ASSESSMENT 2 OF 3: Digital Image Processing Lab using ImageJ
COURSE 704 Imaging Applications III
PROGRAMME: Bachelor of Applied Science (Medical Imaging Technology)
DUE DATE 09/06/2023/ TIME 5:00 pm

Instructions for submitting your assessment:
• Each person is to submit their own work to the appropriate Assessment folder in the 704 Moodle page • Record your process and answers in the Answer booklet

Learning outcomes being assessed:
This assessment will assess the following learning outcomes and will contribute 20% to your final grade: LO1 Demonstrate image manipulation techniques and processes; LO2 Evaluate the processes of medical image generation, storage, and retrieval, to meet patient needs

Individual assessment
Turnitin scores will be used to assess plagiarism.

Instructions for completing this assessment – please read carefully
• Answer all questions, using academic writing style. • Powerpoints used in class may not be used as a source. • Write your answers in the space provided in the workbook • Remember to copy and paste your images • APA 7th edition referencing and it-text citations to be used

Marking schema
Achievement

Marking criteria
• Accuracy of answers; • Proof of your process

Opening and Entering the Practical Exercises

The exercises in 704 Digital Imaging lab use **Paint, File Explorer**, **Photo** (all MS Windows apps or faculties – MacBook will have similar apps), and **ImageJ**. ImageJ is a free, open source product, which is safe to download. If you will be attending the labs you'll have ImageJ already downloaded to the desktops.

Getting started:

Create a folder for this assessment (either on your laptop, or on an external drive).

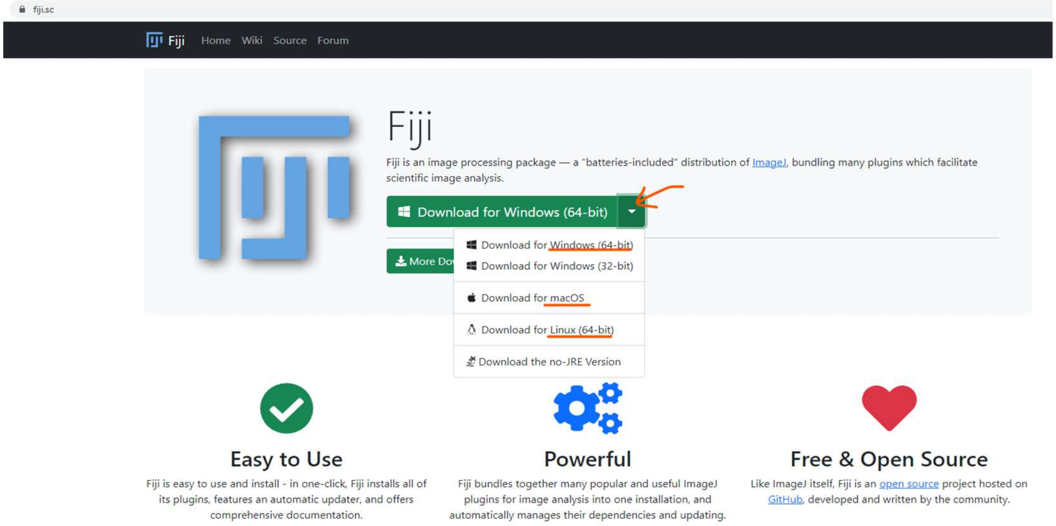
You'll need maximum 1GB free space for the software app, the image folder and your work folder.

If you will be attending the labs, make sure to bring a USB stick or similar to store your work on.

How to download ImageJ on your own device: Ctrl + Click on https://fiji.sc/ to open Fiji in your browser.

The program should automatically scan your system and suggest the most appropriate download. Just click on "Download for…." and choose your system – most probably 64-bit. It is a trusted cite, used by many hospitals across the world for the processing of medical images, so you can rest assured that it is safe.

On my desktop the window that opened up looked like this:



Download the application in the folder you've just created. If you fail to do this, the app will be available in your Downloads folder.

ImageJ will be saved as a zipped file "**fiji-win64**" (Windows users). (In case you were wondering: **F**IJI **I**s **J**ust **I**mageJ – there's no difference.)

Once the download is completed, close your browser and open your ImageJ folder. Right click on the zipped fiji-win64 folder.

Click on "Extract" towards the top of your screen.

After this is completed, close all windows.

Download the images you'll be processing

The file containing the images you need is on the Moodle Digital Image Processing Assessment page – please download this to your ImageJ folder too. The size of the **un**zipped folder is about 12.5MB.

Extract/Unzip this folder too.

Please take note of the following:

All instructions are written for Microsoft Windows, and Windows apps. Apple has similar apps – you'll have to use a different set of steps to get the end product.

Please take screenshots of all the main steps you take get to an answer
(this is similar to showing your working in, for example, a Maths paper.)
If your answer is wrong and I can assess your process,
you might be awarded some marks.

ALWAYS CLOSE (do not save) THE IMAGES YOU HAVE WORKED ON.
Some images are used in more than one question,
and if you have altered and saved it
your subsequent answers will be incorrect.

All sources must be in-text cited and references according to APA 7th edition rules.

You are not allowed to use the lecturing powerpoints as resource.

Use academic writing when answering a question.

You are now ready to start!

Exercise 1

13 Marks

Aim:

To familiarise you with a number of software packages for image display, manipulation and processing, and to become familiar with pixels, Look-up tables (LUT) and measurements.

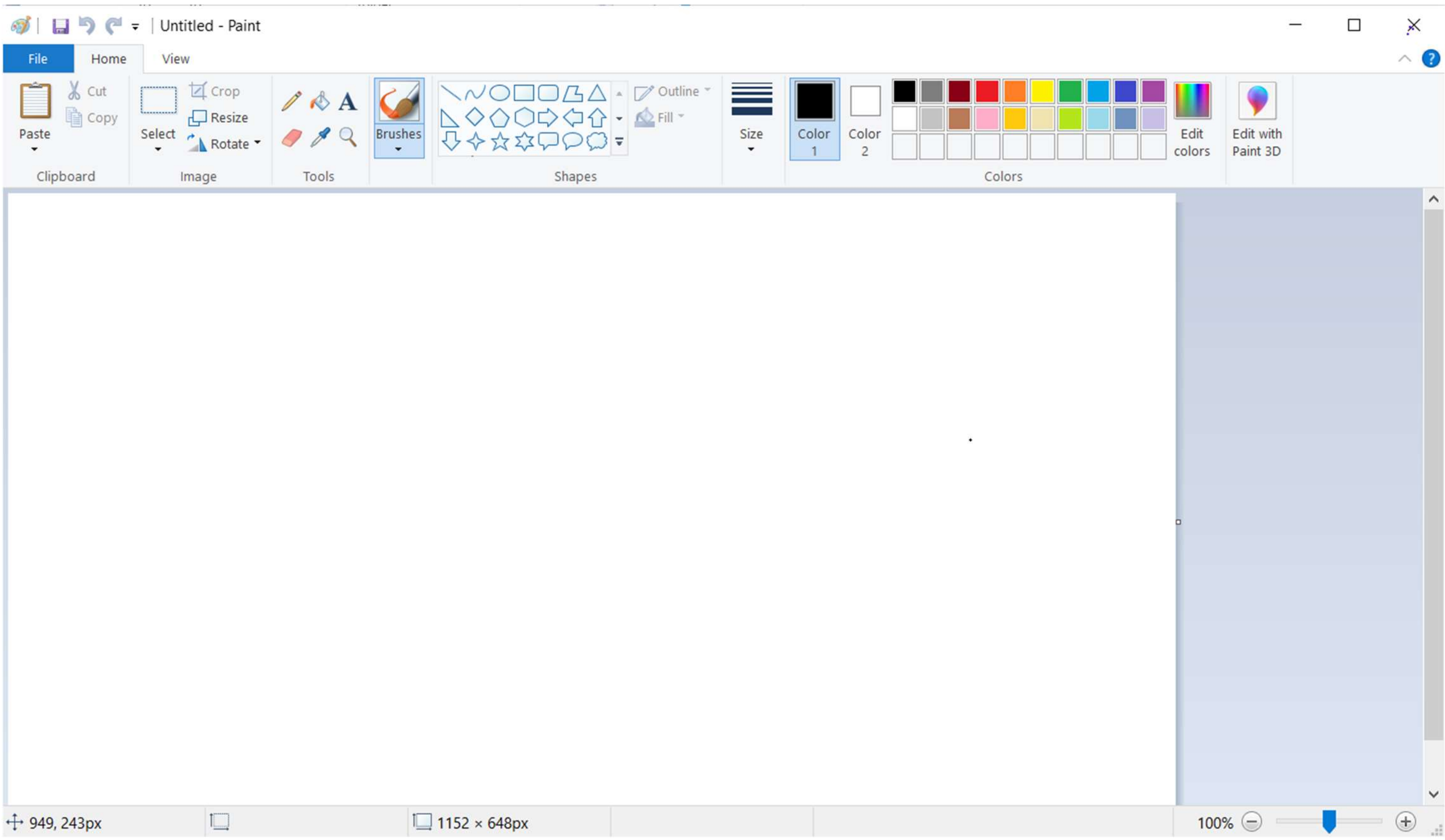
Software:

- Paint (in Windows)
- File Explorer (in Windows)
- ImageJ

PAINT

1. *Click* on the Windows icon on the bottom left of your screen.

2. Find and open Paint in the drop-down menu.
The following window should appear:

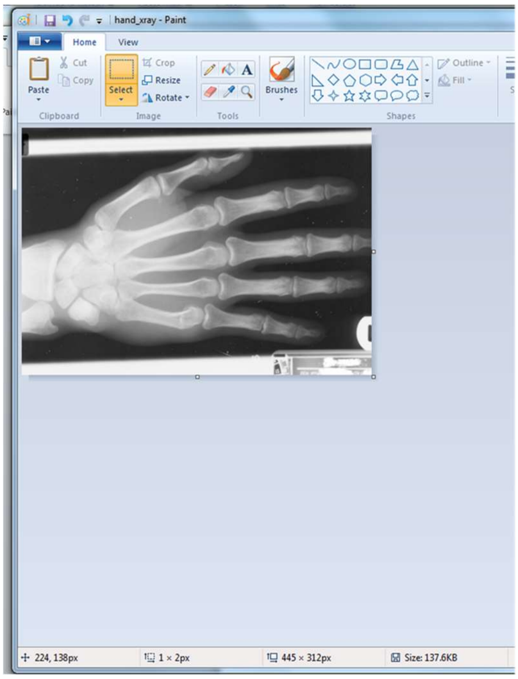


4. *File* - *Open* the image **hand_xray** (NOT hand noisy) from the image folder you've extracted to your dedicated folder. (Please note: the file may show as **hand_xray**.bmp; from here on I will omit the file extention and only give the file name in bold.)

   If *Open* does not take you to where you want to be, type **hand-xray** into the search area normally on the bottom left of your screen. Click "open file location" in the panel on the right, then right click on the **hand_xray** image file, select "*Open with*" in the window which opened, and choose Paint.

5. The radiographic image of a human hand appears as a "positive" with the bones black rather than white.

   To make the image look like the radiograph you're used to, *click* on *Select* on the tool bar then *Select All* in the drop-down box. Then *RIGHT click* on the image of the hand itself and, on the drop down box that appears, and select *Invert color* right at the bottom.



<u>All questions in the framed gray areas should be answered in the Answer Booklet</u>

Question 1.1 Inverting gray scale

Explain one way in which this inversion might have been accomplished.

Question 1.2 Image file size vs. file storage size

Calculate bytes required to store pixels only, by multiplying w x h.

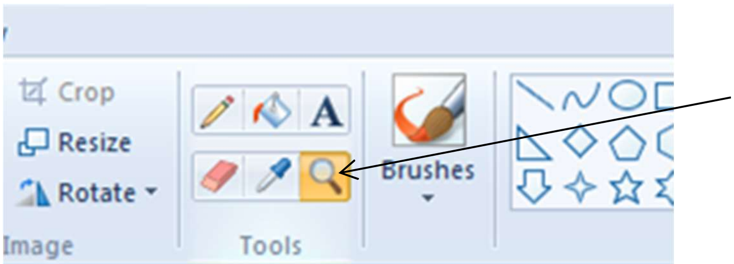
In File Explorer (on the bottom tool bar of your screen, the yellow file, or use the windows logo + E) right click on hand_ xray. Select Properties – General and record file size in bytes. (Careful not to record size on disk.)

Calculate the extra storage used by subtracting the smaller number from the larger one

When **saved,** the image occupies over 140 kB.
What additional data might be stored in the extra bytes?
Research on "*Metadata*" for digital images and photographs will give you good insight.

NOTE: if you are working on a MacBook your values will differ substantially from that of Windows users; give your values and find out why MacBook files occupy more space than Windows files when storing the same image.

Close File Explorer and return to the **hand_xray** image that is open in Paint.



6. Use either the zoom option on the right hand side of the bottom tool-bar (it should say "100%" next to a blue slider tool) to zoom in, or *click* on *View* (next to File and Home on the top left of your screen) and then on "*Zoom in*" to increase the size of the image.

Question 1.3 Zoom and spatial resolution

a) Describe what happens to the pixels in the image when zooming in.
b) Explain the effect that zooming has on spatial resolution.

7. *Close* Paint by clicking on the **X** in the top right hand corner, or choose *File – Exit* (or *alt*+*x*), and *click* "Don't Save" as we will need this image later on.

FILE EXPLORER

8. Use *File Explorer* to find the folder where you have extracted the images to.

9. *Left click* on the file ***flowers*** and then *Right click – Properties* - *Details*

Question 1.4 BMP and Bit Depth

From the Details tab, record the pixel Width and Height.

The File Item Type is a BMP file - what does "bmp" stand for?

Record the *bit depth*.

Note: this is a colour image, which we will use quite a few times later on. The bit depth referred to above allows for 8 bits for each primary colour used in the image: Red, Blue and Green.

10. *Click* on *OK* and close out of *File Explorer* by clicking on the **x** in the top right corner.

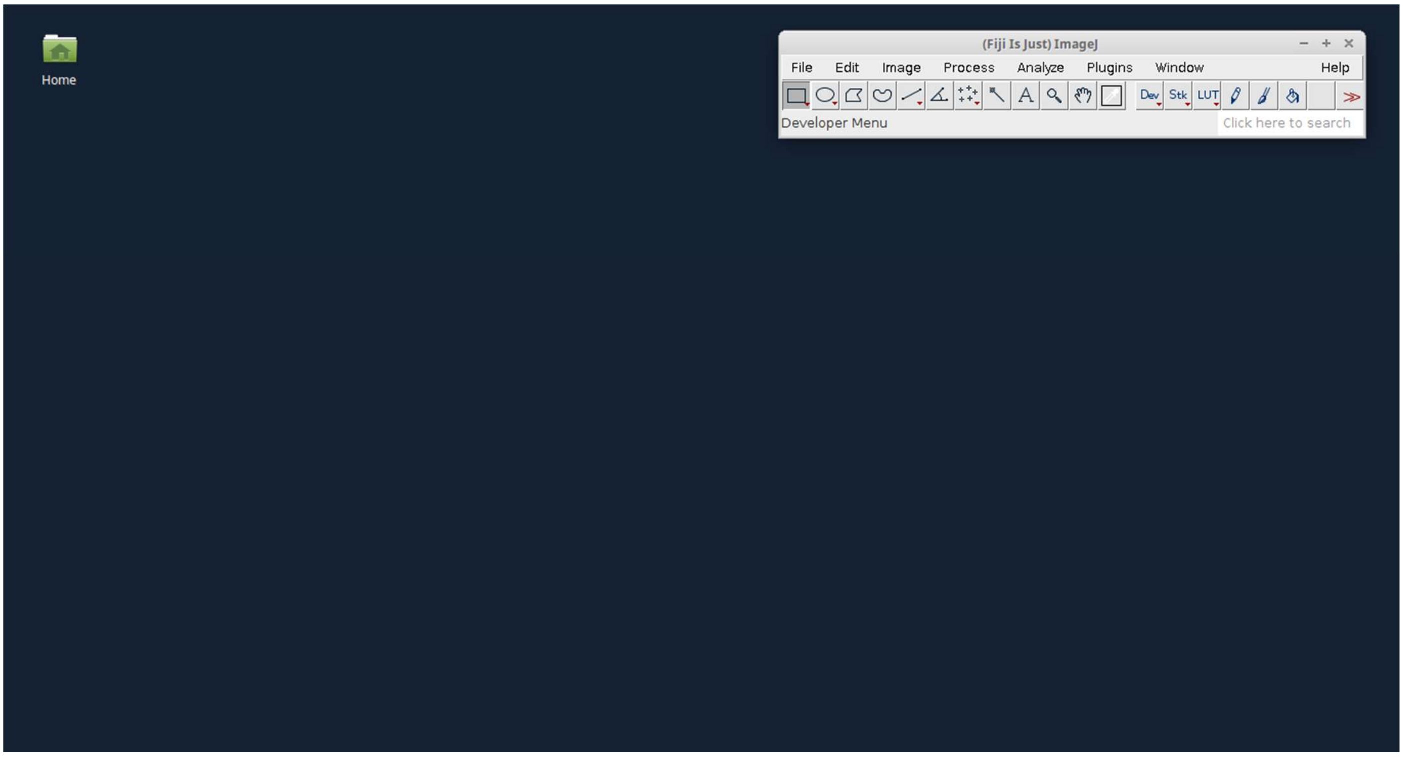
IMAGEJ / FIJI

Before we start using ImageJ, just a few points to note about the app:

- **when you are working on an image, please note that *the image files do not auto save.* If you are interrupted or have to pause you may wish to save what you have done. *Always save your images under a different name* – the original image might be used multiple times, and if you save without renaming them, you won't be able to successfully complete the assessment.**
- All images opened in ImageJ will be in a separate window. If there are two images opened, there will be two separate windows with one image in each.
- **To apply a menu option on an image, the window containing the image of interest should be activated first by clicking on the image or frame of the window containing that image. That window will now have the focus. Any following action will be applied on that particular image.**
- **If this is not done, you may receive an error message stating that the specific task can not be applied to the image type.**

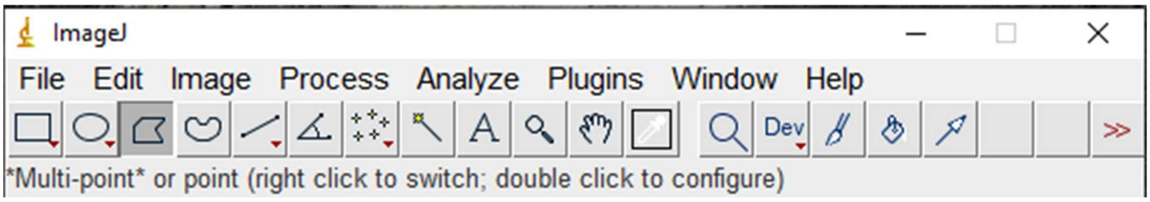
Launch the *ImageJ* app which should be in your main folder, and click on **ImageJ-win64**, the application file with the brown microscope icon.

Once you've opened the app, you will see a small screen opening up, which looks similar to what is shown in the top right corner of the screen shot on the next page:



Note: this is (most of my) whole screen; you can already get a sense that ImageJ is not your normal run-of-the-mill application!

Your ImageJ control panel should look like this (if you have different icons showing that's not a problem):



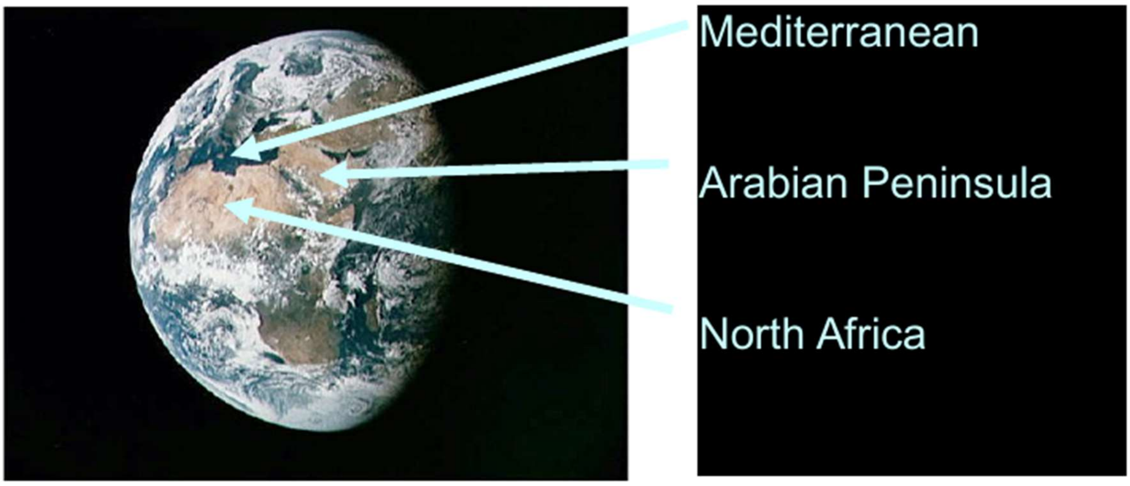
Sometimes an updater screen opens automatically when you launch the app – this can be ignored by selecting the "Remind me later" option, however the app updates only takes a couple of seconds and do not require a system restart.

Using grayscale images to create a colour image?

Aim:
To examine the RGB composition of a colour image.

11. Select *File - open* and select “**earth**”. (You may have to navigate to the folder where you’ve stored the images.)

12. You should see a single colour image of the earth, centered on the Middle East region.



13. Any colour image is a combination of several monochrome images, each consisting of 256 intensity levels.

14. Select **Image – Color – Split Channels**. The colour image will be replaced by three windows containing the red, green and blue (RGB) images “earth.bmp(red)”, “earth.bmp(green)” and “earth.bmp(blue)” .

15. Arrange the windows on the screen so that you can compare them side by side. Compare the relative intensities of the different colour components (i.e. the red, green and blue components), in different areas of the image.

    In particular observe that:
    (a) the North African land mass contains more red than green, and more green than blue (that is northern Africa is brightest on the (red) grayscale image, and darkest on the (blue) grayscale image – why do you think this would be? Are there any deserts in northern Africa, and might this be the reason?)

    and

    (b) the Mediterranean Sea has more blue than green and almost no red (i.e. on the (red) grayscale image the Mediterranean Sea is almost black, it’s brighter on the (green) and brightest on the (blue) grayscale image).

It is important to understand that the *brighter a specific region in any of the split images, the higher the intensity of that particular colour* on the original colour image.

Question 1.5 Combining red, blue and green to give a specific colour

Locate the clouds on the 24-bit colour image (you may want to *open* the **earth** image file again to be able to do this), and explain why, when you compare the three grayscale channels *earth.bmp* (i.e. earth.bmp (red), (green) and (blue)) images, the intensity of the clouds do not appear to change.

Look-Up Table (LUT)

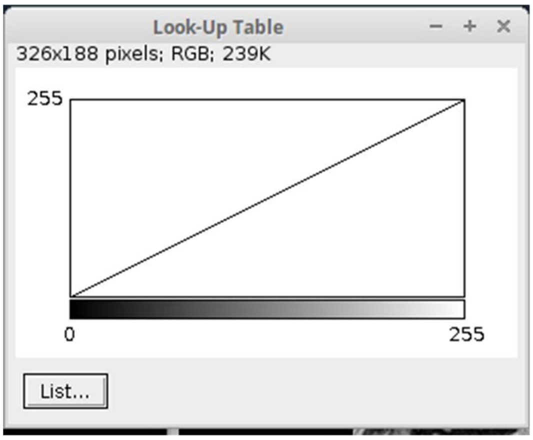
Aim:

To examine the effect of different LUT's.

16. The RGB channels created above can be displayed by assigning various colours to the different intensities. The resulting images are also known as "false colour" or "pseudo colour" images.

    Select the red channel image (earth.bmp (red)) by *clicking* on it (you'll notice the window name shows up a bit darker).

    You can view the current gray scale LUT by selecting **Image – Color – Show LUT**.



    Zero intensity is black, brightest intensity (255) is white.

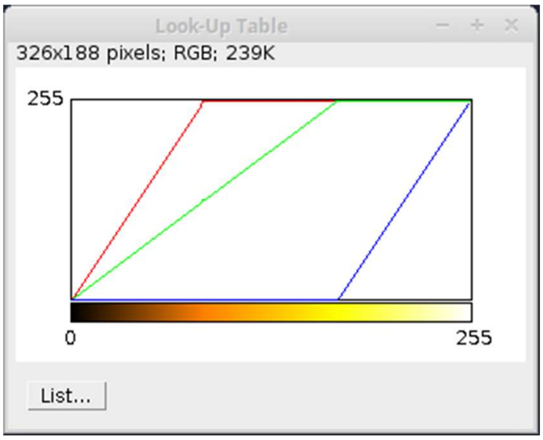
    An LUT displays the 256 grays from black to white on the x-axis, and the intensity for gray, or colour intensities for each colour, on the y-axis. An LUT is thus just a way to visually represent the existing information. It does not add or change any data.

17. Because every image is in a separate window, you need to make sure that the correct window is selected for the next action. *Click* on the image containing the earth.bmp (red) channel information.

    Change the LUT to a false colour by selecting **Image – Lookup Tables– Orange Hot** (you may need to scroll down the list by clicking on the small arrow head pointing down, right at the bottom of the list of Lookup tables, on the left hand side).

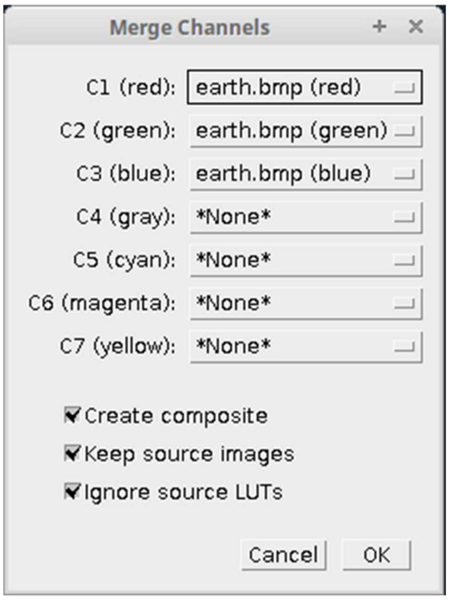
    The image will be coloured according to this LUT. Click on the (red) image again and examine this lookup table with **Image – Color – Show LUT**.

In this LUT the individual RGB colours are applied to the image as shown on the LUT.



Depending on the particular details in an image, the LUT may enhance some difficult to observe features, or can be used to visually discriminate structures, e.g. using blue for colder (dark) areas and red for hotter (white) areas on an image.

18. The individual grayscale images can be merged again into a colour image. Select **Image – Color – Merge Channels**. You will be presented by a window as shown. But read on before you select OK.



The default selection of files for the RGB channels are filled in, but you may choose to select different colours for a channel, e.g. the red earth channel for the blue component.

If “Keep source images” is selected, the individual RGB windows will not be closed.

By default, the merged full colour image will be done with the LUT colours. Select the option "Ignore source LUTs".

Execute by clicking OK.

Create a few of your own combinations by **Image – Color – Merge Channels** , and for example, choosing (red) for the C5 (cyan) as well – you'll see some very interesting effects.

19. To further explore the combination of the different channels, select **Image – Color – Channels Tool**.

    The interactive tool can be used to explore different combinations. This tool relies on the RGB channel images as well as the merged image as described above. (For example choose a single channel at a time, 4 times; then 6 different combinations of two channels, then 3 different combinations of three channels, and then all 4 together.)

20. To display all the available LUTs, select **Image – Color – Display LUTS**. Very interesting to see how the different LUTs are composed, so be sure to have a look.

    Select *File – Close All* without saving, any windows still open can be manually closed as well, remember to do so without saving.

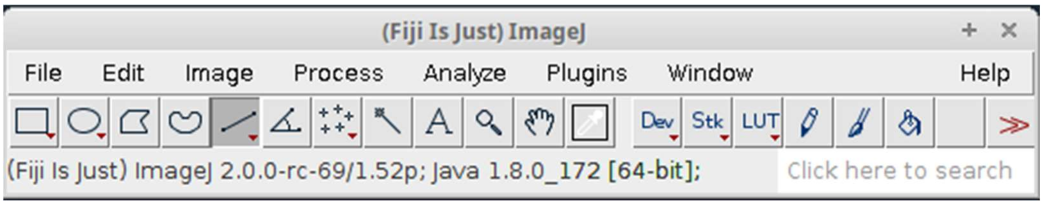
Taking Measurements

21. *File - Open* the image file **earth** again.

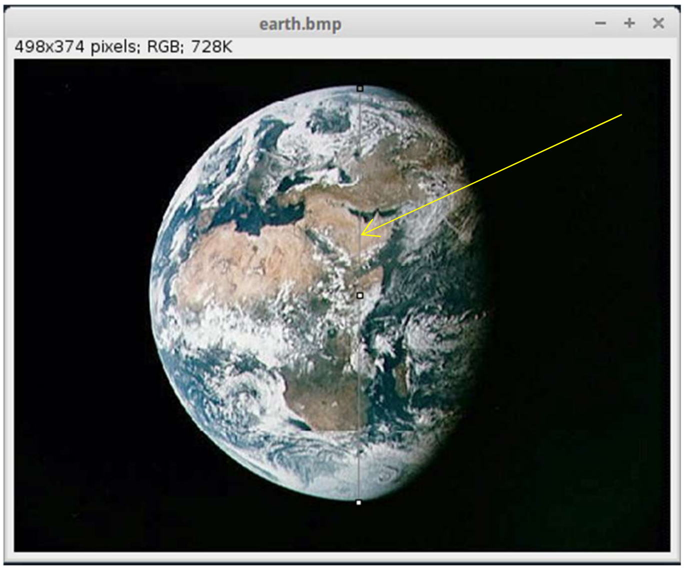
The ImageJ application allows you to make measurements of distances, areas and angles. In medical imaging these techniques are used regularly in certain procedures such as measuring the size of an artery before stenting in DSA, or measuring the size of a urinary bladder in Ultrasound to calculate prostate enlargement.

We are going to use the scaling tool to measure the size of the Arabian Peninsula as shown on the map.

22. Before we measure the area we first have to calibrate the scale. We can use the knowledge that the diameter of the Earth from pole to pole is 12 714 km. *Click* the *line* icon, 5th one from the left as indicated below:



23. *Click* on the one pole of the earth and then on the other. You should have a vertical line as shown (very faintly) below.

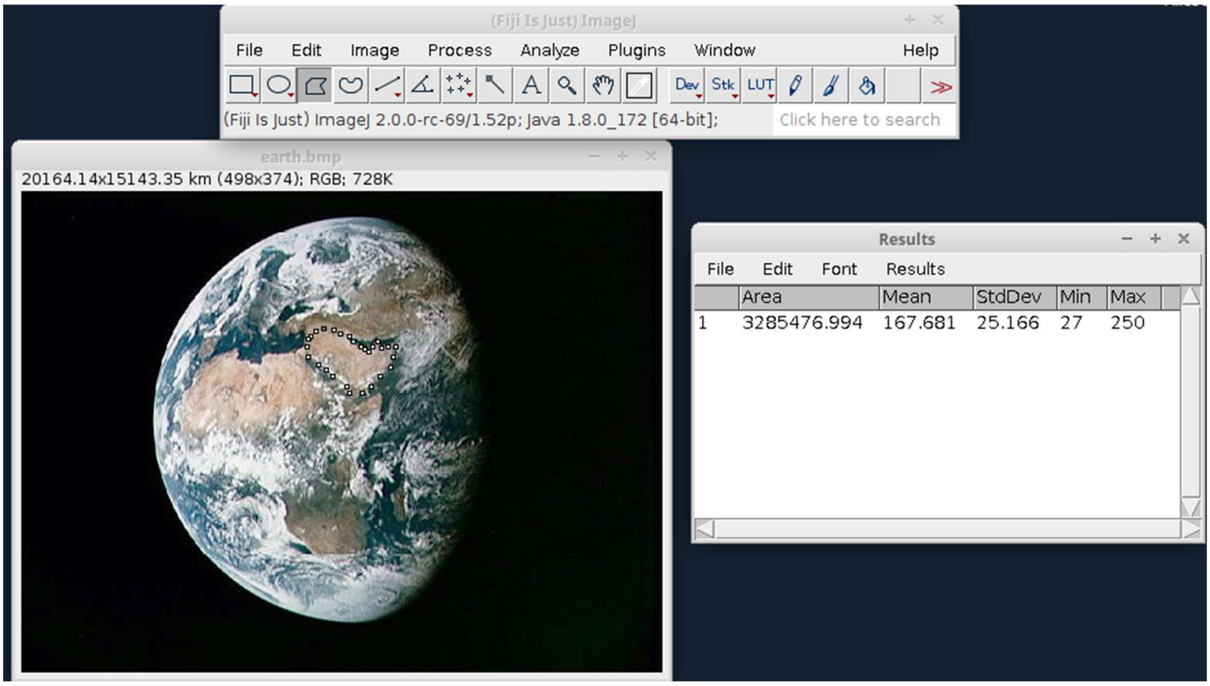


24. Select **Analyze – Set Scale**... and fill the boxes: "Known distance" will be the diameter of the earth (**12 714**); change the "Unit of length" to **km**. Select **OK**

25. *Click* on the *polygon* icon, third from the left (see next page).
Draw a polygon around the Arabian Peninsula as shown. (Remember you can zoom in to get a larger view, but at the cost of resolution. It might also be a good idea to use a search engine to find the exact borders of the Arabian Peninsula first; this is also indicated on the image on the previous page.)

Place your cursor where you'd want to start, then click once; move to the next position and click again, and so on until you get to your starting point again – when you finally click on your starting point the chosen points will briefly light up. *Do not make the distances between your points too long as that will lead to an inaccurate measurement.*

Select **Analyze – Measure** and you should see a table with the measured area shown on the next page.



Question 1.6 Measurement: calculating area

Record your calculated area of the Arabian Peninsula in square kilometres on your Answer Booklet.
Allowances will be made for error, but try to be as accurate as possible. Mine is nowhere near, so don't be tempted to use it :)

Close all windows except the ImageJ control panel.

This concludes **Exercise 1**

Exercise 2

24 Marks

Aim:

To understand pixels and how to apply lookup tables.

Pixel size and file size

1. In the ImageJ application *File - Open* the image file **fetal_face_1**.
   Select the *Scrolling Tool* (little hand) on the ImageJ tool bar. Take the hand over to the image and, while you move it randomly across it, have a look at what happens in the ImageJ panel. See how the x value changes when you move horisontally, and the y value as you move vertically.

   Note how the coordinates differ from those of the Cartesian plane, where (0,0) would be found at the lower left hand corner when we view the first quadrant.

   Find the corner with the highest x- and y-value (be careful not to let it change into an arrow), and record these values in your Answer Booklet. They are the number of bytes – vertically and horizontally, that makes up the image.

   Multiply the two values and record your answer, in kilobytes.

Question 2.1 Magnification and file size

a) Record the height and the width and then calculate the size in the table in the answer sheet. (The width is the number of pixels in a row across the image and the height is the number of pixels in a column down the image.)

b) Repeat for the image files **fetal_face 2**, **fetal_face_4**, and **fetal_face_8**. Find the x and y-values for each image before opening the next.

(The x- and y-values, and the value (or content), is similar to what is stored in a digital radiograph, in terms of pixel position and intensity of the pixel.)

2.1 Use the *zoom tool (the magnifying glass)* to magnify **fetal_face_8** by 8:1 or 800%. Each time you click the magnification is increased. The amount of magnification is shown on the title bar of each image.
Alternatively the “+” and “-” keys on the keyboard may be used.

For quick reference:

	Mouse **(with magnication icon)**	**Keyboard**
Zoom in	left mouse click	Plus key
Zoom out	ctrl+ left mouse click	Minus key
Reset to original size	shift + left mouse click	-

2.2 Magnify **fetal_face_4** by 4:1 (400%), and **fetal_face_2** by 2:1 (200%).

After magnification, all image displays should have the same physical dimensions.

Question 2.2 Detail and file size

For each of the above images, briefly comment on the detail observed, as you would when critiquing a radiograph.
[Important note: the intrinsic resolution of the ultrasound machine is larger (more coarse) than the pixel size in **fetal_face_1**.]

Question 2.3 Detail and file size continued

Explain what the relationship between anatomical detail and file size is.

3. *File – Close All* . *Open* the file **Tall_Guy**

4. Looking intently at this image will probably not help you figure out who it is. Some distance between you and the screen might help. Otherwise you could try squinting. Or removing glasses if applicable.

Question 2.4 Application of pixel size

Who is this?
Hint: This photo was taken around 1953 after he had achieved “great heights”.

This image was achieved through pixelation. This is the same sort of process that the media uses when obscuring a person’s face in a news story or expose.

Question 2.5 Useful pixelation

How would you optimize the pixelation used on television to adequately hide the identity of a person?

LUT’s and Bit depth

5. *Close* the image file **Tall_Guy** and *open* the image file **flowers**.

6. Choose the menu items **Image – Color – Show LUT**. You should be presented with an error message.

An LUT can only be applied on a 8 bit grayscale or colour image, or a 16 or 32 bit grayscale image.

An RGB image will have 256 red, 256 green and 256 blue values, or a total of 16 777 216 colours - called a 24 bit image. If each pixel intensity is embedded in the image, it will have 256 values on top of the 24 bits, making it a 32 bit image. (Why is 16 77 216 equal to 24 bits? Because 16 777 216 = 2^{24} .)

Close the error message box.

Open an information box for the image with **Image – Show Info** (keyboard shortcut c*trl* + *i*).

Notice that the pixel depth is 32 for this image, exactly what was forecasted. *Close* the information box.

You are now going to examine the influence of changing the image bit depth. *Select* **Image – Type – 8-bit Color**. You will have a one time option to select the number of colours to display the image in. For now, choose 256. The resulting image will visually not be any different from the original one.

Open the information message box again (c*trl* + *i*) and notice that a "**Color LUT**" is now applied to the image.

Open the LUT. (**Image – Color – Show LUT**) and have a look at it.

7. *Revert* the image to the original with **File – Revert** (Keyboard short cut *ctrl* + *R*). Do not close the LUT window.

   Remember to select the window for the next task before selecting the task!

   Now *select* **Image – Type – 8-bit Colour**, but *select* **64 colours**. Again view the LUT for this image (**Image – Color – Show LUT**).

   Repeat the process for 16, 8, 4 and 2 colours.

   You should now have five LUT windows. Each image used for these LUTs had the same bit depth, but the lookup table in each case *represented* a lower bit depth. So the LUT does not change the image, only the way it is displayed.

   Note: there is a shortcut to streamline choosing an LUT – on the *right hand side* of the toolbar on the command panel you'll see a selector for "LUT".
   If it is not displayed, click on the 2 double red arrows on the far right, and select **Restore startup tools.**
   Selecting "***LUT***" would display a list of the LUTs available.

Examining an Image using LUTs

8. *Close All* without saving. *Open* **ct_head**.

9. We said earlier that LUTs can be useful to highlight, for instance, under and over saturation, or to improve signal distribution. Select ***LUT***.

Question 2.6 Using colours to highlight various aspects of an image

Apply each of the following three LUTs to **ct_head** and critique each resulting image, stating areas of improvement and degradation for each LUT:

a) Grays
b) 6 shades
c) Fire

10. It is possible to attach a LUT to an image. Select **Rainbow RGB**. This LUT colours intensity in shades of red, blue or green.
The highest 33% of intensities are reds, the middle 33% are greens and the bottom 33% are blues. The different combinations of the three colours create all the non-RGB colours.

Display the LUT (**Image – Color – Show LUT**) to see how it is composed.

Select **Image – Color – Color picker**. As you move your cursor across the CP window, note on the control panel how each colour is represented as a combination. Bear in mind the bit depth is 8 bits, meaning there will be 2^8=256 possible intensities, numbered from 0 to 255.

Question 2.7 Dissecting colours

a) Predict the combination for pure red, pure green and pure blue (remember your prediction will be three numbers, red = …, blue = … and green = ..., each number between 0 and 255).
Write down your three predicted values (you won't be penalised for a wrong but plausible prediction). The combination is normally written as (x,y,z) with x the value for red, y the value for green and z the value for blue – remember, RGB.

b) Now locate pure red, pure green and pure blue (they are the three largest squares on the colour grid), find the combination for each on the control panel, and compare their actual values, and comment on our own prediction ("correct" or "wrong").

c) Choose any colour block on the screen that you find particularly inspiring, write down your prediction of the combination without having a peek on the control panel, and check this against the actual combination. Write down the #xxxxxx code and the name of your chosen colour. But please read on to get more information on the code and where to find the name of your colour.

The #xxxxxx is the hex code for that particular colour combination. Hexcode stands for hexadecimal code.

You are familiar with the decimal number system (base 10, using digits 0-9), and the binary decimal system (base 2, using digits 0 & 1). The hexadecimal system uses base 16 (Hex = 6, decimal = 10), using digits 0-9 and letters A-F.

Open your browser and go to https://www.colorhexa.com/

In the search bar type in the code of your chosen colour, without the #, and click on the magnifying glass. You'll see the RGB intensity combination for your colour (which differs substantially from the number you wrote down in your workbook!), as well as the CMYK code (cyan magenta yellow black) created specifically for printers. (The RGB display combinations were created specifically for display on electronic devices.) You might remember from primary school that the human eye see different colours by combining red, yellow and blue – and artists combine these three colours to create their desired colour. By adding white or black they change the depth of colour. (If you want to read more about hue, saturation and brightness of the RGB system, this site has good information in easy to understand language.)

Scroll right down to the bottom of the page on colorhexa – you'll be able to see how people with monochromacy, dichromacy and trichromacy "see" this colour; if you hover over the colour blocks you'll see not only the hex codes for their perceived colours, but also the percentage of either the whole population, or men/women who have that condition.

Now you can go back to answer Question 2.7 c).

Application of LUT on MRI images

11. Open the file **mri-stack**.tif using **File – Open Samples – MRI Stack**.

12. This is a stack of images. Select an LUT from the previous question which displays the series best, and use the arrow keys to step through the MRI scan images and answer the question below.

Question 2.8 Enhancing MRI Images Using Colour

a) Which LUT did you choose?

b) Write down the frame number on which the following landmarks can best be seen:

(i) nasal cavities
(ii) sockets
(iii) ear canals

Colour Contrast Enhancement

13. *Open* the image file **flowers**. This colour image has poor contrast in *the foliage around the flowers*. You will attempt to improve this.

14. Select **Image – Type – RGB Stack**.
This opens the image as a stack of three images, one for each of Red, Green and Blue (you can see these by using the < and > arrows on your keyboard, or by clicking on the arrows in the bar below the displayed image.

15. Select the monochromatic image for the **Green** stack by clicking on it.

16. Enhance this by selecting **Process – Enhanced Contrast – Equalize histogram**.

17. Now create the colour image with enhanced foliage by selecting **Image – Color – Stack to RGB**.

Question 2.9 Can Colour Improve Contrast?

Comment on this resulting image.

This concludes **Exercise 2**

Exercise 3 **22 Marks**

Aim:
Learn how to use histograms to apply thresholds and do object identification.

Thresholding and Edge detection

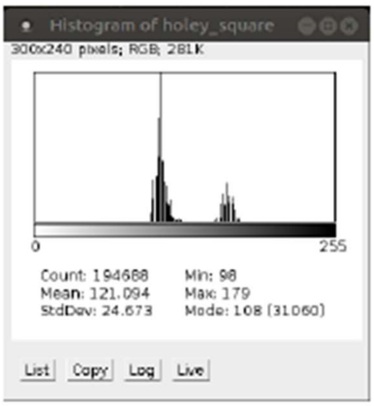
The information contained in an image histogram can be used to achieve image enhancement and feature extraction. In this example we are going to use a histogram to locate the boundaries of an object.

1. Use ImageJ to *open* the image **holey_square**.

2. Use the **Analyse – Histogram** menu options to display the histogram for this image. It should look like the image below.

   NB: For 8-bit grayscale images, ImageJ uses the IBM PC convention that displays zero values as white and 255 as black, i.e. the pixel value represents the amount of blackness, not whiteness. So the left end of the histogram represents white pixels and the right end represents black pixels (as shown in the histogram below).

   The histogram of **holey square** is bi-modal, i.e. it shows two distinct peaks: the left peak represents the lighter pixels and the right peak the darker pixels. Note that the left peak is taller than the right peak, *which means there are more light pixels in the image than dark pixels.*



   It is clear from the histogram that if we are interested in the light pixels, we should investigate the range of intensities in the left peak. Similar for investigating the darker intensities using the peak on the right.

A threshold located between the two peaks will separate the image into two distinct regions, i.e. the object and the background.

Threshold images normally appear as binary images, i.e. black or white.

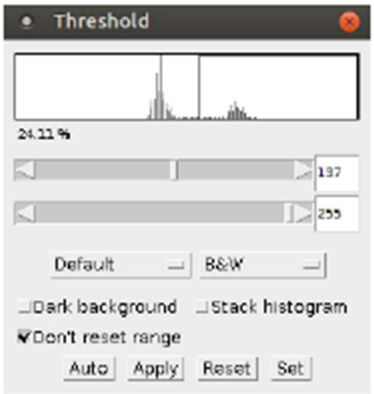
3. To apply a threshold, *select* from the menu **Image – Adjust – Threshold**. There are two adjustment bars that define the left and right side of the threshold applied to the histogram.

   You can imagine the threshold to be a way in which to say only "show me the pixels that are included in these values, as one colour, and the rest as the opposite".

   The default 0 for the top adjustment bar and 136 for the bottom adjustment bar, as shown here, will display the left peak values as black, and the rest of the image as white **(make sure you have *B&W selected* if your image comes up red or green)**.

   Changing the top bar to 136 (you can double click on the window next to the bar, type in "136", select **Set**, click on OK.) and the bottom bar to 255 will show the metal in white and the background in black.

   (The threshold level also can be changed by clicking and dragging on the adjustment bars in the two windows.)



   Set the top value to 0 and the bottom value to 255.

   If at any point you lose functionality select **File – Revert** (or ctrl + R), followed by (ctrl + shift + T) to get the adjust threshold window back.

   Now adjust the top and the bottom threshold levels to give a perfect image of just the square and the hole, with nothing else showing in the image. (You'll see that there are two possibilities – one with the background white (where the left peak is included in the threshold limits), and one where the background is black, (where the smaller right peak is included).

Question 3.1 Diving into Thresholds

Use both adjustment bars and set them to

(a) Top: 92, bottom: 134.
Comment on the image compared to what you saw when the limits were set to 0 and 255.

(b) Top: 92, bottom: 180.
Explain why the threshold selection generated the image you see.

(c) Top: 128, bottom: 149
How can these threshold selection be utilized in practice?

4. *Close* the Threshold window and Revert the image (remember to select it first).

5. Now *Convert* the image to a binary one, i.e. black and white only, by using the **Process – Binary – Make Binary** menu options.

6. Display the histogram for the binary image with **Analyse – Histogram**.

Question 3.2

Take an image of your *histogram*, and paste it under Question 3.2 in your Answer Booklet.

Question 3.3

Comment on the shape of your histograms shape, and provide the interpretation.

Thresholding and Counting Objects

7. *Close* all the image and histogram windows. *Open* a new file **blood**.tif.

8. In order to separate the blood cells from the background, we can apply a threshold to the image. (The background will be all the tiny dots - noise.)

   Select **Image – Adjust – Threshold**. This will change the image to a black and white image. Slide the bottom adjustment bar left and right and see the effect on the image. Adjust the level to separate the blood cells from the background. (Background black, blood cells white, without obvious background noise).

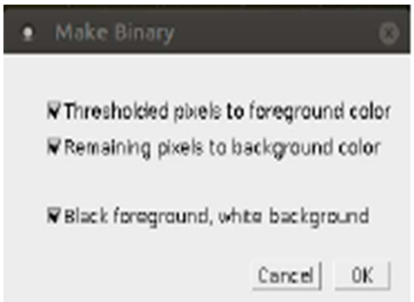
Question 3.4 Threshold Settings for Optimal Cell Count

Write down your threshold selection of the top and bottom adjustment bars for separating the blood cells from the background

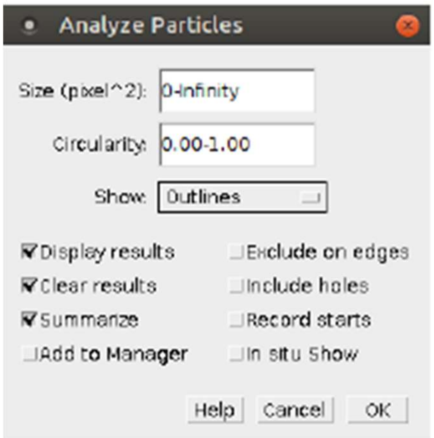
9. C*onvert* the image to binary - **Process – Binary – Make Binary**, but first keep reading before you do!

   Hint: Remember to select the window containing the blood cells first, otherwise the program will try to convert the Threshold setting window to binary!

   Choose the default settings as shown. And now click **OK** :)



10. Now you can count the number of cells using ImageJ software! *Choose* **Analyze – Analyze Particles**. Ensure that **Show: outlines** is selected, that the top 3 boxes on the left, and no boxes on the right of the "Analyze Particles" window, are ticked, and then *click* **OK**.
You will be presented with three new windows, namely **Drawing of Blood**, **Results** and **Summary**.



Question 3.5 Using Software to Count Cells

In the Summary window, it will display a number that the application has counted.

Record the number.

Now count and record the number of red blood cells you can see.

Explain the reason why the software count differs from the actual count.

Contrast Enhancement

Hint: Remember to always select the correct window first!

11. *Close* all windows related to the **blood**.tif image. *Open* **ct_head.**bmp.

12. Show the histogram **Analyse – Histogram**. *Hint: You can use Ctrl-H instead of the menu options.*

Question 3.6 Histogram

Take an image of your histogram, paste it in the "Before" space under Question 3.6 in your Answer Booklet.

13. *Open* an *additional copy* of the **ct head**.bmp image.

14. *Enhance* the new image using **Process – Enhance Contrast**.

    So far, the enhancement has been achieved by only changing the Look-Up Table. The pixel values themselves remain unchanged. You can check this, if you want to, by displaying the histogram of the enhanced image. Compare it to the "before" histogram you sketched, there is no difference.

15. Apply the enhancement to the image pixel values themselves, i.e. make the enhancement permanent, by using **Image – Lookup Tables – Apply LUT**.

    Produce the histogram on this image with **Analyze – Histogram**.

Question 3.7 Apply LUT to Enhance Contrast

Take an image of your enhanced histogram and paste it in the "After" space under Question 3.7 in your Answer Booklet.

Question 3.8 Analyzing histograms

By analyzing the before and after histograms, explain how the contrast has been enhanced.

Histogram equalisation

16. *Open another copy* of the **ct head**.bmp image.

17. Perform histogram equalisation on the new image by using the menu options **Process – Enhance Contrast** and *select* **Equalize Histogram** from the options given.

    Then *display* this histogram **Analyze – Show Histogram** or by using Ctrl-H.

Question 3.9 Contrast Enhancement by Histogram Equalisation

Paste an image of your histogram under Question 3.9 in your Answer Booklet.

Question 3.10 Histogram Analysis

Analyse your histogram to explain how the dramatic increase in overall brightness of the image increased dramatically.

19. Histogram equalisation can produce better results if a histogram of only part of the image is used.

    Open yet *another copy* of **ct head**.bmp. Keeping the previously enhanced images allows you to easily compare results.

20. Use one of the selection tools (as you did for the Arabian Peninsula) to *draw* a *large* selection that lies entirely within the head.

21. *Display* the new histogram.

Question 3.11 **Contrast Enhancement by Histogram Equalization on Selected Region**

Paste an image of your histogram under Question 3.11 in your Answer Booklet.

Question 3.12 **Histogram Analysis**

Refer to histogram analysis to explain why equalisation, performed on a *selected part* of the image, give better results than on the whole image. You can use other arguments as well.

This concludes **Exercise 3**

Exercise 4 **17 Marks**

Aim:
To understand how to apply noise reduction effectively.

Noise Reduction

a) Noise Reduction by Averaging

1. *Open* the file **chest_a**.tif in ImageJ.

2. Using the *rectangular selection tool*, *draw* a small rectangular region of interest (ROI) over the lower spine. *Choose a region of uniform pixel values, e.g. the lower spine*.

   Measure the standard deviation σ (SD) of the pixel values in the ROI using **Analyze – Measure** or with **Ctrl-M**.

Record the standard deviation in the **Answer Booklet, Question 4.1** of **Noise Reduction by Averaging**, as the σ value for chest_a.tif.

   If the Results window does not show the StdDev as a column option, choose **Results – Set Measurements** in the Results window. Select Standard deviation from the options presented. Click **OK**.

   Click on the image *window frame*. If you click on the image, the rectangle chosen will disappear and a new rectangle must be selected. Perform a measurement.

   There will now be two measurements in the Results table. The latest measurement will be at the bottom of the list.

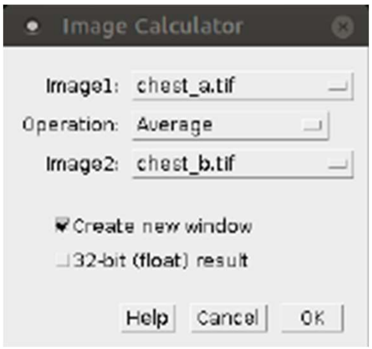
3. Repeat the process with file **chest_b**.tif.

   Again using the rectangular section tool, choose the *same size and region* as you had previously.
   Use **Analyze – Measure** or **Ctrl-M** to get the StdDev.

Record the standard deviation in the **Answer Booklet, Question 4.1** of **Noise Reduction by Averaging**, as the σ value for chest_b.tif.

4. Now you need to *average* the two images using **Process – Image Calculator**. Choose *Image1* to be **chest_a**.tif and *Image2* to be **chest_b**.tiff. *Choose* operation "**Average**".

   Once you complete this box, *clicking* ***OK*** will generate another chest x-ray image which is based on the average results.



5. On the **Result chest x-ray** image, again use the rectangular tool to choose the same size ROI. Then once again **Analyze – Measure**.

Record the standard deviation in the **Answer Booklet, Question 4.1** of **Noise by Averaging**, as the σ value for the result.

6. *Open* **chest_ave_4**.tif. This image is the average of four noisy images. Measure the same ROI as before and record the standard deviation on to the answer sheet.

7. Repeat the process for **chest_ave_8**.tif. This image is the average of eight noisy images. Measure the same ROI and record the standard deviation on to the answer sheet.

Question 4.2 **Standard Deviation for Averaging Four and Eight Images**

Record the σ values for **chest_ave_4** and **chest_ave_8** on the answer sheet.

Question 4.3 Effectivity of Noise Reduction using Averaging of Images

Comment on the standard deviation in the averaged images of questions 4.1 and 4.2, compared to the two original images (chest_a and chest_b), and compare the effect that the number of images averaged has on no*ise and detail visible* in the averaged images, when compared to the original images.

b) Noise Reduction by Smoothing

8. *Close* all open image file windows with **File – Close All**. There may be some windows (measurement) still open. Manually close them.

9. *Open* the image **hand_xray_noisy**.bmp. (You can also open **hand_xray**.bmp if you want to compare the noisy image with the noise free image).
   If you prefer not to have the images displayed as negatives, *change* it with **Edit – Invert**.

10. *Smooth* the noisy image with **Process – Smooth**. This applies a convolution filter that looks like this:

1	1	1
1	4	1
1	1	1

    Observe how this changes the image.

11. Keep *repeating* the smoothing process *at least eight times* while you continue to observe the changes it makes to the image.

    Hint: Use keyboard shortcut Ctrl+Shift+S

Question 4.4 Noise Reduction by Smoothing

Describe the influence of repeated smoothing on the *noise and the detail* in the image.

12. *Close* the image windows. *Open* the images **moon**.bmp and **moon_noisy**.bmp.

13. *Open an additional* **moon_noisy**.bmp image.

14. *Filter one* of the moon noisy images using **Process – Smooth**.
Filter the second noisy image using **Process – Filters – Median**.
Choose a *Radius* of *1*. Click *OK*.

Question 4.5 Noise Reduction by Median Filtering; Comparison

a) Name the specific type of noise in the image.

b) Describe the effectivity of median filtering on a noisy image.

c) Out of these three methods (averaging, smoothing or median filtering) choose the one best suited for radiography, and validate your choice.

The median filter appeared to remove the noise and leave the remainder of the image untouched.

However this is not the case and if you look carefully at the median filtered image and the original noise-free image you will see subtle differences.

These differences can be highlighted by subtracting one image from the other and displaying the result as an image. This is done in the following step.

15. *Close* the *smoothed image* so that the only two images on the screen are **moon**.bmp and the median filtered version of **moon_noisy**.bmp.

16. *Select* **Process – Calculator Plus** from the menus. With the **Operation: Subtract** display a **difference** image. This image will be dark. Apply a histogram equalisation **Process – Enhance Contrast** and select "**Equalize histogram**".

Spatial Filtering

The smoothing performed in the previous question was an example of spatial filtering. Spatial filters can also be used to achieve results other than noise reduction.

a) Edge detection

17. *Open* the image **hand_xray**.bmp twice. You can *invert* them if you wish by using **Edit – Invert**.

18. *Filter* one of them using **Process - Find Edges**. This option applies the two convolution filters, shown below, and combines the results into one image.

	1	2	1		1	0	-1
Horisontal edge:	0	0	0	Vertical edge:	2	0	-2
	-1	-2	-1		1	0	-1

Note that the sum of the values in each of the filters is zero. Therefore, when applied to a uniform area of the image the result will be zero. Non-zero results will only be obtained in non-uniform areas of the image, **i.e. gradients and edges**.

b) Sharpen

19. *Open* a *further copy* of **hand_xray**.bmp and *filter* this using **Process – Sharpen.** Observe the result when compared to the original **hand_xray**.bmp image.

Sharpen applies the filter:	-1	-1	-1
	-1	12	-1
	-1	-1	-1

The large central value of the filter maintains the original pixel value, whereas the surrounding negative values (in combination with the central value) detect edges. The combined effect is **highlighting the edges** within the image.

c) Shadow

The ImageJ application allows you to create your own convolution filters.

20. *Select* the **hand xray**.bmp window and then use **Process – Filter – Convolve** to open the ImageJ convolver editor.

Create a filter that looks like this:

-2	-1	**1**
-1	**1**	1
1	1	2

*Hint: You can use the **Preview option box** to see what the effect would be with different values.*

Note: When typing filters make sure that you leave spaces between the numbers so that the numbers line up in straight vertical columns.

E.g.

-1	-2	1
-1	-2	1
-1	1	1

and not

```
-1   -2    1
-1    1     1
      1          1    1
```

This is particularly important where there are negative values and/or where there are two digit numbers.

21. Use the Save button to *save* the filter with the name **shadow1**.txt or choose another name if that file name already exists. Save it to the same location where you have saved your ImageJ Application and the image files.

22. Examine the filter above. The 1’s on the diagonal (underlined and shown in Bold) maintain the original pixel value and provide some smoothing. The negative values in the top left and the positive values in the lower right add a diagonal edge enhancement. The result is a *3D shadowing effect*.

Question 4.6 Creating a shadow filter (to enhance either the negative diagonal, the vertical or the horizontal edges)

Create a 5 x 5 shadowing filter and apply it to the hand xray.bmp image by repeating steps 20 – 22. Record your filter on the answer sheet. Challenge yourself to set up a filter that enhances another edge than the incline diagonal described in the example. Figure out how to enhance the descent diagonal edges, or the horizontal or vertical ones.

Question 4.7 Describe the Effect

Describe in detail the effect your filter has on the hand xray image.

This concludes **Exercise 4**

Exercise 5

14 Marks

Aim:
To demonstrate image arithmetic
To investigate image processing in the frequency domain

a) Mask subtraction

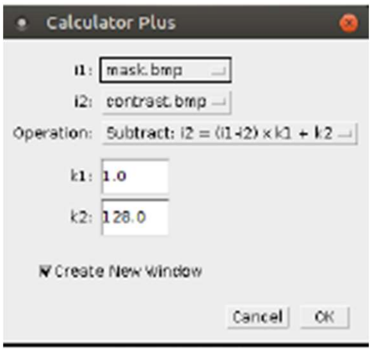
1. *Open* the files **mask**.bmp and **contrast**.bmp in ImageJ.
   These two images were acquired using an X-Ray image intensifier and TV camera. The image mask.bmp shows a wire mesh and contrast.bmp shows the same wire mesh together with a small block of tissue equivalent material.

   Digital subtraction techniques in medical imaging are designed to enhance the contrast in an image by subtracting the background (i.e. that part of the image that remains unchanged) and leaving just the tissues of interest.

2. Use **Process – Calculator Plus** to do the following:

   (mask.bmp − contrast.bmp) × 1 + 128

   (the 128 offset is to allow for negative differences which would otherwise be truncated to 0. Make sure that the multiplier box is 1.)
   Then *click* ***OK***. This will generate a third image titled "Result".



Question 5.1 Simple Subtraction

Comment on the effectivity of the removal of the mesh lines in the new file "Result".

3. *Select* file **mask**.bmp and perform **Process – Math – Log**. This will change the way the image looks.

   *Repea*t the same on file **contrast**.bmp.

   Then repeat the subtraction of the contrast image from mask image with **Process – Calculator Plus**.

   The previous values should still be filled in. *Confirm* and *click* ***OK***.

Question 5.2 Log subtraction

Compare this second Result image with the previous Result image.

b) Intensity Uniformity Correction

4. *Close* all image windows. Open the files **mask**.bmp and **uniformity**.bmp.

   The uniformity image was acquired with the same image intensifier but with no objects in the x-ray beam.

5. Looking at the image, you can clearly see a falloff in intensity towards the edges of the image. To correct for this, you need to get a profile plot.

   Select the *line selection tool* from the tool window and draw a line across the middle of image **mask**.bmp, *being very careful to avoid the horizontal mesh line.*

6. To *generate* a graph, select **Analyse – Plot Profile** to plot a horizontal profile across the centre of **mask**.bmp.

Question 5.3 Horizontal Profile before Intensity Uniformity Correction

Paste the profile of the plot graph of **mask**.bmp under Question 5.3 in your Answer Booklet.

You are now going to use **uniformity.**bmp to correct for sensitivity non-uniformities of the image intensifier.

7. *Use* **Process - Calculator Plus** to perform the uniformity correction

$$\frac{\text{mask.bmp}}{\text{uniformity.bmp}} \times 255 + 0$$

(the multiplication by 255 is to scale the result to 8-bit integers.)

This will generate a new “Result” image.

8. *Repeat step 6* to plot (graph) the image **uniformity**.bmp.

Question 5.4 Corrected Intensity Uniformity

Paste the plot graph produced on the image uniformity.bmp under Question 5.4 in your Answer Booklet.

9. *Repeat step 6* to plot (graph) the image Result.

Question 5.5 Horizontal Profile after Intensity Uniformity Correction

Paste the profile plot produced on the image Result under Question 5.4 in your Answer Booklet.

Question 5.6 Outcome of Intensity Uniformity Correction

Has the sensitivity non-uniformity been corrected? Explain how the profile plot confirms your answer. Give a reason for any unexpected results.

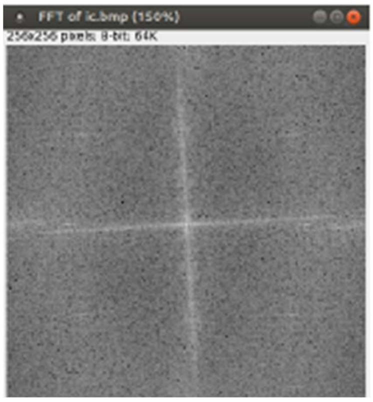
c) Frequency Filtering: High pass filtering

10. *Close* all the image windows. *Open* the image **ic**.bmp. This is an electron microscope image of part of an integrated circuit.

11. Zoom in on the image and you will observe a pattern - which is not random noise - present everywhere in the image. This may be removed if we perform high pass filtering in the frequency domain. A mathematical process known as a Fourier Transform can be used to accomplish this.

12. Perform a Fast Fourier Transform (FFT) on the **ic**.bmp image by *selecting* from the menu **Process – FFT – FFT**.

    The image obtained shows the lower frequency items in the image, e.g. main structures (or slow changing regions) of the image, in the middle, and higher frequency items, like the finer details, closer to the edge. It is not a trivial matter to decode what one sees in such an image.

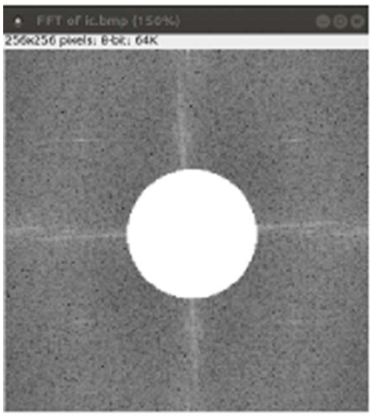


13. To isolate the higher frequencies (the detail), we need to remove the lower frequencies. We do this by applying a **High Pass Filter** to the *FFT*.

    Use the *circular selection tool* and *draw a circle* in the *center* of the Fourier transform so thatit covers approximately a third of the image. Then *select* from the menu **Edit - Cut** (or **Clear**) to remove the low frequencies from the middle of the Fourier transform, as shown on the image on the next page.

    Note: in the frequency spectrum (0,0) is at the center of the frequency transform.

    Then invert the process by selecting from the menu **Process – FFT – Inverse FFT** and observe the effect of the filtering process on the newly created image, compared to the original one.



Question 5.7 Using a High Pass Filter in the Frequency Domain

Describe the effect of applying a High Pass Filter on an image. (If you do not see a significant improvement in at least one aspect try increasing or decreasing your blocked out area.)

You may notice that the FFT high pass filter has produced ringing artefacts on each side of the sharp edges in the image. Use the zoom tool to magnify the image to see these. This is caused by the very sharp cut-off between the passed frequencies (pass-band) and the suppressed frequencies (stop-band). This ringing can be reduced by allowing a more gradual transition from the pass-band to the stop-band. Ringing artefacts are also called ghosting.
Try to eliminate as much of this artefact as possible when answering Question 5.7.

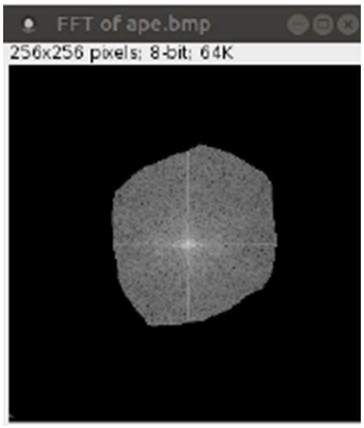
d) Frequency Filtering: Low pass Filtering

15. *Close* all image windows. *Open* the file **ape**.bmp. This is a good image to do low pass filtering on because it has lots of high frequency structures that we can try and remove.

16. Perform low-pass filtering in Fourier transform on the image by *selecting* from the menu **Process – FFT – FFT.** Once you have the FFT image of the age, select the **eraser** from the Tools window and use it to *erase areas* at the outer edge.
If you do not see the eraser, select the rightmost double arrow on the button menu and select "**Drawing tools**"

You can also draw a circle and use **Edit – Clear Outside** to create the low pass filter. This option creates a more symmetrical filter.

The example below shows a **low pass filter** of about 40% achieved using the Eraser tool.



17. When you have removed some of this area and want to see the impact on the image, then *select* from the menu **Process – FFT – Inverse FFT**.

Question 5.8 Using a Low Pass Filter in the Frequency Domain

Describe the effect of applying a Low Pass Filter on the FFT has on the filter (If you do not see a significant difference increase or decrease your blocked out area.)

18. *Repeat* removing more and more of the high frequencies until only a tiny area of low frequencies remain at the center of the frequency image. This will make the whiskers of the mandrill ape appear to fade away.

Question 5.9 Removing a High Percentage of High Frequencies

Approximately what percentage of the high frequency spectrum, i.e. the gray area of the transform around the edges, has to be removed before the ape's whiskers appear to fade / disappear?

To enhance your learning you can play with differently sized low pass and high pass filters applied to both the ic and the ape images, predict what you thing the inverse Fourier transform will look like, and then perform the inverse Fourier transform to see how accurate your prediction was. Once you are able to form an understanding your predictions will become more accurate.

e) Feature Removal

19. *Close* all image windows. Open the file **house**.bmp. Each part of the drawing of the house is made of lines of different frequencies and orientations.

Frequency filtering can be used to remove some of these features, e.g. we can remove the vertical stripes from the wall as follows:

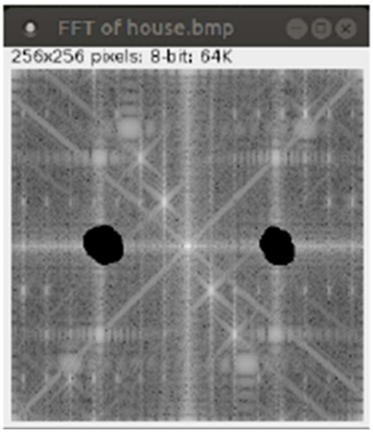
• Perform a Fourier transform by *selecting* menu **Process – FFT – FFT**.

• *Remove* those frequencies corresponding to the lines on the wall. These can be removed either by using the *circular selection tool* from the Tools window and then select menu **Edit – Cut** or **Edit - Clear**, or you can *just erase* the area with the eraser tool.

To look at the new image perform an inverse Fourier transform by selecting menu **Process – FFT – Inverse FFT**.

Hint: the vertical lines on the wall represent a frequency in the horizontal direction, as indicated on the image on the next page.

Once again play around until you are able to predict with some degree of accuracy the outcome of the filter you apply to the Fourier transform.



20. *Open* a fresh copy of **house**.bmp and use frequency filtering as described on the previous page to remove only the diagonal lines that are *in the two windows*, *leaving all other lines untouched, and without creating any artefacts*.

Question 5.10 Removing Specific Features by Applying Filters in the Frequency Domain

a) Copy and paste your Fourier Transform, showing which frequencies you've filtered out.

b) Copy and paste the altered image of the house (i.e. the inverse Fourier transform)

This concludes **Exercise 5**.

Exercise 6 **11 Marks**

Uses File explorer and Photo Viewer

Aim:
To investigate image compression

Note: in the text that follows the file prefix LP, which appears in lowercase as lp, is short for **l**ine **p**airs.

a) Lossy Compression

1. In File Explorer *open* the folder **Exercise6** images.

2. *Hover the cursor* over the file **lp_phantom**.bmp and its file size will be shown (137kB for HP or other laptops supporting Windows). You will find that this has already been recorded on the answer sheet. If you are using a MacBook draw a line through the 137 kB and type in the file size as shown on your device.

   If a pop up box with file size does not appear automatically, you can *Right click* on the image which will bring up a menu, then *Left click* to select **Properties**.
   Note you are interested in **file size**, not size on disc.

3. *Open* the folder **LossyLossless**, and then *open* **Jpeg**.

4. Find the file size for **lp_phantom_100**. As per step 2 get the size of this file (46.7kB). It too has already been recorded on to the answer sheet. (Replace for MacBook.)

5. *Repeat* for the files **lp_phantom 80**, **lp_phantom_40**, **lp_phantom_10** and **lp_phantom_1**.

   The number following the lp_phantom_# indicates the **percentage of compression** used to store the file; lp_phantom_100 is the conversion from bmp to jpeg, lp_phantom_80 is stored with 80% compression, lp_phantom_60 is stored with 60% compression, etc.

6.1 *Calculate* the compression ratios and record the answers in the Q1 table.

$$\text{Compression Ratio} = \frac{\text{Original file size}}{\text{Compressed file size}}$$

e.g. Compression Ratio = 137 KB / 46.7 KB, = 2.9 (one decimal place).

6.2 Continue to calculate the compression ratios for files **lp_phantom_80**, **lp_phantom_40**, **lp_phantom_10**, and **lp_phantom_1**.

Question 6.1	**File sizes and Compression Ratios for JPEG storage (lossy)**
Complete the table in the answer booklet.	

7. Now look at each of the lossy compressed images **lp_phantom_100**, **lp_phantom_80**, **lp_phantom_40**, **10** & **lp_phantom_1.**

   To do this *click* on the image file and *Right click* which will bring up a menu. Use *Left click* to select **Open with (not Edit with)** and then *select* **Photos.**
   You can scroll through each of the compressed images – position your cursor in the image, you'll see a < on the left and a > on the right side of the window – click on these. Click on the magnifying glass with the + use the slider to zoom in, in order to compare for example **lp_phantom_100** and **lp_phantom_80**

Question 6.2	**Compression of JPEG (continued)**
At what JPEG Quality Factor do you feel that the loss of image data becomes obvious?	

Question 6.3	**Compression of JPEG (continued)**
As the JPEG Quality Factor decreases, which components of the image are the first to be affected?	

8. *Close* all the open files and images.

a) Lossless Compression

9. In File Explorer return to the folder **Exercise 6** images.

10. *Hover the cursor* over the file **Ip phantom LZW**.bmp and its file size will be shown (137KB). This has already been recorded on the table under Question 4 in the answer booklet.

    If a pop up box with file size does not appear automatically, you can *Right mouse click* on the image which will bring up a menu, then *Left mouse click* to select **Properties**. Note you are interested in file size, not size on disc.

11. Repeat step 10 for the files **Ip phantom LZW**.tiff and **Ip phantom LZW+Differencing**.tiff. Record the files size in the table under Question 4 on the answer sheet.

Question 6.4 File Sizes and Compression Ratios for LZW storage (lossless)

Record the file sizes in the table on the answer sheet. Then calculate the compression ratios.

12. Look at each of the lossless compressed images. Do they look different from the original? To compare *click on* the image file and *Right click* which will bring up a menu. Use *Left click* to select **Open with (not Edit with)** and then select **Photos**.
    You can scroll through each of the compressed images. Take note of any differences in image quality.

13. Now *Open* the folder **LossyLossless** again, and then *open* **PNG**.

14. These images have been stored at different compression rates. Scroll through them and pay attention to the image quality.

Question 6.5 Compare lossy and lossless compression ratios and corresponding image quality.

Compare and comment on the compression ratios for lossless and lossy compression, and the corresponding image quality.

Question 6.6 Compression algorithms applied to radiography

Suggest suitable applications for each of lossy and lossless compression in Radiography specifically. Comment of the type of files that could be stored using lossy compression, and which types should be stored using lossless compression.

The following table should give you more insight.

Compare Lossy and Lossless Compression:

Lossy	Lossless
Data is altered or lost	Data not altered or lost
Reduces the file by permanently eliminating certain – especially redundant - information	Every bit of data that was in the original file, remains after the file is decompressed
Examples: JPEG, MPEG for videos	Examples: Tiff, PNG, GIF, Lempel-Ziv-Welch algorithm encountered above. Also BMP (which is proprietary, developed for MS Windows)

This concludes the Digital Image Lab

Hope you've had some fun,
and found the application of the theory
interesting and useful.