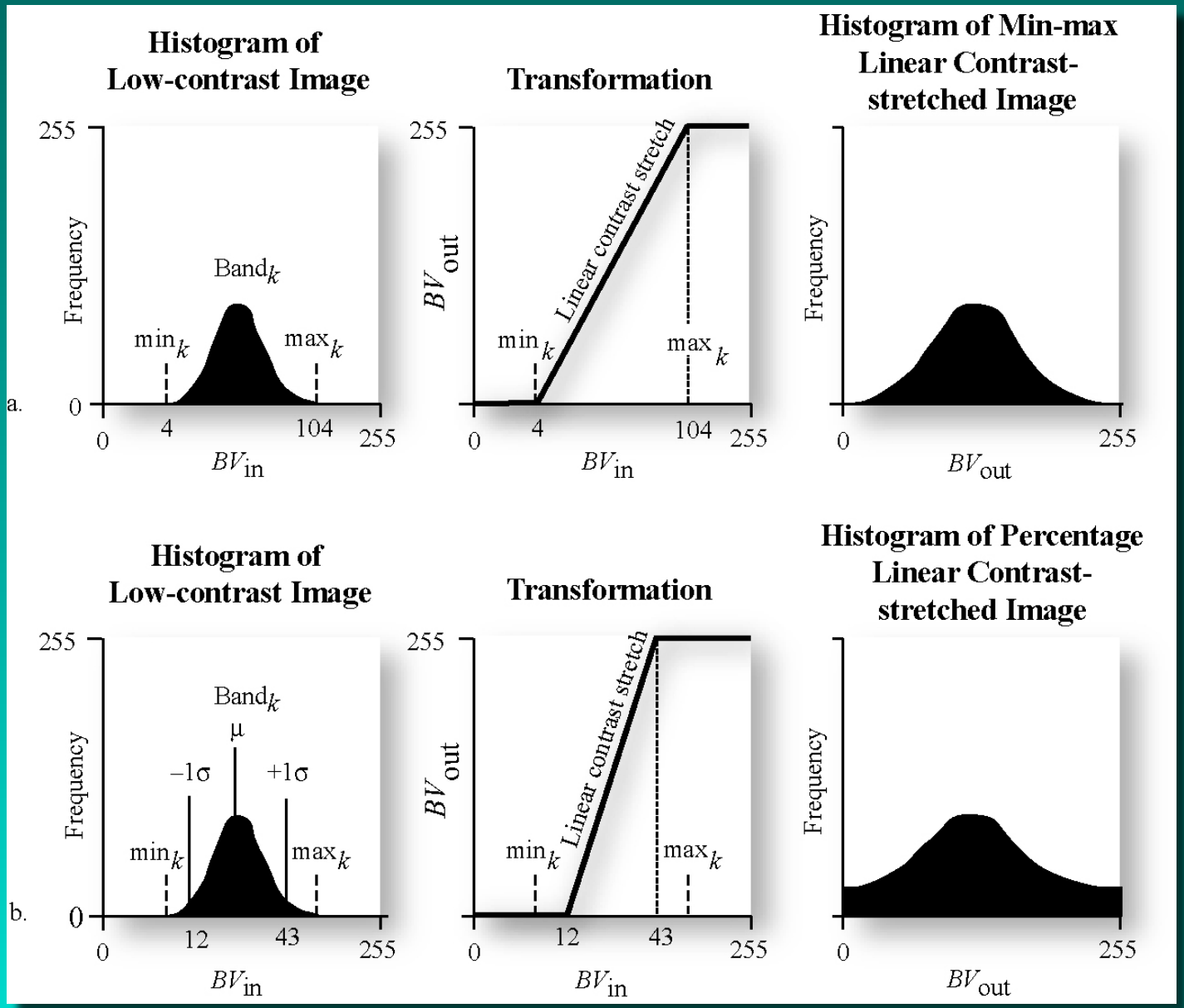
Linear Contrast Enhancement: Minimum- Maximum Contrast Stretch

$$BV_{out} = \left(\frac{4_{in} - 4_{\min}}{105_{\max} - 4_{\min}} \right) 255 = 0$$

$$BV_{out} = \left(\frac{105_{in} - 4}{105 - 4} \right) 255 = 255$$

All other original brightness values between 5 and 104 are linearly distributed between 0 and 255.

Jensen, 2011

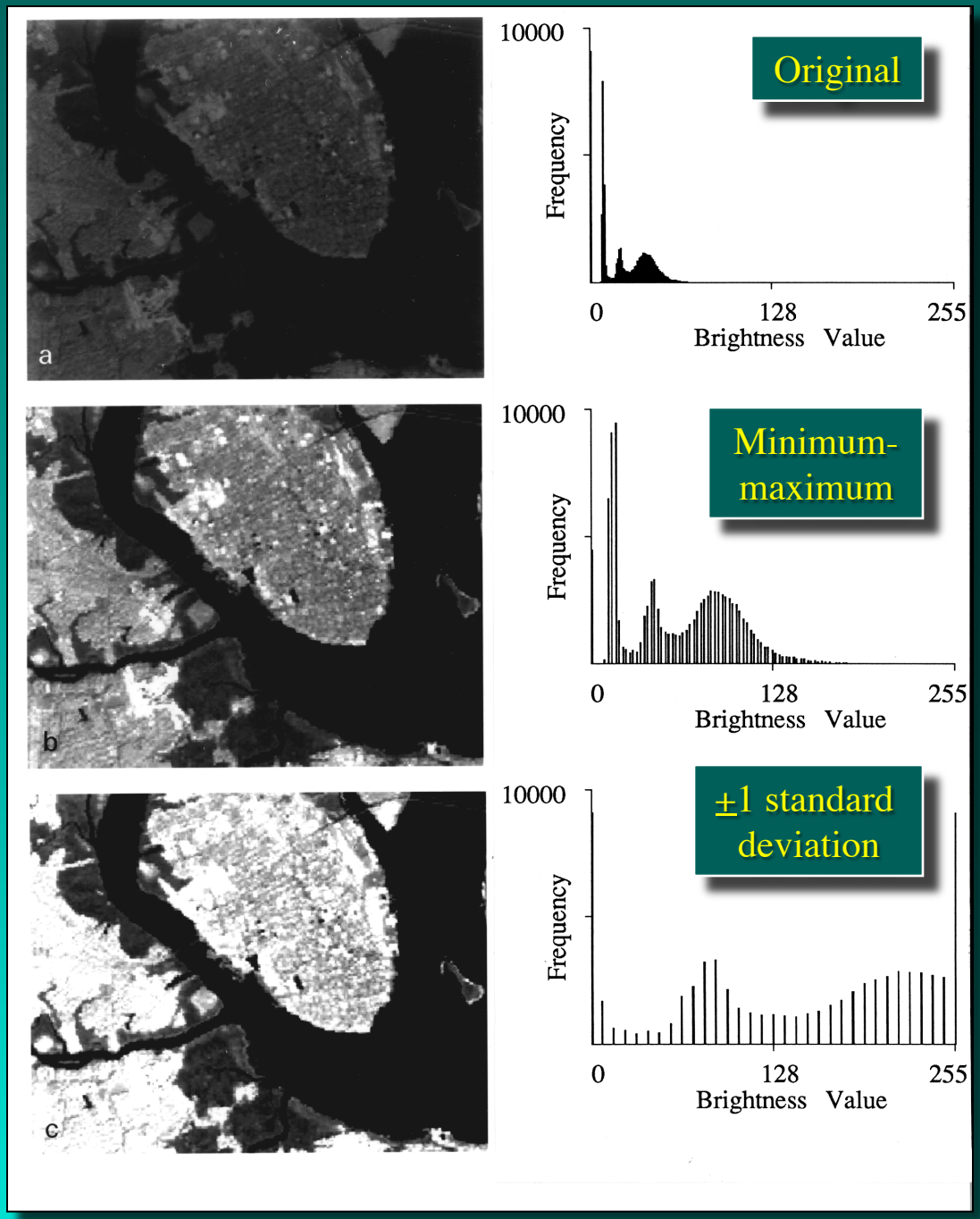


Min-Max Contrast Stretch

±1 Standard Deviation Contrast Stretch

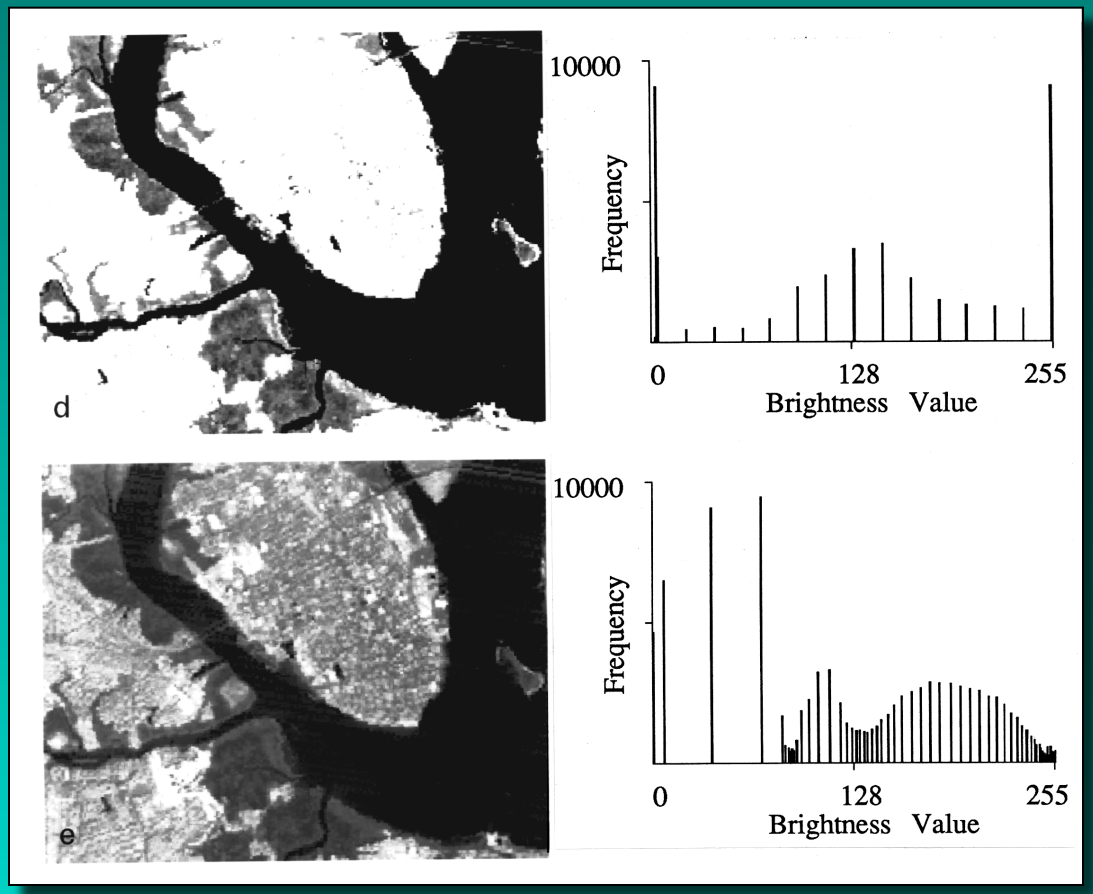
Jensen, 2011

Contrast Stretch of Charleston, SC Landsat Thematic Mapper Band 4 Data



Jensen, 2011

Contrast Stretching of Charleston, SC Landsat Thematic Mapper Band 4 Data

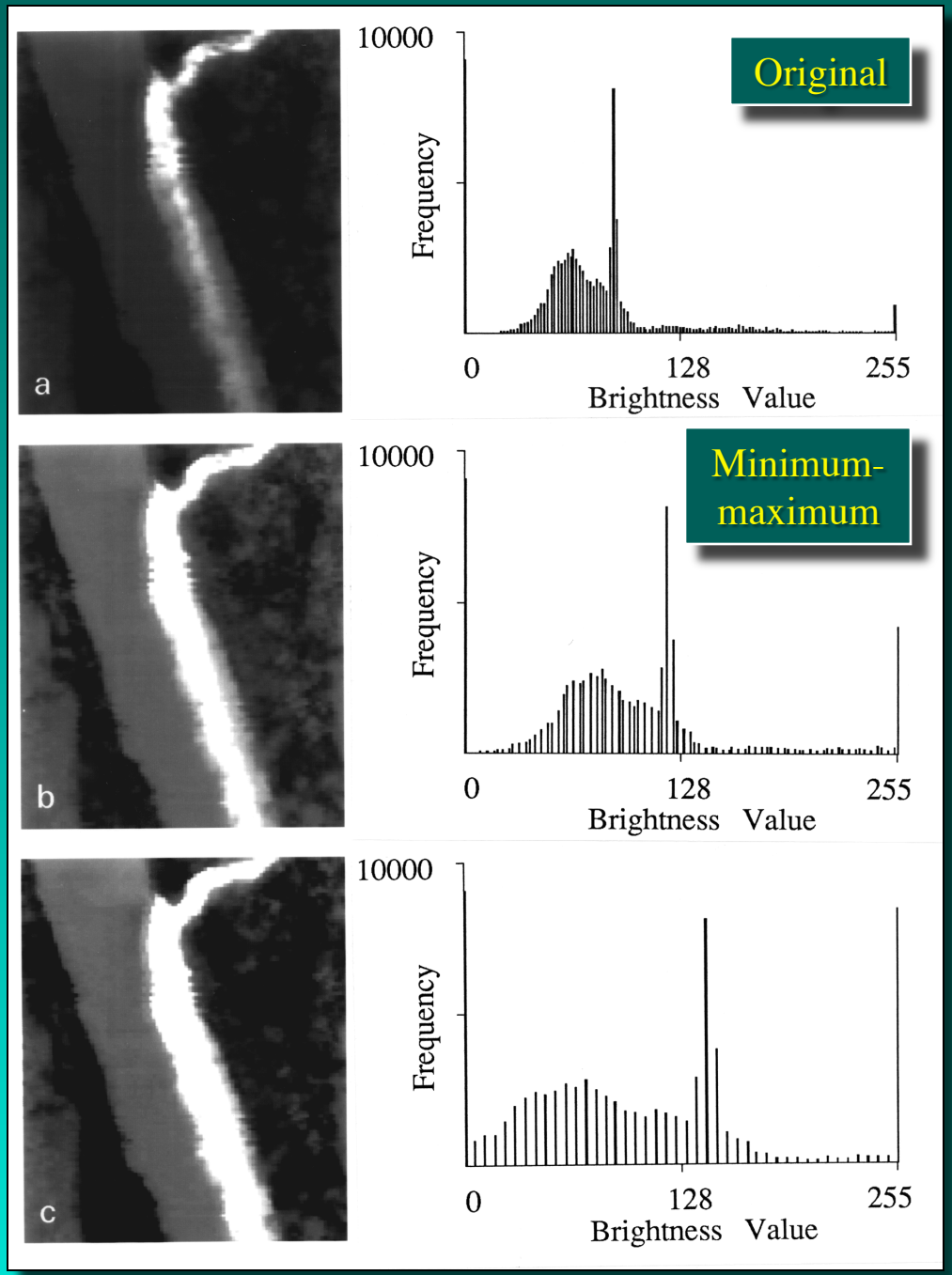


Specific percentage linear contrast stretch designed to highlight wetland

Histogram Equalization

Jensen, 2011

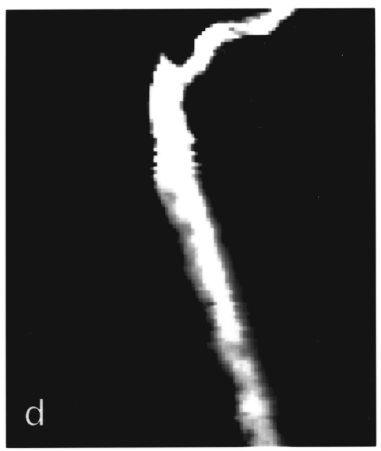
Contrast Stretching of Predawn Thermal Infrared Data of the the Savannah River

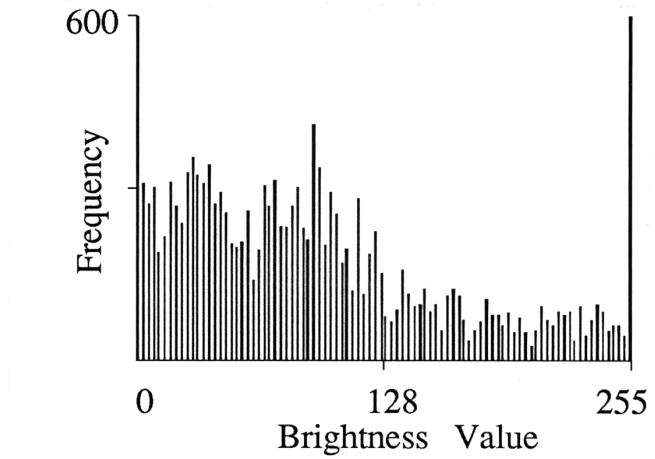


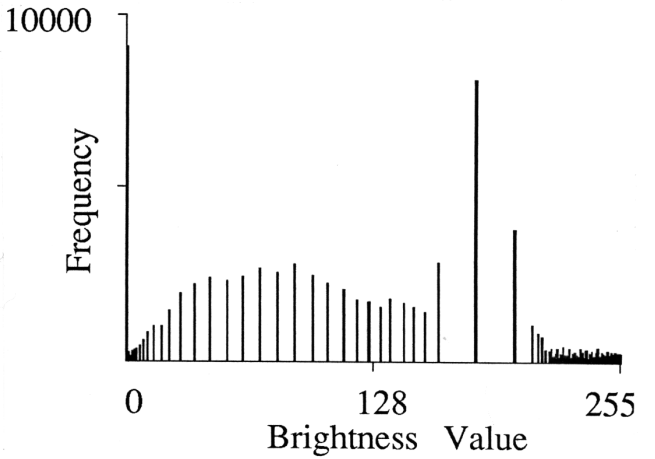
±1 standard deviation

Jensen, 2011

Contrast Stretching of Predawn Thermal Infrared Data of the the Savannah River





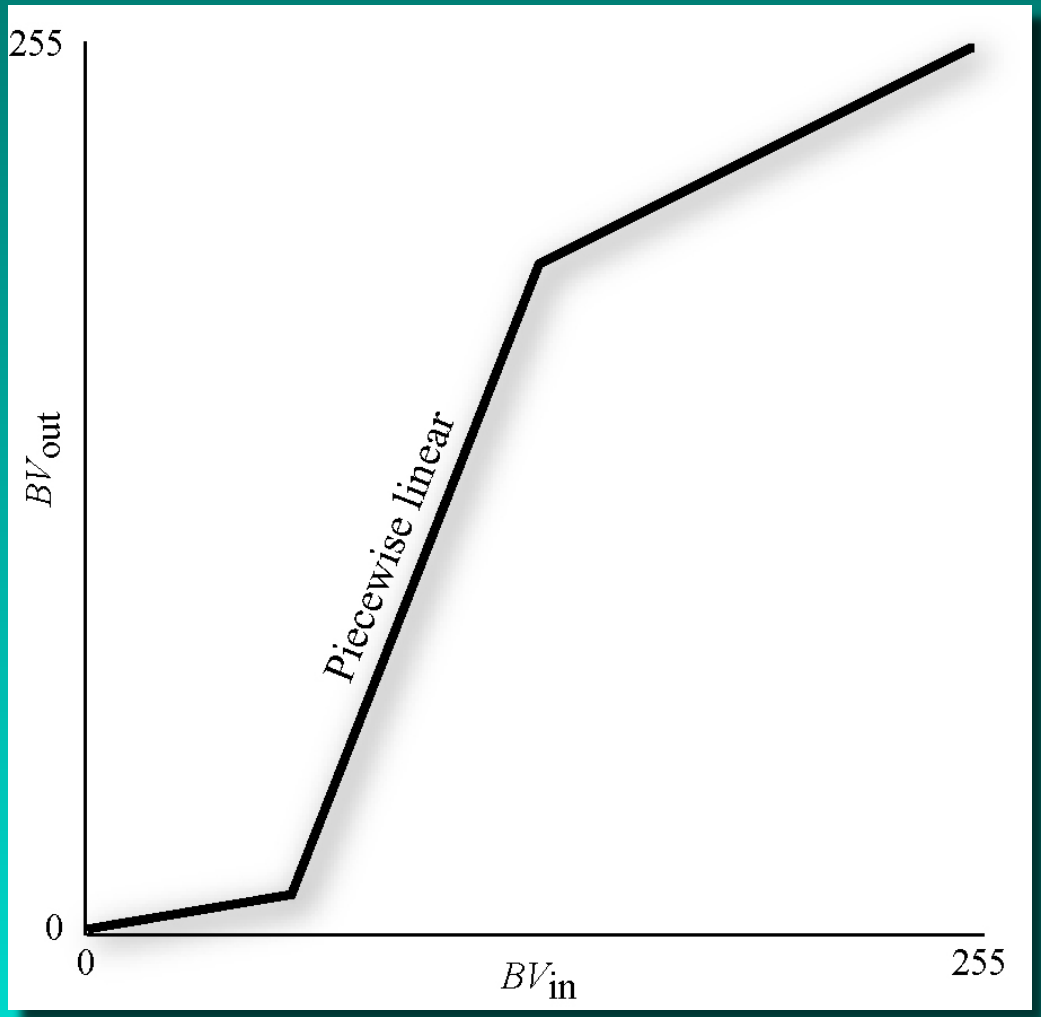


Specific percentage linear contrast stretch designed to highlight the thermal plume

Histogram Equalization

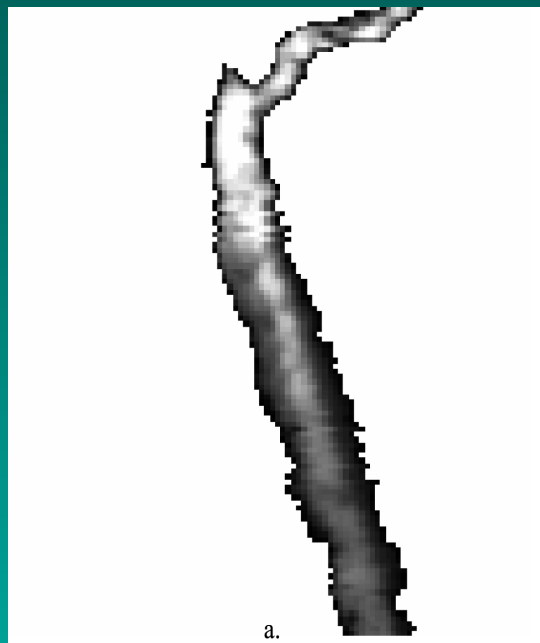
Jensen, 2011

Non-linear Contrast Stretching



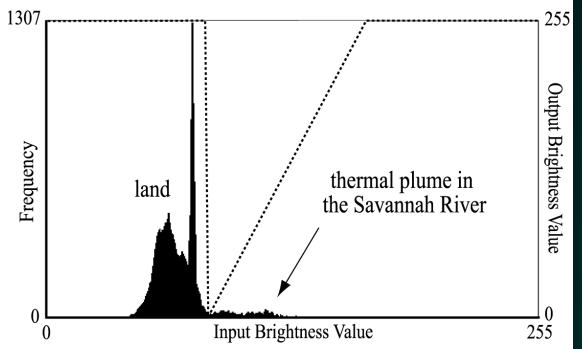
Piecewise contrast stretching (sometimes referred to as using breakpoints)

Jensen, 2011

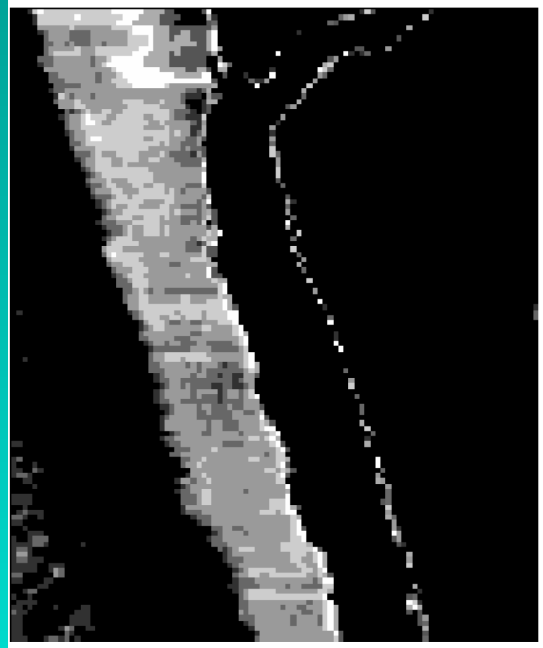


a.

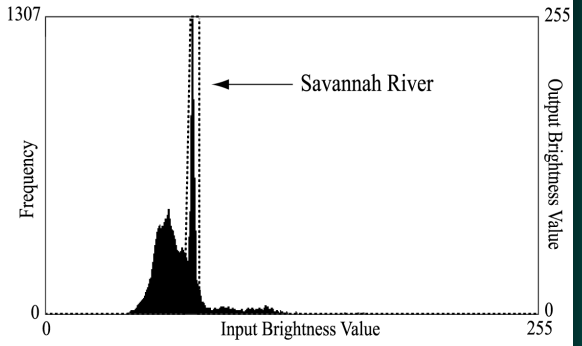
Piecewise Linear Contrast Stretching



b. Enhancing the Thermal Plume in the Savannah River.



c.

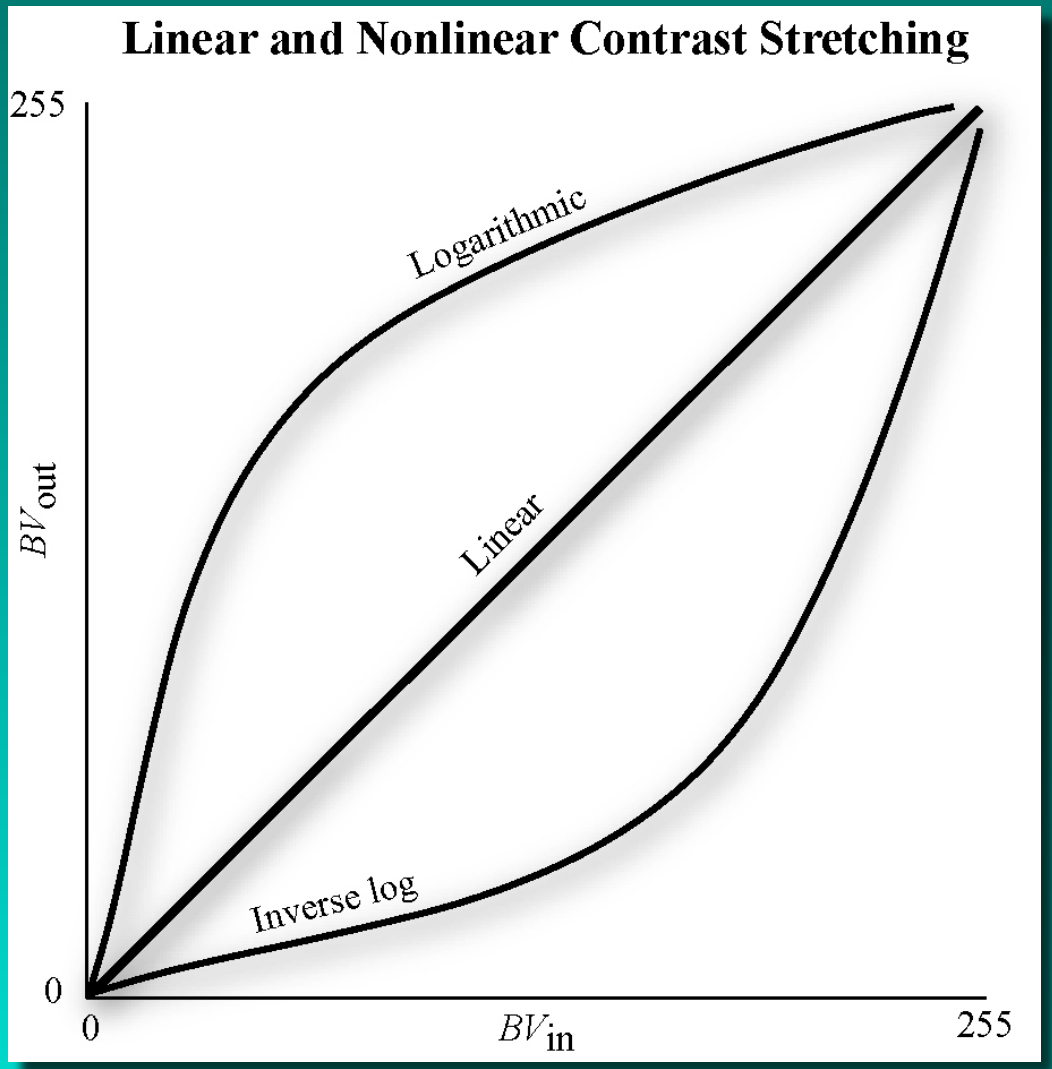


d. Enhancing the Savannah River.

Piecewise Linear Contrast Stretching

Jensen, 2011

Non-linear Contrast Stretching



Logarithmic and Inverse Log

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Spatial Filtering to Enhance Low- and High-Frequency Detail and Edges

A characteristics of remotely sensed images is a parameter called *spatial frequency*, defined as the number of changes in brightness value per unit distance for any particular part of an image.

Jensen, 2011

Spatial Filtering to Enhance Low- and High-Frequency Detail and Edges

Spatial frequency in remotely sensed imagery may be enhanced or subdued using two different approaches:

- *Spatial convolution filtering* based primarily on the use of convolution masks, and

- *Fourier analysis* which mathematically separates an image into its spatial frequency components.

Jensen, 2011

Spatial Convolution Filtering

A linear *spatial filter* is a filter for which the brightness value ($BV_{i,j,out}$) at location *i,j* in the output image is a function of some weighted average (linear combination) of brightness values located in a particular spatial pattern around the *i,j* location in the input image.

The process of evaluating the weighted neighboring pixel values is called *two-dimensional convolution filtering*.

Jensen, 2011

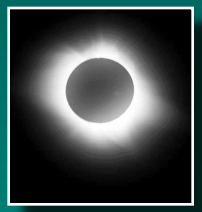
Spatial Convolution Filtering

The size of the neighborhood *convolution mask* or *kernel* (*n*) is usually 3 x 3, 5 x 5, 7 x 7, 9 x 9, etc.

We will constrain our discussion to ***3 x 3*** convolution masks with *nine* coefficients, c_i, defined at the following locations:

$$\textit{Mask template} = \begin{matrix} c_1 & c_2 & c_3 \\ c_4 & c_5 & c_6 \\ c_7 & c_8 & c_9 \end{matrix}$$

3 x 3		
1	1	1
1	1	1
1	1	1



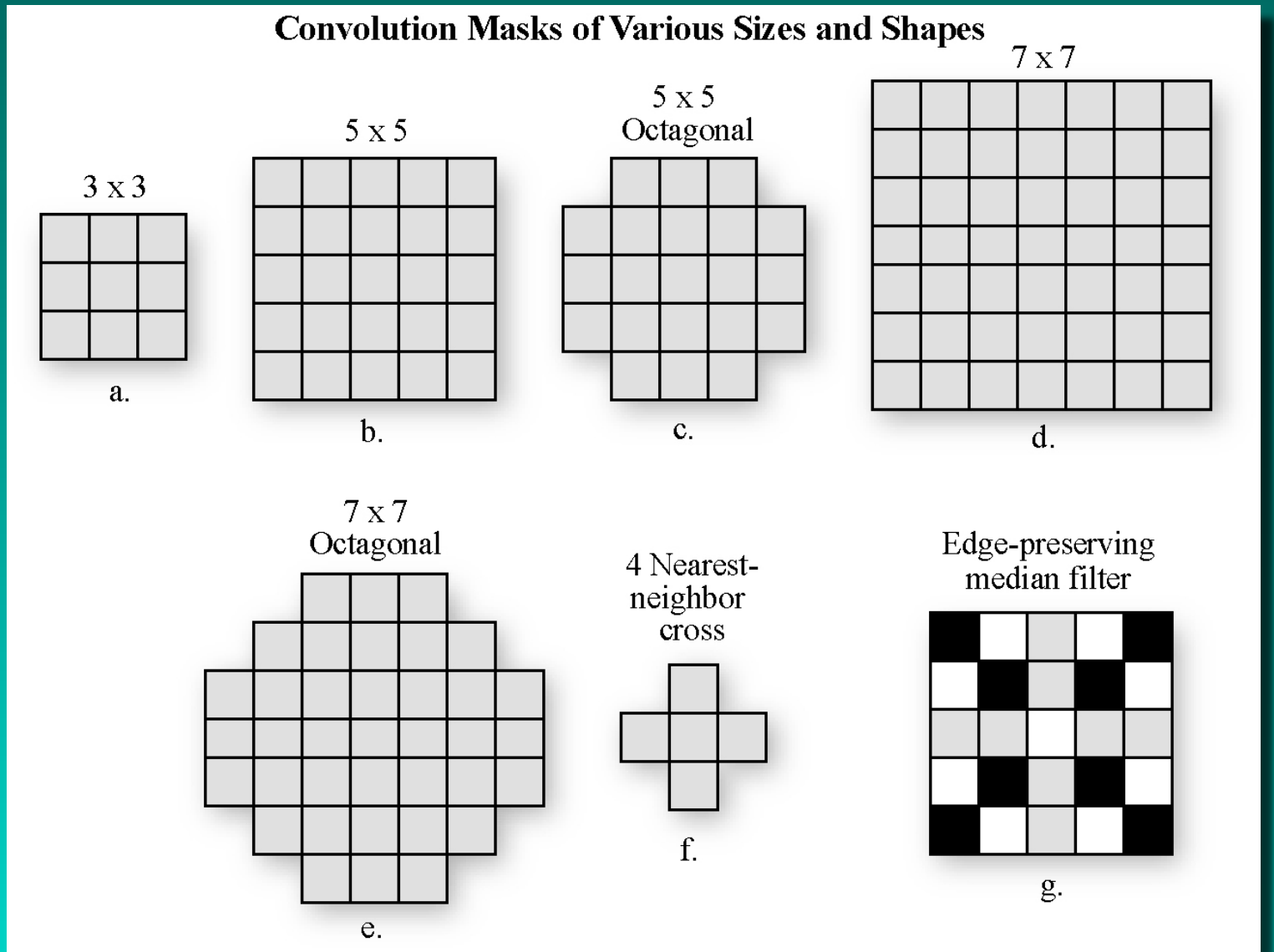
Spatial Convolution Filtering

The coefficients, c_1, in the mask are multiplied by the following individual brightness values (BV_i) in the input image:

$$\text{Mask template} = \begin{matrix} c_1 x\, BV_1 & c_2 x\, BV_2 & c_3 x\, BV_3 \\ c_4 x\, BV_4 & c_5 x\, BV_5 & c_6 x\, BV_6 \\ c_7 x\, BV_7 & c_8 x\, BV_8 & c_9 x\, BV_9 \end{matrix}$$

The primary input pixel under investigation at any one time is $BV_5 = BV_{i,j}$

Jensen, 2011



Various Convolution Mask Kernels

Spatial Convolution Filtering: Low Frequency Filter

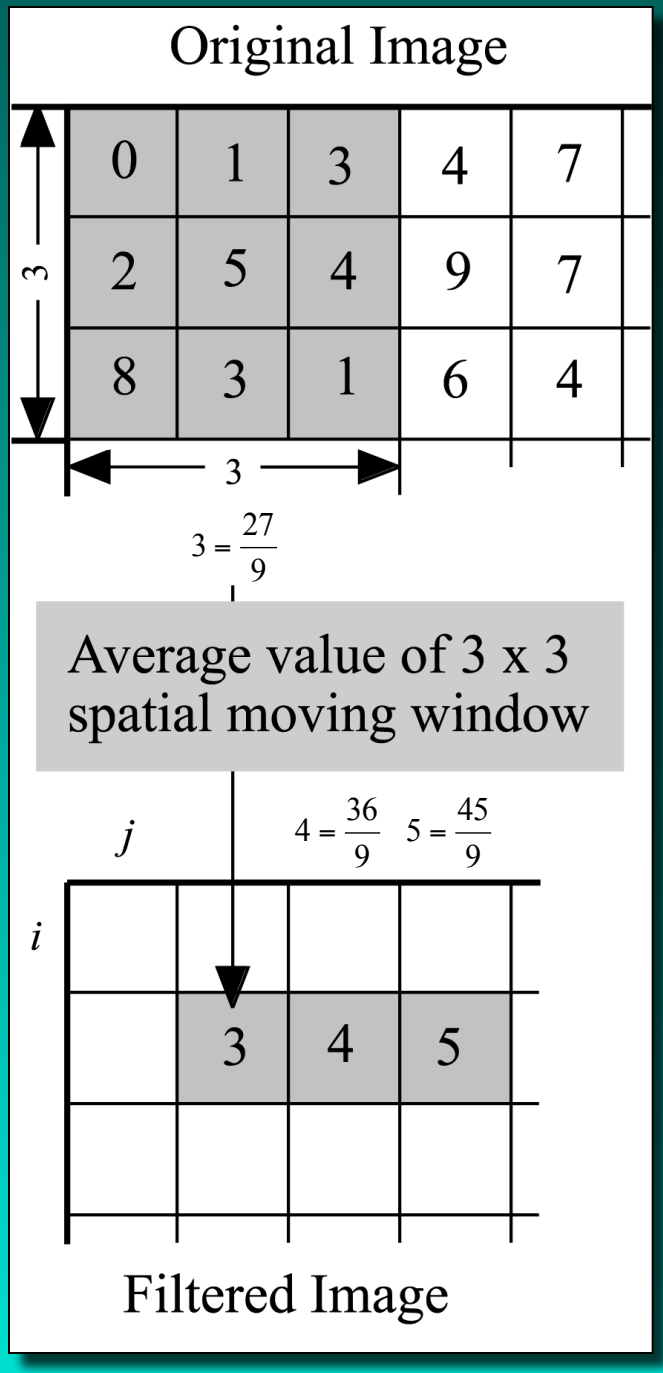
$$LFF_{5,out} = \text{int}\left(\frac{\sum_{i=1}^{9} c_i \times BV_i}{n}\right)$$

$$= \text{int}\left(\frac{BV_1 + BV_2 + BV_3 + \ldots BV_9}{9}\right)$$

3 x 3		
1	1	1
1	1	1
1	1	1

Jensen, 2011

Low Pass Filter



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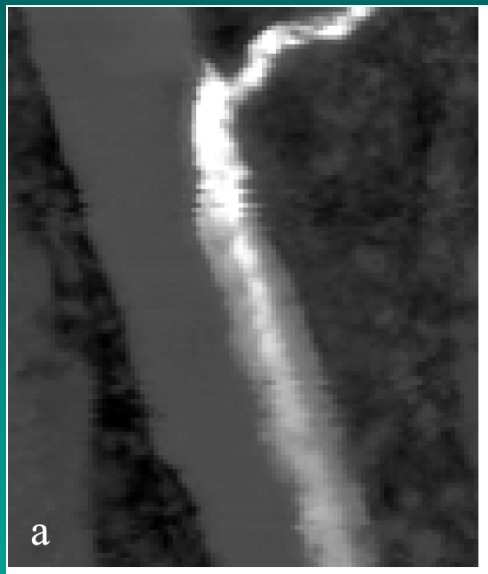
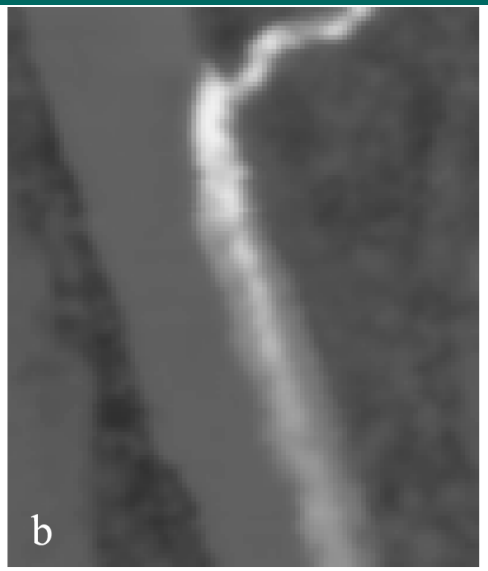
Spatial Frequency Filtering

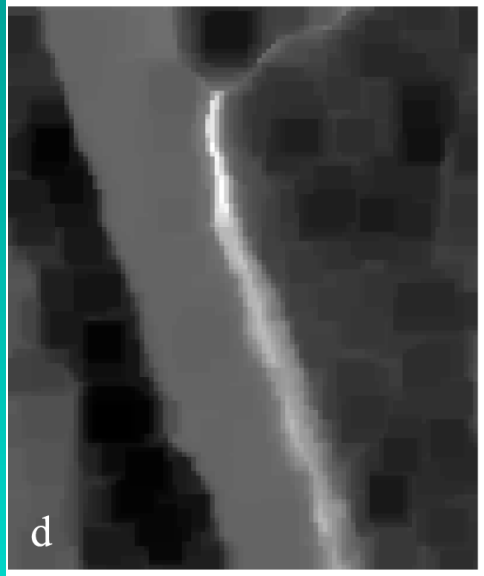


Original contrast stretched



Low frequency

Median

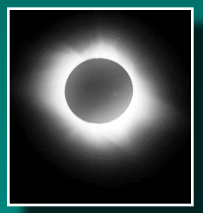


Minimum

Maximum

High frequency

Jensen, 2011

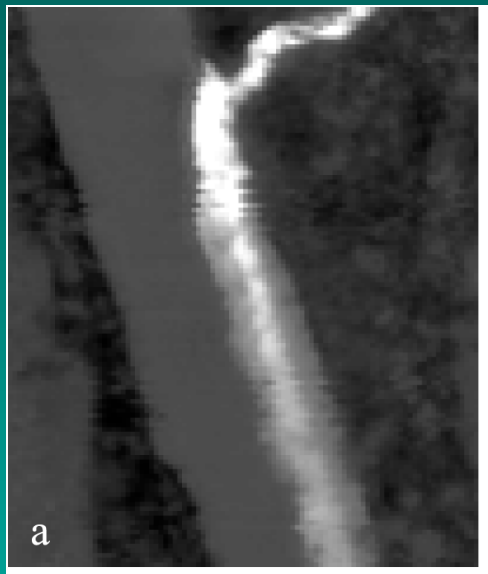


Spatial Convolution Filtering: Median Filter

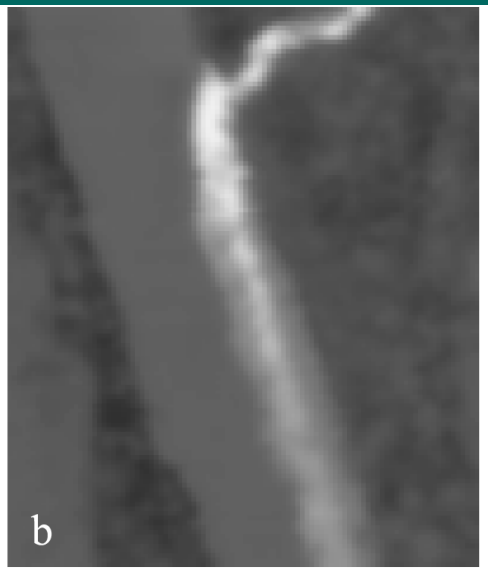
A *median filter* has certain advantages when compared with weighted convolution filters, including: 1) it does not shift boundaries, and 2) the minimal degradation to edges allows the median filter to be applied repeatedly which allows fine detail to be erased and large regions to take on the same brightness value (often called posterization).

Jensen, 2011

Spatial Frequency Filtering

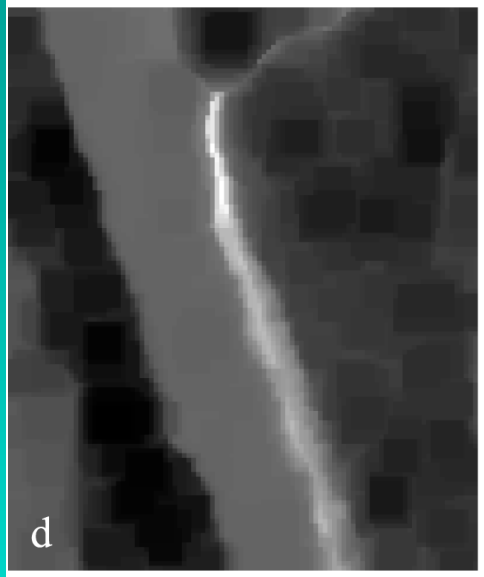


Original contrast stretched



Low frequency

Median



Minimum

Maximum

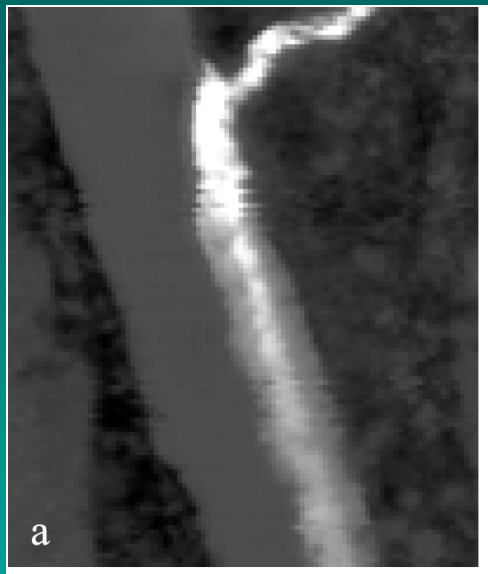
High frequency

Jensen, 2011

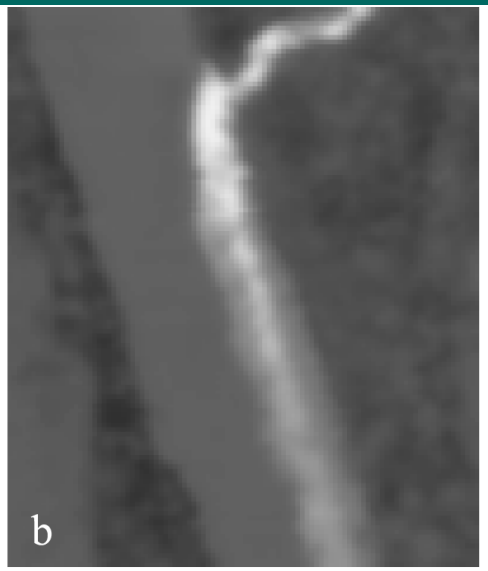
Spatial Convolution Filtering: Minimum or Maximum Filters

Operating on one pixel at a time, these filters examine the brightness values of adjacent pixels in a user-specified radius (e.g., 3 x 3 pixels) and replace the brightness value of the current pixel with the *minimum* or *maximum* brightness value encountered, respectively.

Spatial Frequency Filtering

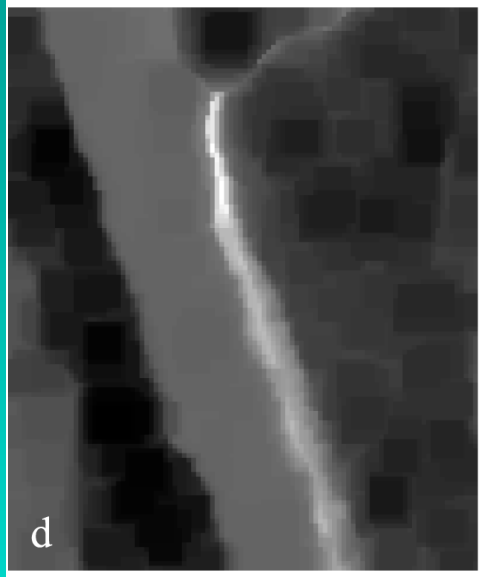


Original contrast stretched



Low frequency

Median



Minimum

Maximum

High frequency

Jensen, 2011

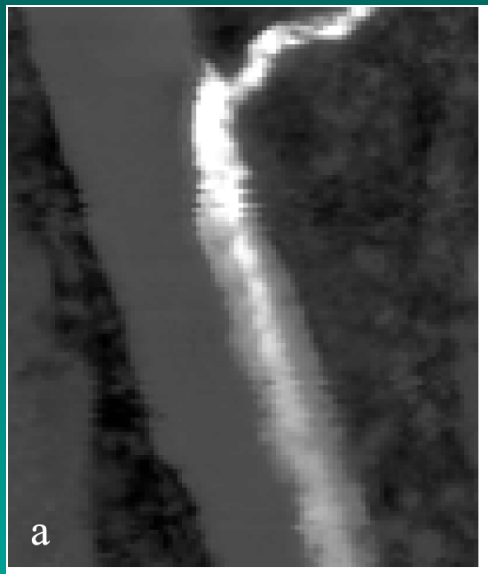
Spatial Convolution Filtering: High Frequency Filter

High-pass filtering is applied to imagery to remove the slowly varying components and enhance the high-frequency local variations. One high-frequency filter ($HFF_{5,out}$) is computed by subtracting the output of the low-frequency filter ($LFF_{5,out}$) from twice the value of the original central pixel value, BV_5:

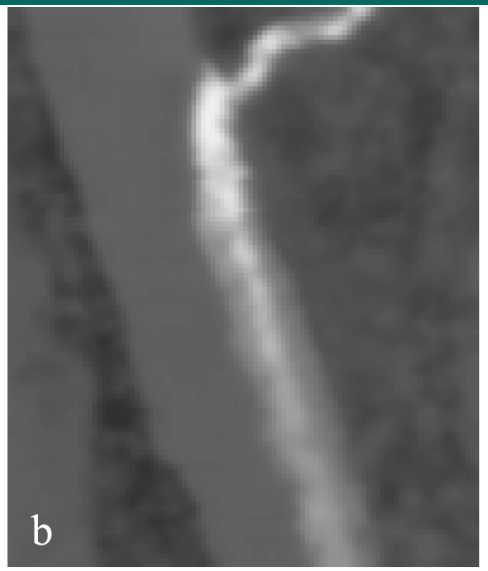
$$HFF_{5,out} = (2 \times BV_5) - LFF_{5,out}$$

Jensen, 2011

Spatial Frequency Filtering

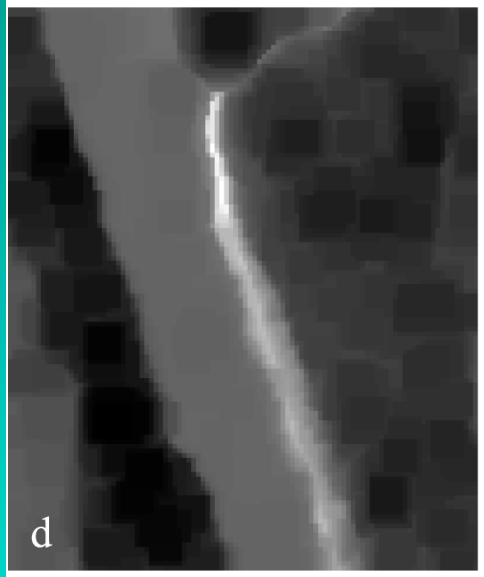


Original contrast stretched



Low frequency

Median



Minimum

Maximum

High frequency

Jensen, 2011

Spatial Convolution Filtering:
Unequal-weighted smoothing Filter

3 x 3		
0.25	0.50	0.25
0.50	1	0.50
0.25	0.50	0.25

3 x 3		
1	1	1
1	2	1
1	1	1

Jensen, 2011

Spatial Convolution Filtering: Edge Enhancement

For many remote sensing Earth science applications, the most valuable information that may be derived from an image is contained in the *edges* surrounding various objects of interest. *Edge enhancement* delineates these edges and makes the shapes and details comprising the image more conspicuous and perhaps easier to analyze. Edges may be enhanced using either *linear* or *nonlinear edge enhancement* techniques.

Jensen, 2011

Spatial Convolution Filtering: Directional First-Difference Linear Edge Enhancement

$$Vertical = BV_{i,j} - BV_{i,j+1} + K$$

$$Horizontal = BV_{i,j} - BV_{i-1,j} + K$$

$$NE\ Diagonal = BV_{i,j} - BV_{i+1,j+1} + K$$

$$SE\ Diagonal = BV_{i,j} - BV_{i-1,j+1} + K$$

The result of the subtraction can be either negative or possible, therefore a constant, K (usually 127) is added to make all values positive and centered between 0 and 255

Spatial Convolution Filtering: High-pass

Filters that Accentuate or Sharpen Edges

3 x 3		
-1	-1	-1
-1	9	-1
-1	-1	-1

3 x 3		
1	-2	1
-2	5	-2
1	-2	1

Jensen, 2011

Spatial Convolution Filtering:
Linear Edge Enhancement - Embossing

3 x 3		
0	0	0
1	0	-1
0	0	0

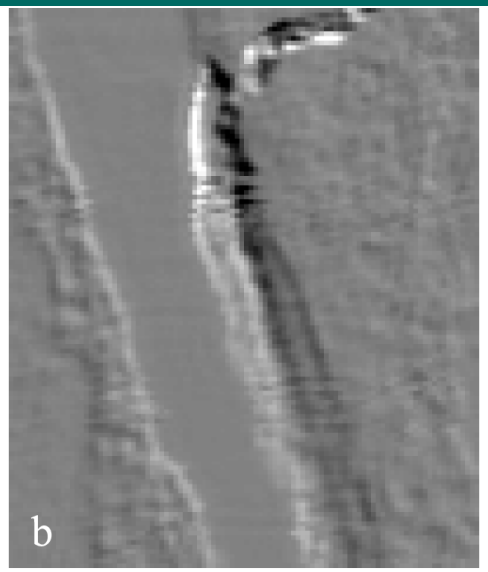
Emboss East

3 x 3		
0	0	1
0	0	0
-1	0	0

Emboss NW

Spatial Frequency Filtering

Emboss East



Emboss NW

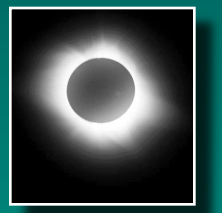
Southwest

East

Laplacian 8

Laplacian 17

Jensen, 2011



Spatial Convolution Filtering:
Compass Gradient Masks

3 x 3		
1	1	1
1	-2	1
-1	-1	-1

North

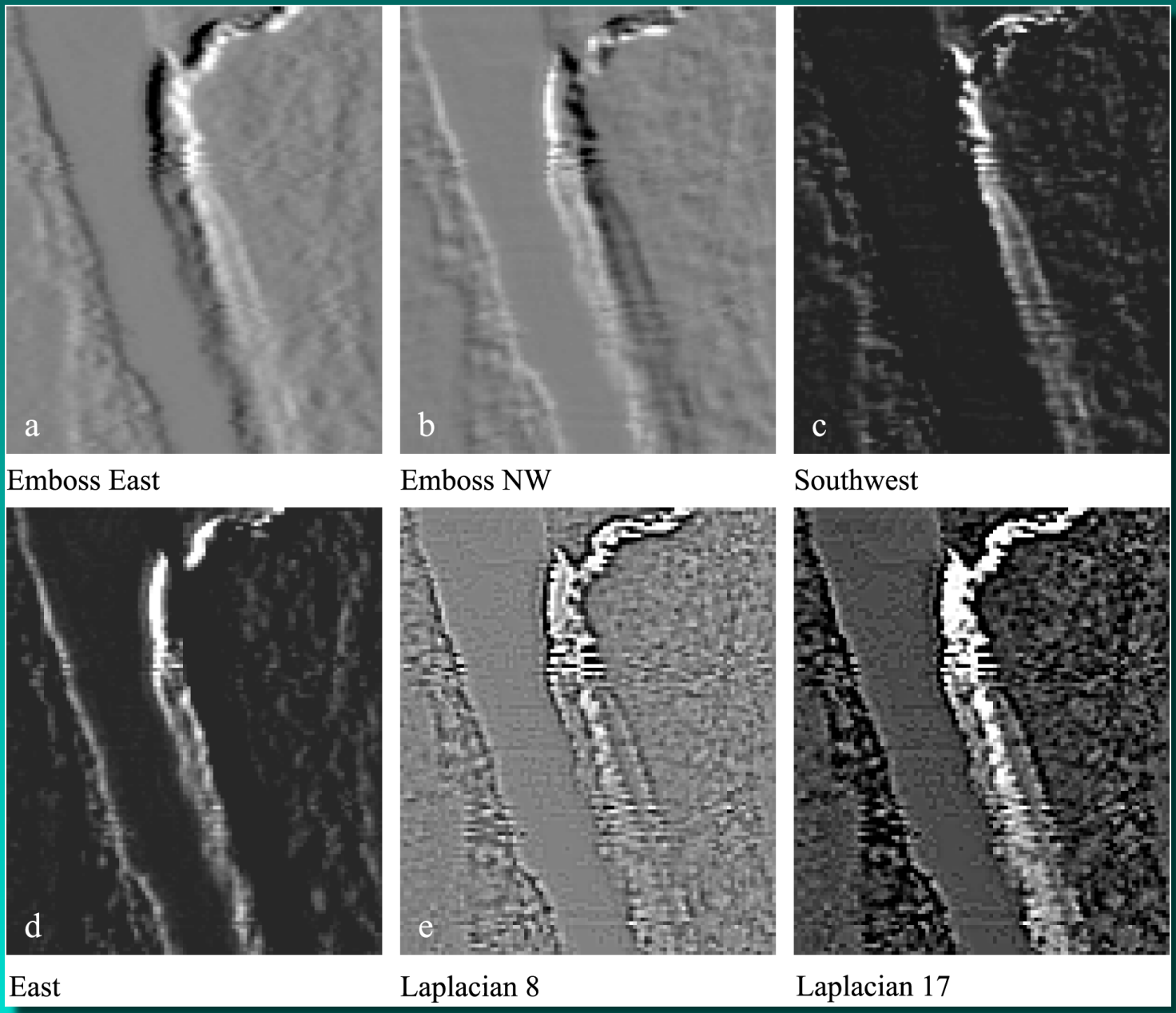
3 x 3		
1	1	1
-1	-2	1
-1	-1	1

Northeast

3 x 3		
-1	1	1
-1	-2	1
-1	1	1

East

Spatial Frequency Filtering



Jensen, 2011

Spatial Convolution Filtering:
Edge Enhancement Using Laplacian Convolution Masks

The *Laplacian* is a second derivative (as opposed to the gradient which is a first derivative) and is invariant to rotation, meaning that it is insensitive to the direction in which the discontinuities (point, line, and edges) run.

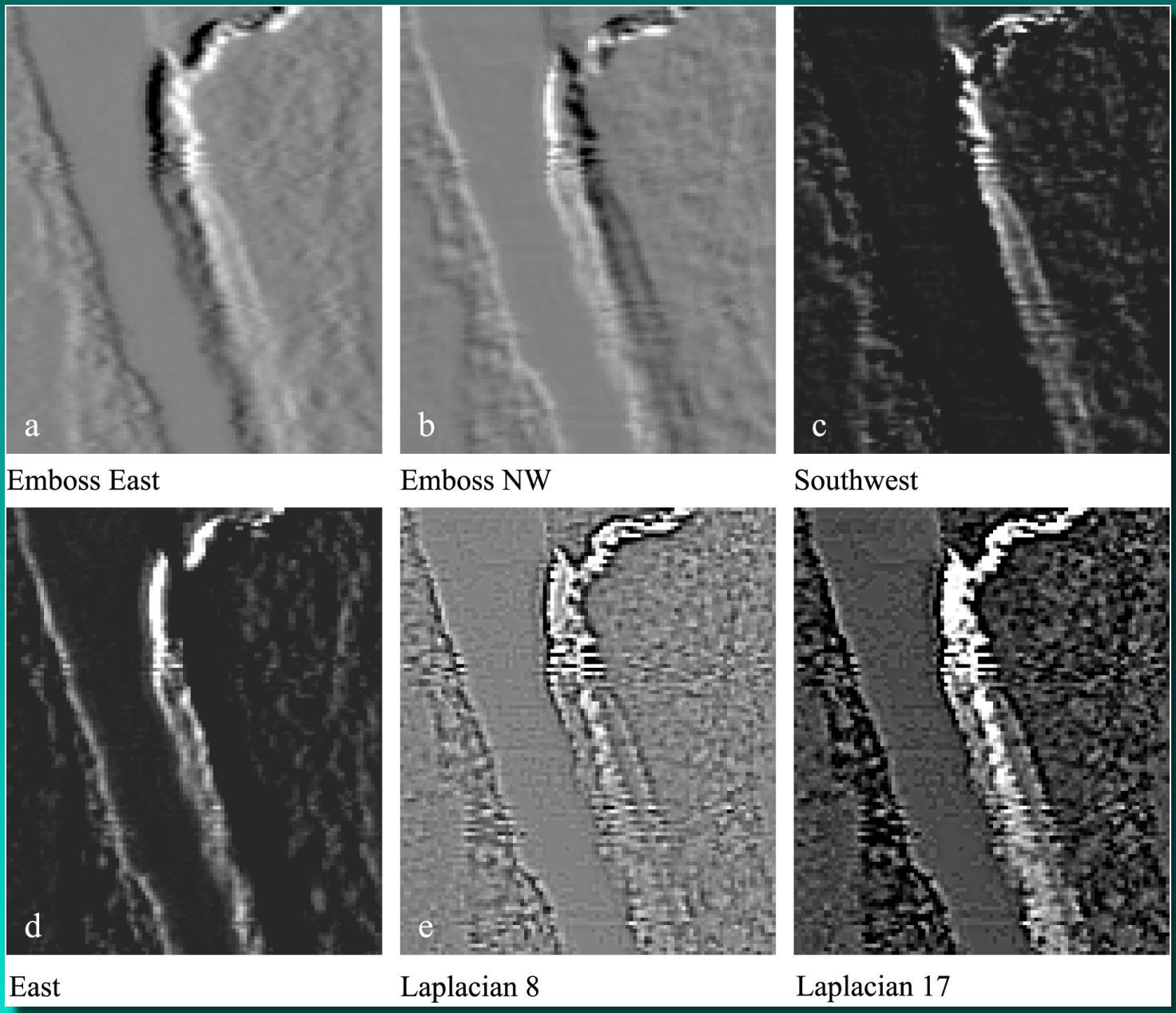
Spatial Convolution Filtering:
Laplacian Convolution Masks

3 x 3		
0	-1	0
-1	4	-1
0	-1	0

3 x 3		
-1	-1	-1
-1	8	-1
-1	-1	-1

3 x 3		
1	-2	1
-2	4	-2
1	-2	1

Spatial Frequency Filtering



Jensen, 2011

Spatial Convolution Filtering: Edge Enhancement Using Laplacian Convolution Masks

The following *Laplacian* operator may be used to subtract the Laplacian edges from the original image:

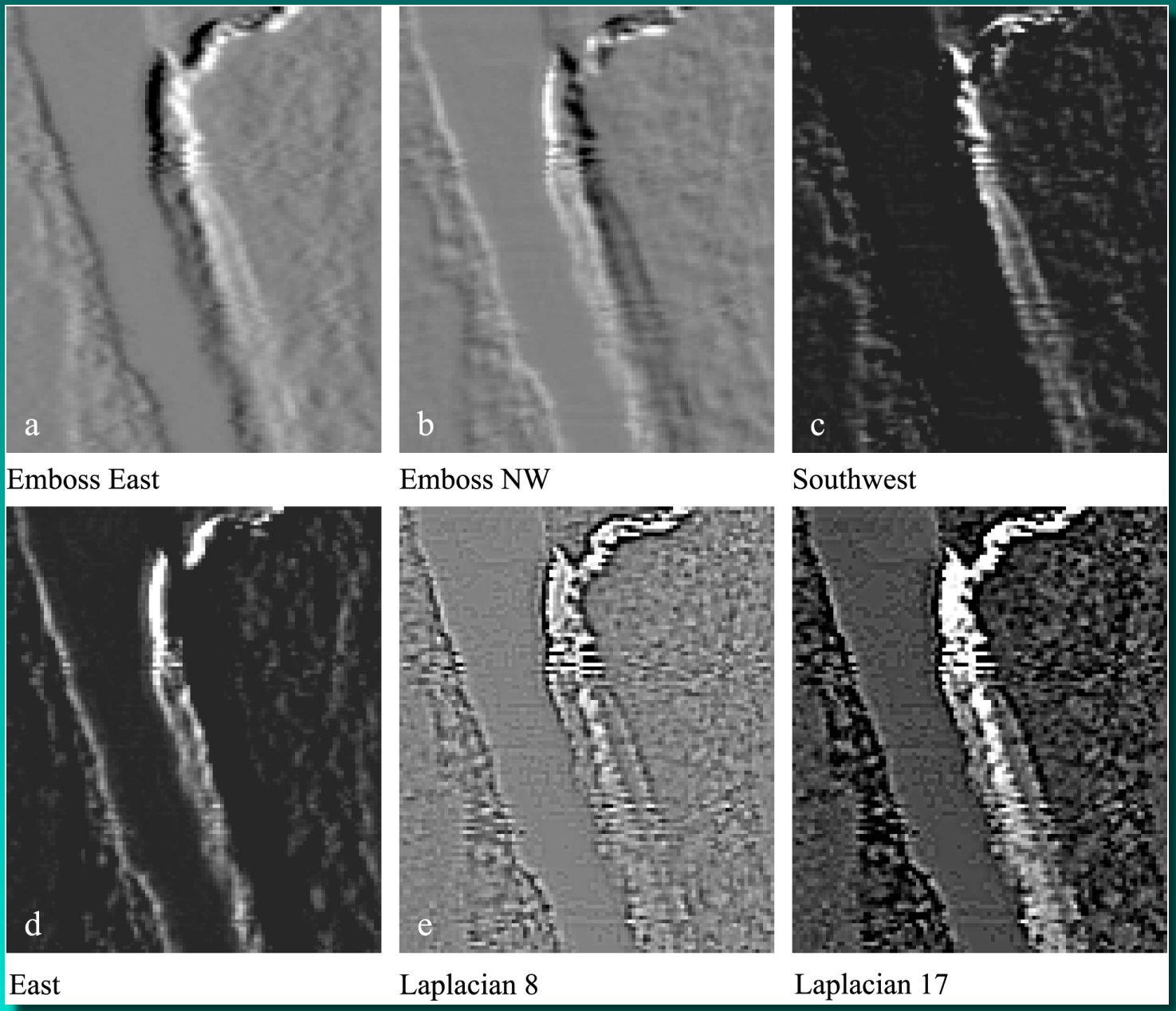
3 x 3		
1	1	1
1	-7	1
1	1	1

Spatial Convolution Filtering: Edge Enhancement Using Laplacian Convolution Masks

By itself, the *Laplacian* image may be difficult to interpret. Therefore, a Laplacian edge enhancement may be added back to the original image using the following mask:

3 x 3		
0	-1	0
-1	5	-1
0	-1	0

Spatial Frequency Filtering



Spatial Convolution Filtering: Non-linear Edge Enhancement Using the Sobel Operator

$$Sobel_{5,out} = \sqrt{X^2 + Y^2}$$

where

$$X = \left(BV_3 + 2BV_6 + BV_9\right) - \left(BV_1 + 2BV_4 + BV_7\right)$$

$$Y = \left(BV_1 + 2BV_2 + BV_3\right) - \left(BV_7 + 2BV_8 + BV_9\right)$$

order

1	2	3
4		6
7	8	9

The *Sobel* operator may also be computed by simultaneously applying the following 3 x 3 templates across the image:

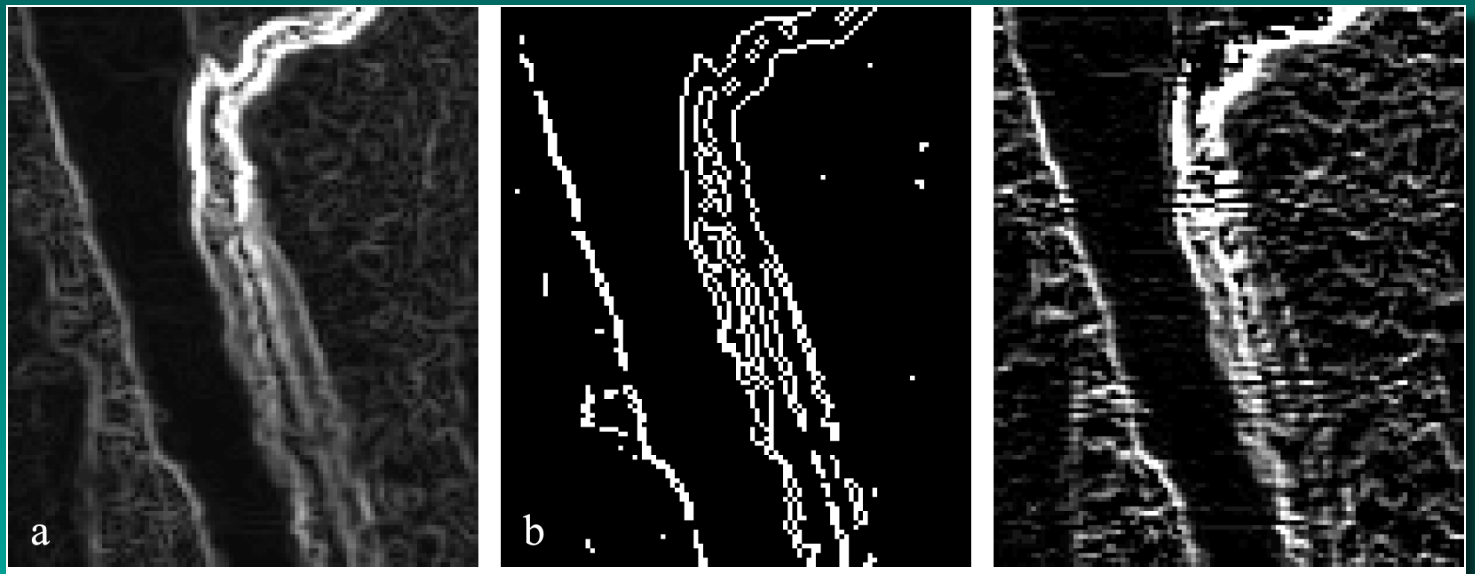
X =

3 x 3		
-1	0	1
-2	0	2
-1	0	1

Y =

3 x 3		
1	2	1
0	0	0
-1	-2	-1

Spatial Frequency Filtering



Sobel | Edge map of Sobel | Robert's

Jensen, 2011

Spatial Convolution Filtering: Non-linear Edge Enhancement Using the Robert's Edge Detector

The Robert's edge detector is based on the use of only four elements of a 3 x 3 mask.

$$Roberts_{5,out} = X + Y$$

where

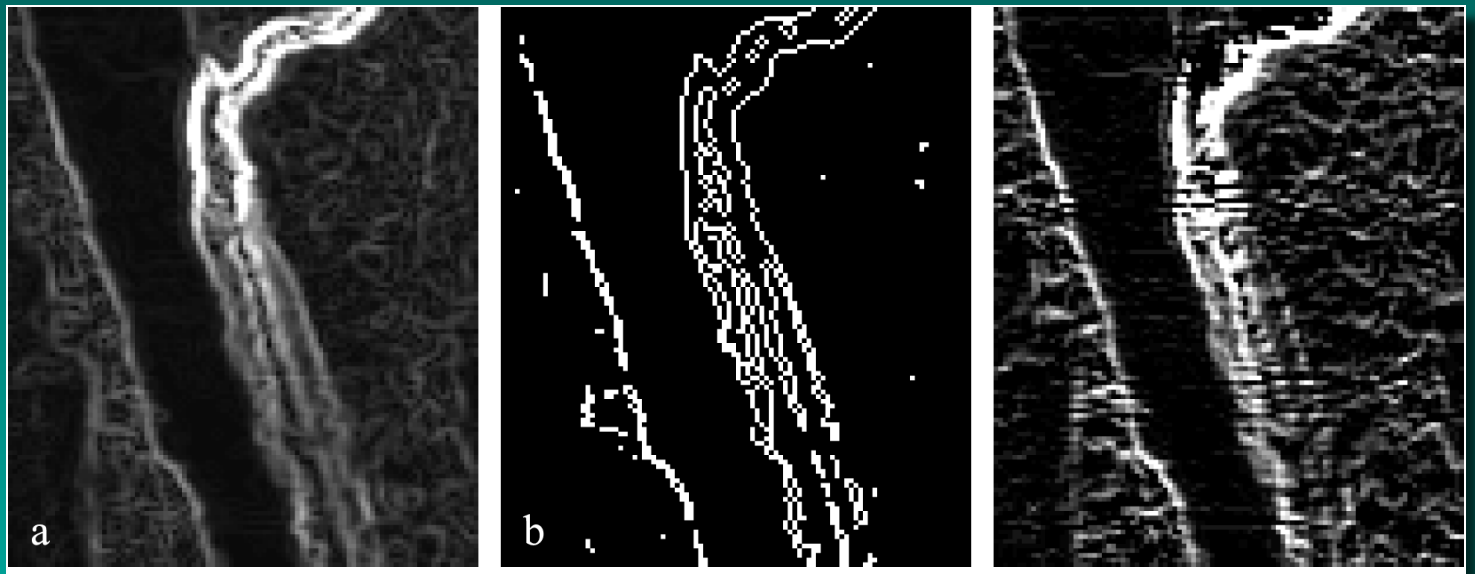
$$X = \left| BV_5 - BV_9 \right|$$

$$Y = \left| BV_6 - BV_8 \right|$$

order

1	2	3
4	5	6
7	8	9

Spatial Frequency Filtering



Sobel | Edge map of Sobel | Robert's

Jensen, 2011

The *Robert's Edge* operator may also be computed by simultaneously applying the following 3 x 3 templates across the image:

X =

3 x 3		
0	0	0
0	1	0
0	0	-1

Y =

3 x 3		
0	0	0
0	0	1
0	-1	0

Spatial Convolution Filtering: Non-linear Edge Enhancement Using the Kirsch Edge Detector

The *Kirsch* nonlinear edge enhancement calculates the gradient at pixel location $BV_{i,j}$. To apply this operator, however, it is first necessary to designate a different 3 x 3 window numbering scheme.

Kirsh window =

$$\begin{matrix} BV_0 & BV_1 & BV_2 \\ BV_7 & BV_{i,j} & BV_3 \\ BV_6 & BV_5 & BV_4 \end{matrix}$$

Spatial Convolution Filtering: Non-linear Edge Enhancement Using the Kirsch Edge Detector

$$BV_{i,j} = \max\left\{1, \max_{i=0}^{7}\left[Abs\left(5S_i - 3T_i\right)\right]\right\}$$

where

$$S_i = BV_i + BV_{i+1} + Bv_{i+2}$$

$$T_i = BV_{i+3} + BV_{i+4} + Bv_{i+5} + BV_{i+6} + Bv_{i+7}$$

The subscripts of *BV* are evaluated modulo ***8***, meaning that the computation moves around the perimeter of the mask in eight steps. The edge enhancement computes the maximal compass gradient magnitude about input image points although the input pixel value $BV_{i,j}$ is never used in the computation

Spatial Frequency Filtering

Sobel

Edge map of Sobel

Robert's

Jensen, 2011

Histogram Equalization

- evaluates the individual brightness values in a band of imagery and *assigns approximately an equal number of pixels to each of the user-specified output gray-scale classes* (e.g., 32, 64, and 256).

- applies the greatest contrast enhancement to the most populated range of brightness values in the image.

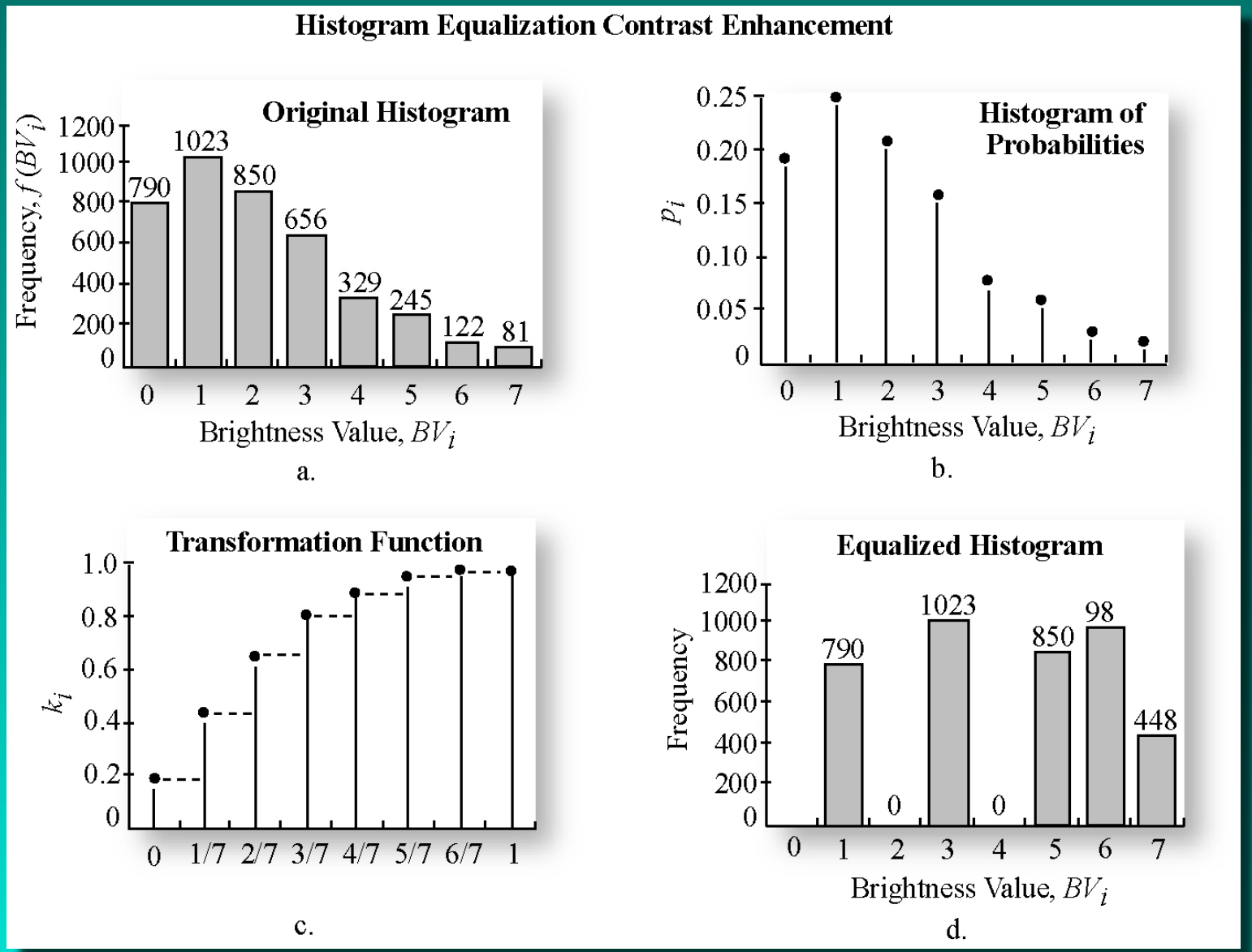
- reduces the contrast in the very light or dark parts of the image associated with the tails of a normally distributed histogram.

Statistics for a 64 x 64 Hypothetical Image with Brightness Values from 0 to 7

Brightness Value, BV_i	L_i	Frequency $f(BV_i)$	Probability[b] $p_i = f(BV_i)/n$
BV_0	0/7 = 0.00	790	0.19
BV_1	1/7 = 0.14	1023	0.25
BV_2	2/7 = 0.28	850	0.21
BV_3	3/7 = 0.42	656	0.16
BV_4	4/7 = 0.57	329	0.08
BV_5	5/7 = 0.71	245	0.06
BV_6	6/7 = 0.85	122	0.03
BV_7	7/7 = 1.00	81	0.02

4096 total

Histogram Equalization



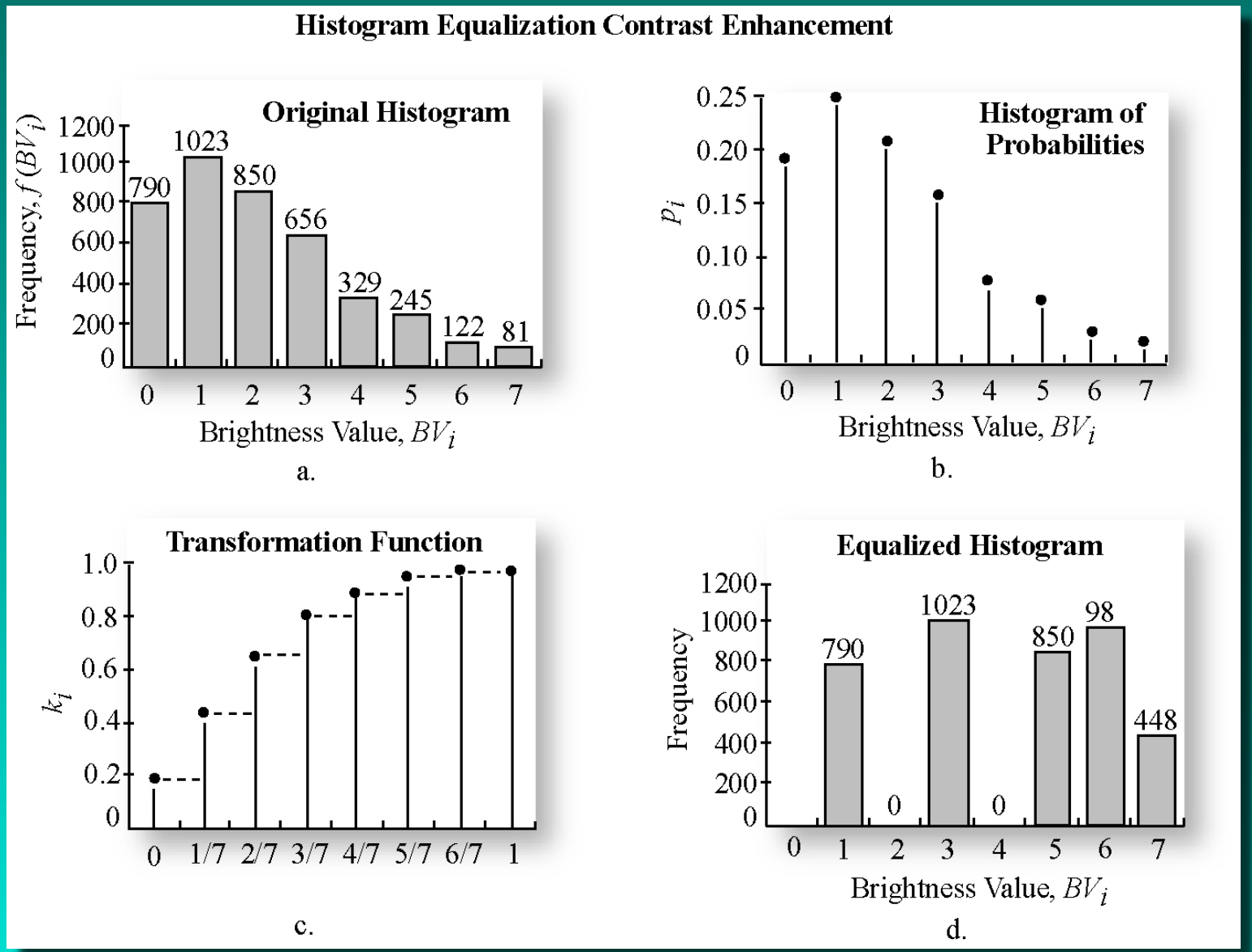
Transformation Function, k_i for each individual brightness value

For each brightness value level BV_i in the $quant_k$ range of 0 to 7 of the original histogram, a new cumulative frequency value k_i is calculated:

$$k_i = \frac{\sum_{i=0}^{quant_i} BV_i}{n}$$

where the summation counts the frequency of pixels in the image with brightness values equal to or less than BV_i, and n is the total number of pixels in the entire scene (4,096 in this example).

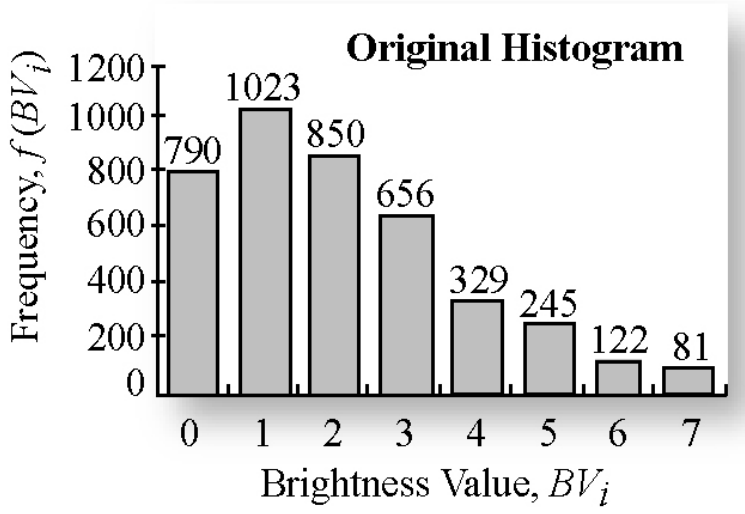
Histogram Equalization



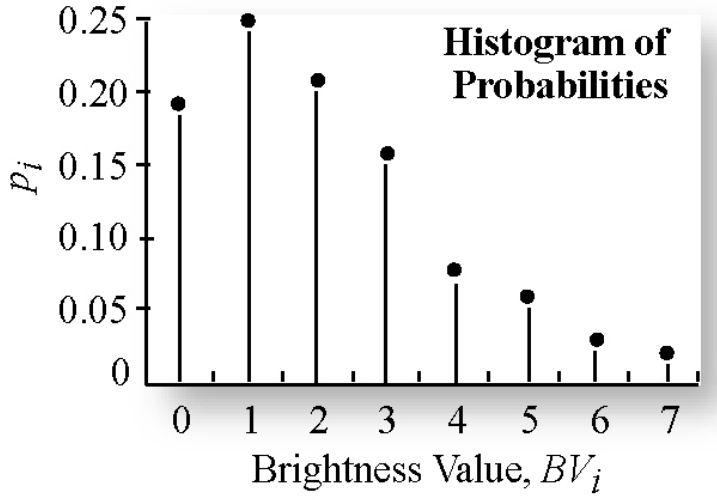
The histogram equalization process iteratively compares the transformation function k_i with the original values of l_i, to determine which are closest in value. *The closest match is reassigned to the appropriate brightness value*.

For example, we see that $k_0 = 0.19$ is closest to $L_1 = 0.14$. Therefore, all pixels in BV_0 (790 of them) will be assigned to BV_1. Similarly, the 1023 pixels in BV_1 will be assigned to BV_3, the 850 pixels in BV_2 will be assigned to BV_5, the 656 pixels in BV_3 will be assigned to BV_6, the 329 pixels in BV_4 will also be assigned to BV_6, and all 448 brightness values in $BV_{5–7}$ will be assigned to BV_7. The new image will not have any pixels with brightness values of 0, 2, or 4. This is evident when evaluating the new histogram. *When analysts see such gaps in image histograms, it is usually a good indication that histogram equalization or some other operation has been applied.*

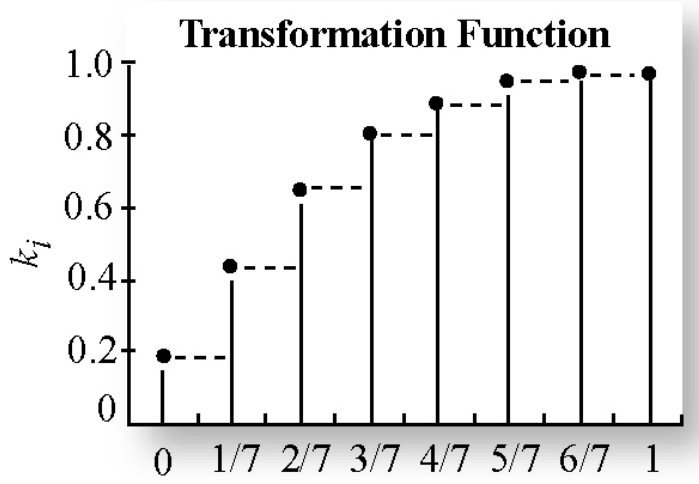
Histogram Equalization Contrast Enhancement



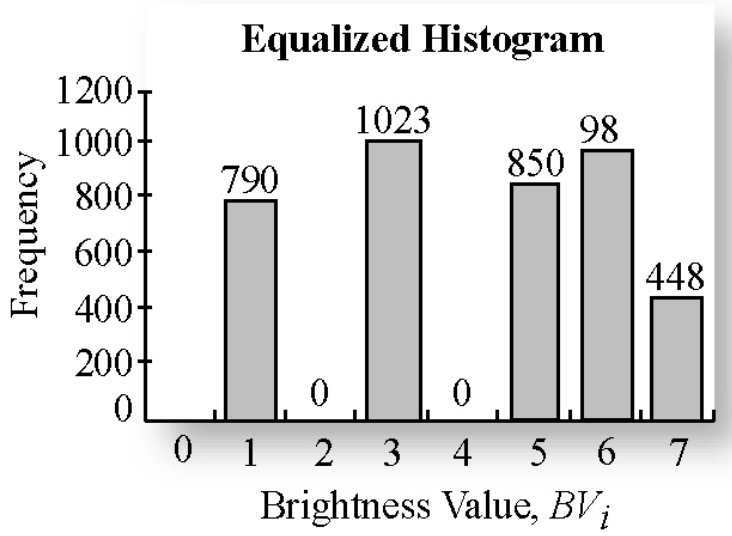
a.



b.



c.

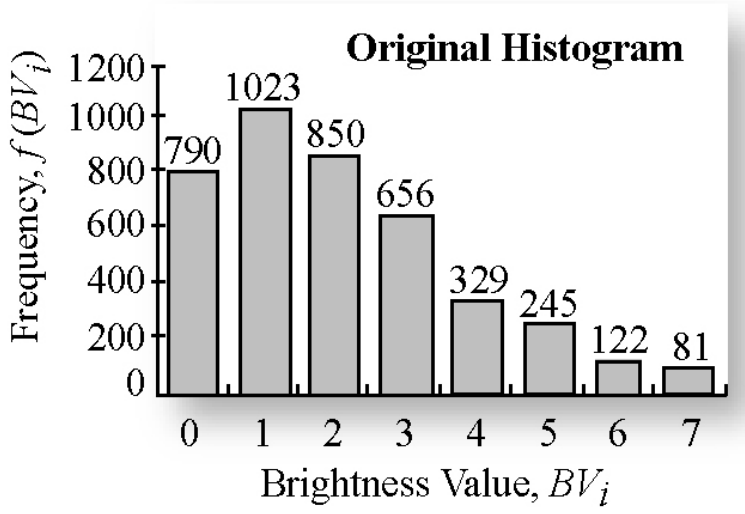


d.

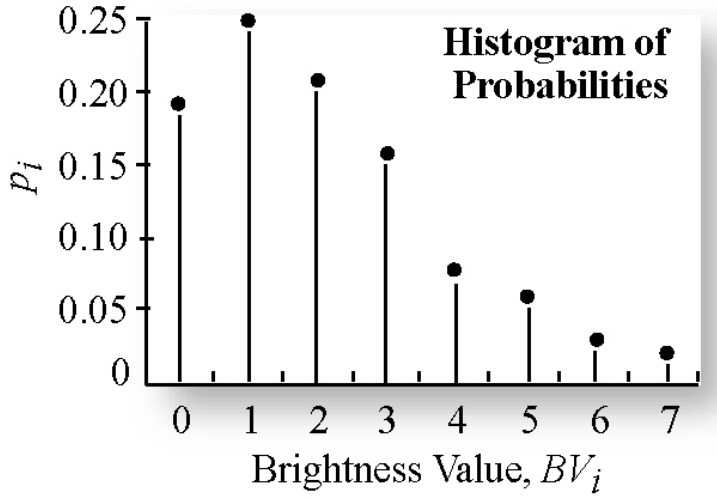
Statistics of How a a 64 x 64 Hypothetical Image with Brightness Values from 0 to 7 is Histogram Equalized

Frequency, $f(BV_i)$	790	1023	850	656	329	245	122	81
Original brightness value, BV_i	0	1	2	3	4	5	6	7
$L_i = \frac{\text{brightness value}}{n}$	0	0.14	0.28	0.42	0.57	0.71	0.85	1.0
Cumulative frequency transformation: $k_i = \frac{\sum_{i=0}^{quant_i} BV_i}{n}$	$\frac{790}{4096}$ =0.19	$\frac{1813}{4096}$ = 0.44	$\frac{2663}{4096}$ = 0.65	$\frac{3319}{4096}$ = 0.81	$\frac{3648}{4096}$ = 0.89	$\frac{3893}{4096}$ = 0.95	$\frac{4015}{4096}$ = 0.98	$\frac{4096}{4096}$ = 1.0
Assign original BV_i class to the new class it is closest to in value	1	3	5	6	6	7	7	7

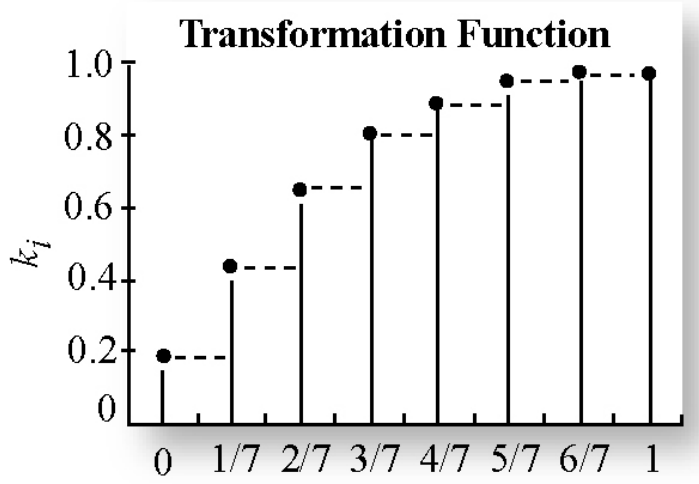
Histogram Equalization Contrast Enhancement



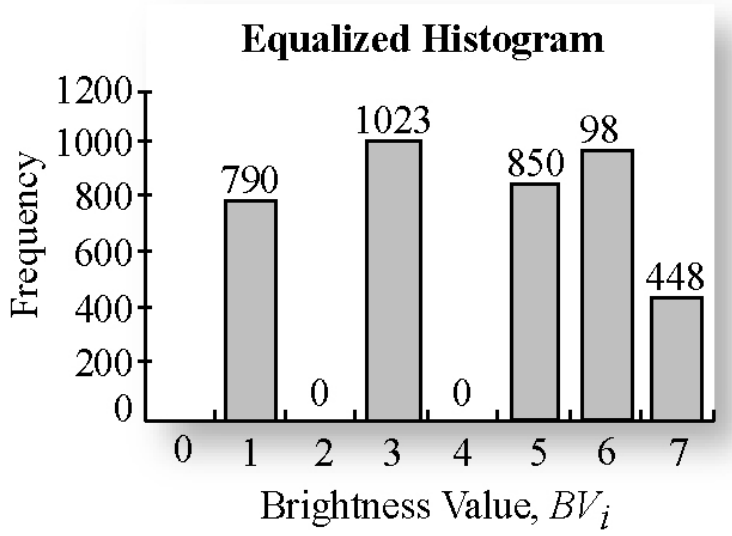
a.



b.



c.



d.