

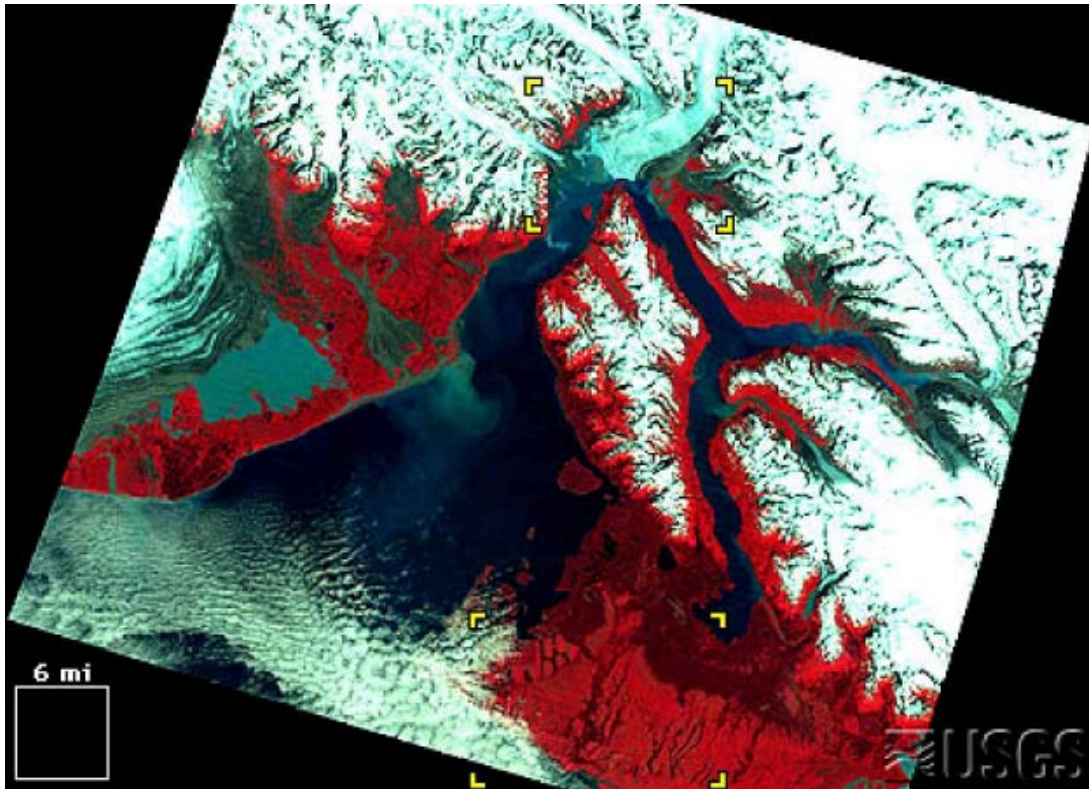
Interpreting Digital Images

July, 2003 Edition

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1. Three-Color Light

Introduction to Three-Color Light

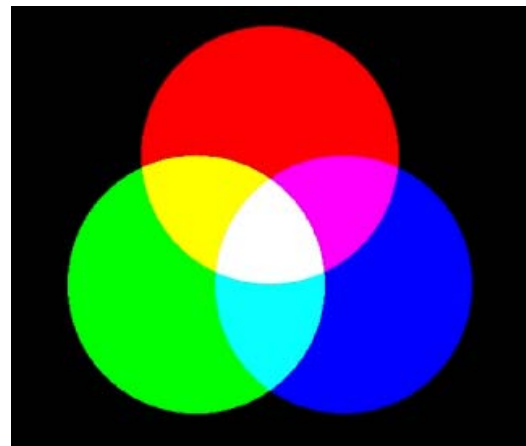
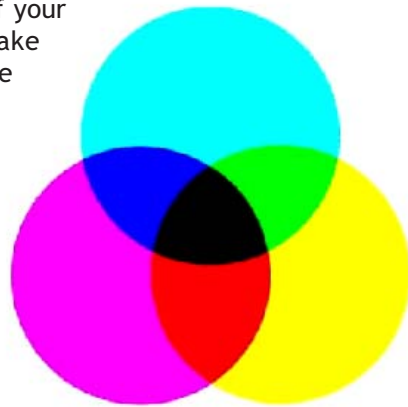
Many of us were taught at a young age that the primary colors are red, yellow, and blue. Our early experiences with color mixing were blending together paints where yellow and blue make green and the three colors stirred together make a color ranging from brown, gray, or black. From this we have two errors in our understanding of color. First, primary colors can be mixed together to create all other colors. Second, that red, yellow, and blue are *the* primary colors.

When we talk about primary colors, we generally think about three colors which can be mixed together to create all of the colors of the rainbow. Have you ever tried to make black out of your red, yellow, and blue? Even more difficult—try to make fluorescent pink, silver, or gold. Primary colors cannot make all other colors, but they can make the most colors from the fewest starting resources.

There are two sets of primary colors: one for pigment (dyes and paints) and another for light. Look at the printing process for the color pages of your local newspaper or a color printer, you will see that the rainbow of colors is created from four colors of ink: cyan, magenta, yellow, and black. Modern printing has found that combinations of cyan, magenta, and yellow (which are very specific shades of blue, red, and yellow) can create the maximum number of colors. When mixed together in equal parts, the three create black (or gray). In printing, the black ink has been added as a fourth color to use less ink. To see how this works, take a microscope or magnifying glass to a color picture in the morning paper or a magazine.

What you will see up close is a series of overlapping dots of various sizes and transparency in those four colors. You may even see a newspaper once in a while where the color layers were not properly lined up so the images appear to be double and the picture colors are not right.

In light, the primary colors are red, green, and blue. Despite what you learned in paint, when you mix yellow and blue light the result is white. Color television and computer monitors use the three primary colors of light to display thousands or millions of different colors. If you now take your magnifying glass to your computer monitor or television, you will see a regular pattern of red, green, and blue lines or dots. Each of these glows at varying intensities, just as a color printer drops varying amounts of ink. In both cases, what you perceive is the mixing of the primary colors and up to 16.8 million different colors on the screen.



The difference here is a matter of reflection and absorption. Pigment and paint are substances that absorb specific wavelengths of light, **subtracting** them from the light energy reflected by the surface. A blue painted surface will absorb all colors of light except the blue, which it reflects back. The reflected light reaches your eyes and you perceive the color blue. A colored light bulb or a computer monitor is a light source which shines or adds light energy of specific wavelengths. A red light bulb shines light directly to your eyes and you perceive the color red.

Computer Monitors

A number of different technologies are used at present for computer displays or monitors. The two most common are the cathode ray tube (CRT) and the liquid crystal display (LCD; common in laptop computers). Here is a brief introduction to the CRT, although this is only the tip of the iceberg.

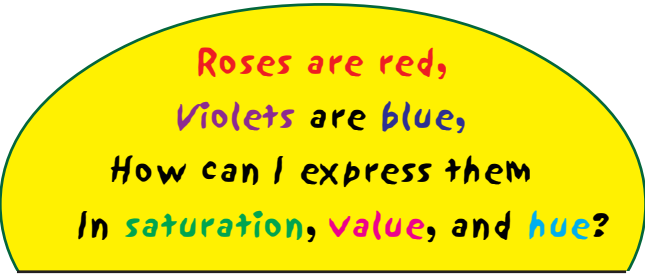
A CRT consists of a negatively charged heated metal filament, called a *cathode*, inside a glass vacuum tube. Coming out from the cathode is a ray of electrons. A positively charged metal piece, called the *anode*, attracts the electron beam and focuses it onto the screen at the front of the glass vacuum tube, which is the front of the monitor. When excited by the beam, a coating of phosphors on the screen glows. A color CRT has three electron beams and the screen is coated with phosphors that glow in three different colors: red, green, and blue (RGB). Each electron beam will excite only the dots or lines on the screen that have been coated for its color (i.e. the beam for red excites the dots coated in a red phosphor).

Naming Colors

People have given many names to the colors they see. When Isaac Newton wrote down the colors he saw in the rainbow, he chose to break them out into

seven names. We still use that list of names today, although you may find it difficult to pick out the color indigo or the color violet somewhere in the room.

There are a number of basic color names that people refer to: red, orange, yellow, green, blue, purple, brown, white, and black. But individual people may not agree on what to call a specific block of color. Is it red, orange-red, salmon, burnt-sienna, or watermelon? Naming or distinguishing between colors is a very subjective process. As you study light and color throughout this course, you may find that what you think is pure red has more blue in it than the computer's pure red. Don't let that confuse you, when it comes to studying color it is not the name of the color that matters most.



Roses are red,
Violets are blue,
How can I express them
In saturation, value, and hue?

In the chart on the next page, guess the combination of red, green, and blue intensity values that would create the color in the left column. Enter your guess in the TriColor program and see what color is created. Write what you would call that color in the last column. If it doesn't match, use the extra lines to guess again.

Tri-Color Creation Chart

Program to use:
TriColor_PC.exe or TriColor_MAC

Guess the color intensity combination to create the following colors:

	Red Intensity	Green Intensity	Blue Intensity	What would you call this color?
Pure Red				
Pure Green				
Pure Blue				
White				
Black				
Yellow				
Violet				
Orange				
Pink				
Your favorite colors:*				
Your least favorite colors:*				

*Write the name of your color in the left column, and then make your guesses.

Put answers on separate paper

Now that you have started to see how the computer creates different colors from the primary colors of light—red, green, and blue—try to translate the colors from the computer’s point of view.

On the next page is the Tri-Color Prediction Chart. You are given a set of intensity values for several “mystery” colors. Using what you learned from the Tri-Color Creation chart, predict what color is produced by these color intensity values. After you have written your guess in the chart, enter the intensities into TriColor and write the color you see in the column on the right. Use the last few lines of the chart to try some colors of your own design. Program to use: **TriColor_PC.exe** or **TriColor_MAC**

Tri-Color Prediction Chart

Red Intensity Value	Green Intensity Value	Blue Intensity Value	What color do you guess this is?	What color do you see with TriColor?
100	100	0		
0	100	100		
100	0	100		
75	75	75		
50	50	50		
25	25	25		
100	50	50		
100	50	0		
100	0	50		
50	100	50		
0	100	50		
0	50	100		
75	50	25		

Put answers on separate paper

Tri-Color Game

Test your understanding of how a computer creates color from intensities of red, green, and blue with a little competition. Play the game against another student or against the computer. Try to match the red, green, and blue intensities of the “secret” color. The software will keep track of the number of guesses each player uses to match the secret color.

Program to use: **Game_TriColor_PC.exe** or **Game_TriColor_MAC**

Here is how you play:

1. **Select the level of difficulty for your game.** There are three levels of difficulty that determine how close the guess color must be to the secret color in order for the colors to ‘match’. On Easy, the guess must match the secret color to within 15% of each of the 3 color intensities; Medium is to within 10%; and Hard is to within 5% of the secret color.
2. **Select your opponent** from the menu button next to ‘Opponent’: “Play a Person” or “Play the Computer.”
3. **Click “Set Secret Color.”** If you are playing a person, Player 1 enters 3 color intensity values in the boxes on the secret color window that pops up. Player 2 should cover his/her eyes or look away while Player 1 enters the numbers. If you are playing the computer, a color is randomly set.
4. **Try to reproduce the color:** make the right box color the same color as the left box color.
5. **Once the color is matched, you can explore** the colors that match for the level selected by clicking on “Explore Matched Colors”, then you can switch roles and Player 2 will set a secret color.
6. **Play as many rounds as time permits.** Your scores appear at the bottom right corner of the screen.

The winner is the player who took the LEAST number of tries to match the colors.

Note: The game can be played with more than 2 players by dividing players into team 1 and team 2.

On the following page, make a chart that summarizes the “formulae” for common colors in terms of intensity values of the three primary colors. Keep it handy—it will help you in interpreting color digital images.

Tri-Color Reference Chart

Use data that you've already collected as well as both software programs (TriColor and Game_TriColor) to fill the color intensity values on this chart.

<i>Color</i>	<i>Red Intensity Value</i>	<i>Green Intensity Value</i>	<i>Blue Intensity Value</i>
Black			
White			
Red			
Yellow			
Green			
Cyan			
Blue			
Magenta			
Orange			
Purple			
Brown			
Pink			
Light Gray			
Medium Gray			
Dark Gray			

Color in Computer Images

Computers use intensities of the colors red, green, and blue to create a myriad of different colors on our monitors. Throughout this activity you have used percentages to create over a million colors—primary color intensities ranged on a scale of 0 to 100 percent. Most digital images use a binary scale with 2^8 levels. Instead of 101 possible intensity values, there are 2^8 , or 256, possible intensity values for each color. These images can display over 16.8 million different colors.

Put answers on separate paper

2: Pictures and Colors

Introduction to Pixels

The term pixel is a truncation of the phrase “picture element” which is exactly what a pixel is. A pixel is the smallest block of color in a digital picture. The term is also used for the smallest block of color on your computer monitor. In fact, to run these activities we recommend that you have the display setting for screen area on your monitor set to at least 1024x768 pixels. What that means is that your monitor has 786,432 blocks of colors arranged in rectangle with 1024 columns and 768 rows.

The resolution of an image refers to the number of pixels used to display an image. A higher resolution image uses more pixels and allows for more detail to be seen in the picture. Scanners and printers will often advertise their resolution in *dots per inch (dpi)*, which is the number of pixels per inch that they are capable of recording or depositing. A document printed at low resolution (fewer dpi) has jagged steps of dots that make up a curve like the letter “O”. From a high resolution printer (more dpi), that same letter looks like a smooth circle.



Images of a rubber duck with large pixels and with very small pixels.



Color Within a Digital Picture

You see color on things around you because light shines into your eye, is received by the cones and rods of your retina, and converted to electrochemical signals that are then processed through your brain. A digital camera detects color because light shines on sensors in your camera which are sensitive to red, green, and blue. The number of sensors in the camera will define the highest resolution possible for that camera.

A traditional film-based camera records an image onto a chemically treated plastic. *Digital* cameras record the red, green, and blue intensities for each pixel into a numerical file - the values of color and position of the pixel are defined with numbers. A number of different file types are used to compress the data so the file takes up a minimal amount of computer memory. To display the image on the computer screen, the computer takes the red intensity value for a particular pixel from the file and shines the red component of the pixel at that amount at that place on the computer screen. It does the same thing for the other two primary colors (green and blue) for every pixel in the image.

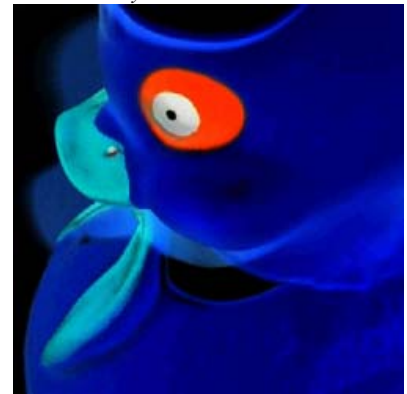
Seeing Only One Color of Light

When we talk about seeing only one color we are not referring to the condition known as color blindness. People who are colorblind have difficulty distinguishing between certain colors, for example red and green, but they are still capable of perceiving light of both colors. What we are talking about is if you could only see the small range of light wavelengths that is called “red”. You would be unable to perceive the spectrum of light including orange, yellow, green, blue, and violet.

In satellite images, each color is data of the image that provides specific information. By turning off all of the light that is not red, we can look solely at the information that red light provides. If we were physically only able to see the range of light that is red, it would appear more like a black and white image than a red and black image. The use of black and white to view such information allows us to make out details and differences in shade and intensity more easily.



Images of rubber duck: above with complete set of red, green, and blue colors, and below with only red and blue colors



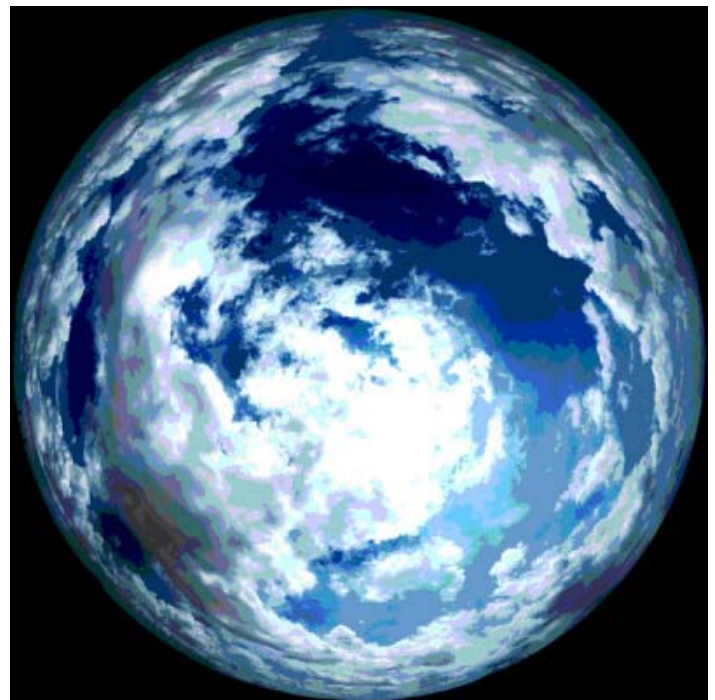
Why is the Sky Blue?

The Sun produces white light. White is the combination of all of the colors of the rainbow. When we view sunlight through a prism, we bend the colors so that they are separated. When sunlight shines through our atmosphere, it is bent and scattered by particles. Our atmosphere, because it is largely made up of nitrogen and oxygen, is most efficient at scattering blue wavelengths of light. If you look

back at your data from Part 1, you will see that if we remove blue from our white light, the color that we are left seeing is yellow. The scattered blue light leaves the sun looking yellow.

But we all know that the sky is not always blue. At sunset and sunrise, the sky includes many more colors from throughout the spectrum. You may have picked up on the use of the word “efficient” above. Other colors of light are scattered by our atmosphere, but not as efficiently as the blue. When the Sun is high in the sky, its light has a shorter distance to travel through the atmosphere and the blue light is scattered. When the sun is low in the sky, the path is much longer and more colors of light are scattered.

While the question “why is the sky blue?” is one of general interest, the reason we are discussing it here is to start thinking about the effect that our atmosphere has on the light that travels through it. If we are going to take an image from space of light that shines from the Sun through the atmosphere and is reflected back up to space, then we must pay attention to what the atmosphere does to that light on its travels.



Pixel Count Chart

The number of pixels in an image tells you the picture's resolution. More pixels means a higher resolution, allowing you to distinguish more details in the picture.

PixelView can increase and decrease the resolution of the image, so that you can see how many pixels are necessary to recognize the picture's subject. When you open an image, it will be at the lowest resolution: $2 \times 2 = 4$ pixels. Increase the number of pixels until you can make out what the picture is. Record the resolution needed to recognize the mystery pictures.

Program to use for the following exercises:
PixelView_PC.exe or **PixelView_MAC**

Mystery Picture #	At what resolution can you recognize the subject of the picture?	What is the subject of this picture?

Question 2.1. How does the resolution of an image affect what you can see? Why would you need more pixels to identify an image?

Question 2.2. When could you identify an image with large pixels? How does resolution affect interpreting satellite images?

Put answers on separate paper

Color of a Pixel

The word *pixel* comes from the phrase "picture element." Each pixel displays the color of a tiny region of the image, and that color is the average color for the entire region. In the following tables you will look at the red, green, and blue intensities of a large pixel and the smaller pixels that define the same region.

- A. Open a mystery picture of your choice in **PixelView**. With the resolution at the minimum, $2 \times 2 = 4$, show the pixel borders for 2×2 . Move the cursor over each pixel and write down the color intensity values shown in the lower, left corner of **PixelView**.
- B. Increase the resolution of the picture to $4 \times 4 = 16$. This time write down the color intensity values for the four pixels that cover the same region as the Upper Left pixel from the 2×2 resolution. In the last row, write the average value of the column.

Question 2.3. Compare the averages from the second chart to the values for the Upper Left pixel from the first chart. How are they alike? What do you expect would be average intensity values for the pixels in this same region if the resolution is 8x8?

2x2 pixel resolution

UL	UR
LL	LR

<i>Pixel</i>	<i>Red Intensity Value</i>	<i>Green Intensity Value</i>	<i>Blue Intensity Value</i>
Upper Left (UL)			
Upper Right (UR)			
Lower Left (LL)			
Lower Right (LR)			

4x4 pixel resolution

1	2	UR
3	4	
LL	LR	

<i>Pixel</i>	<i>Red Intensity Value</i>	<i>Green Intensity Value</i>	<i>Blue Intensity Value</i>
UL – 1			
UL – 2			
UL – 3			
UL – 4			
Average for each:			

Put answers on separate paper

Software to Switch Colors

Have you ever looked really closely at a television or computer monitor? If you haven't, take a magnifying glass or a small droplet of water and look at your computer monitor. Up close, you will see that your monitor screen is actually a series of red, green, and blue dots shining light at different intensities. When your computer displays an image, it takes the red intensity values from the image file and makes the red dots shine by those amounts. The **ColorPicture** program allows you to change which set of colors in the image file shine as which colors on the computer display—in other words change it so the red intensity values from the image file make the green dots or blue dots on the screen shine instead.

Color Circles

Software to use for the following activity: **ColorPicture_PC.exe** or **ColorPicture_MAC**

Open the picture (jpeg file) *ColorCircles.jpg*. Notice that the initial settings of the program have the same colors for Picture Color and Computer Display Color.

Question 2.4. Describe the colors you see in this picture. What color is the circle at the top? On the left? On the right? What other colors do you see in the picture?

Question 2.5. Change the combinations of Picture and Computer Display colors. What happens to the circle at the top? Can you make the picture have only one yellow circle?

Seeing One Color

Open the picture (jpeg file) *MOSBuilding.jpg*. This is a picture of the tower of the Museum of Science, Boston, Massachusetts. Notice all of the colors in this picture—the blue sky, the shades of red and brown in the brick, the white tower, and the green trees. Imagine what things would look like if your eyes could only see one color.

Question 2.6. What would this picture look like if we were blind to ALL colors except red—that is if we could see ONLY red light? How would the image look different in red than with all colors? Move your mouse over the picture to see the red intensity values of pixels throughout the image.

Question 2.7. Change the view of this picture so that you can only see the red intensity values of the image file. To do this, set all three Picture Color choices to 'Red'. What areas look bright in red light? Which areas look dark?

Question 2.8. Now view the picture with only the blue light. How does the picture look different? What details can you see better in the blue light? What is visible in the red light?

Question 2.9. When all of the computer display colors show the red picture color, why does the image appear black and white? If your eyes were only able to see red, do you think that is what the world would look like?

Put answers on separate paper

Colors of the Sky

Open the picture *AllSky.jpg*. This is a picture of the sky using a camera with a fish-eye lens, which allows most of the sky to be seen at once. This picture is courtesy of Chuck Wilcox at the Museum of Science, Boston, Massachusetts.

Now that you have learned so much about color and light, get to know the colors in this picture. Move your mouse around the image and notice the color intensity values throughout the picture. Change which picture colors are seen in the computer display colors.

Question 2.10. Which of the three-color components (red, green, or blue) is dominant in the sky? Which color contributes the least intensity to the sky? See the contribution of a color by setting all of the computer display colors to a single picture color.

Question 2.11. If the sky is blue because of tiny atmospheric particles scattering blue light, why is the Sun yellow? Hint: this is a good time to take a look back at the Tri-Color Reference Chart that you created in Part 1.

Question 2.12. If the Sun appears to be yellow, why do clouds appear so white in the image? If you were riding on a satellite thousands of miles above the Earth, what would be the color of the "sky" (or outer space) and what would be the color of sunlight?

Put answers on separate paper

Open the picture [sunset.jpg](#). This is a picture of the Sun setting over the ocean. Here the sky is yellow and orange while the clouds are dark. Use the **ColorPicture** program to get to know the colors in this picture.

Question 2.13. Why is the color of the sky different at sunset from the middle of the day? What about the clouds and the Sun?

Question 2.14. What color is the dominant color of the water? Where is the blue in this picture?

**Put answers on
separate paper**

3: Exploring & Measuring Light

Introduction

It is now possible with inexpensive technology to measure the intensity of specific wavelengths of light. Light Emitting Diodes (LEDs) were invented in the 1960s. An LED is a device in which electrical energy is converted into light in a very narrow range of wavelengths. They have been refined over the years, becoming smaller, more intense, and emitting light at a greater variety of wavelengths than ever thought possible.

An LED can also operate in reverse: it can convert light energy of a particular wavelength into electric current. The amount of current is proportional to the intensity of light shining on the LED. The wavelength of light needed to produce this effect is approximately the same as the wavelength of light that the LED normally produces when operating in the electricity-to-light mode, but not identical. An LED that emits red light can actually generate electricity from light in orange wavelengths.

LEDs

How does an LED work? Before testing the infrared (IR) and red LEDs, make 3 sketches of each from the top and two views from the side (perpendicular to each other). What are the differences and similarities between the two LEDs?

Put drawings on separate paper

IR LED Top	Side 1	Side 2
Red LED Top	Side 1	Side 2

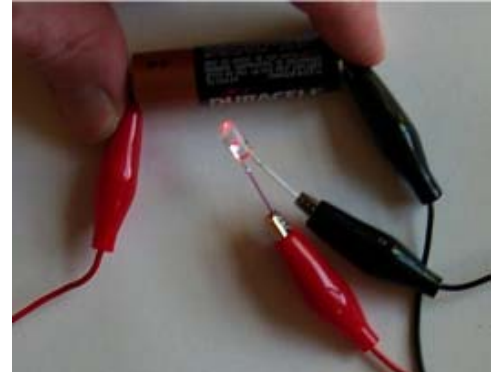
The wavelength of light generated by the LED is controlled by the width of the slot in the metal plate (visible from the side views). Light is emitted from the cup at the top of the LED.

Testing the LEDs

- Start with the red LED.
 - Connect **one** 1.5 volt battery to the LED.
 - Battery's *positive* end connects to the LED's *longest* wire.
 - Battery's *negative* end connects to the LED's *shortest* wire.

NOTE: LEDs may be damaged or destroyed by using more than one battery in series or by connecting them in reverse with the positive charge going to the longest wire of the LED. It is customary to use a red wire to connect to the positive end of a battery and a black wire to the negative end.

When properly connected, red light will be emitted from the LED's top. See photos.



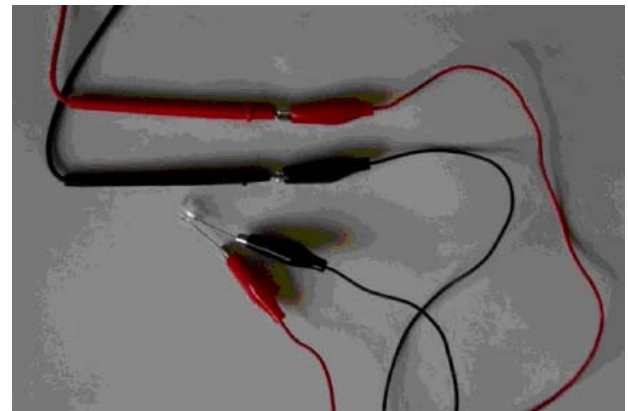
- Now the IR LED.

Repeat the procedure above.

Do you see anything emitted? Does the LED get warm when hooked up? Did the Red LED?

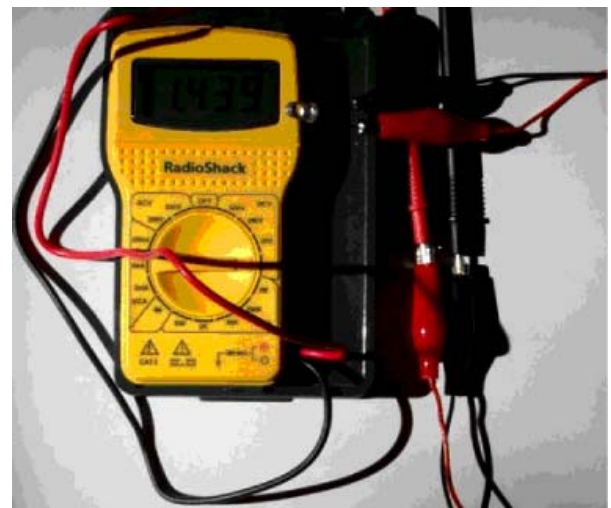
How can we see if it works? Interestingly, a digital camera can detect IR. Use a digital camera with an LCD screen to detect IR. Turn the camera on, point it toward the top of the IR LED after the battery is connected. What do you see?

If you have a TV remote control handy, try pointing it toward the camera, press a button on the remote control. TV remotes work by sending out pulses of IR.



Measuring Light with LEDs

- Connect the red alligator clip from the positive (long) wire of the LED to the red wire of the multimeter. Connect the black clip to other end of the LED and to black wire of the multimeter. Connect the clip in the same way as the photo in order to minimize the chances of wires touching when using the instrument.
- Turn on the multimeter to the voltmeter that measures up to 2 volts.
- Point top of LED toward a bright light and observe how much voltage the LED creates.



Angle of Sensitivity

Using either a light bulb or a red laser, point the top of the LED toward the light source. Slowly rotate the LED to see at what point the voltage on the multimeter drops significantly. Measure this angle for the red LED. If using a red laser, does the IR LED generate any electrical current? Use an incandescent light to test the IR LED.

LED	Angle of Sensitivity
Red	
IR	

Put answers on separate paper

If you have straws that fit over the LEDs, create a sleeve to let only light hit the top of the LED. Test with the LEDs you just used. Does this affect the angle of sensitivity?

Measure Light Sources in the Classroom

Locate several different types of light sources in the room. Regular light bulbs (incandescent), fluorescent light bulbs, halogen bulbs, the source of light for an optical scanner, LEDs on various electronic equipment. Using either tape measures or the tile on the floor (typically 1 foot squares), systematically record the current generated by several of these light sources from various distances away.

Measuring Light Sources in the Classroom

Light Source	Distance	Voltage from Red LED	Voltage from IR LED

Put answers on separate paper

Although these instruments cannot measure the magnitude of red and IR light being emitted from these light sources, are you surprised at how much IR is given off by light bulbs? IR is heat energy and does not contribute the visible light of a light source. In that sense, IR is wasted energy for a visible light source.

Measure Warm and Cold things

How much IR and red does your hand emit? How about a hot pad? Ice?

Use a box, place a warm or cold source in the box and place the LED into the box with the LED still connected to the multimeter outside the box. Make sure the top of the LED is pointing toward the object being measured. You may need to use tape, string, or wire to hold the LED in place. You could also use a dark closet and have a student hold the LED and another record the observation while standing outside the closet.

Warm and Cold Things

Object	Voltage from Red LED	Voltage from IR LED

Although our bodies do emit IR, the wavelengths are in the *far* or *thermal* IR region. The IR being detected with these LEDs is in the *near* IR region, which is generated from very hot light sources. All objects emit light, but cooler objects emit light of longer wavelengths. Hotter bodies emit light of shorter wavelengths. For example, blue stars are hotter than red stars (blue is a shorter wavelength than red).

Put answers on separate paper

Measuring Reflection, Transmission, and Absorption

Although these instruments cannot measure actual light magnitudes, they can be used to measure the *percentage* of reflectance, transmittance, and absorption of light from an object.

- First, determine that the object does not emit light (test in dark room).
- Second, measure the voltage generated by incoming light (use sunlight).
- Third, measure the voltage being reflected off the object. The percent of light reflected is the voltage from reflected light / voltage from incoming light
- Fourth, if you can get behind the object, say it is a leaf or a piece of paper or fabric, measure the voltage of light traveling through the object. The percent of light being transmitted through the object is voltage from transmitted light / voltage from incoming light
- Finally, the light being absorbed from the object is
 $\text{Light absorbed} = 100\% - \% \text{reflected} - \% \text{transmitted}$.

Measuring Reflection of Land Covers

Go outside with your instruments, preferably on a sunny to partly cloudy day.

First, measure the intensity of the sunlight by pointing the LED toward the Sun.

Do not look directly at the Sun while doing this.

Estimate your pointing by either

- (a) watching the voltage and move the LED to find the maximum value, or
- (b) looking at the shadow of the LED on the ground—the smallest shadow of LED will mean it's pointing directly at Sun.

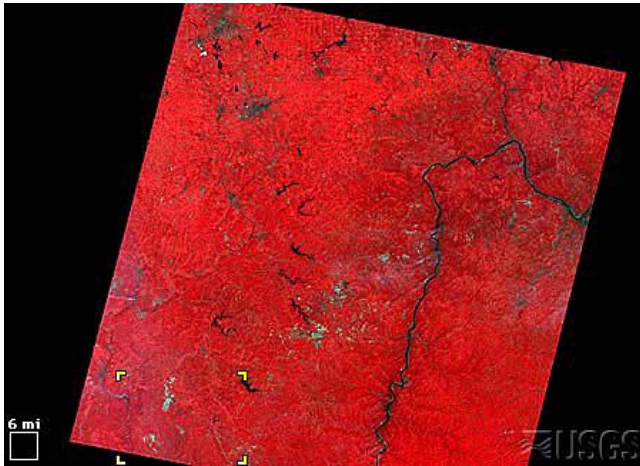
Second, point your LED at the ground and record the voltage and the surface type. If you have a partly cloudy sky, continue to measure the intensity of sun light before each measurement.

Measure a variety of surfaces. Record your observations and measurements.

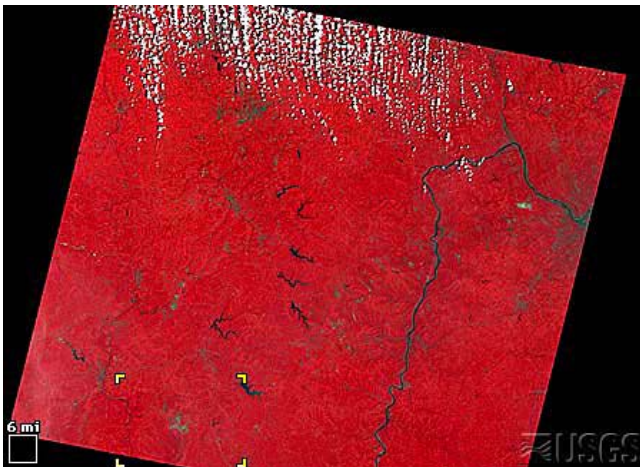
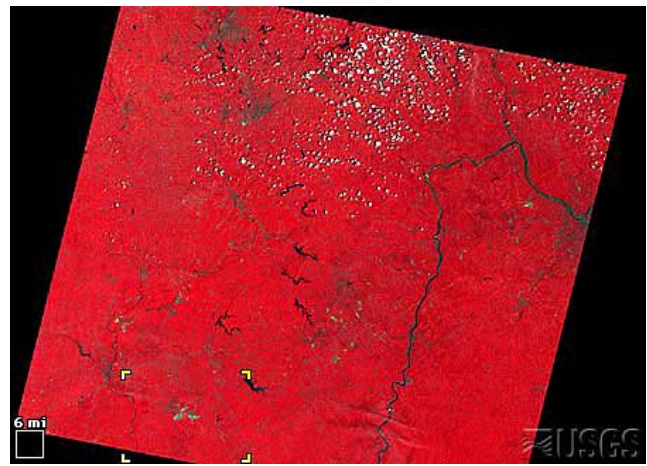
<i>Reflection of Land Covers</i>						
Surface Cover	Voltage of Red LED from sunlight	Voltage of Red LED from reflected light	Reflect Red Light [%]	Voltage of IR LED from sunlight	Voltage of IR LED from reflected light	Reflect IR Light [%]

Put answers on separate paper

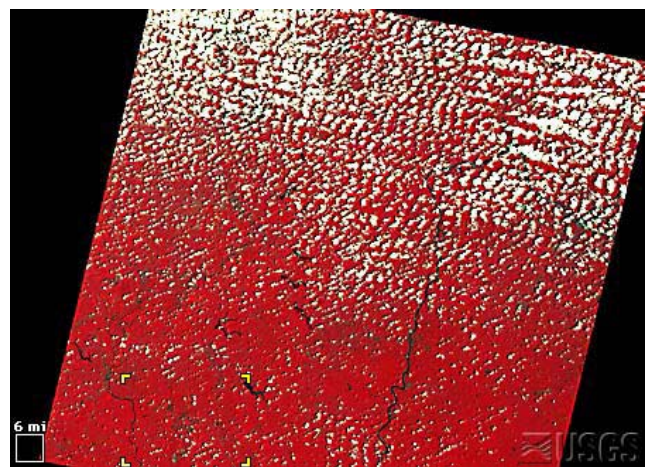
1973



1985



1990



1997

Muskingum mines, Ohio

1973, 1985, 1990, 1997

These images show coal mining in eastern Ohio. In these images vegetation is red, water is black to dark blue, and the mines are bright gray. Federal Law requires the restoration of mined lands to their approximate original contours and that reclaimed land support either the same or better land uses than it supported before mining. To meet this requirement the Muskingum mines, as well as other mines, are replanted to grassland, for agricultural use. The mining company replaces the topsoil, grades the soil, and applies grass seed and mulch.

Satellite images

LM1019032007324690 (Landsat 1 MSS, 3 September 1973)

LM5018032008519990 (Landsat 5 MSS, 18 July 1985)

LM5018032009022990 (Landsat 5 MSS, 17 August 1990)

LT5018032009718410 (Landsat 5 TM, 3 July 1997)

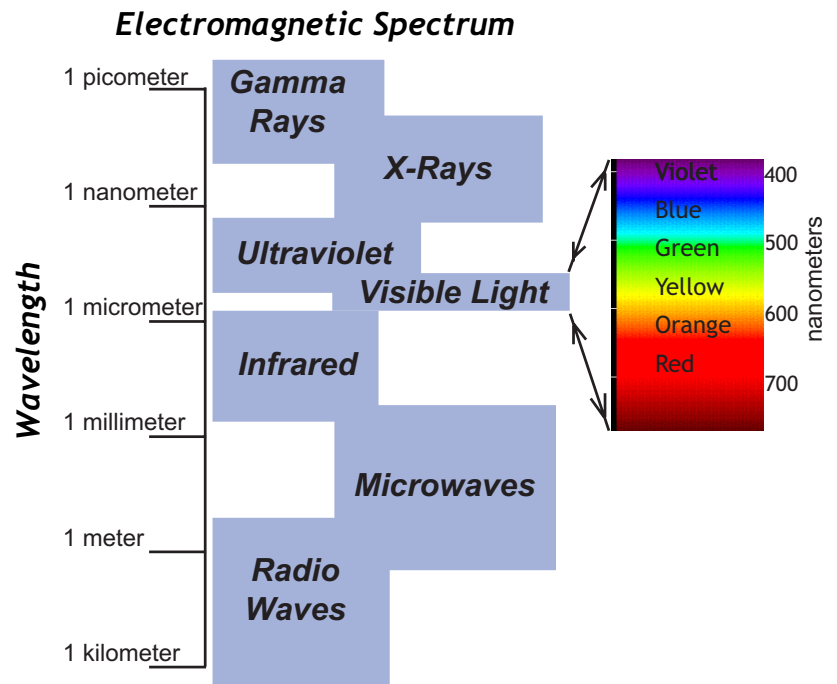
024009220810 (Landsat 4 TM, 26 July 1992)

4: Displaying Invisible Light

Introduction

What would the world look like if you could see light that is currently invisible to us - say infrared, ultraviolet or microwaves? What color would we interpret them as? Remember all electromagnetic energy is colorless—we see color because of functions going on in the eyes and brain. For a refresher on the names and general characteristics of various portions of the electromagnetic spectrum, see the figure on this page.

Some animals can sense energies of light (electromagnetic energies) that are invisible to humans. Bees sense ultraviolet from flowers, crucial to discriminating types of flowers for pollination. Snakes sense infrared, which they rely upon to locate their prey. These powers of seeing energies invisible to the human eye are critical to their survival. Then there is Superman with his X-ray vision, but that's another story..



Man-made satellites have sensors that detect energies that are invisible to our eyes, and we use clever ways to display such energies on computers. With the earliest satellites, only one band of electromagnetic information could be visualized at one time by using gray shades. With the development of color display monitors (originally television screens), three sets of measurements could be displayed at once by placing each set of information in one of the primary colors of the display. This technique requires the viewer to understand how colors are created on a computer display monitor. Colors visible on the computer display are based on the overlap of the three satellite detector intensities, which depend on the physical properties of the system object being observed. With satellite sensor data, it's possible to display images Earth's surface, gas components of the atmosphere, the Earth's magnetic field, etc.

False Color

Start the **FalseColor** program and open the satellite image **MtStHelens_1973.jpg**. This picture was taken of Mt. St. Helens in southwestern Washington by sensors on board Landsat, the first satellite designed to measure and monitor land resources. The sensors could measure a number of narrow bands of electromagnetic radiation, but only three are available for this image: infrared, and visible red and green light. The initial display shows no representation of invisible energy, only the intensities of red and green light detected by the satellite sensors.

Note that the initial settings of the software control buttons are:

Display: Red	set for	Satellite Sensor Energy: Red
Display: Green	set for	Satellite Sensor Energy: Green
Display: Blue	set for	Satellite Sensor Energy: none (off)

Put answer on separate paper

Question 4.1. In this “blue-less” world, what colors would you expect to see? Do you see these all of these colors on this image? What colors are seen and what colors are missing?

Just for a lark, try making the red satellite sensor energy show as display color green and vice versa: green satellite sensor energy show as red display color. What do you make of that? False colors!

Making the invisible visible. Infrared energy is invisible to human eyes but is measured with one of the satellite sensors. We can assign this invisible energy data to a computer display color as a “false color” that we can see. We can assign it to any color: red, blue, green, yellow, cyan, or magenta. Try out different display colors for the infrared measurements.

Question 4.2. How does the intensity of the infrared data compare to that of the visible red and green light?

Characterization of Surface Reflectance.

Use the following pictures to complete the table below. Change the way you display the satellite data to see how much each set of measurements is contributing to the combined intensities within the image.

MtStHelens_1973.jpeg : volcano in Washington State

Rondonia_1975.jpeg : tropical rain forest in Brazil

GreatSaltLakeUtah_1987.jpeg : city, lake, and desert in Utah

OrlandoDisney_1986.jpeg : city and large developed area in Florida

Common way to view Landsat imagery.

Although Landsat measured many wavelengths of the electromagnetic spectrum, three measurements are commonly used when viewing Landsat imagery: infrared, red, and green. A commonly used false color scheme for viewing this type of Landsat data is to make ALL the energies false color:

Display: Red	set for	Satellite Sensor Energy: Infrared
Display: Green	set for	Satellite Sensor Energy: Red
Display: Blue	set for	Satellite Sensor Energy: Green

Task: Using the FalseColor program, rank the intensities of reflected infrared, red, and green light from the list of surfaces.

5 = maximum reflected values, 0 = no reflected light.

Put answers on separate paper

Surface Cover	Infrared	Visible Red	Visible Green	Color in Standard Landsat Imagery
Forest				
Lawns				
Crops				
Water				
Snow				
Cloud				
Rock / Soil				
Buildings				
Paved Roads				

5: Using Analysis Tools

Introduction

It's time to apply the concepts of color, light, and images toward understanding satellite images, one important type of digital image. So far we have described land surface types, but now we'll use analysis tools to examine detailed values and lengths of features in satellite images.

As in any digital image, you can't see anything smaller than a pixel in size. If you look at this computer screen or a photograph with a magnifying glass, you will see tiny blocks of a single color. Your eye doesn't see these blocks as separate, but as a continuous, flowing portion of the image. Even though pixels appear to be small on the computer image, they actually represent a relatively large area of real estate on a satellite image. The latest technology is producing satellite images that can see very fine features on the Earth's surface. As you look at these images, can you see individual trees, rooftops, or roads?

What to Do

Start the **SurfaceType** software application and open 'MtStHelens_1973.jpeg' by clicking the "Select Satellite Image" button. This picture was taken of Mt. St. Helens in southwestern Washington in 1973. The volcano violently erupted in 1983, creating dramatic changes to the vegetation around the volcano.

Visualization Tools

Use the selections within the menu button below "Satellite Image Visualization" to examine the relative intensities of infrared (IR), and Red (R) and Green (G) light reflected from the Earth's surface and displayed in the image on your screen.

- 13 Visualizations

- #1) Standard color composite of Landsat imagery

- IR displayed in the computer display's Red

- Visible Red displayed in the computer's Green

- Visible Green displayed in the computer's Blue

- #2-7) IR, Red, or Green as Color or Gray: A color or gray shade image of *only one* set of satellite measured intensities. Gray shades allows unbiased viewing of the intensities, and color illustrates the actual contribution to the color composite being displayed on the screen.

Use the remaining six visualizations to quickly see which surface features reflect greater amounts of IR, Red, or Green light.

- #8-10) IR v R, IR v G, or R v G: Display the difference between two sets of measurements (A v B means Intensity A - B).

The color of the *greater* value is displayed, with bright colors showing large differences and dark colors indicating little difference.

IR is displayed as a shade of Gray; Red as a shade of Red; and Green as a shade of Green

Example: using IR v R, if a pixel has 10% IR and 20% Red, the difference is 10% and will be displayed in the computer's Red.

#11-13) Normalized versions of IR v R, IR v G, or R v G

The formula is

$(\text{Intensity A} - \text{Intensity B}) / (\text{Intensity A} + \text{Intensity B})$.

The color of the *greater* value is displayed:

IR is displayed as a shade of Gray

Red as a shade of Red; Green as a shade of Green

This formula tends to minimize difference in illumination of the surface caused by shadows of clouds and slope of the land surface that cause uneven illumination of the surface by the Sun.

Example: using IR v R, if a pixel has 10% IR and 20% Red, the normalized difference is 10% divided by 30% = 0.33. This value is scaled to 33 and will be displayed in the computer's Red. Compare this to 10 displayed earlier.

Analysis Tools

Select tools from the menu button next to “Analysis Tool”.

Pixel Tool:

- Cross hair appears where click on the image
- Move by click and drag or with arrows next to x and y position
 - x increases from left to right
 - y increases from top to bottom
- Intensity of IR, red, and green light of pixel beneath center of cross hair output

Line Tool:

- Yellow line appears when click and drag on the image
 - Blue circle at the end of line where cursor clicked
 - Red circle at the end of line where released mouse click
- Adjust end of line with arrows next to x and y position
 - x increases from left to right
 - y increases from top to bottom
- Length of line in pixels is output in lower left edge of the window.

Question 5.1. What are the maximum and minimum x and y values you can find on the satellite image?

Question 5.2. Using the small white square, which represents one mile along each edge, in the lower left of the image, what is the number of pixels that represents 1 mile? Assuming the edge of one pixel touches the edge of the neighboring pixel, what is the size of one pixel? How many pixels represent 10 miles?

Question 5.3. This image is oriented so that north is up and east is to the right. The east-to-west and north-to-south extents of the satellite image are how many miles? What is the distance from the upper-left corner to the lower-right corner of the image? Hint: you will need to use the Pythagorean Theorem if you are using the pixel analysis tool or you may use the line length in pixels output from the line analysis tool.

Question 5.4. What is the greatest distance across the snow cover observed on Mt. St. Helens in the lower left corner of the satellite image?

Question 5.5. What is the greatest width across the lake observed in the left center of the satellite image? What is the greatest length across the lake?

Question 5.6. Using the line analysis tool, measure the diameter of caldera formed by the eruption. A caldera is the crater formed by a volcanic explosion or by the collapse of a volcanic cone. Find the location (x,y coordinates) of the center of the caldera and compare this to the location of the center of the volcano as seen in 1973. Does this explain the direction where most of the volcanic ash fell?

Combine this measurement with an interesting measurement reported by on the USGS Earthshots web site to estimate how large an area of solid rock was turned into volcanic debris: “Before the eruption, Mount St. Helens towered about a mile above its base, but on 18 May 1980 its top slid away in an avalanche of rock and other debris. When finally measured on 1 July 1980, the mountain’s height had been reduced by 1,313 feet— from 9,677 feet to 8,364 feet.” From Foxworthy and Hill, 1982, p. 11. Lipman, Peter, W., and Mullineaux, Donal, R., (ed.), 1981, The 1980 Eruptions of Mount St. Helens: Washington, U. S. Geological Survey Professional Paper 1250, Washington, D. C. (844 p.), p. 134.

Vegetation Measurements

One way to identify different surface covers has been to compare the intensity of the infrared to the visible light being reflected from the Earth's surface. An early technique was to subtract the visible red from the infrared intensity. Since vegetation reflects more IR than visible light, the difference between IR and red is an indication of vegetation cover—a sort of “Difference Vegetation Index.” This works well for ground without steep slopes, but for steep surfaces, there is a shadow effect: some areas reflect different intensities of light just because of their slope. But the *percent* of light reflected is the same, regardless of the intensity of light, so one way to eliminate the shadow/slope problem is express the Difference Vegetation Index as percent by dividing the difference between IR and red intensities by the total light being reflected. This technique is called *normalization*, and the scheme, which is commonly used to identify the amount of vegetation cover, is called the “Normalized Difference Vegetation Index” or **NDVI**.

You will need to decide what to do when the intensity of infrared and red light are both 0 since the sum of the intensities is zero and cannot be used to divide the difference of intensities. Discuss your ideas in a group.

Using the 1973, 1983, and 1996 images of Mt. St. Helens fill in the following table.

Location		Satellite Sensor Data				Vegetation Indices		
X	Y	Year	IR	Red	Green	IR – Red	$\frac{(IR - Red)}{(IR + Red)}$	Surface Feature
319	180	1973						
		1983						
		1996						
321	167	1973						
		1983						
		1996						
278	257	1973						
		1983						
		1996						
167	77	1973						
		1983						
		1996						
186	89	1973						
		1983						
		1996						
276	206	1973						
		1983						
		1996						

Question 5.7. What are the maximum and minimum values possible for NDVI, provided you cannot divide the sum of the intensities when equal to zero. Based on the colors observed on the Landsat imagery of Mt. St. Helens, an NDVI value near the maximum value corresponds to what type of land surface cover? What about for NDVI values near 0? And what appears to produce NDVI values near the minimum value? Does this technique appear to work for the satellite images of Mt. St. Helens? Does it have problems?

Now that you have studied these three satellite images of Mt. St. Helens, read the accompanying article provided by the United States Geological Survey for a discussion of the observed changes around Mt. St. Helens. The article and additional pictures and maps can be found on the Internet at

<http://edcwww.cr.usgs.gov/earthshots/slow/MtStHelens/MtStHelens>

Read the article on the colors observed on Landsat images. Do your findings agree?

If possible, read the article that is provided on the Internet so the many figures and illustrations are available in color and linked to the text. The article is found at

<http://edcwww.cr.usgs.gov/earthshots/slow/Help-GardenCity/Help-GardenCity>



Western Las Vegas in 1986 (above) and 1992 (below).



<http://edcwww.cr.usgs.gov/earthshots/slow/tableofcontents>

These images show the rapid growth of Las Vegas, Nevada. This is by far the fastest-growing metropolis in the United States. The population has grown in recent decades as follows:

1964: 127,000	1986: 608,000
1972: 273,000	1992: 863,000
	1997: 1,124,000

These are the same kind of standard false-color images that appear throughout Earthshots, simulating color-infrared aerial photographs. Remember “RGB = NRG”: red, green, and blue in the image represent how much near-infrared, red, and green solar energy the ground reflects.

As the city expands you can see a sort of landcover succession through human construction.

- *Pre-construction land appears medium gray-green indicating sparse desert vegetation, reddish soils, and stone.*
- *Construction land appears brighter. Bulldozed soil, bare of vegetation, is very reflective.*
- *A young neighborhood appears medium green (medium green) again, perhaps a bit brighter from all the reflective pavement and roofs. The trees are small, and some developments now conserve water by landscaping with rock and desert plants rather than grass.*
- *An old neighborhood appears dark, brownish red, from the mature trees and more grass.*
- *Golf courses appear bright red because they are the most intense vegetation.*
- *Water appears almost black because at this angle it scatters little light back to the Landsat sensor.*

Satellite images

The 1972, 1986 and 1994 scenes are from the NALC dataset.

LM1042035007225790 (Landsat 1 MSS, 13 September 1972)

LM5039035008625390 (Landsat 5 MSS, 10 September 1986)

LM5039035009225490 (Landsat 5 MSS, 10 September 1992)

6: Satellite Analysis

Question 6.1. How do you think the rain forests of the Earth are being destroyed? Is it by insects? Drought? Large-scale forest fires?

Question 6.2. Do you think the United States lost much of its forests of the 1700s to 1800s in different ways compared to the rain forests?

Now that you see how to analyze vegetation in satellite images, you are ready to use software that has *automated* calculation and graphing tools: the **VegetationAnalysis** program. The analysis tools, which include pixel, line, and area tools, are fashioned after those you already used. Clicking and/or dragging the cursor on any of the images allows the selected tool to become active in an identical fashion in the displayed series of satellite images. So if you see an interesting feature in one satellite image and want to study it, you also get the same type of analysis at the same location for each of the time-related satellite images. There are many useful features in the **VegetationAnalysis** program, and additional information is available in the 'Help' menu.

Getting Started

First, run **VegetationAnalysis** and select *three* satellite images to work from the 'File' menu

Open 'Rondonia_1975.jpeg' file first, followed by 'Rondonia_1986.jpeg' and then 'Rondonia_1992.jpeg'.

Pick the earliest (oldest) picture first, followed by the next oldest, and the most recent image last. You will not be allowed to continue if you pick images that are not of the same area or not in increasing year.

A window will pop up that asks you to enter the numerical value of the map scale value visible in the lower left corner of each satellite image.

In Rondonia_1975.jpeg, you will see the box is 6 mi on a side, so type '6' in the available white box. The program will ask separately for the unit (mi).

If you type an incorrect value, reload the 3 satellite images with the 'Select Satellite Images' button. This calibrates the line and area analysis tools.

Visualize Vegetation

Use the menu button to the right of 'Visualization' to toggle between an RGB picture and a NDVI enhancement.

NDVI	Surface Cover
+1	Vegetation
0	Exposed soil or rock
-1	Water, snow, clouds

Page Setup and Print

To print the images and graphs, first use 'PageSetup' in the File Menu (Mac users). Select 'landscape' printing and set scale to 75%.

Tools for Analyzing Satellite Images

Select one of three tools from the menu button to the right of 'Analysis Tool.'

Point Analysis Tool

- Explore intensities of infrared, red, and green light and the vegetation index, NDVI, at the same pixel for each satellite image.
 - Intensities are scaled from 0 to 100%
 - Move the cross hair in three ways:
 - 1) Click the mouse on an area of interest
 - 2) Click and drag the mouse to an area of interest
 - 3) Use the small up and down arrows along the upper-right edge

Line Analysis

- Click and drag the cursor to draw a line.
 - Move ends of line in similar way as the Point Tool.
- NDVI values for pixels along the line are graphed.
- Automatically calculates number of pixels along the line and length of line
- Average NDVI is calculated and color-coded by the year of each image.
 - Move cursor to each satellite image to see yearly data on the graph.
 - To see all data, move the cursor to the graph window.

Area Analysis

- Click and drag the cursor to draw a rectangle.
 - Move ends of line in similar way as the Point and Line Tools.
- Creates histogram (graph) of NDVI values for all pixels inside the rectangles.
 - Histogram shows the percentage of values within narrow ranges of NDVI values.
 - Data viewed year by year when cursor moved to each satellite image.
 - By changing the range of min/max NDVI values to calculate the percent of NDVI values between the selected range.
- Automatically calculates number of pixels within area and size of the area.

Question 6.3 What is the distance between roads that run west to east on the satellite image.

Question 6.4. Draw a north-south line across these east-west roads and describe how the vegetation changes along the line. What are the average or mean NDVI values along the line for each of the 3 years? Compare you values to those observed in your class.

Put answers on separate paper

Question 6.5. Create a box with corner #1 at $x=363$ and $y=178$ and corner #2 at $x=378$ and $y=190$.

How many square miles does this box cover?

How many pixels are within this box?

What surface features appear in this box for the 1986 and 1992 images?

What is the average of the NDVI values for all pixels within the box for each of the three images?

Question 6.6. Create a box with corner #1 at $x=66$ and $y=14$ and corner #2 at $x=295$ and $y=141$.

How many square miles does this box cover?

How many pixels are within this box?

What is the average of the NDVI values for all pixels within the box for 1975 to 1992?

Change the min NDVI value (white box in upper right corner) to 0.6 and click the 'Run' button. From the graph that results, what is the percent NDVI values within the box that fall within this range of NDVI values (0.6 to 1.0) from 1975 to 1992?

Challenge. Use these satellite images and tools to describe how vegetation is changing in this section of Brazilian rainforest from 1975 to 1992. Examine the many features on the images, such as roads and villages, and explore how vegetation changes within and near these features. Based on these observations, what is your projection for the forest ground cover? In this projection, consider how well the NDVI identifies the type of vegetation covering the ground. Present your findings and your conclusions to the class.

Conclusion

Discuss the observations and conclusions of your classmates.

Is there agreement among views? Are there conflicting opinions and data?

Did your views of deforestation change after working with the satellite data?

What additional data would help complete any questions you still have about deforestation in this area of Brazil?

**Dallas,
Texas
1974**



**Dallas,
Texas
1989**



These images show the Dallas - Fort Worth metropolis, in northeast Texas. This city has grown significantly in recent decades, from 2,378,000 in 1970 to 3,776,000 by 1988. These images show the urban/suburban areas expanding into arable land in the countryside.

Satellite images

[LM1029037007407190](#) (Landsat 1 MSS, 12 March 1974)

[LM5027037008908190](#) (Landsat 5 MSS, 22 March 1989)

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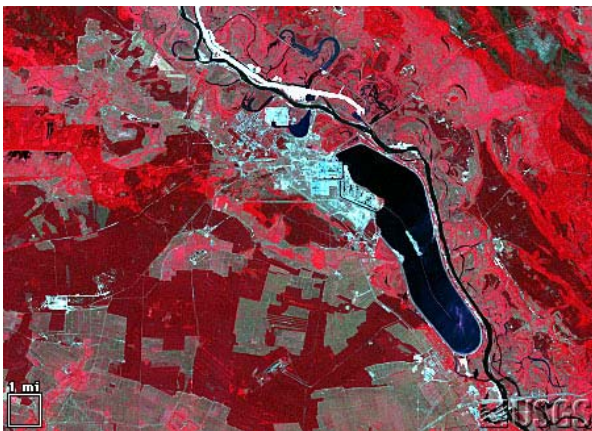
Remote Sensing Specialists, Atmospheric and Environmental Research, Inc., Lexington, MA

Gary Gustafson, Robert D'Entremont, Jennifer Hegarty, Alan Lipton, Mark Leidner, and Rick Rosen.

<http://edcwww.cr.usgs.gov/earthshots/slow/tableofcontents>



Chernobyl, Ukraine
1986 (above), 1992 (below)



A devastating nuclear accident happened at Chernobyl, Ukraine, on 26 April 1986. These images show the area around the nuclear power plant approximately one month after the accident, and six years after the accident. This area is near the common borders of Ukraine, Belarus, and Russia.

The images clearly show farm abandonment. Agriculture appears as a collage of bright red (growing crops) and white (highly reflective bare ground). Many of these areas appear a flat tan-green in 1992, indicating natural vegetation which has taken over the abandoned fields. While the reactor was still on fire, all settlements within 30 km were evacuated, including Pripyat (1986 population 45,000), Chernobyl (1986 population 12,000), and 94 other villages (estimated total population 40,000). As of 1992, this area remained almost completely abandoned.

The radiation also affected wild plants and animals around Chernobyl. Pine forests soon died, cattails grew three heads, and wild animals declined in number. But in the coming years, as the short-lived radionuclides decayed and the longer-lived contaminants settled deep into the soil, the wildlife rebounded. Human abandonment also made habitat available for birds, deer, rodents, wolves, boar and other animals. These populations appear to be increasing despite the extraordinarily high mutation rates caused by contamination in the food chain and by one of the highest background radiation levels in the world.³

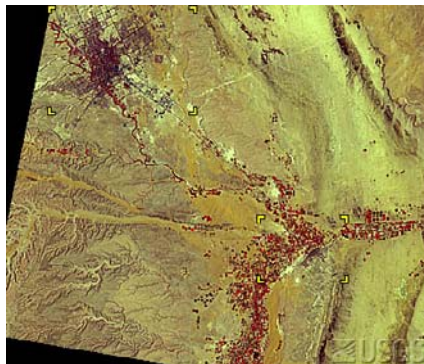
Satellite images

LT5182024008615110 (Landsat 5 TM, 31 May 1986)

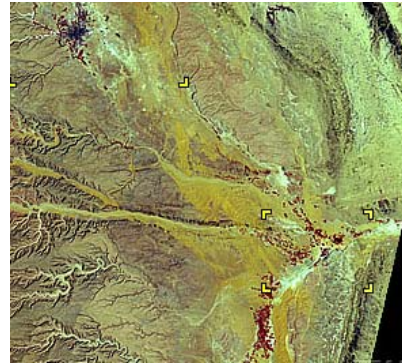
LT4182024009220810 (Landsat 4 TM, 26 July 1992)

	Computer Display Color	Wavelength of Satellite Sensor Measurement
Standard convention of color settings for Landsat imagery	Red	Infrared
	Green	Visible Red
	Blue	Visible Green

Riyadh,
Saudi
Arabia
1990



Riyadh,
Saudi
Arabia
1972



<http://edcwww.cr.usgs.gov/earthshots/slow/tableofcontents>

These images show rapid growth in 's cities and agricultural areas. Riyadh, capital of Saudi Arabia, grew from about a population of half million in 1972 to almost two million in 1990. Southeast of Riyadh, irrigation clearly increased due to the investment of part of Saudi Arabia's oil revenues in an effort to modernize agriculture. The smaller city of Buraydah, northwest of Riyadh, shows the same pattern of urban growth and agricultural development. From 1972 to 1986 the population of Buraydah almost tripled, from 60,000 to about 180,000 people.

Satellite images

[LM1178043007226890](#) (Riyadh, Landsat 1 MSS, 24 September 1972)

[LT4165043009024310](#) (Riyadh, Landsat 4 TM, 31 August 1990)