

# Pixelated Pictures

## Understanding Digital Images



**Student  
Guide**

### What is a digital image?

 Open **X-ray.tif**.

You are looking at an X-ray image of major arteries in the neck and chest. The patient is facing you, although his head is turned to the side. Notice how the fillings in the patient's teeth are visible. The large loop at the bottom of the image is the aorta. When pictures like this are displayed on a computer screen, they are digital images. But, what exactly are digital images? How are they used, and what characteristics do they possess?

 Use the Magnifying Glass tool  to click on the image four or five times to zoom in. (You can click  while holding down **Control** [Win] or **Option** [Mac] to restore the image.)

1. What do you see?

The small squares that make up a digital image are called picture elements or *pixels*.

 Watch the status bar as you move the  tool across the pixels.

2. What do you notice about the status bar? (Be specific!)

You should see numbers changing. The pixels in a digital image represent a grid or table of numerical values. Each pixel value is a single measurement recorded at a specific time and place. By assigning a specific color to each different pixel value, a picture or *digital image* is formed. An X-ray is an image made up of X-ray “brightness” measurements. Where the X-rays are blocked, by bone for example, the brightness is low. Where the X-rays pass through, in substances such as air or soft tissue, the brightness is high. Scanners and digital cameras collect these brightness measurements and display them as digital images.

With image processing technology you can analyze and change features of pixels such as their brightness, contrast, or numerical value.

 Choose **Image > Adjust > Brightness/Contrast** to open the **B&C** (Brightness & Contrast) window. Adjust each of the four slider controls, and watch how each slider affects the image appearance.

3. Describe what happens to the appearance of the image when you move each of the four sliders in the **B&C** window.

You should have noticed that changing the brightness and contrast changes the appearance of different features in the image. Changing the appearance of an image to make features easier to see is called *image enhancement*. Another simple way to enhance images is to change the colors used to display the pixel values.

 Choose **Image > Lookup Tables > Spectrum**, and observe the details now visible in the image. (Feel free to “try on” some of the other color tables.)

 Close **X-ray.tif** and the **B&C** window.

 File > Open

### **Gray is a color too!**

Most people don't think of black, white, and gray as colors, but we'll call them colors and we encourage you to do it too!

### **Enhancing science**

Image enhancement is a powerful tool. For example, being able to better see the details of a person's heart and vessels can help a doctor to make a more accurate diagnosis.

 File > Close

## Big pictures from little squares

-  Open **Stadium Picture.tif**. This image is really three images, each in a separate layer, or *slice*.
-  Press the > and < keys to move through the slices of **Stadium Picture.tif**. Or use the arrows on the slider bar at the base of the image.

Have you ever seen fans in a stadium form a big picture as part of a halftime show? Each seat in the “card section” is assigned one or more large cards, each a solid color. On command, each fan holds up the appropriate card. Viewed from across the field or from high above the stadium, the individual cards blend together to form a large picture.

Close up, all you can see are the individual colored cards. The pixels in a digital image are similar to the cards held by each fan.

4. How would the stadium picture look if the fans randomly traded cards with each other?

The location of each colored card is extremely important for displaying the picture. Stadium sections have “addresses” for every seat—locations are given by seat and row numbers. Digital images have a similar system for describing the location of each pixel.

-  Close **Stadium Picture.tif**.

## Discovering pixel “addresses”

-  Open **Mona Lisa.tif**.
  -  Click , then click the image several times until you can see individual pixels.
  -  Move your cursor horizontally across a row of pixels, and watch the changes in the status bar.
5. Which number in the status bar changes one unit for every one pixel you move in the horizontal direction?
    -  Move the cursor vertically (up or down) in a column of pixels, and again watch the changes in the status bar.
  6. Which item in the status bar shows a pixel’s vertical location?
  7. Describe how seat and row numbers in a stadium compare to the coordinate system used to locate specific pixels in a digital image.
  8. How is the X,Y coordinate system in this digital image similar to mathematical graphs you have used?
    -  Double-click  to view the entire image again.
    -  Based on what you observed, move your cursor to the *origin* of the image (the pixel with the lowest X,Y coordinates).
  9. Where is the origin (row 0, seat 0) of the image?
  10. How could you find out the total number of pixels in this image?
  11. How many pixels are in this image?

## Mona Lisa’s pixel locations

The Mona Lisa image is moderately large and is not displayed at full size by ImageJ. As a result, pixel locations will not change uniformly as you move the cursor over the image.

To display it at full size, select **Edit > Options > Image . . .** and click **Open Images at 100%**. Then reopen **Mona Lisa.tif**.

Make sure you reset this option when you have finished this part of the lesson (click **Open Images at 100%**).

## Image width and height

Remember that in ImageJ, the “row” and “seat” numbers start with 0,0 not 1,1. That means that you have to add 1 to the maximum X and Y coordinates to get the width and height of the image.



## The value of a pixel

Besides the specific address given by X and Y coordinates, each pixel in a digital image has another number associated with it.

-  Use the  tool to zoom in several times until you can see individual pixels.
-  Place your cursor on the lightest pixel in your field of view and read its **Value** in the status bar. Do the same for the darkest pixel you see.

12. What are the highest and lowest pixel values you can find in this image?

## Assigning colors to values

In a stadium picture, each fan is given a card with a specific color. Likewise, in a digital image each pixel value is represented by a specific color. In digital images, a color is assigned to every pixel value using a *lookup table*. A simple lookup table for an image with up to 16 different values is shown at the right.

ImageJ uses 8-bit lookup tables containing  $2^8$ , or 256, different colors. Normally, pixels with a value of 0 are shown as white and pixels with a value of 255 are shown as black. (If that seems backward to you, ImageJ can also be set to assign 0 to black and 255 to white—both ways are “correct.”) Two hundred fifty-four colors or shades of gray are used to show the values between white and black.

13. Zoom in on any pixel in your image. Write down its location and value.

-  Choose **Image > Lookup Tables**, and pick a new lookup table from the available choices. The new lookup table assigns new colors to each pixel value.
-  Move your cursor back to your test pixel from question 13.

14. Has the pixel value changed?

-  Try other lookup tables, and check the value of your test pixel.

15. What happens to the pixel values when you apply a new lookup table to an image?

16. Describe how the lookup table affects the appearance of a digital image.

-  Change the lookup table back to grayscale when you are finished by choosing **File > Revert**.

### A 4-bit lookup table

A 4-bit lookup table has  $2^4$  or 16 different colors or shades of gray.



## Bit depth

The number of possible pixel values in an image is often called the *bit depth* of the image. Bit depth is determined by the number of binary digits, or *bits*, that are used to represent the value of each pixel. ImageJ can work with 8-, 16-, and 32-bit images. The table below shows the number of different values that are possible at each bit depth.

| <b>Bit Depth</b> | <b>Possible Pixel Values</b> |
|------------------|------------------------------|
| <b>8-bit</b>     | $2^8 = 256$                  |
| <b>16-bit</b>    | $2^{16} = 65,536$            |
| <b>32-bit</b>    | $2^{32} = 4,294,967,296$     |

Wow! A pixel in a 32-bit image can represent any one of more than 4 billion possible values! Unfortunately, ImageJ uses lookup tables with only 256 colors. When displaying 16- and 32-bit images, ImageJ divides the range of possible pixel values into 256 groups, called *bins*, and assigns a single color to all of the pixels in each bin. That means that in a 16-bit image, a single color can represent a range of up to 256 different pixel values, and in 32-bit images, each color of the lookup table can represent nearly 16.8 million different values! The trick to working with 16- and 32-bit images is learning how to assign the 256 available colors to the range of pixel values you're most interested in. This process is called *windowing*.

 Open the **Galaxy.tif** image. (Do not close **Mona Lisa.tif**)

This is a 16-bit image of the Andromeda Galaxy taken with a digital camera mounted on a telescope on Kitt Peak in Arizona. The image doesn't contain a full 65,000 different pixel values, but it does use far more than 256 different values to record faint details of the galaxy. At first, it doesn't look like much, but looks can be deceiving.

 Choose **Image > Lookup Tables > Fire**.

Our eyes are more sensitive to different colors, so you should see a little more detail in the image using the Fire lookup table.

 Choose **Image > Adjust > Window/Level**.

The **Window/Level (W&L)** panel contains two sliders. One controls the *window width*—the range of pixel values in the image that the lookup table is applied to. Pixel values above this range are displayed as black, and values below it are displayed as white. The other slider controls the *Level*—the pixel value where the window (and the lookup table) is centered. These adjustments will make more sense after you experiment with them a bit.

 Adjust the **Window** and **Level** controls in the **W&L** panel until you think the maximum detail is visible in the image.

17. What **Window** and **Level** settings produce the best range of detail in the image?

 Close the **Galaxy.tif** image and the **W&L** window.

## Back to the stadium

Imagine that you want to create the *Mona Lisa* as a stadium picture. To produce the individual cards to give to the fans, you will need to know how many cards of each shade to paint.

 Choose **Analyze > Histogram** to see a histogram of the pixels used to create *Mona Lisa*.

Think of a histogram as a way of organizing your stadium cards. If you sort them by pixel value along a number line from 0 to 255, the resulting piles of cards would resemble a histogram. The most-used colors (values) would have the highest piles while the least-used colors would have smaller piles. The piles show the amount (the number of cards) of each color (value) needed to produce the picture.

18. What is the most frequently used pixel value (color) in *Mona Lisa*?

 Close the **Histogram** window.

## 32-bit floating point

The 32-bit image format used by ImageJ represents values using 32-bit floating point notation. This allows pixels to represent values containing a decimal point. It is especially useful for scientific imaging, because each pixel value can be an actual measurement value, such as **31.625 W/m<sup>2</sup>**. (The units, of course, are not stored with the pixel value.) These "32-bit float" values can represent numbers ranging from about  $1.7 \times 10^{38}$  to  $5.9 \times 10^{-39}$ . The possibilities are nearly endless!

## More practice

If you want to practice working with more 16- and 32-bit images, you will find them in the **16-bit Images** and **32-bit Images** folders.

## Sorting the cards



## Mona a la mode

Another name for the most frequently used value is the **Mode**.

## Highlighting pixels in the image

Sometimes it is useful to identify the pixels in an image whose values are within a certain range. For example, let's pretend for a moment that the pixel values in *Mona Lisa* represent temperature instead of brightness. As part of a diagnostic procedure or research study, you might want to know which parts of the image are between 30°C and 45°C.

If the back of each “card” used to create the image was colored bright red, you could highlight where specific pixel values occur in the image. Imagine flashing this message on the scoreboard while the card section is showing the *Mona Lisa* image:

IF THE NUMBER ON YOUR CARD  
IS BETWEEN 30 AND 45, SHOW  
THE RED SIDE OF YOUR CARD!

You can do something similar in ImageJ. It is a process called *Thresholding*.

- ☞ Choose **Image > Adjust > Threshold** to turn on Thresholding mode.

In Thresholding mode, the pixels whose values are within a range of values are highlighted.

- ☞ Highlight all of the pixels with values between 30 and 45 by adjusting the Threshold range using the two slider controls in the **Threshold** panel.
- ☞ You can also set the upper and lower Threshold limits precisely by clicking the **Set** button and entering exact values. Use this method to set the Threshold range to 49–73.
- ☞ With Thresholding on, create a new histogram to see which pixels are within the Threshold limits.

You can highlight a single pixel value by setting the upper and lower limits of the Threshold to the same value.

- ☞ Set the Threshold to highlight pixels with a value of 227 in the *Mona Lisa* image.

19. Where in the image are most of the pixels with a value of 227 located?

- ☞ Close **Mona Lisa.tif** and the **Threshold** window.

## Careers using digital images

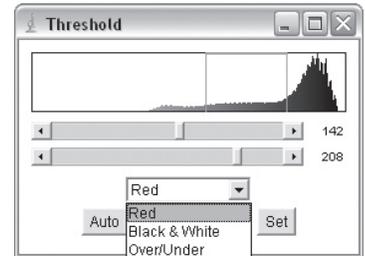
Many careers use digital images. Government and public agencies as well as private businesses use digital images to display, interpret, and archive information. For example, space agencies, weather bureaus, and hospitals make digital images or scan images and documents for storage onto CD-ROMs and other media. Today, image processing is used in a variety of fields ranging from graphic arts to medical technology to city planning. In this section, you will explore a few workplace applications of digital imaging.

- ☞ Open **Medical Image.tif**.

This is a magnetic resonance image (MRI) of a patient's head. In the field of medicine, image processing techniques can allow a doctor to visualize anatomy without surgery. Health-care technicians use a wide variety of specialized equipment for collecting images like this.

## Thresholding

The **Threshold** dialog box lets you choose from three different methods of highlighting a range of pixel values.



## MRI = NMR

Magnetic resonance imaging is sometimes called nuclear magnetic resonance imaging (NMR) because it measures the response of atomic nuclei to strong magnetic fields.

Essentially, MRI maps the locations of different kinds of atoms along a plane or slice of an object, usually some part of a person's body.

Since an MRI is in a digital format, technicians can easily isolate and select specific structures and types of tissue for further analysis. In this image, the dark areas behind the eyes and nose are the sinus cavities. A doctor may want to study these to identify or diagnose breathing disorders.

- ☞ Turn on Thresholding, and adjust the range to highlight the sinuses.
- ☞ Close **Medical Image.tif** and the **Threshold** window.

When an image is in a digital format, technicians can easily isolate and enhance particular portions of the image, whether it's the image of a heart or the surface of another planet.

- ☞ Open **Mercury Surface.tif**.

In 1974-75, the Mariner 10 spacecraft made three passes by the planet Mercury. This image of Mercury's surface is one of the photos taken by Mariner 10. Interference from radio waves and the sun produced static, or *noise*, that gives the image a salt-and-pepper appearance. Noise like this can be removed by processing the image with a digital filter that identifies and replaces the noisy pixels with new, more realistic values. Planetary geologists and astronomers frequently use such filtering techniques to enable them to more clearly see features they might not otherwise notice or be able to detect.

- ☞ Use the Rectangular selection tool  to select part of the image.
- ☞ Choose **Process > Noise > Despeckle** to process the image.

20. What happened to the part of the image inside the area you selected?

- ☞ Close **Mercury Surface.tif**.
- ☞ Open **Math Image.tif**.

Any grid of numbers can be displayed as a digital image. This image was created using a spreadsheet program and shows the equations  $xy = 1$  and  $xy = -1$ . Some mathematical functions show intricate and attractive patterns when displayed as digital images. Artists, scientists, and engineers create interesting and beautiful images using mathematical functions to generate pixel values. The colors in the image depend on the lookup table used.

- ☞ Apply various lookup tables to the image, and observe how its appearance changes.
- ☞ Close **Math Image.tif**.
- ☞ Open **Painting.tif**.

This image is a drawing created by artist Patti Parsons. She selectively changed pixel values from white to a new color using the selection tools as drawing tools. Patti uses the computer as a sketchbook to try out different color combinations before painting her works on canvas. Graphic artists rely heavily on digital imagery to create print and electronic art, advertisements, and video special effects.

- ☞ Close **Painting.tif**.

## ***Sinuses?***

The sinuses are the large, air-filled cavities between the forehead, eyes, nose, and the brain. The air outside the patient is black, so black areas inside the head are likely filled with air.

## ***Filtering noise, Part II***

Another way to filter noise is to choose **Process > Filters > Median**. Try this method on another part of the Mercury image, and compare the results to the first method you used. Experiment with the Median filter's radius setting to find the radius that gives the best results.

## ***On your own***

- Look at a newspaper photo with a magnifying glass. Describe how the picture is similar to and different from a digital image.
- Design and create your own stadium picture. Use a piece of graph paper to create your design.
- Visit someone in a career that uses digital images. Describe how they use digital images in their job.





**Data  
Sheet**

# Pixelated Pictures

1. What do you see?
2. What do you notice about the status bar? (Be specific!)
3. Describe what happens to the image when you move each of the four sliders in the **B&C** Window.
  - a. Minimum
  - b. Maximum
  - c. Brightness
  - d. Contrast
4. How would the stadium picture look if the fans randomly traded cards with each other?
5. Which number in the status bar changes one unit for every one pixel you move in the horizontal direction?
6. Which item in the status bar shows a pixel's vertical location?
7. Describe how seat and row numbers in a stadium compare to the coordinate system used to locate specific pixels in a digital image.
8. How is the X,Y coordinate system in this digital image similar to mathematical graphs you have used?
9. Where is the origin (row 0, seat 0) of the digital image?



10. How could you find out the total number of pixels in this image?
  
11. How many pixels are in this image?
  
12. What are the highest and lowest pixel values you can find in this image?
  - a. highest = \_\_\_\_\_
  - b. lowest = \_\_\_\_\_
13. Zoom in on any pixel in your image. Write down its location and value.
  - a. location: X = \_\_\_\_\_, Y = \_\_\_\_\_
  - b. value = \_\_\_\_\_
14. Has the pixel value changed?
  
15. What happens to the pixel values when you apply a new lookup table to an image?
  
16. Describe how the lookup table affects the appearance of a digital image.
  
17. What **Window** and **Level** settings produce the best range of detail in the image?
  - a. Window = \_\_\_\_\_
  - b. Level = \_\_\_\_\_
18. What is the most frequently used pixel value (color) in Mona Lisa?
  
19. Where in the image are most of the pixels with a value of 227 located?
  
20. What happened to the part of the image inside the area you selected?

