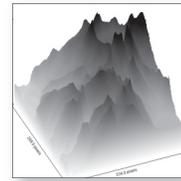


# More Than Numbers

## Graphing digital images



### Lesson

## Part 1: “See” the numbers

As you look at an image, your eyes give your brain clues about the shape, environment, and meaning of objects in the image. However, some of the data contained within an image may be difficult for your eyes to detect or interpret effectively. Graphing image data can help you obtain useful information you might not otherwise be able to see. In this lesson, you will create and interpret graphs of the numbers that make up digital images.

 Open **1 Colorado DEM.tif**.

Many digital images are like photographs; the pixel values in the image are directly related to the brightness in the original scene. In some images, however, the pixel values represent measurements other than brightness.

 Choose **Analyze > Set Measurements...**, and set the number of decimal places to zero. This will simplify things by displaying all measurements as whole numbers.

1. Look carefully at this image. Then, describe what you see.
2. What do you think this image shows?

 Move your cursor across the image, and read the pixel values in the status bar of the ImageJ window.

3. What do you think the pixel values in the image represent?

This image, called a Digital Elevation Model, or DEM, displays a regular grid of elevation measurements for a section of Earth’s surface. It is a type of digital map that is similar to a topographic map since it allows you to read elevation data. The data from a DEM can be used to create maps that show the locations of animal communities, soils, and vegetation types. This particular DEM image shows the state of Colorado.

 Move your cursor around the image again as you observe the values in the status bar.

This DEM is an 8-bit image with possible pixel values ranging from 0 to 255. These values are converted to elevation using an equation that was saved with the image. In the status bar, the calibrated pixel value is followed by the raw, uncalibrated pixel value in parentheses.

4. What are the highest and lowest elevations you can find? What raw pixel values correspond to each elevation?

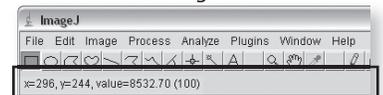
Rather than simply examining this image with your eyes, you can create a graph to help you “see” the numbers—in this case, the elevation data of the image. A *histogram* is a graph that shows the frequency distribution of values in the image—in other words, it shows the number of pixels there are for each different value in the image.

 Choose **Analyze > Histogram...** to create a histogram for the image.

 **File > Open**

### The status bar

The status bar is located below the tool bar in the *ImageJ* window.



Status Bar

### Calibrated and uncalibrated images

In uncalibrated (raw) images, the pixel values are proportional to some measurement but are not measurement values themselves. They have meaning relative to the other pixel values in that image but don’t tell you what the actual measurement was at each point in the image.

In calibrated images, the pixel values are converted to approximate measurements using an equation. For this image, the calibration equation is:

$$\text{elevation} = 45.6 \times \text{raw value} + 3,304.4$$

(To see the calibration equation, choose **Image > Show Info...**)

 **Analyze > Histogram**

 Move your cursor across the histogram plot, and read the **Value** (calibrated pixel value, or elevation) and **Count** (number of pixels) in the bottom part of the histogram window.

5. How many pixels in the image represent an elevation of 8,002 feet?
6. According to the histogram, what are the highest and lowest elevations in the image? (Reported as **Max** and **Min** in the **Histogram** window.)
7. What elevation occurs most often in this DEM? (Reported as the **Mode** in the histogram window.)
8. What is the average (**Mean**) elevation in the DEM?

Sometimes, it is useful to produce a detailed list of the information in the histogram.

 Click the **List** button in the **Histogram** window. Scroll down the histogram list, and examine the numbers. Double-check your answer to Question 5.

The histogram list shows the raw pixel values (**level**), the calibrated pixel value (**value**), and the frequency (**count**). This list can be saved or copied and pasted into a spreadsheet for further analysis.

 Close the **Histogram** and **List** windows.

## Profile plots

 Move your cursor around the image to explore elevation patterns.

9. Where are the areas of highest elevation located?

Another type of graph called a *profile* can help you interpret image data.

 Use the Straight Line Selection tool  to select a line across the image.

 Choose **Analyze > Plot Profile**. (In the future, simply press **K** on your keyboard to create a profile plot.)

The **Plot Profile** function creates a graph of the pixel values along the selected line, or *transect*. The y-axis of the profile shows the elevation, and the x-axis shows the distance along the transect. The scale of the y-axis ranges from the lowest to the highest value encountered along the transect.

10. What are the lowest and highest elevations along the transect?

 Use  again to select another transect across the image, then create a new profile plot.

The Y-axis scale is not the same for these two plots, making them difficult to compare. To compare data from several graphs, it helps to have a fixed scale for the y-axis.

 Close both of the profile plot windows.

 Choose **Edit > Options > Profile Plot Options**, and use the highest and lowest elevations of the image (from Question 6) to set the **Minimum Y** and **Maximum Y** values.

 Create another profile plot along the same transect.

11. How does this profile plot compare to the previous one you created?

## Histogram shortcut

Press the **H** key on your keyboard to make a histogram of the current image.

## Colorado Landsat

This lesson includes an image named **2 Colorado Landsat** that shows a satellite view of Colorado at the same scale as the DEM image. Feel free to open this image at any time and compare it to the DEM.

## Uncalibrated image histograms

When you create a list for an uncalibrated image histogram, only the raw pixel value (value) and frequency are reported.

## Keeping it horizontal

To force a line selection to be horizontal or vertical, hold down the **Shift** key while making the selection.

 Make several horizontal profile plots across sections of the image.

12. What kinds of landforms does this image show?

 Close all the profile plot windows.

 Choose **Edit > Options > Profile Plot Options...**, and turn off the **Fixed Y-axis Scale** option.

 To cancel any line selections, choose **Edit > Selection > Select None**.

## Surface plots

It is difficult to visually translate shades of gray into elevation, so you will apply a lookup table that is used to represent elevation on relief maps.

 Choose **File > Open...**, and open the **Elevation.lut** color table.

This helps, but to get a more meaningful view of the shape of the land, you will create a surface plot. Imagine drawing a profile plot for every row of pixels in the image, stacking these plots next to one another, and then looking down on them at an angle. Essentially, that is what a surface plot is.

13. Predict what a surface plot of this DEM will look like.

 Create a surface plot using the settings shown at right. (Choose **Analyze > Surface Plot ...**.)

14. Describe the shape of the land. Where are the Rocky Mountains?

Your surface plot shows a view of the landscape from the southwest, looking to the northeast. By rotating the DEM to the right you can surface plot a view from the southeast, looking toward the northwest.

 Activate the **1 Colorado DEM.tif** window and choose **Image > Rotate > Rotate 90 Degrees Right** to rotate the DEM clockwise a quarter-turn.

 Create another surface plot of the rotated image.

15. Compare this surface plot from the southeast to the one from the southwest. What details are visible in this view that you could not see before?

 Experiment with different sizes and shapes of selections and different option settings for making surface plots.

16. How does a surface plot created from a small area compare to one created from a larger selection?

 Close all the open image and plot windows.

## Part 2: Interpreting digital data

 Open **3 Sea Surface Temperature.tif**.

In this image, pixel values represent the temperature, in degrees Celsius (°C), of the ocean's surface. Black represents land, ice, or missing data. As you move your cursor around the image, you can read the changing temperature in the status bar. Note where the highest and lowest temperatures are located, as well as the value of the black areas.

 Choose **Analyze > Set Measurements...**, and set the number of decimal places to **1**. This will allow you to read temperatures to the nearest 0.1°C.

### Surface plot options



Note: Checking the **One Polygon Per Line** option disables the **Polygon Multiplier** setting.

### Plots of plots (Warning!)

When you are creating profile and surface plots, always remember to be sure the original image window is active before making the plot. Otherwise, you may accidentally make a plot of the previous plot window instead of the image!

### Temperature calibration

The calibration equation for the sea surface temperature image is:

$$\text{Temp (}^\circ\text{C)} = 0.15 \times (\text{raw px value}) - 3$$

- ☞ Create a histogram of the image.

According to the statistics displayed in the histogram window, the mode (the most common value) is  $-3^{\circ}\text{C}$ . Move your cursor over the image to see what areas this value corresponds to.

17. What parts of the image have a calibrated value of  $-3^{\circ}\text{C}$ ? Do you think this value is the surface temperature in these areas?

In this case, you can't use the mode value calculated automatically by ImageJ to find the most commonly occurring sea surface temperature. Instead, move your cursor over the highest peak in the histogram, and read the temperature that corresponds to that peak.

18. What sea surface temperature occurs most frequently in this image?

- ☞ Make several vertical (up and down) profile plots across the ocean basins.

19. What do these north-south profile plots tell you about the relationship between latitude (distance north or south of the equator) and sea surface temperature?

- ☞ Close all the open image and plot windows.

- ☞ Open the **4 Tree Rings.tif** image.

This image shows growth rings in a cross-section taken from a tree.

- ☞ Create a profile plot along an interesting part of the cross-section. You may need to reset the Y values in the **Profile Plot Options**.

20. What do the peaks and dips on the plots represent?
21. What do you think the different widths of peaks and dips show?

Tree ring scientists (dendrochronologists) use similar methods to establish dates of wood samples and to understand how a tree's growth is affected by its environment.

- ☞ Close all the open image and plot windows.

- ☞ Open the **5 Lambert Crater.tif** image. This Apollo 15 image shows Lambert Crater, which is approximately 30 km (19 miles) wide and 2400 m (8,000 ft) deep.

22. Before you make a profile plot across the crater, sketch your prediction of what you think the profile plot will look like.

- ☞ Make a profile plot across the crater.

23. Sketch the resulting plot, and compare it to your prediction.

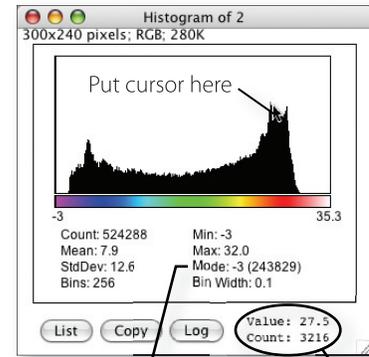
Many people predict the shape of the plot incorrectly because they expect to see a plot of elevation. Remember that profile plots are based on pixel values. If the pixel values represent elevation, then you will get an elevation plot. However, the pixel values in the Lambert Crater image represent the *brightness of the surface*, including areas of shadow, so the profile plot is a brightness—not elevation—plot.

- ☞ Close all the open image and profile plot windows.

- ☞ Open **6 Crater Lake.tif**. The pixel values in this image represent elevation measurements of the area surrounding a famous lake in Oregon that sits in the crater of a dormant volcano.

## Reading mode value of data from histogram

The Mode value given in the **Histogram** window represents No Data values in the image. To find the modal value of the data, read the value of the peak of the histogram. (Hint: The peak value has the highest count.)



Ignore this! → Read the Value and Count here

## Apollo 15

Apollo 15 was the fourth mission to land on and explore the moon. While two astronauts were exploring the surface, a third was orbiting the moon taking photographs and making other observations of lunar features.

24. How does this image look different from the Lambert crater image?

- ☞ Make several profile plots across sections of the Crater Lake image. Try different tools for making the plot profile selections. The Freehand Selection tool  can be used to try to find a smooth route up and over the rim of the crater.

Since the pixel values represent elevations in this image, you get elevation profiles. If the pixel values represented temperature, you would get temperature profiles, and so on.

- ☞ Make surface plots of several selections.

25. Plot profiles across the crater usually include a long flat section. What is the flat part?

- ☞ Close all the open image and plot windows.

## Part 3: Visualizing numeric data

Sometimes the pixel values in a given image represent mathematical functions or matrices of numbers. Any spreadsheet of numbers can be displayed as a digital image. Histograms, density plot profiles, and surface plots can make it easier to see the numerical patterns in the data.

- ☞ Open the **7 Paired Images** folder. Open both the **Stepped Ramp Right.tif** and **Smooth Ramp Right.tif** images in the **Pair 1** folder.

- ☞ Choose **Window > Tile** to tile the images.

 Window > Tile

26. What differences can you detect between the two images by looking at them?

- ☞ Activate and create a histogram for each image.

27. What information does the histogram tell you about an image?

- ☞ Move your cursor horizontally and vertically across each image to discover numerical patterns of the pixel values. Pixel values and coordinates are displayed in the status bar of the ImageJ window.

- ☞ Activate each image and create a horizontal profile plot for each one.

- ☞ Activate each image and create a surface plot for each one.

28. Briefly describe what you see in each surface plot.

29. Compare how profile plots show numerical patterns in images to how surface plots show them.

## Exploring digital data

Examine each of the images in the **Pair 2**, **Pair 3**, and **Pair 4** folders. Predict what a resulting histogram, density plot profile, and surface plot might look like for each image.

- ☞ Create a histogram, density plot profile, and surface plots for each image.

30. Briefly describe the pattern of the values in each image. How did the plots of each compare to your predictions?

- ☞ Close all images when you are finished.

## Crater Lake surface plots

Explore Crater Lake by making surface plots of the DEM. For example, open the **Elevation.lut** lookup table file, and turn on the **wireframe** option in the **Analyze > Surface Plot** window.



## **Advanced technique: Density calibrating an image**

Some of the images used in this lesson were density calibrated. This means that the raw pixel values were converted to some meaningful, real-world measurement through a mathematical equation. In this exercise, you will work through the density calibration procedure yourself.

 Open **8 Calibration.tif**.

Mammals and reptiles use different methods to regulate their body temperature. These images of a rat (top) and a snake (bottom) were taken with a special camera that records thermal infrared radiation. The images on the left show both animals at room temperature, and the images on the right show them after 15 minutes under a heat lamp.

In the image, dark blues represent lower temperatures, and reds and oranges are higher temperatures. The orange object entering the top of the frame at upper right is the hand of the person handling the animals. You can easily tell what is warmer and what is cooler based on the colors.

31. Which animal's body temperature appears to change the most from exposure to the heat lamp?

Wouldn't it be nice to be able to measure the actual temperatures of the animals before and after the heat lamp? That would require converting the pixel values to *temperature* values. To do this, you need to have at least two known temperatures in the images.

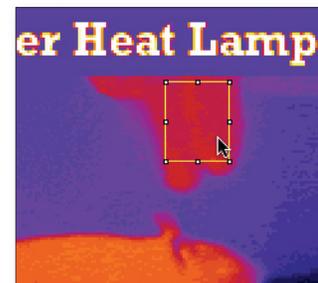
Fortunately, we know that the room temperature when the images were made was 23°C, and we know that the human's skin temperature was approximately 33°C. You can use these two known temperatures to calibrate the image. After calibration, you will be able to read the temperature anywhere in the image, including the rat and the snake's body surface temperatures.

-  Choose **Analyze > Clear Results** to get rid of any previous measurements you have made.
-  Choose **Analyze > Set Measurements** and turn off all the measurement options except **Mean Gray Value**. Set the number of decimal places to **1**, and close the **Set Measurements** dialog box by clicking **OK**.
-  Use one of the area selection tools to select a large sample of pixels from the person's fingers in the upper right frame (see example at right).
-  Press the **M** key to measure the mean (average) value of the pixels in the person's fingers.
-  Drag the selection outline from the fingers to an area of the background, and press **M** again to measure the mean value of the pixels that represent room temperature.
-  Choose **Analyze > Calibrate** to open the calibration dialog box. The two mean pixel values you just measured should be listed in the left-hand column. Enter the corresponding known temperatures of the person (33) and the background (23) in the right-hand column. Choose the **Straight Line** option on the **Function** menu, and enter **degrees C** in the **Unit** box. Then click **OK**.

### **What snake?**

Many people question whether there's really a snake present in the **Before** image. If you look very carefully in the lower left corner of the image, you will see a dark blue spot with a dark blue line extending below it. This is the snake's nose and tongue, which are cooled as moisture is evaporated by the surrounding air. You should also be able to easily see the snake's nose and tongue in the **After** image.

### **Sampling human skin temperature**



The graph that appears shows the mathematical relationship between pixel value and temperature. The computer uses the formula represented by this calibration line to convert the raw pixel values to temperature values. Once the image is calibrated, the pixel value in the status bar shows the actual temperature at the location under the cursor.

 Move your cursor around the image to determine the temperature of different areas.

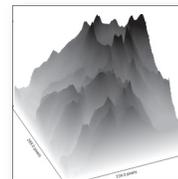
32. Use the area selection tools to sample and measure the surface temperature of the rat and the snake before and after they were exposed to the heat lamp. Use this information to complete Table 1.

**Table 1**

Animal	Body Surface Temperature (°C)	
	Before Heat Lamp	After Heat Lamp
Rat		
Snake		

33. What do these results tell you about the differences between how mammals and reptiles regulate their body temperatures?





**Data  
Sheet**

# More Than Numbers

1. Look carefully at this image, and describe what you see.
2. What do you think this image shows?
3. What do you think the pixel values in the image represent?
4. What are the highest and lowest elevations you can find? What raw pixel values correspond to each elevation?
  - a. lowest elevation = \_\_\_\_\_ ( raw value = \_\_\_\_\_ )
  - b. highest elevation = \_\_\_\_\_ ( raw value = \_\_\_\_\_ )
5. How many pixels in the image have a value of 8,200 feet?
6. According to the histogram, what are the highest and lowest elevations in the image? (Reported as Max and Min in the histogram window.)
  - a. lowest elevation = \_\_\_\_\_
  - b. highest elevation = \_\_\_\_\_
7. What elevation occurs most often in this DEM? (Reported as the Mode in the histogram window.)
8. What is the average (Mean) elevation in the DEM?

9. Where are the areas of highest elevation located?
  
  
  
  
  
  
  
  
  
  
10. What are the lowest and highest elevations along the transect?
  - a. lowest elevation = \_\_\_\_\_
  - b. highest elevation = \_\_\_\_\_
  
  
  
  
  
  
  
  
  
  
11. How does this profile plot compare to the previous one you created?
  
  
  
  
  
  
  
  
  
  
12. What kinds of landforms does this image show?
  
  
  
  
  
  
  
  
  
  
13. Predict what a surface plot of this DEM would look like.
  
  
  
  
  
  
  
  
  
  
14. Describe the shape of the land. Where are the Rocky Mountains?
  
  
  
  
  
  
  
  
  
  
15. Compare this surface plot from the east to the one from the south. What details are visible in this view that you could not see before?
  
  
  
  
  
  
  
  
  
  
16. How does a surface plot created from a small rectangular selection compare to one created from a larger rectangular selection?



17. What parts of the image have a calibrated value of  $-3^{\circ}\text{C}$ ? Do you think this value is the surface temperature in these areas?
  
18. What sea surface temperature occurs most often?
  
19. What do these graphs show you?
  
20. What do the peaks and dips on the plots represent?
  
21. What do you think the different widths of peaks and dips show?
  
22. Before you make a profile plot across the crater, make a sketch to predict how you think the plot will look.
  
23. Sketch the resulting plot, and compare it to your prediction.
  
24. How does this image look different from the **Lambert Crater.tif** image?



25. Plot profiles across the crater usually include a long flat section. What is the flat part?
  
26. What differences can you detect between the two images by looking at them?
  
27. What information does the histogram tell you about an image?
  
28. Briefly describe what you see in each surface plot.
  
29. Compare how profile plots show numerical patterns in images to how surface plots show them.
  
30. Briefly describe the pattern of the values in each image. How did the plots of each compare to your predictions?
  
31. Which animal's body temperature appears to change the most from exposure to the heat lamp?
  
32. Use the area selection tools to sample and measure the surface temperature of the rat and the snake before and after they were exposed to the heat lamp. Use this information to complete Table 1.

**Table 1**

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