# Worksheet I

## Introduction

The exercises set out below illustrate some of the major techniques and principles of digital image processing and analysis. They provide an opportunity to apply these to a range of images and to investigate and compare the results obtained. The exercises are based upon a software package *NIH Image*, originally developed for Macintosh computers by staff at the U.S. National Institute of Health. This has been adapted for IBM PC compatibles by Scion Corporation, from whose WWW site the *Scion Image* PC package may currently be obtained free of charge, either for MS Windows 95 or NT 4. Although the package is quite powerful, there are a few areas in which unexpected behaviour is observed.

The approach used in the exercises is one of 'learning by doing'. Demonstrators will be on hand to assist, and will be happy to advise where difficulties arise. For those who wish to find out more about *Scion Image*'s features, a User's Reference is provided on-line - **Start** > **Programs** > **Scion Image** > **Scion Image Manual (.PDF)**. A printed copy will also be available.

## Getting started

- Enter *Scion Image* by using the mouse to give the command:
  **Start > Programs > Scion Image > Scion Image**.
- Note that when it starts up the program creates the following windows on the screen by default:-
  - Menu bar
  - Information window
  - LUT (Look-up Table) menu
  - Tools menu
- Using the mouse, explore each of the options provided in *Scion Image*'s pull-down menus. To do this, left click on the **File** menu; then, with the left button held down, drag the mouse from left to right along the list of menus. Note particularly the **Help > Contents** option, which you can access at any later stage if you need fuller details of any of commands you may use subsequently.
- Give the command: **Special > Make Horizontal Grey Scale**, and observe that a new image **Horizontal Grey Scale** is generated in which there is a steady gradation of displayed grey levels from left to right. The command that generated the grey scale is not in fact a native *Scion Image* command, but is a sequence commands assembled as a *macro*. The *macro* is a powerful technique for encapsulating complex or frequently-used sequences of low-level commands in a convenient form, and you will see other examples in these exercises.
- Move the mouse so the pointer is over the new image; observe the information displayed in the **Info** window. Note how this information is updated as the pointer (displayed as a cross-wire) moves around over the image.

  a) What grey levels correspond to the brightest and darkest parts[1] of the image?
  b) Determine the X-coordinates of those columns of pixels having grey levels lying between 50 and 70 (inclusive);

[1]Note. The convention used in *Scion Image* to represent grey -levels is slightly unusual, but it can be changed using the command: **Options > Preferences** to enable the **Invert Pixel Values** option.

## 1 Grey Level Histogram and Look-up Tables

### 1.1 Using the cursor

- With the image **Horizontal Grey Scale** activated, create a grey-level histogram of the image using: **Analyze** > **Show Histogram** (Ctrl+H). The histogram appears in a dedicated window of its own, and since with this basic command, no axes or labels are provided, it may be a little difficult to interpret.
- Using the mouse, place the cross-wire cursor in the **Histogram** window and slowly traverse it across the body of the histogram; observe the Info window. The labels: **Level** and **Count** indicate the number (count) of pixels at the corresponding level.
- Determine, using the cross-wire cursor (in the **Histogram** window menu) the total number of pixels at each grey level (dimensions of image are 256 x 256 pixels).
- (*Optional*) Experiment with the macro: **Special** > **Plot Histogram using bins**. Try different numbers of bins. Notice that this macro provides axes and labels, but is typically slower to execute.

### 1.2 Using the Intensity Profile

- Generate the intensity profile along a horizontal line in the **Horizontal Grey Scale** image. The command required to achieve this is **Analyze** > **Plot Profile** (Ctrl+K). However**,** *Scion Image* requires you to select first the part of the image from which the profile comes. Click once on **Rectangular Selection Tool** (rectangle at top right in the **Tools** menu), and move the cursor to the **Horizontal Grey Scale** image. Pressing the left mouse button, drag out a rectangle stretching the full width of the image, release the button and give the **Plot Profile** command.

**Tip**: you can use the **Straight Line Selection** tool from the **Tools** menu to define the track for the profile in any arbitrary direction.

- Use the **Edit** > **Invert** command to invert the value of every pixel in the **Horizontal Greyscale Image**. Create a further intensity profile along a horizontal line, and compare it with the previous profile; verify that it takes the form you expect.

### 1.3 Reading an image from disk

- Give the **File** > **Open** command, and select the file: **Clay.tif**. The image will be read in and displayed in a new window.
- Using the histogramming and profiling commands described above, try to determine the grey-scale range in the **Clay.tif** image. What are the maximum and minimum grey level values?
- **Tip**: to view *all* the images held in a folder on disk, navigate to that folder, select a single image with the mouse, check the **Open All** box and click **OK**. (This technique has been found to be unreliable if there are other kinds of file present in the folder).

### 1.4 Using Look-up Tables (LUTs)

As described in lectures, LUTs are used to vary the correspondence between the each pixel value and the brightness (or colour) by which the pixel is represented on the display. In *Scion Image*, both monochrome and pseudo-colour LUTs are available, and different kinds may be accessed via the **Options** menu. The **Map** window is provided to facilitate adjustments to an existing LUT (e.g. for contrast stretch).

- With the **Horizontal Grey Scale** image activated (if necessary, click the mouse within it), bring the cursor over the **Map** window. This contains a small graphical representation of the relationship between pixel values and colour/brightness. Observing the **Horizontal Grey Scale** image, click on the centre of the plot; with the mouse button held down, drag to move the plot. Note the effect on the plot, and on the **B** (brightness) and **C** (contrast) sliders below.
- Experiment with the **B** and **C** sliders by clicking and dragging with the mouse.
- Investigate the effect of clicking on the two tiny plots at the foot of the **Map** window. What purpose might these serve? (Discuss with a demonstrator if you are unsure).
- It is worth noting that the operations just carried out do not affect stored pixel values. Verify this by generating a histogram or line profile (see above).
- Scion Image provides the command: **Process > Apply LUT**. This command applies the mapping defined by the current LUT to each pixel, actually changing the grey level stored. It then restores the LUT to a default law, so that the display will be seen to remain unchanged. However, a histogram or profile will show that the pixel values have truly changed. You can *undo* these changes by using the command: **Edit > Undo**. In certain circumstances (e.g. if you have updated the image more than once) you may find that **Undo** fails to work as expected. In such cases try the command: **File > Revert to Saved**, which effectively re-reads the image from the data stored on disk, or use **File > Open** to obtain a fresh copy.
- Use the **Options > Color Tables** to select one of the available pseudo-colour LUTs. Note that pixel grey levels are now depicted as discrete colour combinations. Investigate other colour tables if time permits. Note that **Apply Look-up Table** is not available under these circumstances..
- Activate the image **Clay.tif**, (by clicking it with the mouse); repeat the operations just described with the monochrome and colour LUTs. Note that by use of colour LUTs, subtle variations in grey level can be represented as much more conspicuous changes in colour. Can you identify any disadvantages or problems arising from the use of pseudo-colour?
- Scion Image tries to maintain separate LUTs for each of the images on the screen, although this becomes increasingly difficult as more and more images are opened or captured. Scion Image provides a feature: **Options > Propagate > Look-up Table**, which applies a chosen look-up table to all other images being displayed.

## 2 More on Point Operations

### 2.1 Reading images from disk

- Open the SEM image **Clay.tif** (**File** > **Open**).
- Create a grey level histogram and use it to determine the grey-scale (the range of grey levels) occupied by the image. Make a note of the maximum (zmax) and minimum (zmin) grey level values.

### 2.2 Contrast stretch operations

- Using only the operations **Process** > **Arithmetic** > **Subtract** and **Process** > **Arithmetic** > **Multiply**, attempt to effect the maximum possible enhancement of contrast in the image **Clay.tif**.

  a) In which order should these operations be applied?

  b) Determine the numerical constants which, when used with these operations, bring about maximum contrast enhancement. Read in a second copy of the image **Clay.tif** (**File** > **Open**), and compare the original with your contrast enhanced version. Keep the second, unprocessed version available for exercise **2.3**.

  c) Write down the general algebraic expression in terms of zmax and zmin, for this grey-scale transformation relating the grey levels (z2) in the new image to those in the old image (z1).

  z2 =

### 2.3 Contrast enhancement using the LUT

- With the greyscale LUT activated, use the LUT manipulation facilities available in the **Map** window in an empirical way to achieve the greatest possible perceived contrast. Use **Process** > **Apply LUT** to apply the transformation to the image itself, and generate a histogram of the result. Compare the result achieved with the original image, and with the result of exercise **2.2**.

### 2.4 Histogram equalisation using the LUT

- Obtain a further copy of the unprocessed image: **Clay.tif**. Use the command: **Process** > **Equalise** to perform grey-level histogram equalisation on the image. Note the appearance of the modified LUT profile. Apply the transformation to the image, generate the grey-level histogram, and compare the results achieved with exercises **2.1** and **2.2**.
- Comment on the three techniques for contrast enhancement in terms of:

  a) ease of use;

  b) subjective appearance of the two images.

### 2.5 Contrast enhancement with noisy images (if time permits)

- Obtain a fresh copy of the image **Clay.tif**. Use the macro command: **Special > Inject Salt & Pepper noise** to simulate a ‘noisy’ image. **Note**: this macro takes some seconds to run. Create a grey-level histogram and determine the new maximum and minimum grey levels present.
- How must the method of section 2.1 be modified in the light of these values, and what are the new numerical constants needed?
- Now repeat the procedures of sections 2.2 and 2.3. Which of these techniques is the most effective in enhancing contrast in the presence of noise?

# Worksheet II

## 3 Neighbourhood (local) operations & spatial filters

*Scion Image* provides a simple method of implementing arbitrary spatial filter kernels up to 63 x 63. Each kernel is specified by means of a text file – for example **LowPass3x3.txt**. *Scion Image* provides a basic text editor to allow kernels to be created or edited directly.

- Use the **File > Open** command to open one or more of the filter kernels provided in the **Filters** folder, and try to reconcile the displayed values

### 3.1 Low-pass and high-pass filters

- Open a copy of image **Froad.tif**. Although this image has little to do with microscopy, it is useful in the present context because it is an easily recognisable scene, and contains a number of 'typical' image features. Explore the effect of the following convolution filter kernels, and observe their effect. You may wish to make a number of copies of **Froad.tif** using **File** > **Duplicate**, since the convolution result overwrites the original image:

  - **LPmild.txt** (*Low-pass - mild*), and **LPsevere.txt** (*Low-pass - severe*)
  - **Hpiso.txt** (*High-pass - isotropic*)
  - **HPUnsharp.txt** (*Unsharp-mask*)
  - **HPLaplacian.txt** (*High-pass: laplacian*)

Note that certain of the hard-coded filters provided in *Scion Image* (e.g. **Process > Smooth**, **Process** > **Sharpen**) resemble those listed above. If time permits, investigate these.

### 3.2 Using low-pass filters on noisy images

- Inject noise into a copy of image **Froad.tif** (**Special** > **Inject Salt & Pepper noise)**. You may wish to make a number of copies using **File > Duplicate** since subsequent operations will overwrite the source image.
- Experiment with the effects of **LPmild.txt** and **LPsevere.txt**, both of which are low-pass filters, on the resultant noisy image. What happens to the noise spikes?
- Creating a new copy of the noisy image if necessary, explore the effects of **HPUnsharp.txt**, and, if time permits, other high-pass filter kernels. Note any effect on the noise spikes.

### 3.3 Median filter with noisy images

- Inject noise into a copy of image **Froad.tif** and try the effects of the 3 x 3 median filter for reducing noise. This is provided via menu command: **Process > Rank Filters …** and select the Median Filter option. Note that this command overwrites the original image.

### 3.4 Setting up your own filter kernels.

- Use the **File > New** command (select **Text Window** in the resulting dialogue box) to create a text window, and set up the two Sobel edge detectors; use **File > Save** to save each result as a text file; choose appropriate names of your own for them. The required values are shown below.

| | | |
|---|---|---|
| -1 | 0 | +1 |
| -2 | 0 | +2 |
| -1 | 0 | +1 |

| | | |
|---|---|---|
| +1 | +2 | +1 |
| 0 | 0 | 0 |
| -1 | -2 | -1 |

- Determine the effect of each filter on a copy of the image **Froad.tif** (without injected noise), and on any others of particular interest to you.

# Worksheet III

## 4 Image Segmentation and Thresholding

### 4.1 Determining characteristic grey levels

**Njaws.tif** is a low-magnification dental X-ray, and is a negative – light areas (low grey levels) correspond to features of high optical density; darker regions (high grey levels) represent features of lower optical density (e.g. soft tissue, voids). Dentine (the interior of the teeth) is represented by intermediate values. This is a convenient image to demonstrate segmentation techniques (as well as image analysis).

- Obtain a copy of the image **Njaws.tif**. Using the cursor and the **Information** window, determine the average grey levels corresponding to:-

  (a) amalgam fillings;
  (b) soft tissue;
  (c) dentine;
  (d) voids

### 4.2 Thresholding the image

In this section we shall explore how practical it is to use simple thresholding to distinguish key features in the original greyscale images

- With the Njaws.tif image active, select the *Thresholding* mode of operation, by giving the command: **Options > Threshold**.
- Bring the cursor into the LUT window – a vertical double-headed arrow should appear. Gradually move the threshold level (the transition between black & white in the LUT window) until the level (shown in the Information window corresponds to the value you determined for amalgam fillings.

Note that in making these adjustments you are not affecting the stored image, but are simply varying a LUT profile (see the Map window).

- Study the image, and adjust the threshold to give the most satisfactory segmentation for amalgam fillings.
- Is the same technique applicable for segmentation of dentine, soft tissue and voids? What problems arise with these features of intermediate grey level?
- Can you devise a suitable set of arithmetic operations (for example, subtract, multiply) to assist in this? If time permits, implement your arithmetic solution, and briefly document your chosen procedure.

### 4.3 A more advanced technique based on density slicing

Segmentation of features at intermediate grey-levels is inconvenient with a single thresholding operation. If an upper and lower threshold may simultaneously be applied, a range of otherwise tricky segmentation operations can be accomplished. In *Scion Image*, this can be achieved by means of the program's *Density Slicing* mode.

- Give the command: **Options > Density Slice**. This invokes a special form of thresholding LUT with independently adjustable upper and lower thresholds. You can alter the upper and lower thresholds in the LUT window (just as with the single threshold) by 'grabbing' the chosen threshold with the double-headed arrow and dragging it up and down by means of the mouse. As you do so, the upper and lower thresholds are displayed in the Information window. In the active image, pixels with grey levels lying between the thresholds are coded red; those outside the range defined by the threshold are displayed unchanged.

- Adjust the upper and lower thresholds experimentally to obtain in turn the most satisfactory thresholding of amalgam filling, dentine, soft tissue and voids; note the thresholds.

Once again, this procedure does not affect the stored image since it is accomplished by means of LUT manipulations. You can convert the thresholded or density-sliced image into a *binary* image (comprising pixels of only two values: 0 and 1, or *not-object* and *object*) by means of the command: **Process > Binary > Make Binary**; or alternatively: **Process > Apply LUT**. If density slicing is active, a dialogue box appears to confirm how you wish the highlighted pixels to be displayed. You should set the options so that highlighted pixels are converted to *foreground* or *object*, and the remaining pixels are converted to *background* (*not-object*).

### 4.4 Edge image

In this section we shall demonstrate the principles of another class of techniques for segmentation based on *edge detection*.

- Obtain a further copy of the image **Njaws.tif**

- Carry out the command: **Process > Find Edges**, and observe how the fringes of the amalgam, voids, etc are highlighted by this process. The **Find Edges** command is based on the Sobel edge detector mentioned in lectures, and is a form of high-pass filter. Try and assess the extent to which edges in every direction are clearly distinguished by the procedure.

- If time permits, experiment with other forms of high-pass filter (available under the **Process** and **Process > Convolve** menus, as well as by means of some of the macros supplied under the **Special** menu.

# 5 Segmentation and Analysis

## 5.1 Segmentation in action

- Obtain a copy of the image: **Astro.tif**
- Use the techniques introduced in sections 4.1 – 4.4 (**Threshold** and/or **Density Slice** modes) to determine the most effective threshold(s) for segmentation. Convert the segmented image into a true binary image.

## 5.2 Analysis of a binary image

A binary image is one in which the pixels can assume only two different values: WHITE and BLACK (or OBJECT and BACKGROUND). Such images can be produced by use of segmentation and related techniques. This section makes use of utilities in *Scion Image* to indicate some of the techniques available for analysing and editing binary images.

- Obtain a copy of the binary image: **Nuts.tif**, which has been derived from a greyscale image of some familiar engineering artefacts. In this case the objects of interest are represented by *bright* pixels (rather than *dark* as conventionally used by *Scion Image* to signify objects).
- Try to find a suitable *Scion Image* procedure to convert this image into binary form, with nuts, bolts etc represented as *dark* pixels. If you are unsure how to proceed, discuss with a demonstrator. You will need this binary image for the next section.

## 5.3 Detecting objects

In this section we shall explore Scion Image's facilities for *analysing* binary images and extracting useful measurement from fields of objects.

- With the appropriate binary form of **Nuts.tif** (see previous section) activated, use the command: **Analyze** > **Analyze Particles** to detect and measure objects in the image. When the dialogue box appears, check that **Minimum Particle Size** and **Maximum Particle Size** are set to 1 and 999999 respectively; and make sure that the following boxes are checked:-

  **Label particles**
  **Reset Measurement Counter**

- The remaining boxes should be *un*checked. OK the box to proceed with analysis.

Each detected object should appear shaded grey, and should be annotated with an ID number, (used to help to reconcile measurements with displayed objects).

- Use the command: **Analyze** > **Show Results** to display the information so far accumulated about each object (Results window).
- How many objects are detected? Does this agree with your visual inspection?

You will notice that in certain cases pairs of objects are in physical contact, and actually appear as single objects after the segmentation process. Touching objects can be a source of difficulty in automated image analysis.

### 5.4 Exploring the table of information

In this section we shall investigate the some of the measurements carried out by *Scion Image* on a binary image.

- Use the scroll bars to scroll up/down or left/right through the data in the Results window; if you prefer, resize the window to give a more convenient display. Study the quantitative information displayed. Is this information consistent with your own visual impressions?

By default, Scion Image determines the area of each object; however, the package can calculate in excess of ten different quantities for each object.

- In order to display this additional information it is first necessary to enable each feature required, using the Measurement Options dialogue box generated in response to the command: **Analyse > Options**. Examine the options available, and try to decide which parameter (or combinations of parameters) might be of greatest help in automatically discriminating between objects of different types within the field.
  **Note**: after changing the Measurement Options it is necessary to repeat the **Analyze > Analyze Particles** command and the **Analyze > Display Results** commands in order to see the effect. When you carry out analysis a second or third time you will need to OK a warning dialogue informing you that earlier measurements will be lost if you proceed.

### 5.5 Calibration and real dimensions

*Scion Image* measures objects by counting pixels. Hence, by default, the results are shown in units of pixels (or square pixels, etc). The size of each pixel depends not only on the physical dimensions of the specimen being measured, but also on the instrumental magnification, capture parameters, and any geometric processing that may have been applied to the image. In order for measured values to be of use, they need to be expressed in real units, e.g. nanometres, inches. This can be accomplished by means of a *calibration* procedure, in which a scaling factor is applied to convert measurements in pixels to meaningful values. *Scion Image* provides the command: **Analyze > Set Scale …** for this purpose. This offers a dialogue box in which a reference measurement (some known feature measurement) and the name of a convenient measurement unit can be entered, plus the corresponding on-screen dimension given in pixels. This last parameter can be determined either by noting the cursor coordinates of the feature extremities and taking the difference, or, more simply, by using the **Straight Line Selection** tool.

To calibrate the measurements, proceed as follows.

- Use the **Magnify Glass** tool to give a conveniently magnified view of the reference feature; left-click the mouse over the feature of interest to increase magnification; press the **Ctrl** key and left-click to revert to original magnification.

- Click on the **Straight Line Selection** tool, and bring the cursor to one edge of the reference; click and hold down the left button while dragging the cursor to the other edge; release the button when the cursor exactly coincides with the opposite edge. A 'marching-ants' line should be seen superimposed on the object.

- Double click on the **Straight Line Selection** tool to bring up the **Set Scale** dialogue box; you should see the measurement you just took (in pixels) displayed in the **Measured Distance** field. Select the preferred units using the **Units** drop-down menu, and enter the reference dimension in the **Known Distance** field. Leave **Aspect Ratio** set to 1.000, and OK the dialogue box.

As a result of this procedure, measurements displayed from this point on will be shown in the selected system of units. Naturally, the accuracy achieved depends on the care with which the measurement is taken; however, it is very important to remember that despite the fact that numbers can now be displayed to many decimal places, the best accuracy obtainable can be no better than about one pixel. If you are unclear about this point, discuss it with a demonstrator.

- In this instance the largest circular washer (object 13, at lower centre) in the **Nuts** image has outside diameter 18.0 mm. Using the procedure just described, determine the **Area** and **Perimeter** in millimetres of objects 1, 2 and 3.

### 5.6 Identifying objects

Image analysis is sometimes regarded as one of the preliminary (or *low level*) stages of *machine vision*, in which a computer inspects a scene, recognising the components of which it is constructed, and makes intelligent deductions, possibly responding to the information gathered by controlling a mechanism (as in industrial robotics or compuer-aided manufacture).

- Consider how you might discriminate between, or *recognise* the following image features, based on the statistical measurement information available from *Scion Image*:

  (i) bolts of different sizes;
  (ii) nuts and bolts;
  (iii) springs and bolts;
  (iv) nuts and lockwashers (corrugated interior).

### 5.7 Touching objects

You have probably noticed that the **Nuts** image contains two touching objects (nuts comprising object 11) which are treated as a single object for the purposes of measurement. Touching objects can cause particular difficulty in automated image analysis. *Scion Image provides a* number of commands in the **Process > Binary** menu which can be useful in these circumstances. Alternatively it is possible to separate objects manually by ‘painting’ or ‘drawing’ with background pixels.

- If time permits, experiment on the thresholded (binary) version of **Nuts.tif** with the following *Scion Image* morphological commands: **Erode**, **Dilate**, **Open** and **Close** (all provided in the **Process > Binary** menu).

## 6.1 A Case Study - Segmentation and Analysis

Section 5 served as an introduction to this section, which involves the use of a variety of commands in *Scion Image*'s menus for processing and analysis. Full instructions are not given here, but the demonstrators will be pleased to help and advise you as you plan how to proceed.

### 6.1 Segmentation and Analysis of an Astronomical Image

- Obtain a copy of the astronomical image **Astro.tif**.
- You may wish to consider using arithmetic operations to enhance contrast, and/or spatial or rank filters to smooth or moderate noise present in the image.
- Produce a binary image of the field. You should investigate which of the various approaches – e.g. thresholding or density slicing – gives the best result. Discuss any practical difficulties that arise.
- Using the utilities in the **Analyze** menu, estimate the following:-

(a) the total number of objects in the field,
(b) the number of stars,
(c) the number of galaxies.

- Try to estimate these numbers by visual inspection of the image, and compare with your computer analysis.

### 6.2 Morphological operations

- Try distinguishing stars from galaxies (in the binary image) using morphological commands from the **Process > Binary** menu.

# Worksheet IV

## 7 Fourier Transforms and Fourier Filtering

### 7.1 Fourier Transforms of simple images

Images **S800.tif**, **S1600.tif**, etc. all consist of simple sine-wave variations. Since Fourier transforms express image or other data in terms of superposed sine or cosine functions, these images are expected to have Fourier transforms that are quite simple in form.

- Read image **S800.tif**.
- Use the **Process > FFT > FFT** command to perform the forward Fourier transform on the image **S800**. Note that the original image is not affected. A second image is generated, showing the *frequency spectrum* of **S800.tif**. To make this more visible you are recommended to invert the contrast image of the spectrum; use **Edit > Invert** to do this
- Note that the spectrum consists of a bright central spot, with two further bright points positioned symmetrically to left and right. The central spot corresponds to 'zero frequency', and relates to the average brightness of the original image.
- Repeat the same operations, this time using image **S1600.tif**. Perform the FFT and generate the spectrum. Compare the two spectra you have generated from **S800** and **S1600**, and try to determine any differences and why they have arisen.
- Repeat the same set of operations, this time using image **S845.tif**, and generate its spectrum. What are now the differences that can be observed? Why have these arisen?

### 7.2 Fourier transform and spectrum of natural images

Natural images typically contain more complicated variations than do the simple sinusoidal images examined in section 7.1. Consequently we expect their transforms and spectra to be more complicated in appearance.

- Obtain a copy of the grey scale image **Njaws.tif**, which is a low-magnification dental X-ray image. (You can repeat the operations described on further images if you wish).
- Use the **Process > FFT > FFT** command to generate a spectrum of this image.

You will probably observe little more than a bright central spot, with perhaps some slight evidence of further structure away from the centre. The reason you cannot see the additional information referred to at the head of this section is because it is much smaller in amplitude compared with the 'zero-frequency' component represented by the central spot. When the spectral data is linearly scaled, as here, for viewing with a grey scale of 256 levels, much of the 'interesting' variations are lost. One way round this is to display the logarithm of the spectral data (or more usefully, log(1+data)).

- Try using the **Process > FFT > Inverse FFT** command to confirm that you are able to regenerate the original spatial image from the transform data, confirming that for most practical purposes, the Fourier Transform is reversible.

Once you have reached this stage, you are ready to explore the vast potential of the Fourier Transform for filtering, reconstruction, and many other applications. Several of these can be carried out effectively with *NIH Image*, and you are welcome to experiment with these.

D M Holburn March 2006