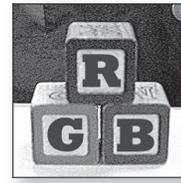


Color by Number

Working with color images



Lesson

Reproducing color

Although digital imaging is not new, recent increases in image quality and decreased prices are converting more amateur and professional photographers from film-based to digital technology. They are finding that digital images are easier and more economical to store, transmit, reproduce, and manipulate than the film-based counterparts.

- Launch ImageJ, locate the **08 Color By Number** folder, and open **Balloon GS.tif**.

This image of a hot air balloon is an *8-bit grayscale* image. (Note the “8-bit” image type shown in the image window status bar, below the image window title bar.) This means that each pixel in the image is described by a number between 0 and 255, which represents the brightness measurement at that location in the scene.

- Move your cursor around on the image and watch the **value** displayed in the ImageJ status bar as you examine light and dark areas of the image.

- Does the pixel value in ImageJ represent “how much light” (black = 0 and white = 255) or “how much black” (white = 0 and black = 255)?

- Open the **Balloon RGB.tif** image.

According to the image window status bar, the image type is now **RGB**, which stands for Red, Green, and Blue. If you look very closely at your color computer screen (with a magnifying glass or hand lens), you will see that the image is made of countless tiny red, green, and blue dots or bars. By mixing different amounts of these three colors of light, your computer can create nearly any color of the rainbow.

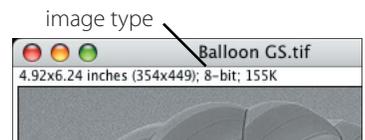
- Move your cursor around this image and watch the changing pixel values in the ImageJ status bar.

Each pixel is now represented by three values instead of one. The RGB values are a kind of recipe, showing the amounts of red, green, and blue light that are mixed to produce the color of each pixel.

- Complete the following table by moving your cursor to any pixel in the image of the color shown, then write down that pixel’s red, green, and blue values.

Go to a pixel of this color	Record its RGB values		
	Red	Green	Blue
Red			
Green			
Blue			

Understanding how different colors are formed is called *color theory*. A tool that is often used to help understand color theory is a *color wheel*.



ImageJ Status Bar

 Close the balloon images, and open the **Color Wheel.tif** image.

The three large circles represent the three main, or *primary*, colors: red, green, and blue.

3. Predict what the “recipe” (R, G, and B values) for each of the primary colors will be:
 - a. Red = ____, ____, ____
 - b. Green = ____, ____, ____
 - c. Blue = ____, ____, ____

 Check your predictions by moving your cursor to the red, green, and blue parts of the color wheel and examining the RGB values in the ImageJ status bar.

The areas where two primary colors overlap, or “mix,” are called the *secondary* colors. The table below shows the names of the three secondary colors and the primary colors that mix to form them.

4. Based on the RGB recipes for the primary colors, complete the table by predicting the recipe for each of the secondary colors.

Mix these Primary Colors	To get this Secondary Color	RGB “recipe” of Secondary Color		
		Red	Green	Blue
Green + Blue	Cyan			
Blue + Red	Magenta			
Red + Green	Yellow			

 Check your predictions by moving your cursor to the cyan, magenta, and yellow parts of the color wheel and examining the RGB values in the ImageJ status bar.

In the center of the color wheel, all three primary colors mix together.

5. What “color” do you get when you mix the maximum amount (255 units) of Red, Green, and Blue light?
6. What “color” would you get by mixing the minimum amount (0 units) of Red, Green, and Blue light?

Color separations

In the printing industry, color pictures are created the same way as on a computer screen—by printing patterns of small dots using three colors of ink. Printers must first separate color pictures into three separate images, which are used to make three printing plates, one for each color of ink.

 Choose **Image > Color > RGB Split**.

 Choose **Window > Tile**.

The color wheel image has been split into three separate images or *channels*. Each of these channels is a grayscale image with pixel values ranging from 0 to 255. The title bar of each image contains the original image name followed by the color channel, in parentheses. [For example, **Color Wheel.tif (red)**.]

 Examine the pixel values of the three color channel images.

More about color printing

Reproducing color using ink on paper is a little different than making color pictures with glowing primary color dots on a television or computer screen. If you look closely at a color picture in a magazine, you will see patterns of tiny dots of cyan, magenta, and yellow ink.

Mixing these three colors produces muddy-looking shadows, so printers add a layer of black ink dots to give the images more “snap.” This four-color printing process is called CMYK. (Cyan, Magenta, Yellow, and Black. The “K” is used because “B” stands for the primary color Blue.)

The pixels in the three channels of the color wheel image are all either minimum (0) or maximum brightness (255). Next, you will explore what happens to the color when the pixel values of each channel are something other than 0 or 255.

-  To fill one or more of the circles of the color wheel channels with a different brightness value:
 - Double-click the Color Picker tool  to choose a new brightness level (shade of gray) from the grayscale on the left side of the color picker window. (Remember the value you choose.) Close the **Color Picker** window.
 - Use the Wand (tracing) tool  to click inside the circle you want to “re-color.”
 - Choose **Edit > Fill**, or press **Ctrl-F** (the **F** key on a Mac) to fill the selected area with the new brightness value.



7. You have just changed the “recipe” for the color in the center of the color wheel. What are the “new” RGB values for this color?

Red = _____ Green = _____ Blue = _____

8. Predict the new color that this new RGB recipe will create. (Describe it in your own words.)

To see what your new color looks like, you will combine the three separate color channels back into a single, composite RGB image.

-  Choose **Image > Color > RGB Merge...**, and click **OK**.

9. Calculate the number of different colors that you can produce using 8 bits (0 to 255) for each of the three color channels. Since there are 256 possible values for each of three colors, the total number of possible colors is:

$256 \times 256 \times 256 =$ _____ colors!

-  Close the **Color Wheel** image(s), and open the three images in the **Blocks** folder, in order (red first, then green, then blue).

-  Choose **Image > Stacks > Convert Images to Stack**.

You have seen how to create a *color composite* image by merging three separate grayscale images. You can also create a color composite image from a three-slice stack, where the slices are in Red-Green-Blue order. Before you create the color composite from these images, you will try to predict the color of each block.

-  Using the slider control at the bottom of the stack window, flip through the stack. Use the brightness of the blocks in each channel to predict the color of each block.

10. Predict the color of:

- a. the “T” block.
- b. the “C” block.
- c. the “I” block.

-  Choose **Image > Color > Convert Stack to RGB** to convert the stack to a color composite image, and check your predictions.

-  Close the color blocks stack and stack (RGB) images.

RGB merge options

The three color channel images should already be assigned to the correct color. If you want to keep copies of the original color channels open when you create the color composite, check the **Keep source images** option.

🖥️ Open the **Rainbow Bridge Stack.tif** image.

This image is another RGB stack. Before you convert it to a color RGB image, you will practice predicting colors from the separate channels one more time.

🖥️ Using the slider control at the bottom of the stack window, flip through the stack.

11. On the grayscale version of the image below, circle and label three areas—one that should appear red, one that should be green, and another that should look blue in the color composite version.



🖥️ Choose **Image > Color > Convert Stack to RGB** to create an RGB color image, and use it to check your predictions.

Indexed color

Not all color images are created equally. The RGB images you have been looking at so far store the picture by saving the RGB recipe consisting of three 8-bit numbers for each and every pixel in the image. While this reproduces colors very accurately, you pay the price for storing so much information. RGB color image files are three times as large as a grayscale image of the same scene.

One solution to this color image file size dilemma is to reduce the number of possible colors in the image. ImageJ gives you the option to create and save color images with up to 256 colors (including black and white), creating a color image that's the same size as the grayscale version. The colors are saved in a color lookup table, and the image is stored as pixel values from 0 to 255 that are *indexed* to the location of the appropriate color in the lookup table. This color image mode is called *indexed color*, or *8-bit color*. Next, you will create an 8-bit color version of the **Rainbow Bridge** image.

🖥️ Choose **Image > Duplicate...** and rename the copy of the image **Rainbow Bridge Indexed Color**.



- ☞ Choose **Image > Type > 8-bit Color**, set the number of colors to 256, and click **OK**. Note the *8-bit Color* image type in the image window's status bar.

Arrange the two windows side by side. The 8-bit color image does not look too bad, but take a closer look.

- ☞ Use the Magnifying Glass tool  to examine both images more closely. (On a Mac, you can use the + and - keys to magnify or reduce the image.)

12. Compare the quality of the RGB color and the 8-bit color version of the **Rainbow Bridge** image.

There are other differences between the two color image types that aren't so obvious. For example, let's say you decided that the images are too dark and you want to lighten them a little. (You will need to repeat the following steps for both images. Click on an image window to work with that image.)

- ☞ Double-click  to zoom back out to see the entire image.
- ☞ Starting with the RGB color version, choose **Image > Adjust > Brightness/Contrast**. Adjust the **Minimum**, **Maximum**, **Brightness**, and **Contrast** sliders until you are happy with the image, then click the **Apply** button.
- ☞ Repeat the above process with the 8-bit color image.

13. Describe what happens.

Changing the brightness and contrast of an RGB color image changes the color recipe of the pixel values, but does not drastically alter the appearance of the image. In other words, a red pixel is still a red pixel. However, adjusting the brightness and contrast of an 8-bit color image re-indexes each pixel to a completely different color on the lookup table.

14. Describe at least two advantages and two disadvantages of RGB color and 8-bit color images.

- ☞ Close all open image windows.

Color for science

Most cameras used for scientific purposes record only the brightness information of the scene they are aimed at. To create color images, grayscale (brightness) pictures are taken through colored filters. These images are then combined into a color composite by assigning each image to the appropriate color channel. To create a *true-color* picture, images are taken through red, green, and blue filters, which are then assigned to the red, green, and blue channels, respectively. When images taken through a filter are assigned to a color channel that does not match the filter, the result is a false-color image. While these images may look strange to us, they can be very useful in helping to understand the information the images contain.

True and false color in ImageJ

You may have noticed that ImageJ's **RGB Merge** dialog box allows you to assign any image to any color channel. First, you will "color inside the lines" and create a true-color version of the image.

- ☞ Open the **Landsat** folder, and open all seven images in the **Santa Cruz Valley, AZ** folder.

Lots o' colors!

Scientific cameras may contain two, three, or more filters. Some imaging systems actually record in hundreds or even thousands of different wavelengths!

Landsat Bands

Band 1 (blue)	0.45-0.52 μm
Band 2 (green)	0.52-0.60 μm
Band 3 (red)	0.63-0.74 μm
Band 4 (near IR)	0.76-0.90 μm
Band 5 (mid IR)	1.55-1.75 μm
Band 6 (thermal IR)	10.4-12.5 μm
Band 7 (mid IR)	2.08-2.35 μm



- Choose **Image > Color > RGB Merge...**, and use the popup menus to assign the **Santa Cruz Valley TM 3.tif** to the red channel, **Santa Cruz Valley TM 2.tif** to the green channel, and **Santa Cruz Valley TM 1.tif** to the blue channel. Check the **Keep source images** option so that you don't have to re-open the original images again.

Since the filters used by the Landsat camera for bands 3, 2, and 1 really were red, green, and blue, the scene is reproduced approximately as your eyes would see it.

Scientists use a simple shorthand to describe how the bands are assigned to color channels—they write them in RGB order. Thus, true color Landsat images are described as *3,2,1 (RGB)*.

- Close **ONLY** the RGB composite color image window, and leave the seven Landsat band images open.

False color

What if you “break the rules” and assign the bands to the “wrong” channels? You can't break anything, so try it!

- Choose **Image > Color > RGB Merge...**, and use the popup menus to create a 4,3,2 false-color image. (Remember to check the **Keep Source Images** option.)

15. How does vegetation appear in a 4,3,2 false-color image?

- Experiment with creating false-color images with different band assignments. (With 7 bands, there are a total of 210 different ways to assign the bands to color channels!)

You can even assign the same band to two, or all three color channels.

16. Predict what an RGB composite image with the same band assigned to all three channels would look like.

17. Test your prediction, and describe the results.

- When you have tried out all 209 different false-color composites (or are tired of making them), close all seven of the Landsat band images.

Creating 3-D stereo images

The technique of creating color composite images can also be used to produce three-dimensional or “stereo” images. To create the illusion of depth, slightly different images representing two separate viewpoints of an object must be sent to the brain.

- Open the two images in any of the subfolders inside the **Mars Rover 3D** folder.

These images were taken by the twin rovers, *Spirit* and *Opportunity*, that landed on and explored the surface of Mars in 2004.

- Choose **Image > Stacks > Convert Images to Stack**.
- Use the slider control at the bottom of the stack window to flip back and forth between the two views.

18. What appears to happen to the scene of the surface of Mars?

Image registration

Since it takes time to move a different filter in front of the lens, images created through filters are not taken at the exact same time. This means that if the subject or the camera is moving, the images will not be registered. That is, they will not show exactly the same scene.

 Choose **Image > Stacks > Convert Stack to Images**.

When you unstack the images, they are now labeled **001** and **002**, instead of **Left** and **Right**.

One way to create a 3-D effect is to combine the left and right eye views in the same image window, assigning a different color to each view. You then control which view is seen by each eye using colored filters, and your brain is fooled into believing it sees three dimensions (height, width, and depth).

There are two possible ways to assign the views to the red and blue color channels, so you will create two versions of the 3-D image and compare them to see which produces the best results. If you don't assign anything to the green channel the image looks too dark, so you will assign the same view to both the green and blue channels.

 Create the first 3-D scene. Choose **Image > Color > RGB Merge...**, and use the popup menus to assign the **Left** (or **001**) image to the red channel and the **Right** (or **002**) image to both the green and blue channels. Check the **Keep Source Images** box, then click **OK**.

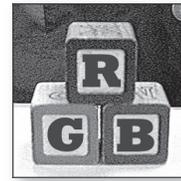
You can reverse the channels assigned to each image to create a second 3-D image for comparison.

 Choose **Image > Color > RGB Merge...** again, and use the popup menus to assign the **Right** (or **002**) image to the red channel and the **Left** (or **001**) image to both the green and blue channels.

 Put on your red and blue glasses, and look at the images. It may take several seconds before your eyes relax enough to allow the images to overlap.

19. Which of the two channel assignments you tried produces the image with the best 3-D effect?
 20. 3-D images are fun to look at, but how do you think they would be useful to a scientist?
-  When you have finished creating 3-D images, close all open images.





Data Sheet

Color by Number

- Does the pixel value in ImageJ represent “how much light” (black = 0 and white = 255) or “how much black” (white = 0 and black = 255)?
- Complete the following table by moving your cursor to any pixel in the image of the color shown, then write down that pixel’s red, green, and blue values.

Go to a pixel of this color	Record its RGB values		
	Red	Green	Blue
Red			
Green			
Blue			

- Predict what the “recipe” (R, G, and B values) for each of the primary colors will be:
 - Red = ____, ____, ____
 - Green = ____, ____, ____
 - Blue = ____, ____, ____
- Based on the RGB recipes for the primary colors, complete the table by predicting the recipe for each of the secondary colors.

Mix these Primary Colors	To get this Secondary Color	RGB “recipe” of Secondary Color		
		Red	Green	Blue
Green + Blue	Cyan			
Blue + Red	Magenta			
Red + Green	Yellow			

- What “color” do you get when you mix the maximum amount (255 units) of Red, Green, and Blue light?
- What “color” would you get by mixing the minimum amount (0 units) of Red, Green, and Blue light?
- You have just changed the “recipe” for the color in the center of the color wheel. What are the “new” RGB values for this color?
 Red = _____ Green = _____ Blue = _____
- Predict the new color that this new RGB recipe will create. (Describe it in your own words.)
- Calculate the number of different colors that you can produce using 8 bits (0 to 255) for each of the three color channels. Since there are 256 possible values for each of three colors, the total number of possible colors is:

256 x 256 x 256 = _____ colors!

10. Predict the color of:
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11. On the grayscale version of the image below, circle and label three areas—one that should appear red, one that should be green, and another that should look blue in the color composite version.



12. Compare the quality of the RGB color and the 8-bit color version of the Rainbow Bridge image.
13. Describe what happens.
14. Describe at least two advantages and two disadvantages of RGB color and 8-bit color images.
15. How does vegetation appear in a 4,3,2 false color image?



16. Predict what an RGB composite image with the same band assigned to all three channels would look like.

17. Test your prediction, and describe the results.

18. What appears to happen to the scene of the surface of Mars?

19. Which of the two channel assignments you tried produces the image with the best 3-D effect?

20. 3-D images are fun to look at, but how do you think they would be useful to a scientist?

