Image Enhancement
(from Chapter 13) (V6)

Astronomical images often span a wide range of brightness, while important features contained in them span a very narrow range of brightness. Alternatively, interesting features could span a range of brightnesses too great for the limited range of a computer monitor (or printer). Thankfully, there are a number of techniques (usually classified as "point operations") that can be used to bring out details in images that would otherwise not be seen because of their low contrast. These examples will demonstrate what does what. More than just producing "pretty pictures", these techniques can be used to enhance details and show structures that, because of their low contrast, would otherwise be invisible. However, some of these techniques must be used with care because they change the information in the image. After an image is calibrated, the pixel values in the image are directly proportional to the amount of light that fell on the CCD. The operations used here will modify the data in a non-linear manner, rendering them useless for photometric purposes. Some techniques modify the spatial distribution of the data, reducing their astrometric validity. So when using these techniques, be sure to have a clear idea of what your final goal is.

For the following, you will need a calibrated and stacked image. Review Image Analysis to see the procedure.

Two particularly helpful routines are gradient correction and sky background correction. These are important given Mt. Cuba's light pollution issues.

You will need a calibrated science image such as the one(s) you created in Image Analysis (Handout 2). If you did not save your images from that handout, follow the steps to create a calibrated image to work with.

Gradient Correction

Most images can benefit from gradient correction. You may have noticed that most of our images are brighter in the upper right corner. This is artificial, and can certainly benefit from gradient correction.

1. To start, go to Measure→ Pixel Tool. Select "Annulus with preset radii", set the inner radius to 0 and the outer radius to 10. Measure and record the Mean pixel value at the centers of each of the 4 sides of your image.
2. Now go to Edit→Gradient Correction. Click on the "Plane" tab. This is a simple gradient correction that will just interpolate across the plane of the image using values you input. You will input your 4 Mean measurements, but in reverse (the top Mean gets entered in the bottom of the Gradient Correction, and left/right are reversed as well). Click on Preview to make sure the correction is good. You may need to fiddle with the input values bit.

Sky Background Correction

The gradient correction removes a simple brightness gradient from the image, but does not necessarily remove sky brightness irregularities. Here at Mt. Cuba, we have quite a few of those!

1. Click on Edit→ Sky Background fixer. To use the Sky Background Fixer, you must designate at least ten spots that should have the same sky pixel value. For best results, you may need to select several hundred spots.
2. Set the size and spacing of the spots in the Spot Parameters frame. Radius is the radius of the spot measured in pixels. If you plan to place spots automatically, the Pixels per Spot parameter determines their spacing. The Spot Coordinates gives you the current cursor location and the Number of Spots tells you how many spots you have placed.
3. For best results, you should use about 250 spots per megapixel on those parts of the image where the sky background should be the same.
4. DO NOT place spots on galaxies, stars, or nebula.

You can place spots two different ways:
Manual: click on the image wherever you want a spot. To remove a spot, click on an existing spot. It will change to a black circle with an "x" through it. Click on the Refresh button to remove deleted spots.
Automatically: Click on the Auto-Spot button. A regular grid of spots will appear on the image. To remove all spots automatically, click on the Clear button.
When you are satisfied with the number and distribution of spots, click on the Execute button. The image size and number of spots determine how long the computation will take. If you do not like the result, click on the Undo button.

Save your gradient and sky corrected image. Use this image in the following.

Brightness scaling

Any computer software program uses a brightness scaling algorithm when displaying any image. Sometimes the range of background counts and star counts hides some low contrast detail. Experiment with the following techniques.

1. Display your gradient and sky corrected images. To make the results of what we are going to do more visible, set the default image stretch mode to Black/White stretch. You do this be selecting the Default Black/White button on the Image Display Control. Make sure the Black/White Stretch values are set to 0 and 65535. The images will only display the brighter stars, with no hint of the faint objects hidden within. In this mode, a pixel value of 0 is assigned a grey level of 0 (black), and a pixel value of 65535 is assigned the gray value of 255 (white).

2. Right click on your image. The image status box will appear. Record the information (min, max, mean, and standard deviation for the central 95%) in your journal.
3. Make sure your calibrated image is the active window. Leave the Image Status window on the screen. You will be using it later.
4. Click on the Enhance -> Brightness scaling button. Manipulating brightness scaling redistributes the way the computer displays the whole range of available counts from the pixels. The Brightness Scaling Tool has the following controls and displays…
    a. A Transfer function display, which shows the histogram of the image, overlaid with the transfer function curve being applied. This curve shows how the distribution of pixel values will be remapped. The transfer function is simply the rule used to convert old pixel values to new pixel values. You can transfer pixel values using a linear function (the default), or reverse the range, raise the pixel values to a power, take their logarithm, or do just about anything to make the features you want to emphasize stand out more clearly.
    b. An Inputs tab, which contains the Low and High Pixel Values controls, used to set the black and white pixel values in the image. The Low and High Pixel Values controls are automatically updated by clicking the Auto button after adjusting the Black Point and White Point controls. They can also be set manually.
    c. The Outputs tab, which we will not change.
    d. An Options tab, which contains controls that allow you to adjust what information is displayed in this tool. If you do not see the transfer or preview window, turn them on in this tab.
    e. A Preview display, allowing you to see the results of a scaling operation before it is performed on the whole image. This is updated by clicking the Preview button, or by changing any of the parameters on this tool.
5. **Set the Scaling Range.** Initially, the Min PV and Max PV values are determined by the default settings of the Black Point and White Point controls. These are the values that determine the shades of gray used to display the image. Every pixel with a value lower than the minimum is displayed as black, and everything higher than the maximum is displayed as white.
    a. Record the default values for the Black Point, White Point, and the Low and High Pixel values.
    b. Experiment with changing the Low and High pixel values. Start by setting the Black Point to 0.01 and the White Point to 0.98. Record the new Black Point, White Point, and Low and High Pixel values. Compare with the default values. How have they changed? How has the image changed in the Preview window?
6. Continue to experiment with changing the Black Point and the White Point values. When you have an image you like, Record the Black Point, White Point, and the Low and High Pixel values for this image. Click “Apply” to create a new image. The new image will be scaled from using the parameters you determined.

7. Click on the update button in the Status window Info window. Record the information and compare it to your original image.
   a. How have the Min and Max pixel values changed?
   b. How does your scaled image differ from your original?
8. **Gamma Scaling** The above used "Linear Scaling" techniques, a simple way of changing the displayed image that does not emphasize one subset of pixel values over another. Nonlinear scaling techniques can be used to emphasize certain ranges of pixel values.
   a. Click on your original image.
   b. Set the Black Point to 0.01 and the White Point to 0.98.
   c. Click on the "Transfer" tab in the Brightness scaling window.
      i. The default transfer function, or scaling function, is linear.
      ii. Click on "Gamma". The gamma function takes advantage of an interesting property of numbers in the range between 0 and 1: 0 to any power is 0, and 1 to any power is still 1. Gamma scaling helps bring out low level detail by emphasizing mid-range pixel values and muting high pixel values. The basic gamma function is: $f(p)=p^{1/\gamma}$, where p lies in the range from 0 to 1, and $1/\gamma$ is the exponent. How gamma scaling works is explained in detail on page 349 "Chapter 13 Remapping Pixel Values Point". The display in the Transfer Function window shows the histogram of the original image (fainter) and the transfer function that will be applied (blue line).
      iii. Set the Gamma control to 1.0 to start.
      iv. Click "Preview".
         1. What does the transfer function for Gamma=1.0 look like?
         2. What does the transfer function for Gamma < 1 look like?
         3. What does the transfer function for Gamma > l look like?
      v. Experiment with various values for the Gamma control.
         1. Do you have to increase or decrease Gamma to emphasize the fainter background?
         2. What does the transfer function for Gamma=2.3 look like? What pixel values does it emphasize?
         3. What does the transfer function for Gamma=0.9 look like? What pixel values does it emphasize?
         4. Save your images for gamma =2.3 and gamma=0.9.
9. **Gamma Log Scaling** Repeat the above with "Gammalog Scaling". The gammalog function is a mixture of the gamma function and a logarithmic function. The gammalog equation is: $f(p)=(\log p)^{1/\gamma}$. The stellar magnitude system we use is a logarithmic scale because the response of the human eye to light is highly nonlinear. Logarithmic scaling compresses a large linear dynamic range into a smaller nonlinear range. Start with the default of 0.350. Choose one of your original images to begin with. Make sure you reset the Black Point to 0.01 and the White Point to 0.98 to start.
      i. What is the overall effect of logarithmic scaling? (imagine graphs of something that varies between 0 and 10000. Now imaging a

graph of the logarithm of this same distribution. How would the y scales of each graph compare?)

ii. Compare the gammalog function with γ=0.9 to the gamma function with the same value of γ (from step 3).

iii. Use a gammalog value of 0.1 to scale your image. Subtract this gammalog image from the gamma=0.9 image (from step 3). To do this, click on Multi-Image → Image Math. What does the subtracted image look like? Use the cursor to find where the pixel value is zero. If it is zero, it means the two images were the same. Where is the pixel value zero? Where is it not zero? If it is not zero anywhere, try varying gammalog slightly.

iv. Can you determine what the major difference is between Gamma and Gammalog scaling?

10. **Sawtooth and Quantized scaling**. The purpose of these scaling functions are to trace the size and shape of edges in an image. The discontinuities in the transfer function helps enhance regions with the same brightness. Remember to select your original image and set the Black Point to 0.01 and the White Point to 0.98.
    a. What does the sawtooth function look like?
    b. What does the quantize function look like?
    c. Can you think of any situation where you might want to use sawtooth function? A quantize function?
    d. Experiment with the sawtooth function on your first image. Describe what it does to the image.
    e. Experiment with the quantize function. What values do you find that best brings out the faint stars? Describe this quantize function. Which technique is best for bringing out the faint stars?
    f. Save your images for the sawtooth and quantize brightness scaling.

Histogram Shaping

Histograms of astronomical images show the number of pixels (y axis) as a function of pixel value (x-axis). The histograms often have well-defined ranges. At the faint end, the cutoff may be the sky brightness, at the high (bright) end, most of the pixel values are from stars in the image. Histogram shaping is a tool that manipulates the shape of the histogram to calculate the scaling of the image. It is possible for the user to specify the desired characteristics for the new image by specifying the histogram. The computer (via AIP2WIN) will then compute the transfer function necessary to reshape the histogram of the original image into the desired histogram. This is an effective technique with deep-sky images because most such images have the same histogram (rise very rapidly to a peak representing the sky background, and then descend exponentially to zero, with bright spikes corresponding to star images thrown in). The details of histogram specification are given in Chapter 13.6.

To avoid confusion, close all your open images except your original ones.

1. Choose one of your original calibrated science images.

2. Click Measure-> Histogram to create a histogram of the image. The x-axis is counts, and the y axis tells you the number of pixels with that count.
    a. Describe the shape of the histogram of your image.
    b. What count value has the most pixels in each?
    c. What feature in your images do you think is responsible for these pixels?
    d. What is the highest count value you found in each image?
    e. What feature do you think is responsible for these pixels?
    f. Most of the detail in the images is hidden in the narrow peak around 3000-5000.
    g. Saturated stars are represented by peaks with pixel values greater than 60,000.
    h. In the following, we will work on changing the shape of the histogram in various ways to bring out the details in the image.
3. **Exponential Histogram Shaping** Click on "Enhance -> Histogram shaping. The histogram shaping window is very similar to the brightness scaling window.
    a. Click the Transfer tab. There are different kinds of histogram shaping.
    b. The default is **Exponential**. The equation for Exponential Histogram Shaping is: $h(x)=e^{-kx}$. (k is the parameter to be set).
        i. Examine the Preview display and see how it works on the image.
            1. In the Histogram shape window, the red curve shows the histogram of the original image, and the blue curve shows the histogram that will result from the application of this tool.
            2. Bear in mind what the features in the original histogram represent (sky, stars, ect) and notice what the new histogram will emphasize.
            3. Slide the Peak Skew slider around and notice how the pre-calculated histogram shape changes (you are changing the value of k). This is intended to help you visualize how you are shaping the image histogram.
            4. In the next three steps, be sure you are performing the histogram shaping on the original image.
        ii. Slide the peak skew button all the way to the left. Describe the blue curve and what image features you think the new image with emphasize. Click "apply". How does the new image compare to the original?
        iii. Slide the peak skew button to a mid point position. Describe the blue curve and what image features you think the new image will emphasize. Click "apply". How does the new image compare to the original?
        iv. Slide the peak skew button to the right. Describe the blue curve and what features you think the new image will emphasize. Click "apply". How does the new image compare with the original? .
    c. Return to your original image. Display its histogram (click on Measure → Histogram).
        i. Describe the features of this histogram.

ii. Set the Peak Skew slider to a point around 40 (a little box with a number in it will appear as you slide the Peak Skew slider).
iii. Click “Apply” to create a new image.
iv. Now examine the histogram of the new image. Click on the still-open Histogram window and click the Refresh button. This histogram is radically different from that of the original image. It now stretches from 0 to 65535, and is evenly spread across the entire range.
v. What features does the new image emphasize?
vi. Repeat for a Peak Skew value of 160.

4. **Gaussian Histogram Shaping.**
    a. A Gaussian distribution assumes a uniform variation about a central mean. The Gaussian distribution plays an important role in many aspects of statistics, and nature. However, most astronomical images are dominated by sky pixels with an exponential decline in the number of pixels that are brighter than the night sky (review the histogram of your original image).
    b. Repeat step 3 using Gaussian Histogram shaping. Use peak skew values of 40 and 160. Describe the histograms of your new images. How are they different from the original image? How do they differ from the results for exponential histogram shaping?