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Lecture 4: Introductory digital image analysis

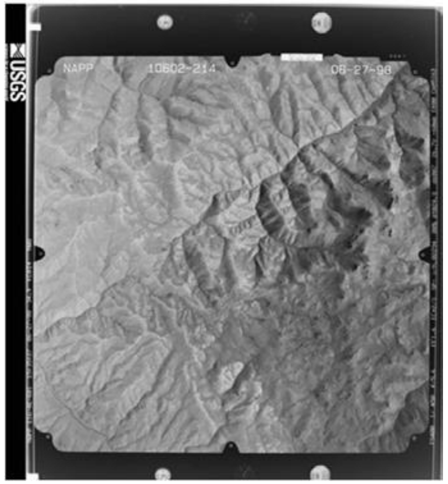
November 1, 2022

Outline

- Concepts
  - Digital image formats
  - Histogram
  - Normal distribution
  - Descriptive statistics
  - Image fusion
  - Contrast stretching
- Objectives
  - Understand the principles of image data storage, statistical evaluation and contrast enhancement

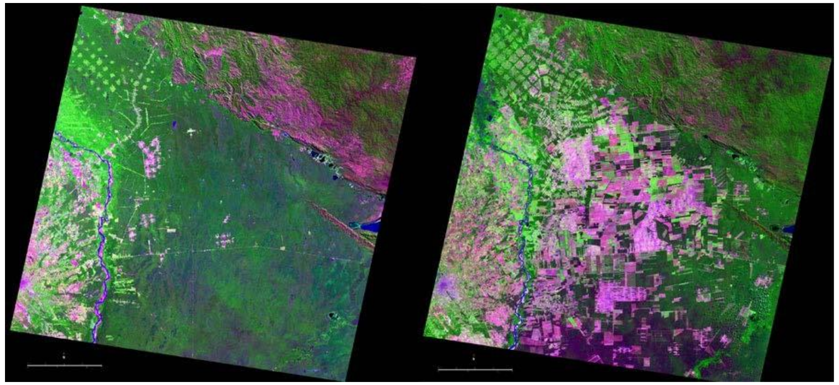
Digital imagery

- Analog format:
  - Hard-copy, need to convert it to a digital format (e.g. aerial photos)
  - Color photography (Red, green, blue)
  - Color-infrared photography (Near-infrared, red, green)



NAPP image taken on B & W film, Idaho,1998/6/27.

- Digital format:
  - Ready for processing (e.g., Landsat imagery)
  - Multispectral
  - Hyperspectral



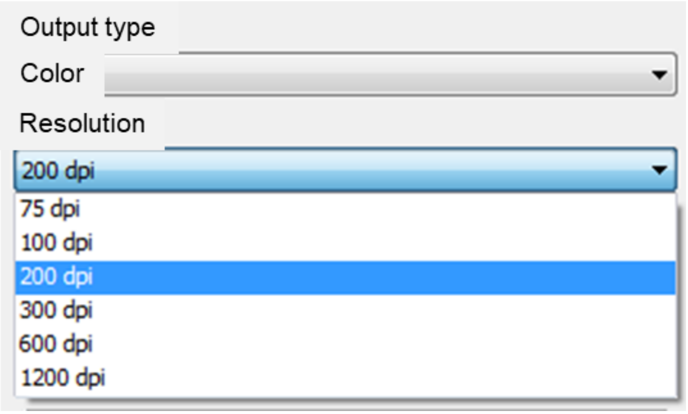
Progression of Bolivian deforestation from 1986 to 2000. Figure courtesy of USGS.

Guidelines for digitalization

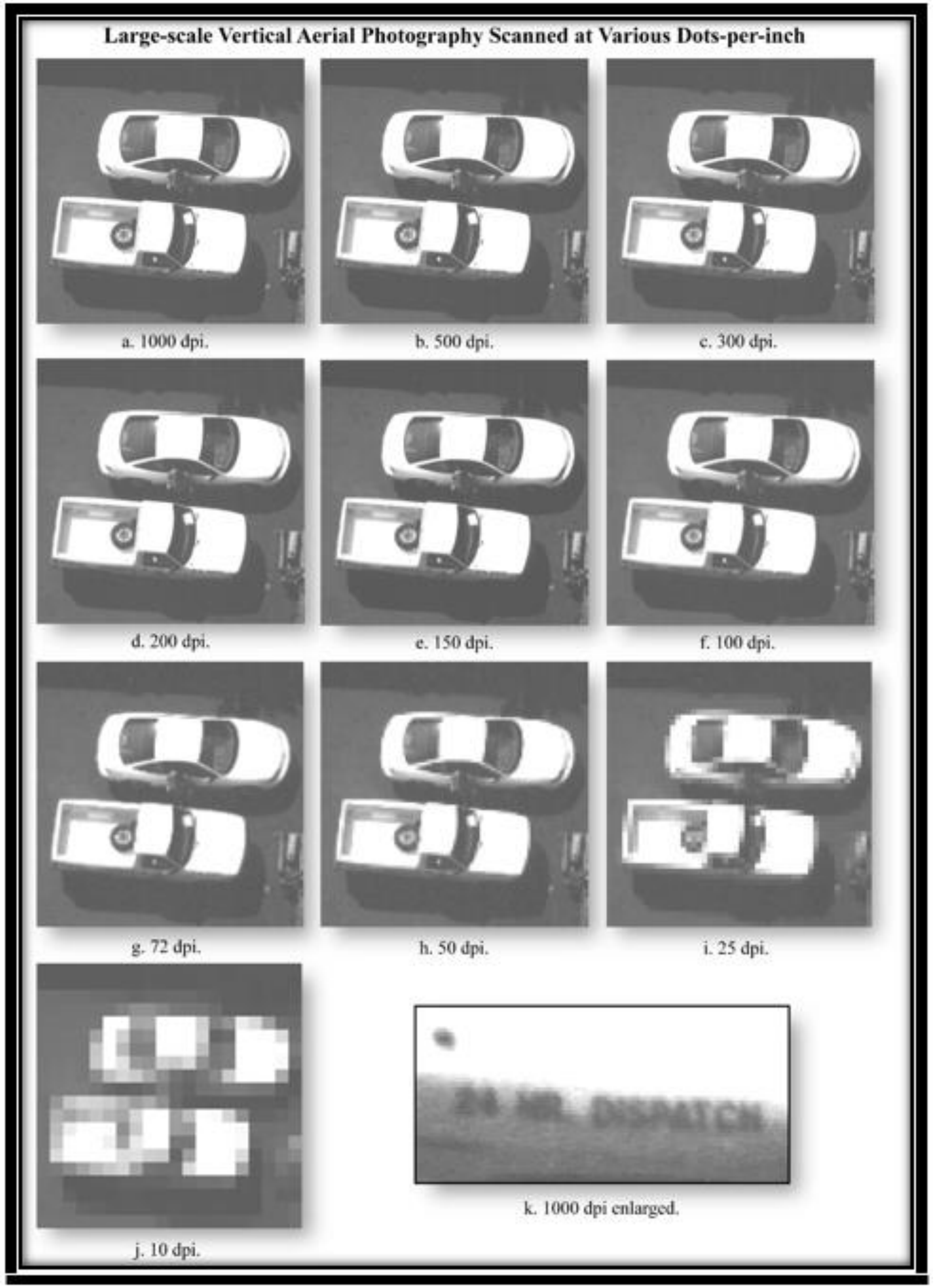
- Choose a *dpi* for scanning based on:
  - Scale of the original imagery
  - Desired spatial resolution
  - 1:40,000 photography scanned at 1,000 dpi yields 1x1 m spatial resolution pixels.

- For visualization purposes, it is usually not necessary to scan at extremely high resolutions (e.g., > 300 dpi).

DPI: dots per inch, scanning resolution.



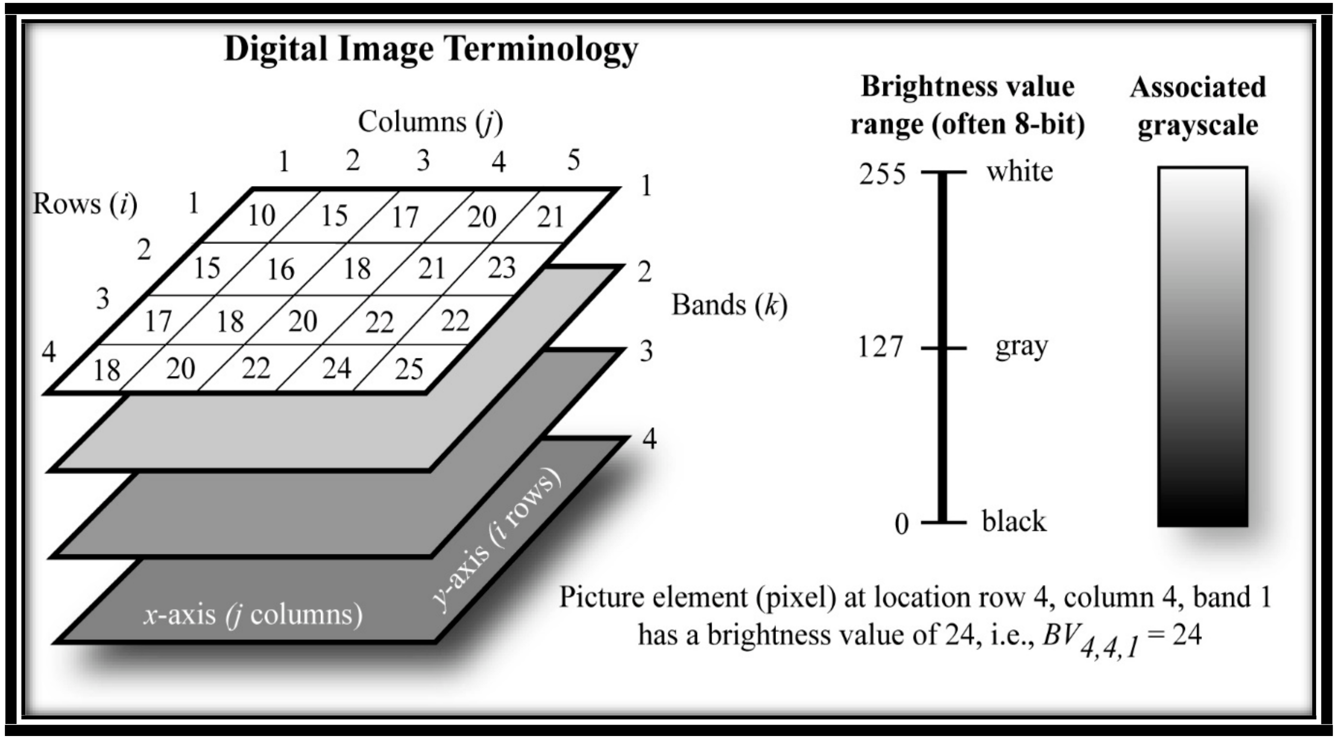
Difficult to discern difference in image quality when resolution > 150 dpi.


Large-scale Vertical Aerial Photography Scanned at Various Dots-per-inch
a. 1000 dpi.
b. 500 dpi.
c. 300 dpi.
d. 200 dpi.
e. 150 dpi.
f. 100 dpi.
g. 72 dpi.
h. 50 dpi.
i. 25 dpi.
j. 10 dpi.
24 HR. DISPATCH
k. 1000 dpi enlarged.

Jensen (2005)

Digital image terminology

- Images are stored as a matrix or (2-D array) of numbers.
- Pixel: the primitive element of a digital image.
- Brightness value (BV): also call digital number (**DN**).
- Image columns, image rows, bands



Jensen (2005)

Major commercial image processing software packages

- ENVI (Hyperspectral data analysis)
  - https://www.l3harrisgeospatial.com/Software-Technology/ENVI
- ERDAS Imagine
  - http://geospatial.intergraph.com/products/ERDAS-IMAGINE/Details.aspx
- IDRISI http://www.clarklabs.org/
- PCI Geomatica
  - http://www.pcigeomatics.com/
- eCognition (Object-based image analysis)
  - http://www.ecognition.com/

Important image processing functions

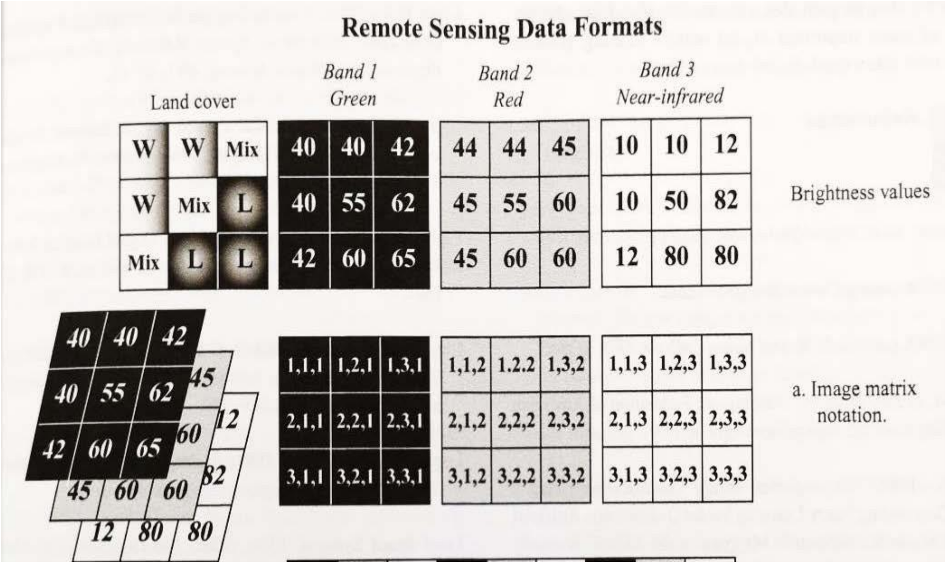
- **Preprocessing (Radiometric and Geometric)**
- **Display and Enhancement**
  - B/W or color display, Zooming in/out, Contrast manipulation
  - Transformations (principal component transformation)
- **Information Extraction**
  - Pixel DN, profiles (spatial/spectral)
  - Descriptive statistics (univariate/multivariate: mean, covariance)
  - Classification (supervised/unsupervised: maximum likelihood)
  - Object-based image analysis (OBIA): segmentation and classification
  - Change detection
  - Segmentation map to GIS

Example QuickBird imagery from ENVI.

Digital image formats

- **Data storage:**
  - Band Interleaved by Line (BIL)
  - Band Sequential (BSQ)
  - Band Interleaved by Pixel (BIP)

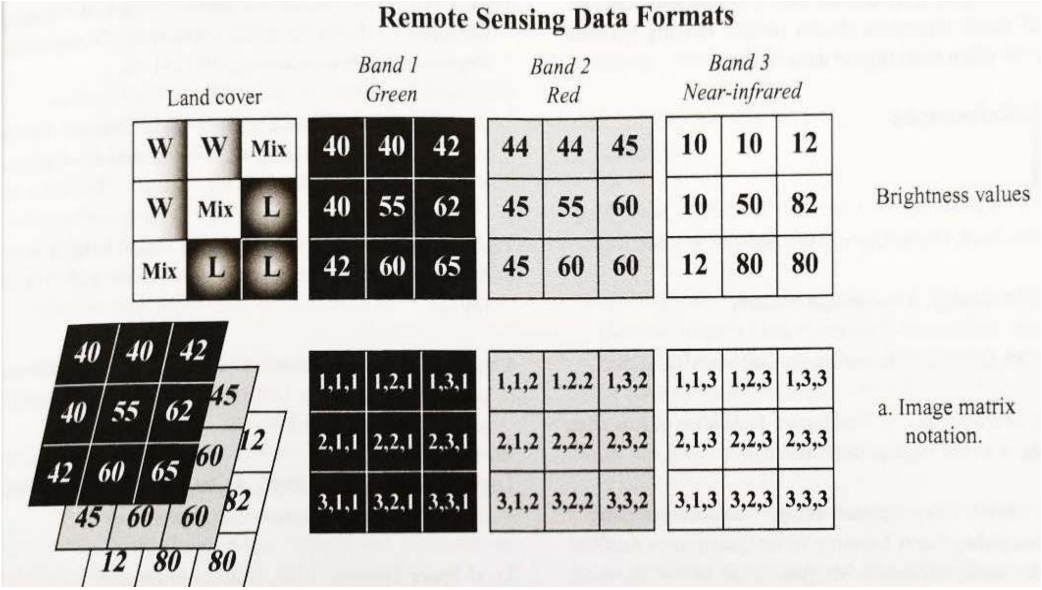
- Very important for **reading/writing data** while programming with IDL or Matlab.

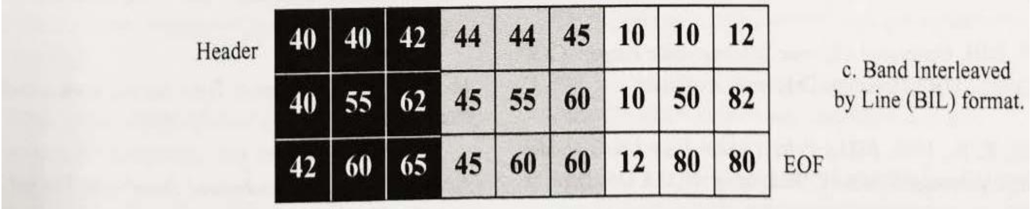


Jensen (2005)

Digital image formats

- **Band Interleaved by Line (BIL)**
  - Places the DNs in each band for pixels in each line in sequential order
  - DNs for pixels in *(band 1, line 1)*, followed by DNs for pixels in *(band 2, line 1)*, and then DNs for pixels in *(band 3, line 1)*, ……

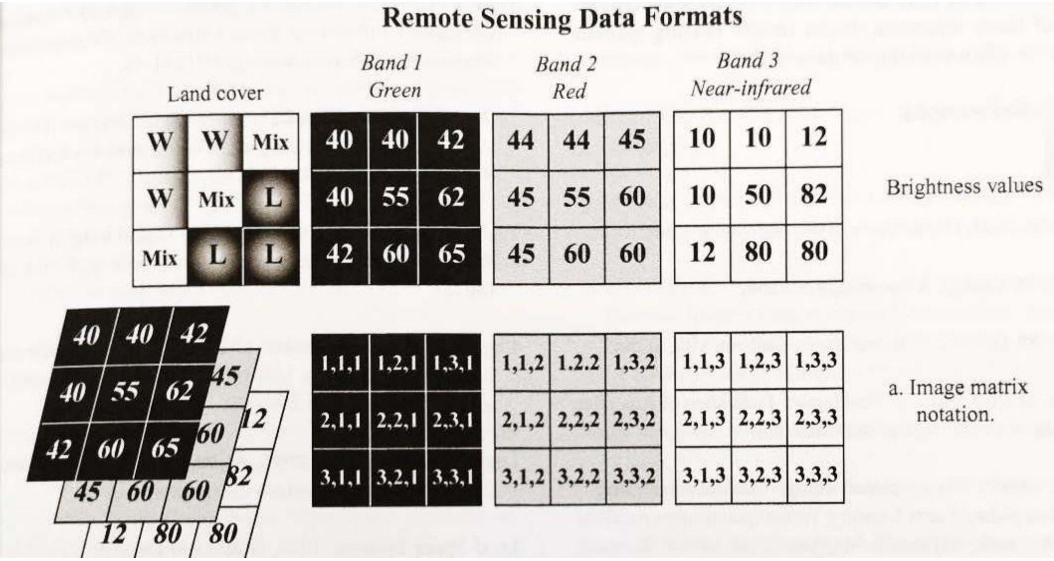


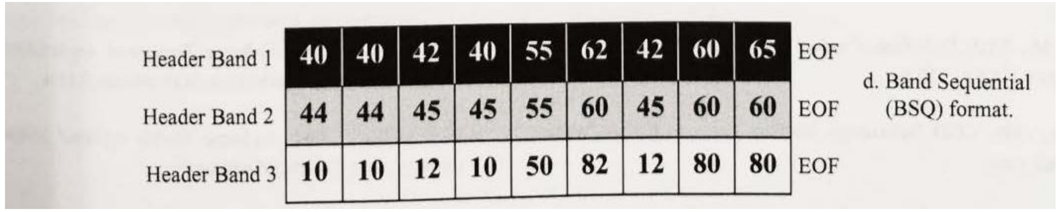


Jensen (2005)

Digital image formats

- **Band Sequential (BSQ)**
  - Places the DNs in each band for all lines in sequential order
  - DNs for pixels in *(line 1 band 1)*, followed by DNs for pixels in *(line 2, band 1)*, and then DNs for pixels in *(line 3, band 1)*, ……



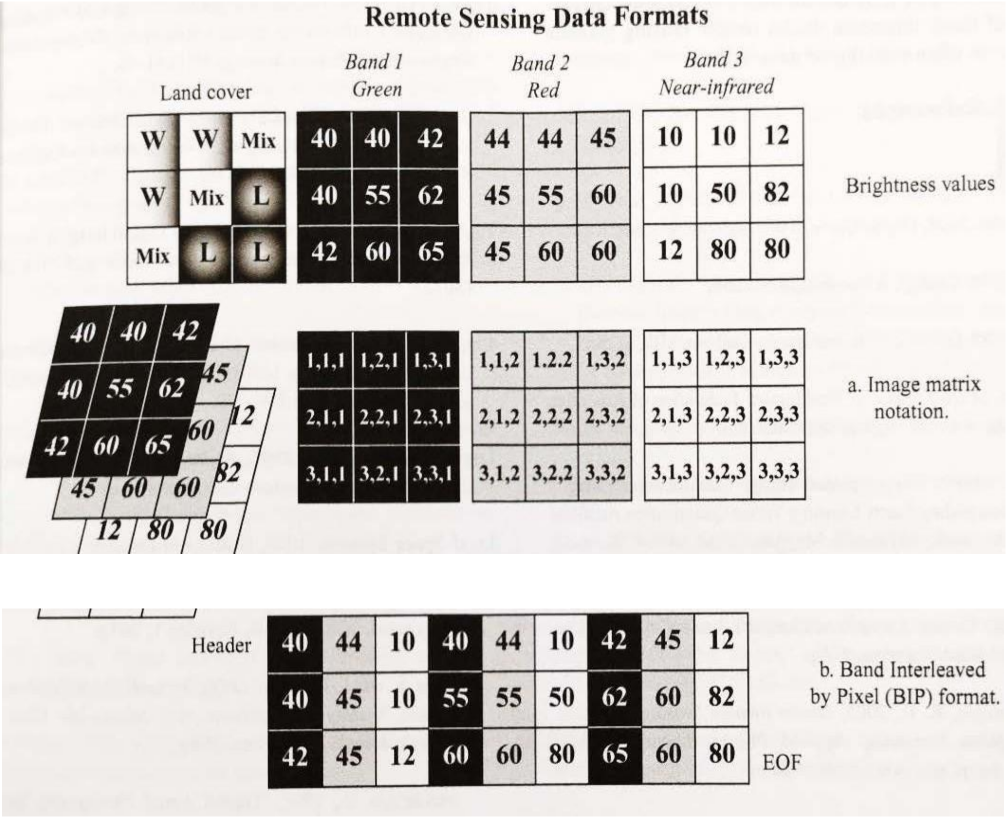


Note the differences between software packages:

- Existence of header and EOF (Yes for ERDAS, no for IDL)
- Line first (*Matlab*) or column first (*IDL*)

Digital image formats

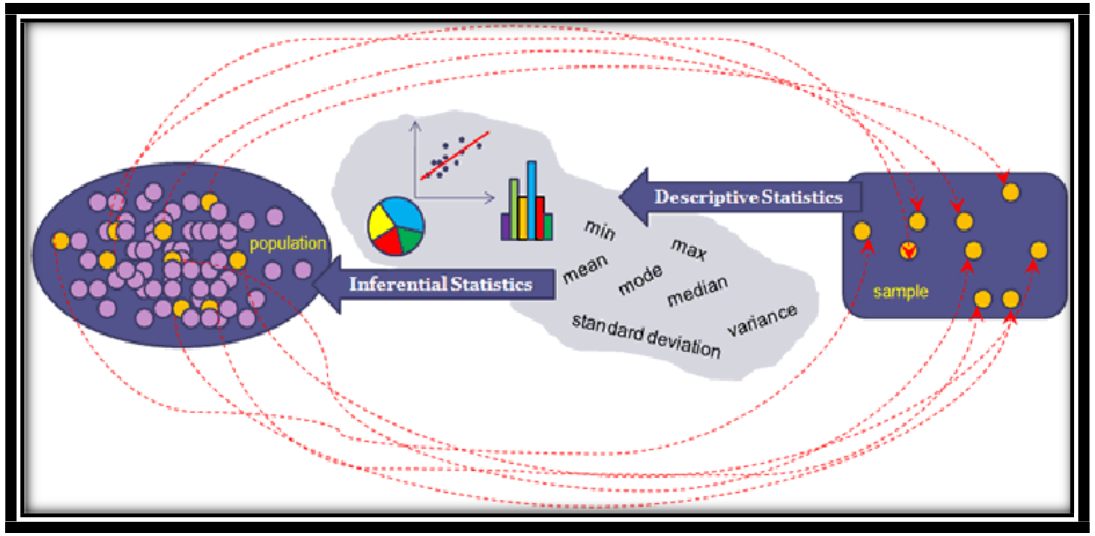
- Band Interleaved by Pixel (BIP)
  - Places the DNs in n bands for each pixel in sequential order
  - DNs in all bands for *the 1st pixel*, followed by DNs in all bands for *the 2nd pixel*, … …



Q1: what is the motivation of having multiple data storage formats?

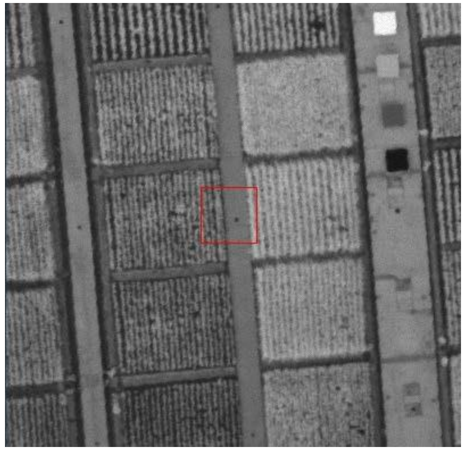
Statistical evaluation of images

- Review some concepts in statistics
- Population:
  - An infinite or finite set of elements
- Sample: (DN values of pixels in an example image)
  - A subset of the elements drawn from a population for making inferences about the population
- Sampling error of a characteristic:
  - the difference between the true value from the population and the value inferred from the sample.

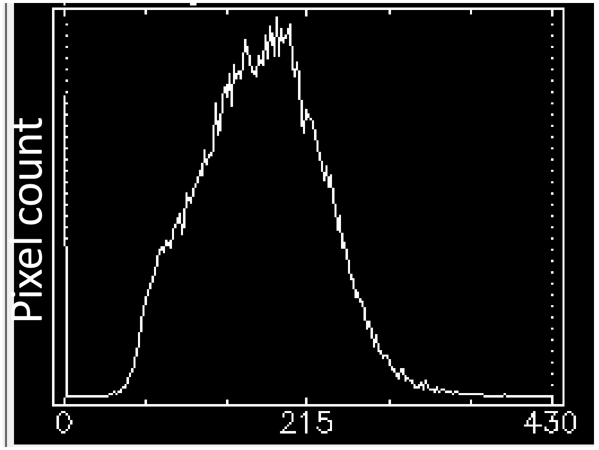


Credit: Mikolaj Letkowski (doingstats.com)

Histogram



Image



Histogram

- Histogram:
  - A math function characterizing the frequency distribution of DN values for all pixels in an image
  - Image statistics are derived from histograms
  - Independent from inter-pixel relationships (spatial patterns)

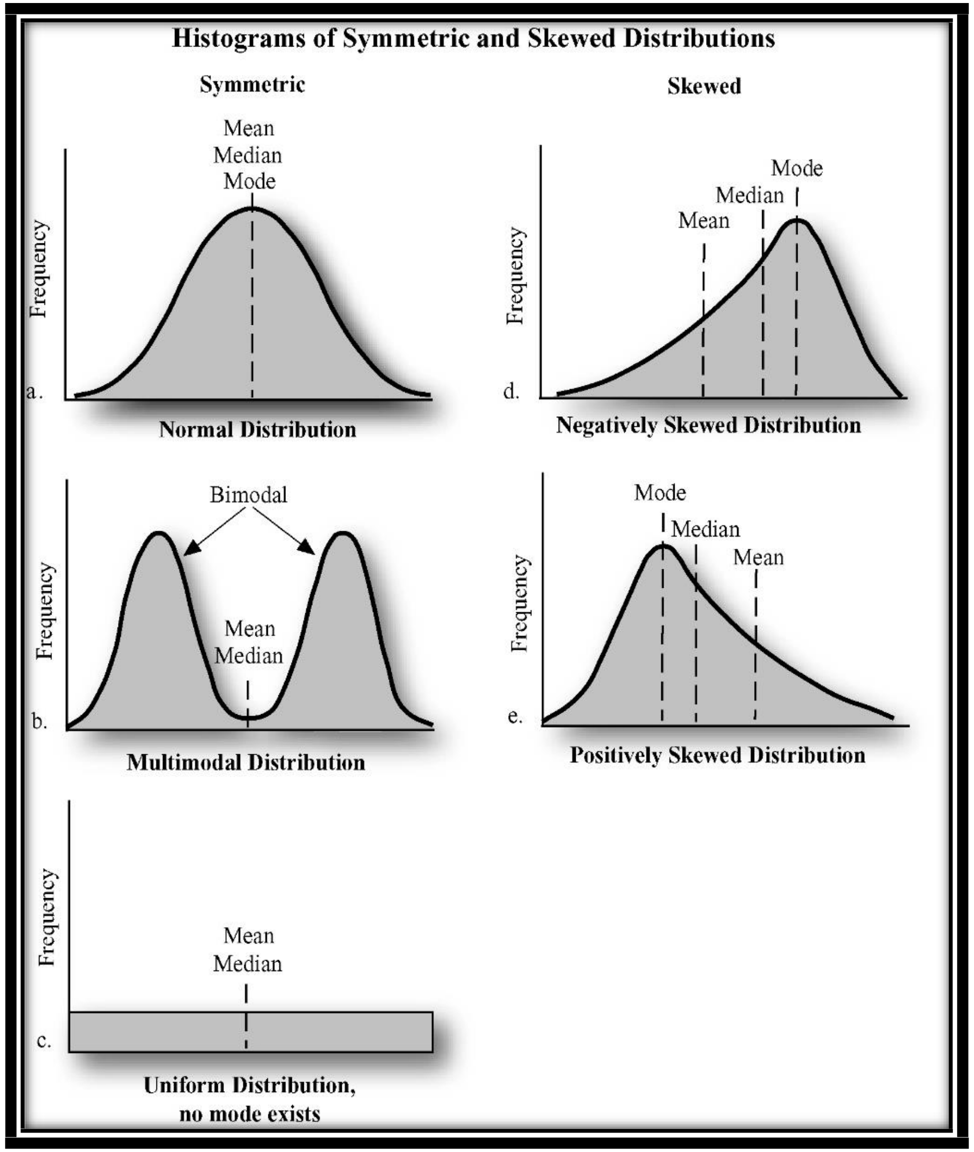
Q2: if an image in BSQ is converted to BIL and BIP formats, do they have the same histogram?

Normal distribution

- **A histogram:**
  - Represents the frequency of occurrence of each DN within an image
  - Useful for evaluating the image quality (contrast)

- Large samples drawn randomly from natural populations usually follow a ***normal*** distribution.

- DN values from an image are **not always** normally distributed.



Jensen, (2005)

An example

2.4 m QuickBird multispectral imagery. Band combination: 3-4-2.
(Courtesy of Digital Globe)

Spectral ranges (µm)	0.45-0.52 0.52-0.60 0.63-0.69 0.76-0.90
Spatial resolution, IFOV	2.4-2.6 m (GSD), 5.47µrad
Swath width, FOV	16.5 km (450 km altitude), 2.12º
Data quantization	11 bits (DN range: 0~2047)

Filename: C:\Program Files\Exelis\ENVI51\data\qb_boulder_msi
Dims: Full Scene (1,048,576 points)

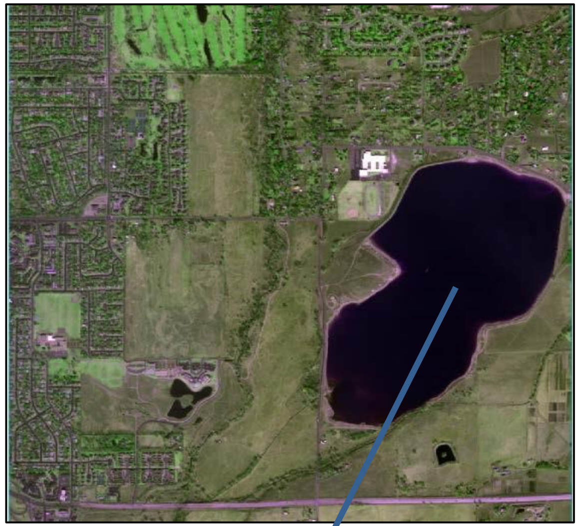
Basic Stats	Min	Max	Mean	Stdev	Num	Eigenvalue
Band 1	138	1492	242.291791	37.553299	1	29948.278159
Band 2	154	2047	357.317511	71.552232	2	3147.196907
Band 3	92	1785	271.472336	83.538228	3	271.486304
Band 4	52	1807	359.511358	141.078708	4	44.848169

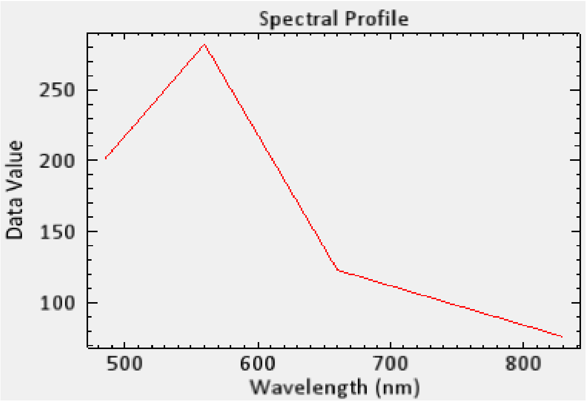
Covariance	Band 1	Band 2	Band 3	Band 4
Band 1	1410.250289	2612.678907	2688.061083	3397.705711
Band 2	2612.678907	5119.721918	5494.079398	7251.871048
Band 3	2688.061083	5494.079398	6978.635466	10418.717628
Band 4	3397.705711	7251.871048	10418.717628	19903.201866

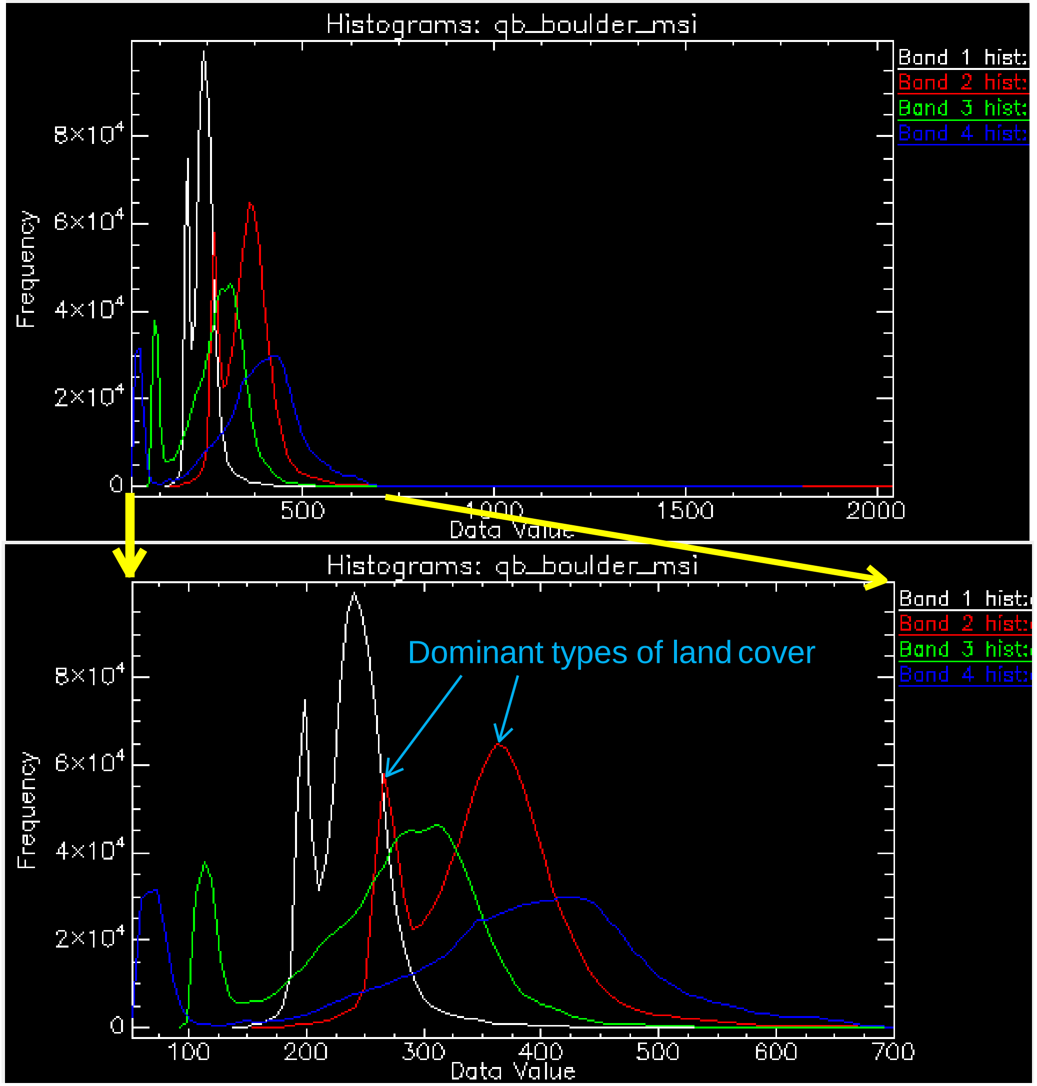
Correlation	Band 1	Band 2	Band 3	Band 4
Band 1	1.000000	0.972332	0.856852	0.641322
Band 2	0.972332	1.000000	0.919150	0.718398
Band 3	0.856852	0.919150	1.000000	0.884031
Band 4	0.641322	0.718398	0.884031	1.000000

Eigenvector	Band 1	Band 2	Band 3	Band 4
Band 1	0.170599	0.352704	0.464548	0.794161
Band 2	0.385093	0.653274	0.326814	-0.564029
Band 3	0.393111	0.369256	-0.811178	0.226061
Band 4	0.817351	-0.559002	0.139203	-0.008743

An example

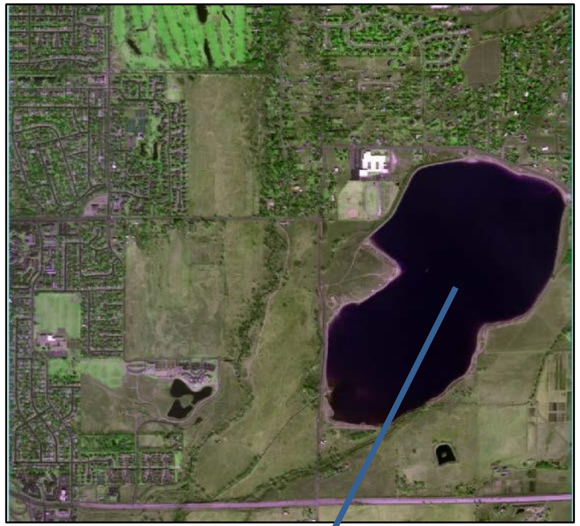


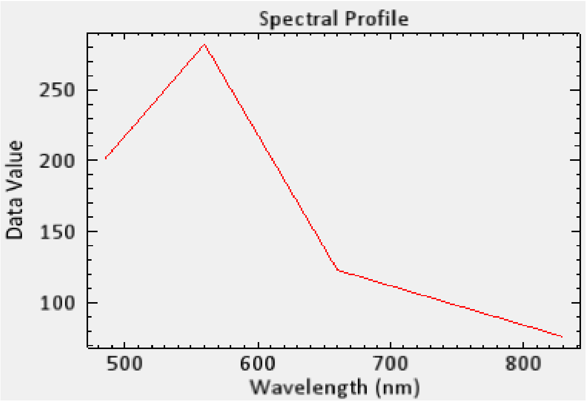


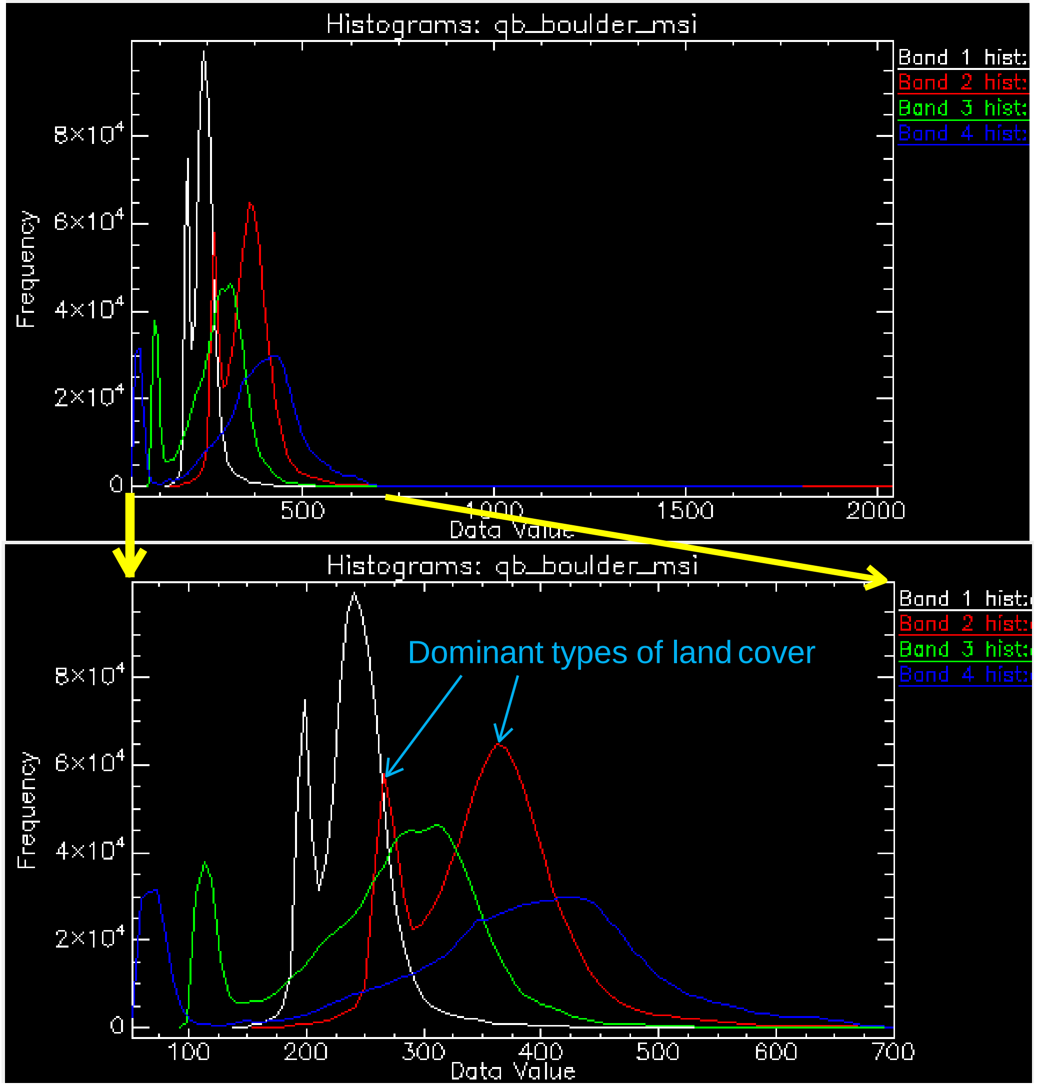


Q3: why does each histogram curve have two peaks, not one or three?

An example







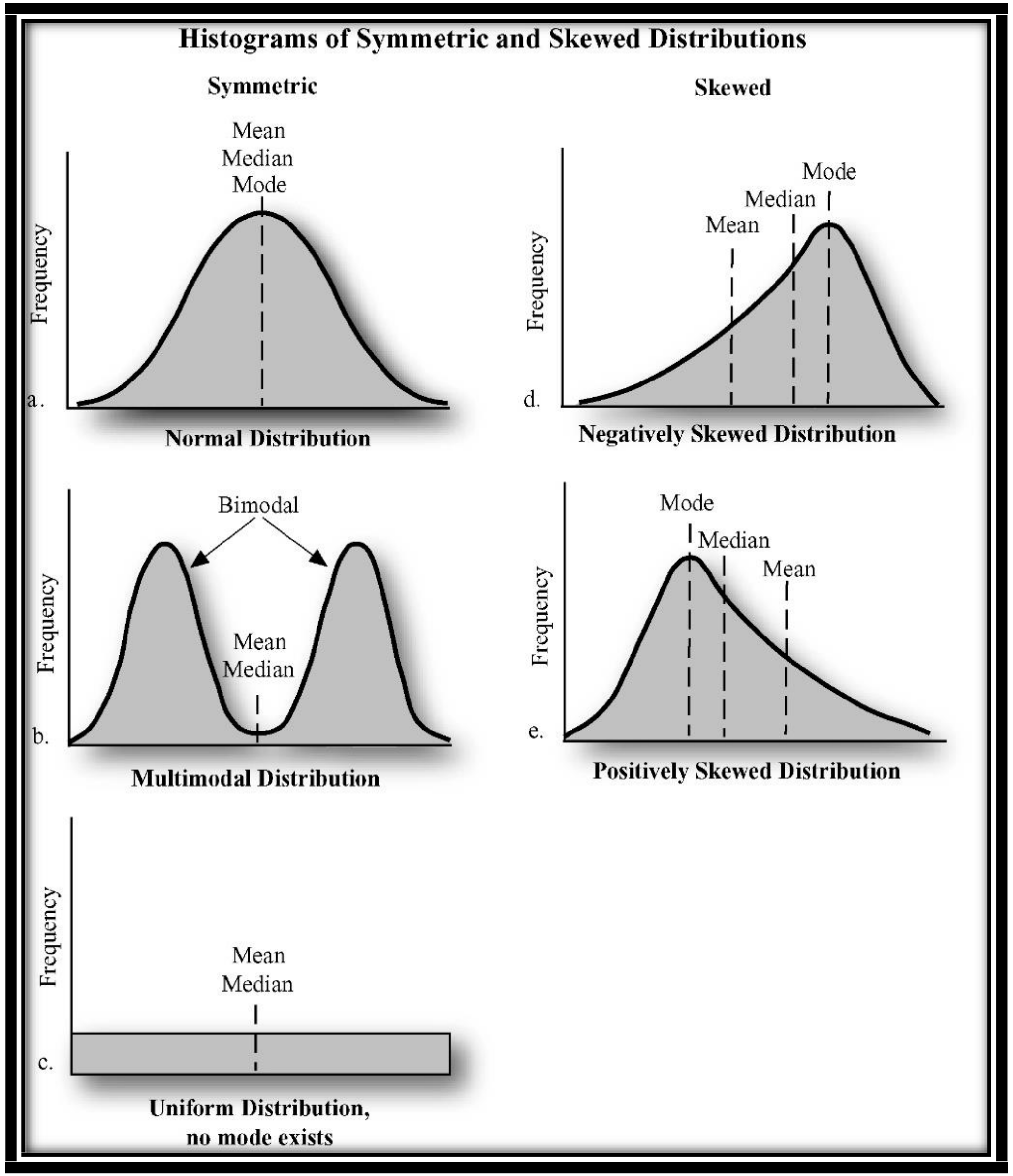
Q4: why do the peaks appear at different DN values?

Descriptive image statistics

Measure of central tendency

- Mode:
  - the peak value on the histogram curve
- Median
  - the value at 50% frequency
- Mean:
  - The arithmetic average

$$u_k = \frac{\sum_{i=1}^{n} DN_{ik}}{n}$$



Jensen, (2005)

Univariate statistics

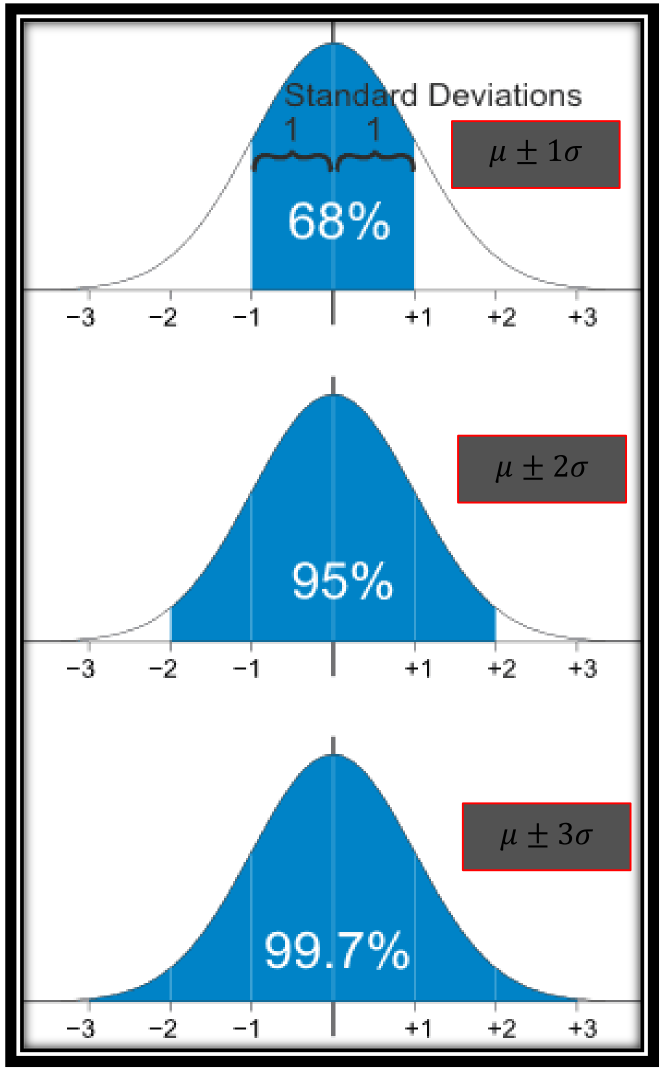
- Measures of dispersion
  - About the mean of a distribution
  - Range: $\boldsymbol{range_k = max_k - min_k}$
  - Variance:

$$\boldsymbol{var_k = \frac{\sum_{i=1}^{n}(DN_k - u_k)^2}{n-1}}$$

  - Standard deviation:

$$\boldsymbol{\sigma_k = \sqrt{\frac{\sum_{i=1}^{n}(DN_k - u_k)^2}{n-1}}}$$

  - Small $\boldsymbol{\sigma}$: tight clustering of DNs
  - Large $\boldsymbol{\sigma}$: wide scattering of DNs



Source: www.mathsisfun.com/data/standard-normal-distribution.html

Multivariate statistics

- Compute covariance and correlation among bands:
  - To determine how radiometric measurements for one band covary with those for another band (useful for calculate class separability).

$$cov_{kl} = \frac{\sum_{i=1}^{n}(DN_{ik} - u_k)(DN_{il} - u_l)}{n-1}$$

Variance-covariance matrix of the sample data

	Band 1	Band 2	Band 3	Band 4
Band 1	1410.25			
Band 2	2612.68	5119.72		
Band 3	2688.06	5494.08	6978.64	
Band 4	3397.71	7251.87	10418.72	19903.20

- This matrix is symmetric, i.e., $cov_{12} = cov_{21}$
- Diagonal elements: variance
- Off-diagonal elements: covariance.

Multivariate statistics

- Correlation between bands

$$r_{kl} = \frac{cov_{kl}}{s_k s_l}$$

Correlation matrix of the sample data

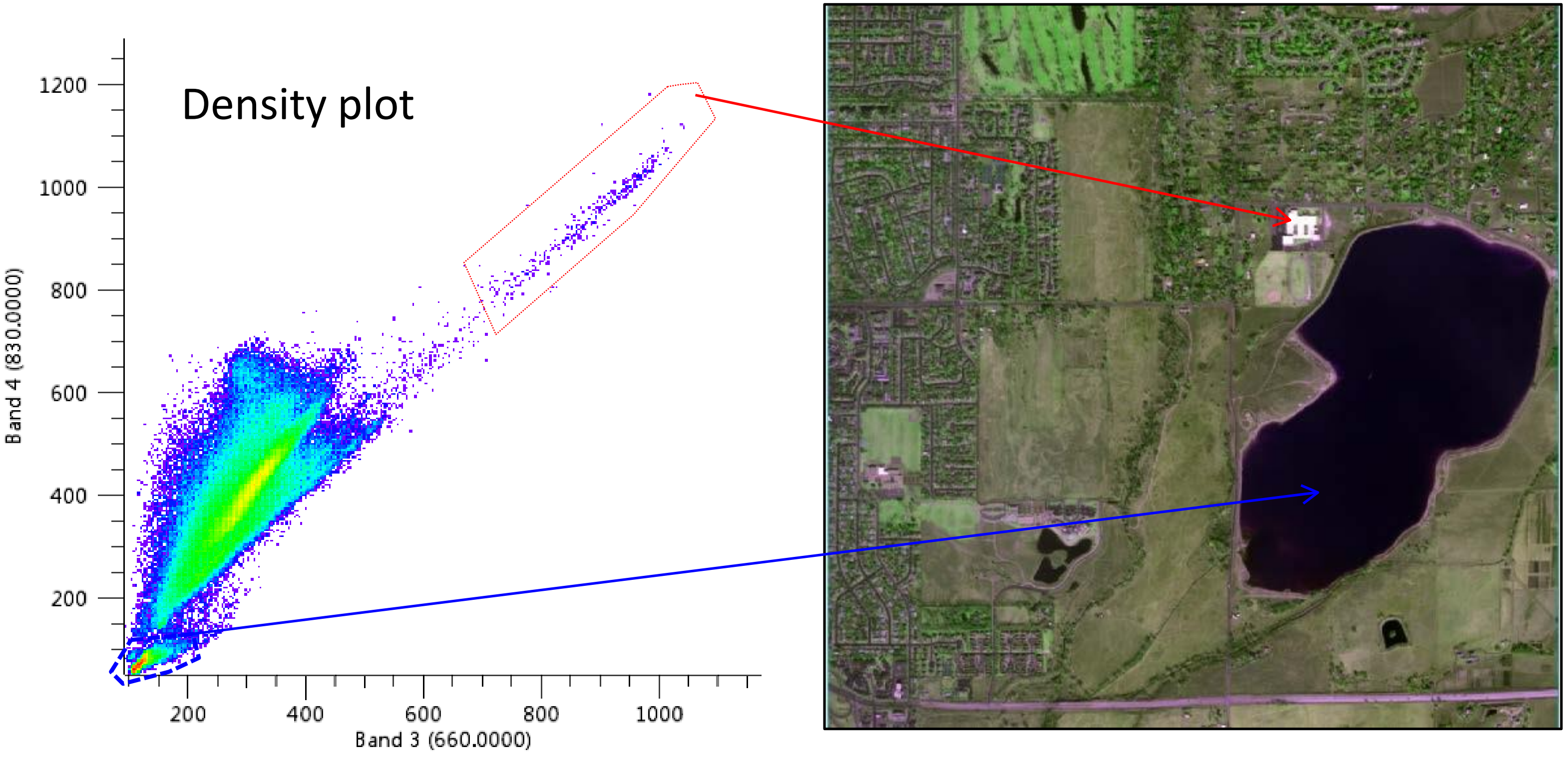
	Band 1	Band 2	Band 3	Band 4
Band 1	-			
Band 2	0.97	-		
Band 3	0.86	0.92	-	
Band 4	0.64	0.72	0.88	-

- This matrix is symmetric, i.e., $cov_{12} = cov_{21}$
- Diagonal elements: variance
- Off-diagonal elements: covariance.

Q5: what if we split the image into two halves? Are we going to have a different correlation matrix?

Feature space plots

- *Bands* of *remotely sensed data* corresponds to *features* in the *pattern recognition* community.
- Plots of pixels in the feature space (useful for classification).



Feature space

Image space

Q6: why are several clusters clearly separated?

Image fusion: merging remotely sensed data

- **Image fusion:**
  - To use complementary information from different data sets
  - Merging data from different sensors (optical data with RADAR data)
  - Merging panchromatic (PAN, spatial detail) data with multispectral (XS, spectral detail) data (also referred to as pan-sharpening)
  - Should be based on well registered data

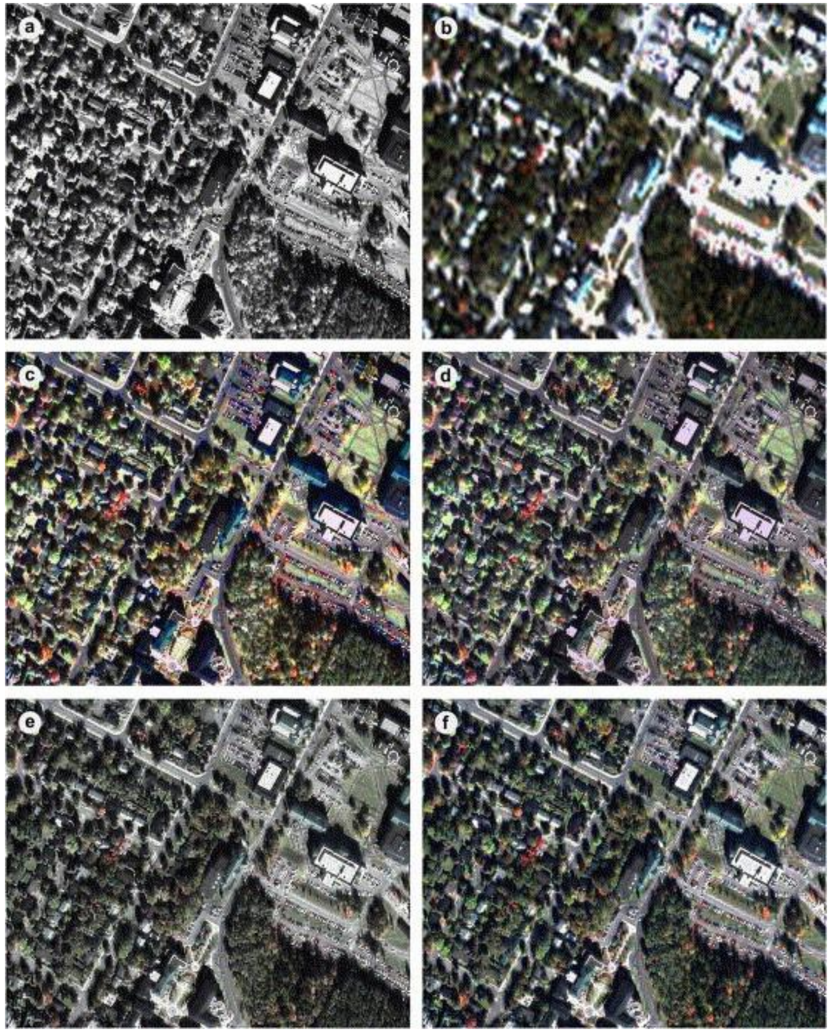
Landsat-8

Band No.	Wavelength (um)	Resolution (m)
1	0.433–0.453	30
2	0.450–0.515	30
3	0.525–0.600	30
4	0.630–0.680	30
5	0.845–0.885	30
7	2.100–2.300	30
8	1.360–1.390	30
9	0.500–0.680	15

WorldView-2

Band No.	Wavelength (um)	Resolution (m)
1	0.400-0.450	2
2	0.450-0.510	2
3	0.510-0.580	2
4	0.585-0.625	2
5	0.630-0.690	2
6	0.705-0.745	2
7	0.770-0.895	2
8	0.860-1.040	2
9	0.450-0.800	0.5

Pan-sharpening



IKONOS 1 m
(a) and 4 m XS
(b) images of Fredericton, Canada

Fusion results (c) & (d) using
IHS methods.

Fusion results (e) & (f) using
wavelet and integrative methods.

Fused images have spatial details from PAN data and spectral details from XS data.

Zhang, Y., & Hong, G. (2005). An IHS and wavelet integrated approach to improve pan-sharpening visual quality of natural colour IKONOS and QuickBird images. *Information Fusion*, *6*(3), 225-234.

Pan-sharpening

Image pan-sharpening with QuickBird images

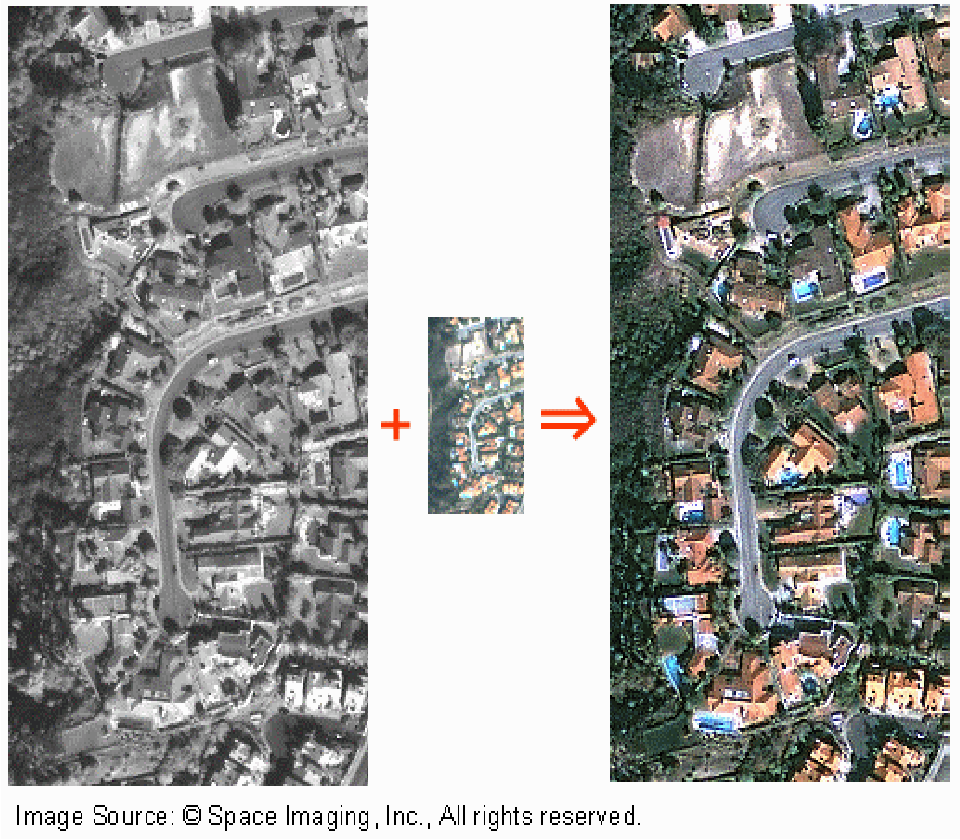
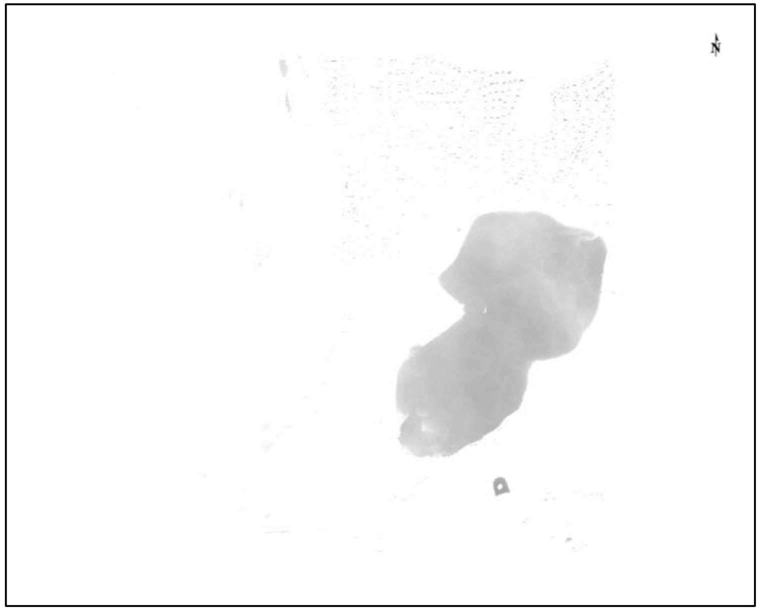


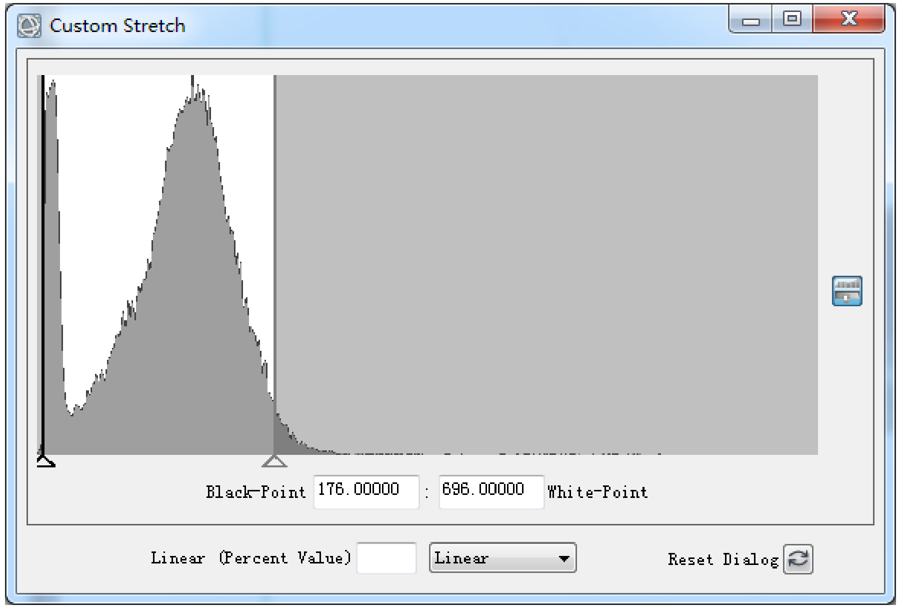
Image pan-sharpening with IKONOS images

Q7: What is gained from pan-sharpened images?

Image enhancement: contrast stretching

- **Problem**: the amounts of radiant energy over the EM spectrum are often similar for different materials, which results in *low-contrast* imagery.
- **Solution**: improve the contrast for better display, so that users can discern different objects on images more easily.

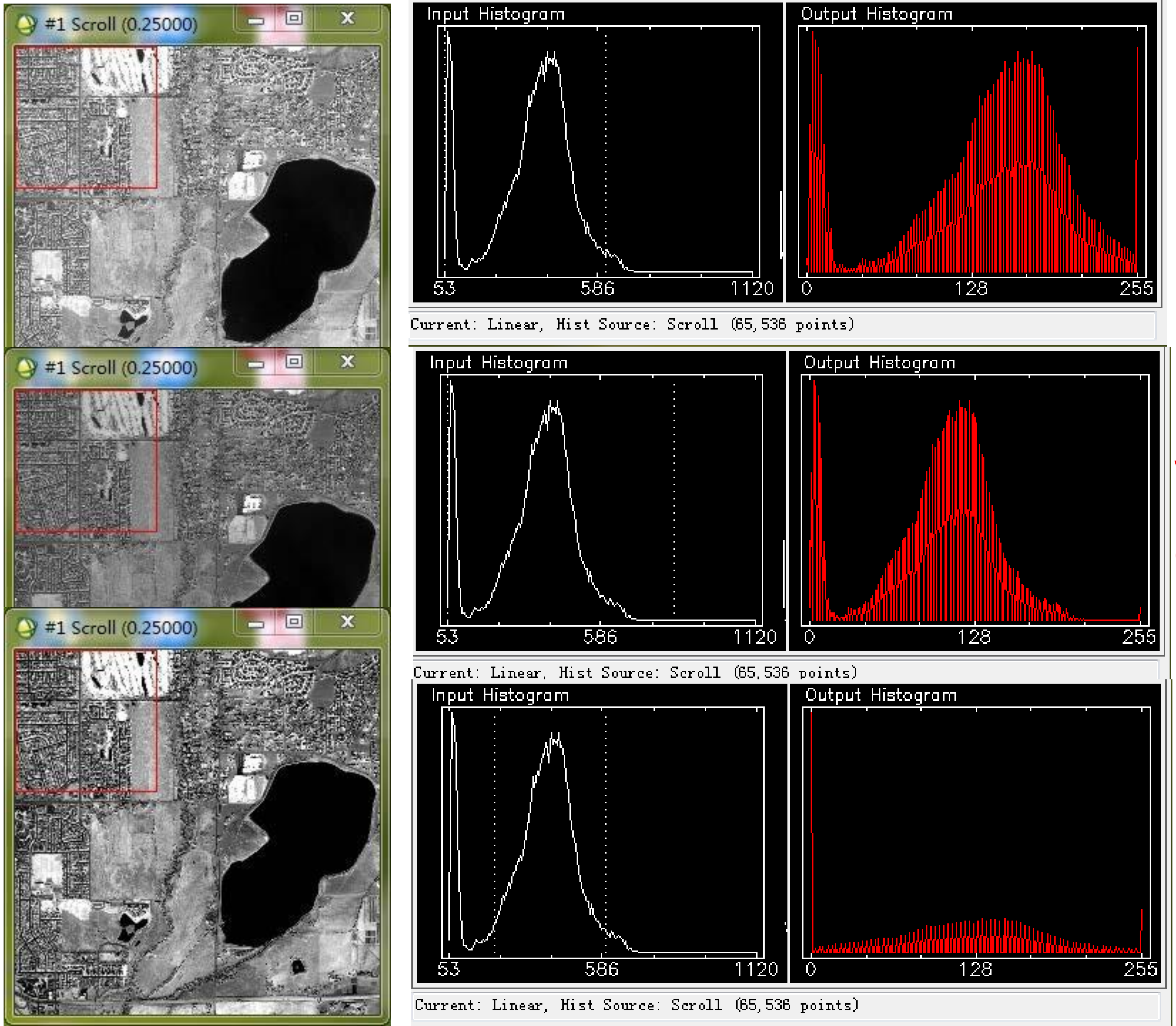




Normal

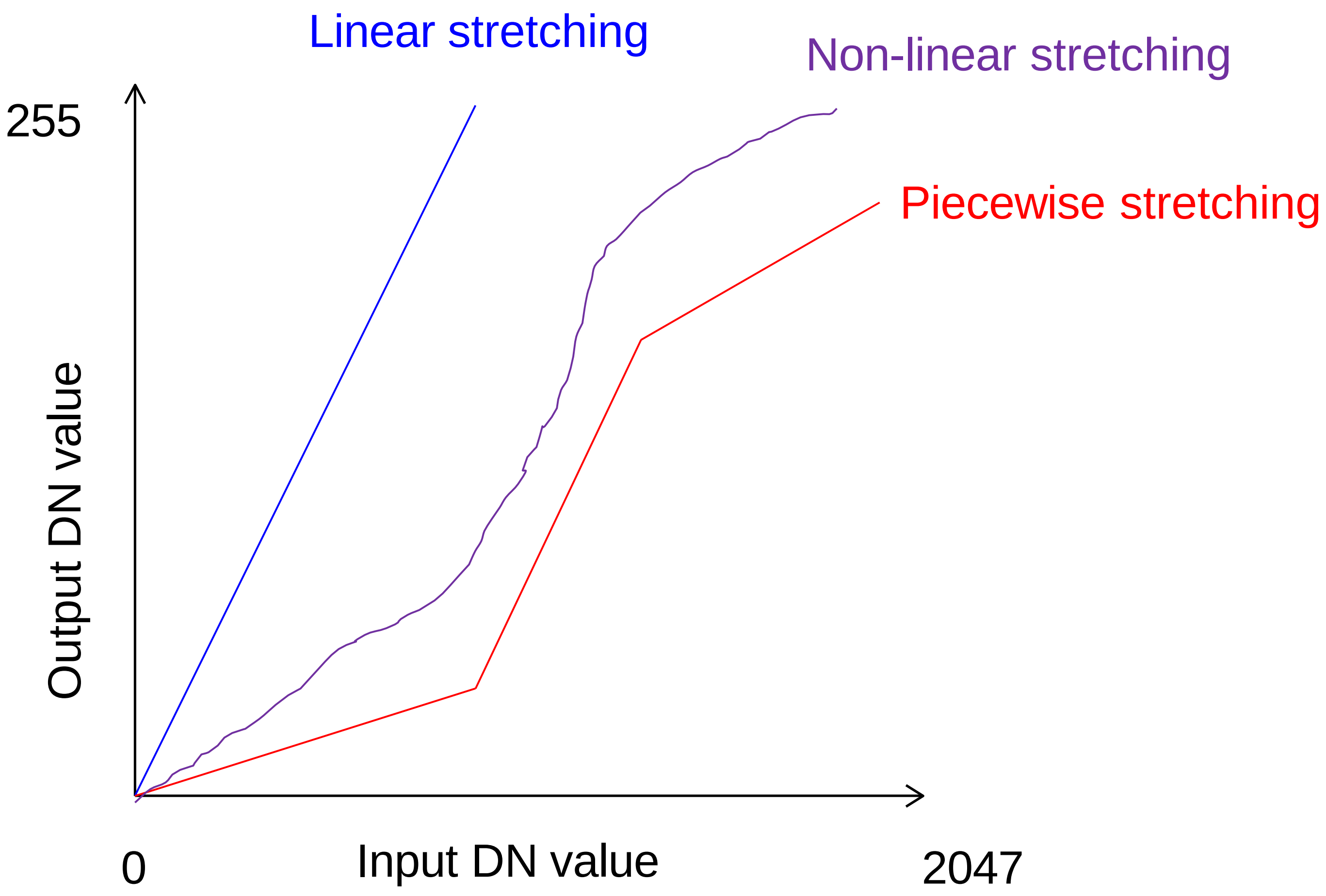
Lower contrast

Higher contrast



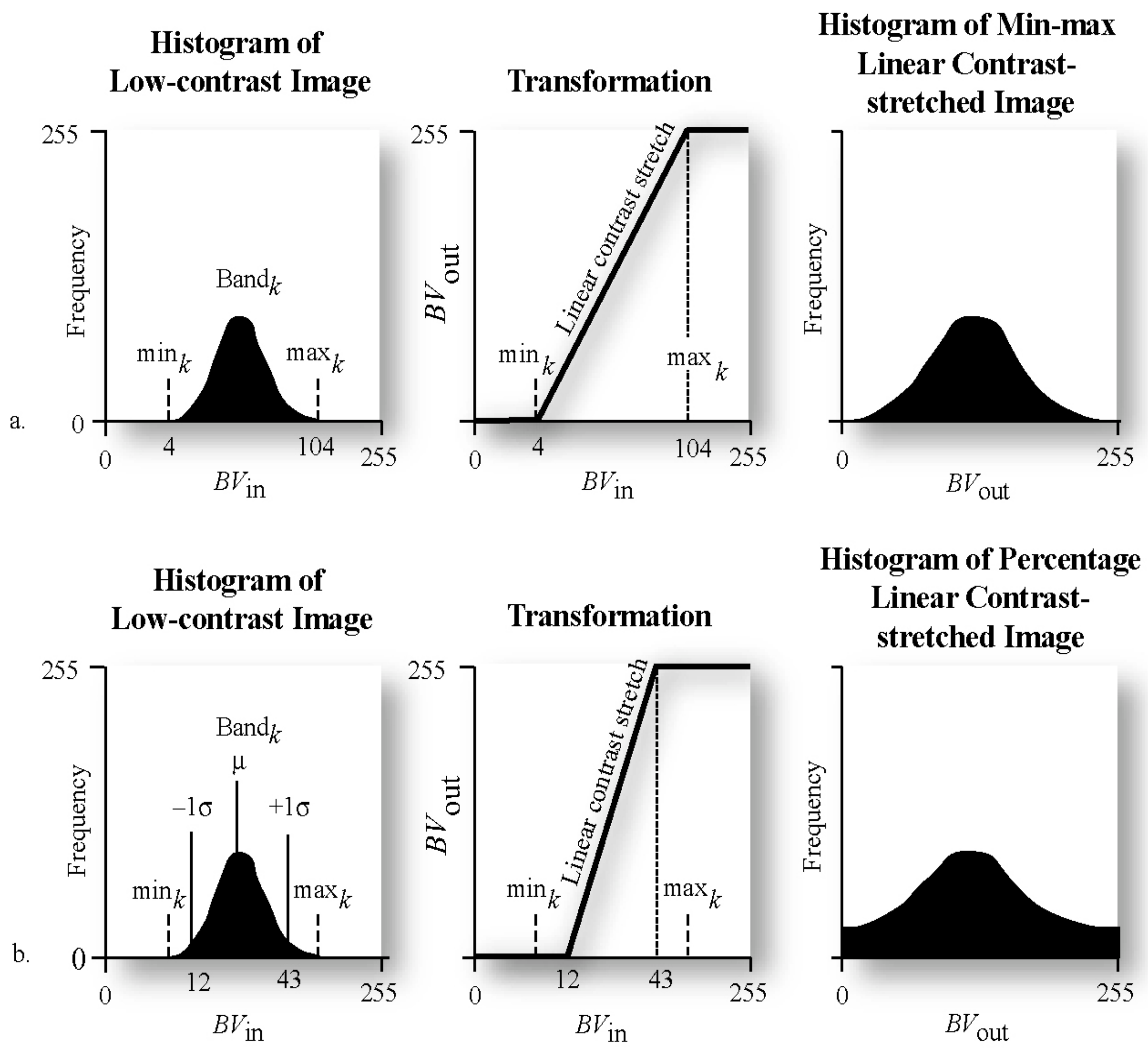
Q8:
what has changed to the image and histogram after stretching?

Stretching methods



* The max (e.g., 2047) varies with bit-level.

Contrast stretching

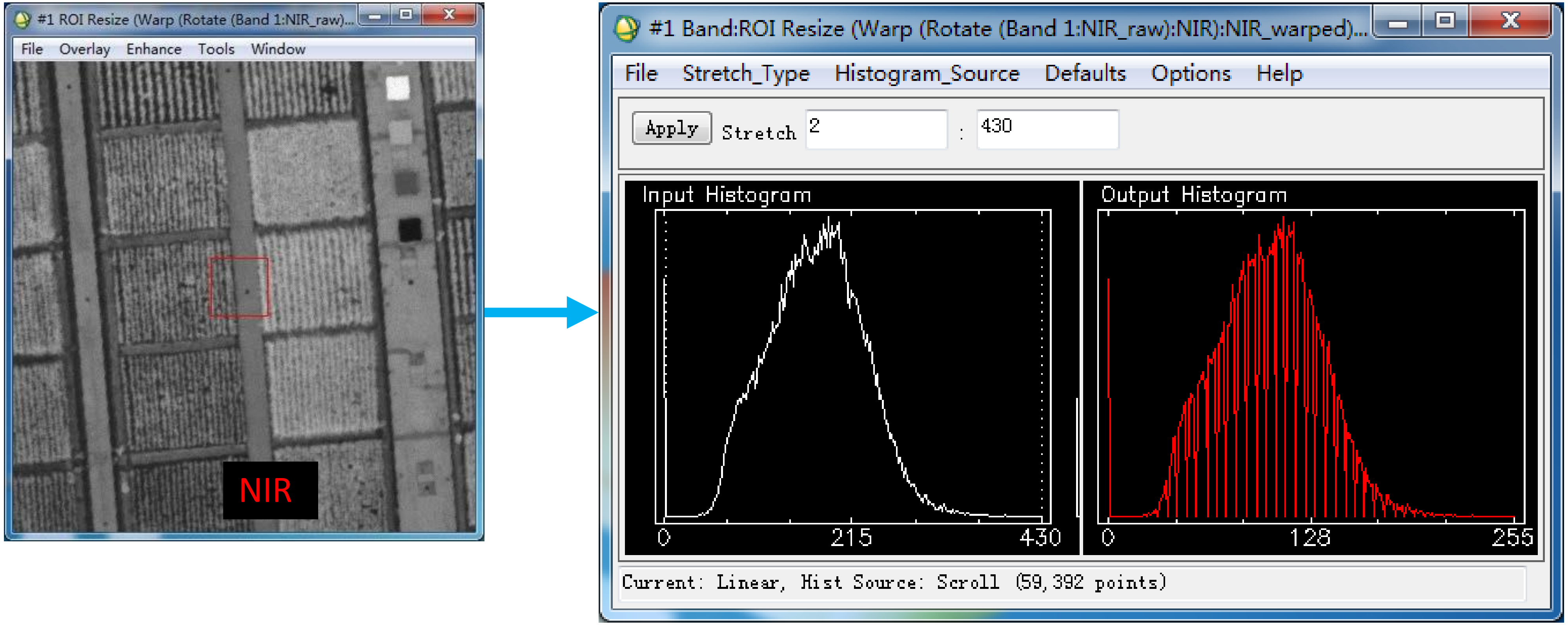


Max-min stretching

Percentage stretching

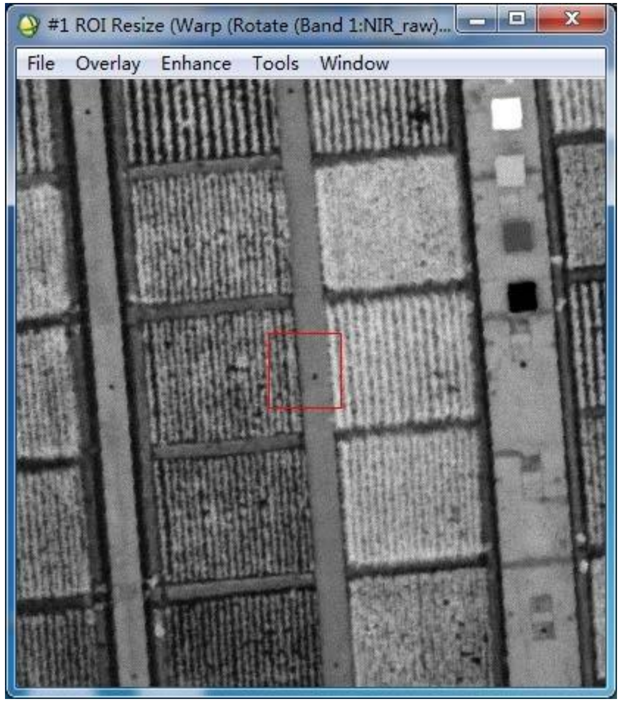
(Jensen, 2006)

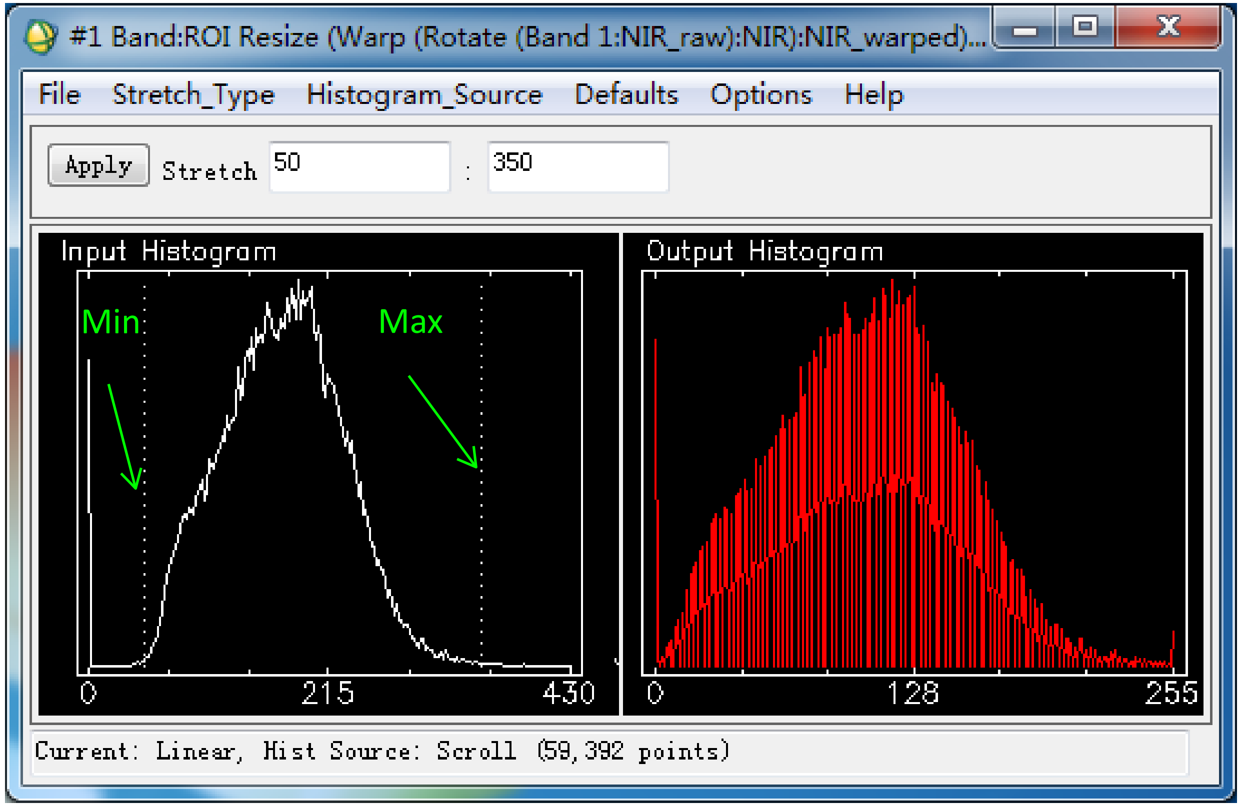
Original image without stretching



A low-contrast image and its histogram

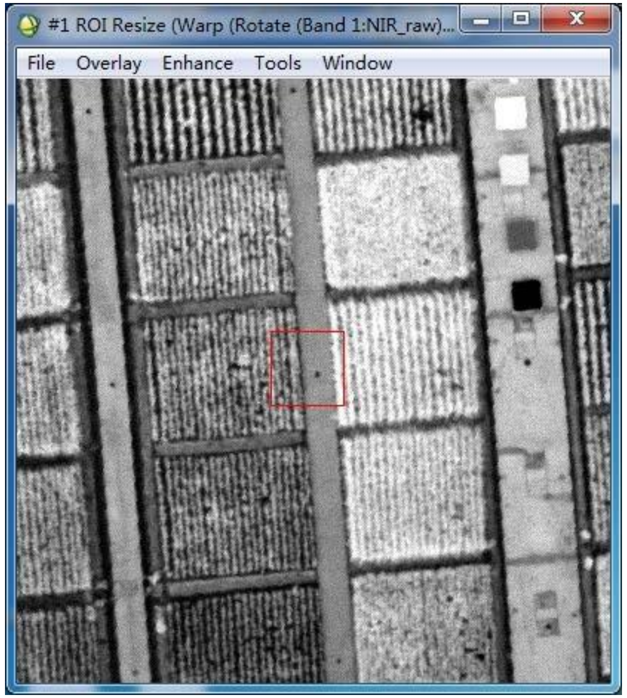
Stretching improves visualization

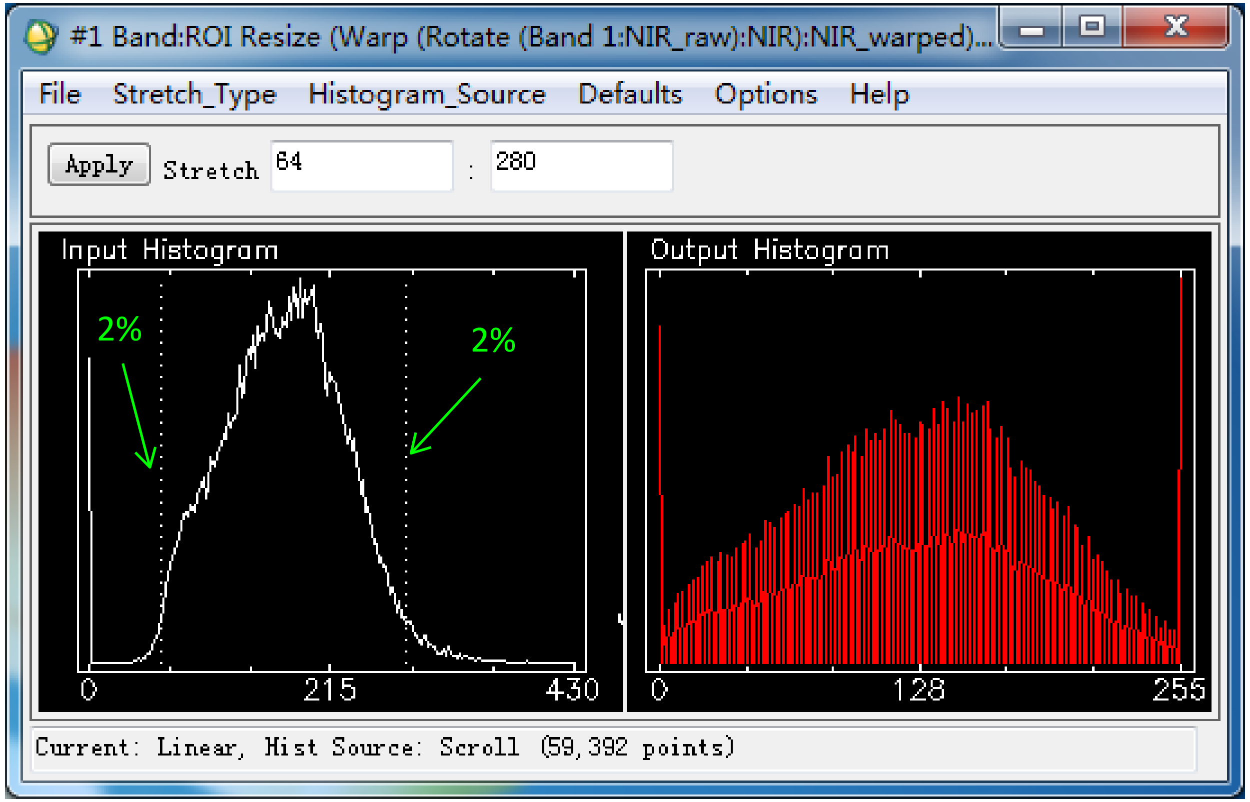




The image after max-min stretching and its histogram

Even better visualization

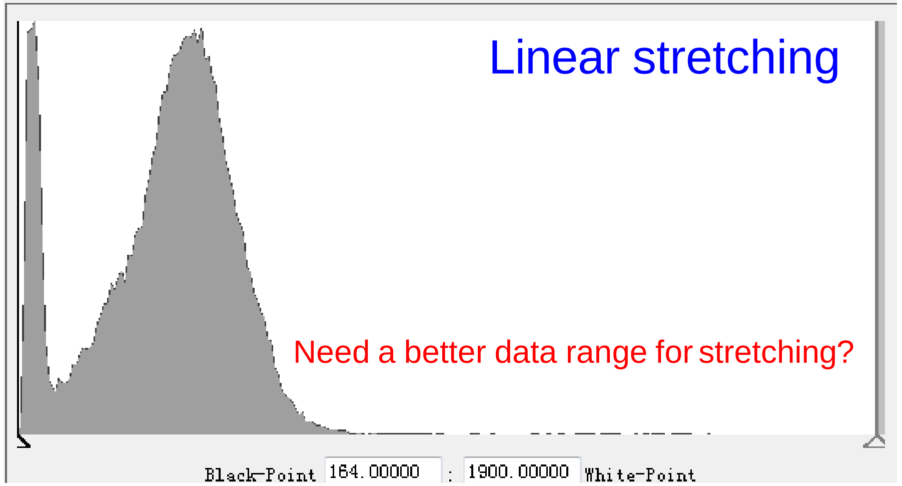


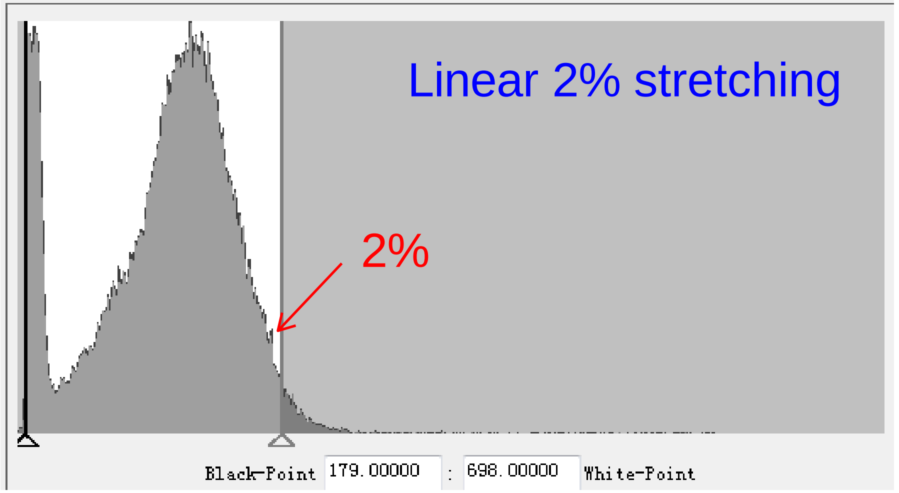


The image after percentage stretching and its histogram

Note: DN values have not changed in the physical memory.

Stretching





Pixel values between Black-Point and White-Point are stretched.
Pixel values < Black-Point are assigned 0; pixel values > White-Point are assigned 255.

Q9: what is the advantage of linear 2% stretching as compared to linear stretching?

Further readings

- Textbook DIP:
  - Relevant sessions in chapters 3, 4, 5, 6.