Nikos Nikolaidis   Ioannis Pitas

3-D Image Processing Algorithms

Lab exercises in EIKONA 3D

Chapter 2

Volume Filtering / Interpolation

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Exercise 2.1: Filtering an image

In this exercise we show how to use EIKONA3D to filter a volume with some of the available 3-D filters. The filters we are going to use are the following:

- moving average filter
- minimum / maximum filter
- median filter
- weighted median filter.

2.1.1. Filtering an image with the moving average filter

Lets suppose that we have loaded in volume 0 a 128x128x128 grayscale 3-D image from the files head0.tif to head127.tif (Figure 1). To apply the moving average filter in this image one has to follow the procedure described bellow.

Figure 1: The 33rd frame of the 'head' image.

- Choose the "**Operations→Filtering→Moving Average Filter**" menu option.
- The *Input Volume* dialog box appears on screen (Figure 2). This dialog box is used to select the volume on which the filter will be applied. Click on volume "0" and then click the "OK" button to continue. If desired one can also change the Volume of Interest (VOI) as described in the previous chapter. By doing so the filtering procedure will be applied only on the sub-part of the volume defined by the volume of interest.
- At this time, a dialog box that prompts us to select the volume where the output will be stored appears on the screen. One may select an already existing volume or create a new one (Figure 2).
- Then a dialog box where the user specifies the filter window dimensions appears. In our example we will use a 3x3x3 filter window (Figure 3). If the z dimension is set to one, the procedure is equivalent to performing 2-D filtering independently on each frame.

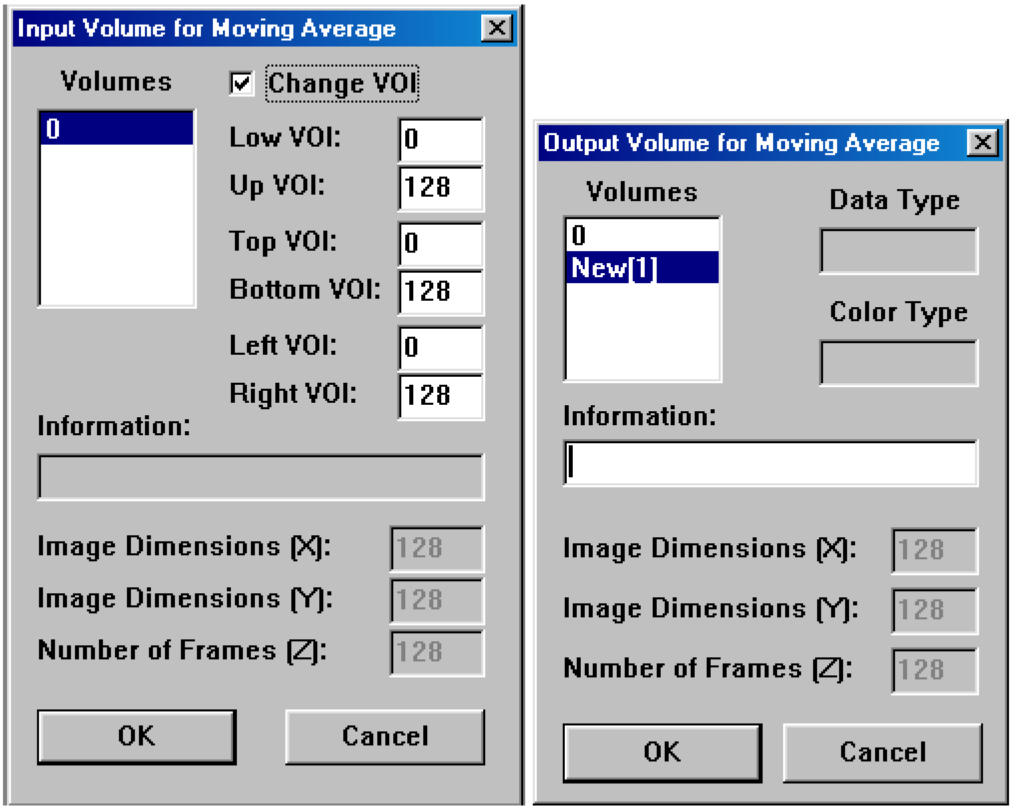


Figure 2: The input and output volume dialog boxes.

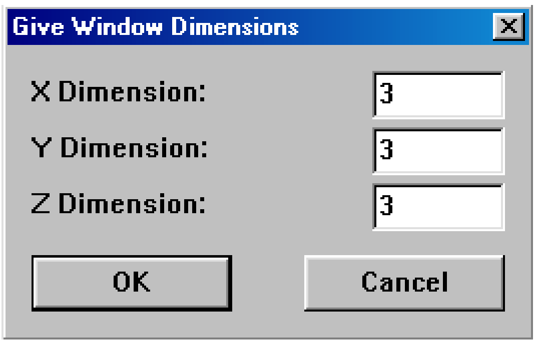


Figure 3: The window dimension selection box.

Upon completion of the above procedure, the filtered volume is automatically displayed on the screen. The 33rd frame of the filtered volume is depicted in Figure 4.

Figure 4: The 33rd frame of the 'head' 3-D image filtered by the moving average filter.

2.1.2. Filtering an image with the minimum and maximum filters

A similar procedure must be used in order to apply the minimum or the maximum filter on a 3-D image. For using the minimum filter one should do the following:

- Choose the "**Operations→Filtering→Min Filter**" menu option
- Select input and output volumes (Figure 2).
- Decide for the filter window dimensions (Figure 3).

Upon completion of the above procedure, the output volume containing the filtered image is automatically displayed on the screen. The 33rd frame of the 'head' volume after applying the minimum and the maximum filters can be seen in Figure 5.

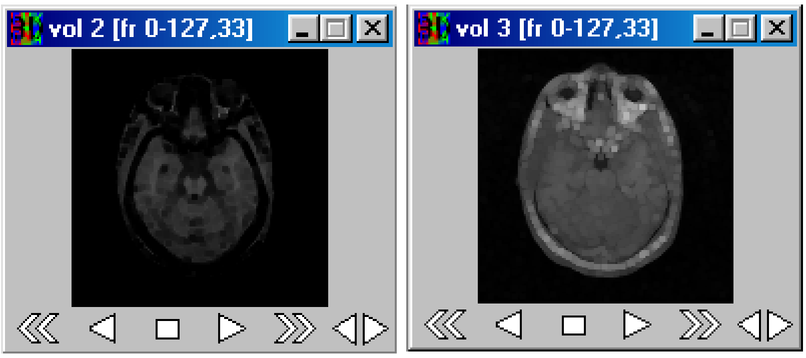


Figure 5: The 33rd frame of the 'head' 3-D image filtered by the min and max filter.

2.1.3. Filtering a 3-D image with the standard median filter and the weighted median filter.

The median family of filters includes the standard median, the running median the multistage median and the weighted median filters. In this section we will see the procedure for applying the standard and the weighted median filter on the ‘head’ 3-D image.

The procedure for applying the standard median is the similar to that described in the previous sections:

- Choose the “**Operations→Filtering→Median Filters→Standard Median**” menu option.
- Select an input and an output volume (Figure 2).
- Set the filter window dimensions (Figure 3).

The result of the median filter on the 33rd frame of the ‘head’ 3-D image is shown in Figure 6.

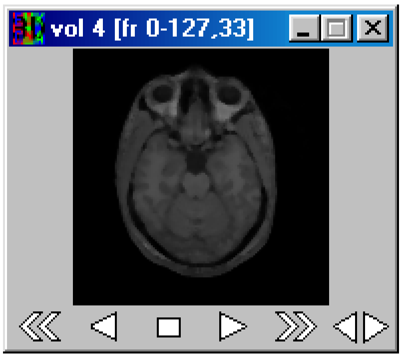


Figure 6: The 33rd frame of the ‘head’ 3-D image filtered by the standard median filter.

The weighted median filter replicates the samples within the 3-D window according to a set of weights and then calculates their median value. Every weight value, specifies how many times will the corresponding voxel be replicated before calculating the median on the specified window. Thus, a voxel that has been assigned a weight equal to 3 is replicated three times before proceeding to the median evaluation. By assigning bigger weights on certain image voxels we can increase their impact on the output value. The procedure for applying the weighted median filter is the following:

- Choose the “**Operations→Filtering→Median Filters→Weighted Median**” menu option.
- Select an input and an output volume (Figure 2).

At this stage a dialog box that allows us to select the weights source appears on the screen. Two options are available (Figure 7):

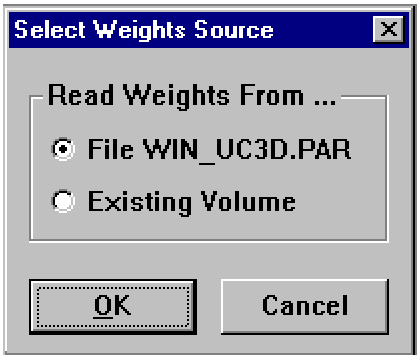


Figure 7: The weight source selection box.

A. Load the weights from a text (ascii) file. This file should be named win_uc3d.par and should reside in the same folder as the EIKONA3D executable. An example of a win_uc3d.par file can be seen in Figure 8 . The first three lines specify the window dimension whereas the rest of the values it contains, specify the weights in a frame/row/column manner. In our case we have weighted the central voxel of the 3x3x3 window with a weight equal to 3 and all other voxels with weights equal to 1.

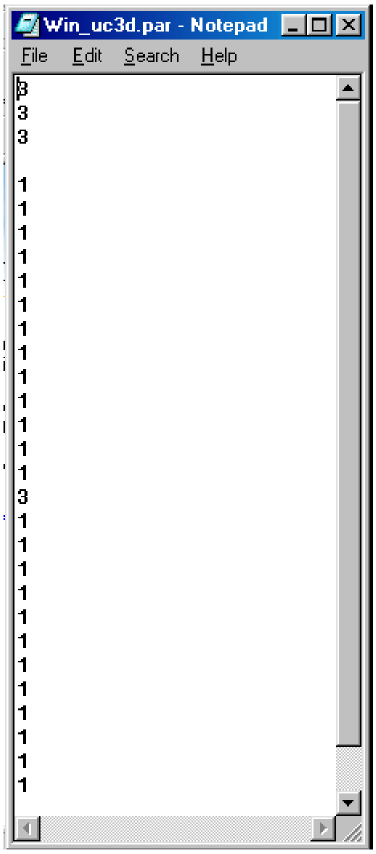


Figure 8: The WIN_UC3D.PAR file containing the weights for the weighted median filter.

Upon completion of the weights loading operation the weights are stored in a new volume of appropriate dimensions. The dialog box shown below (Figure 9) informs us where the coefficients from the file WIN_UC3D.PAR have been loaded (volume 99).

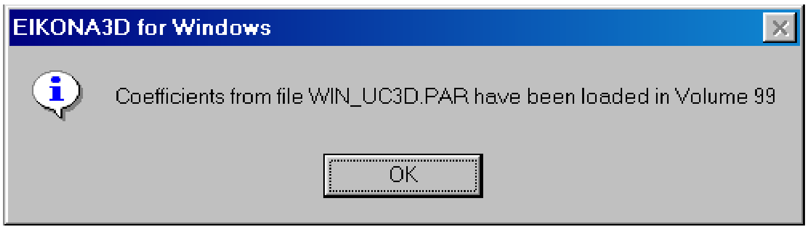


Figure 9:

B. Select an existing volume to read the weights from, i.e. use as weights the voxel values of a volume of appropriate dimensions. For example if a 3x3x3 window is to be used, the weights can be determined by the intensity values of a 3x3x3 volume. So if the user selects the option `Existing Volume' in the 'Select Weights Source' dialog box, he must specify the (already existing) volume from where the weights will be taken (Figure 10).

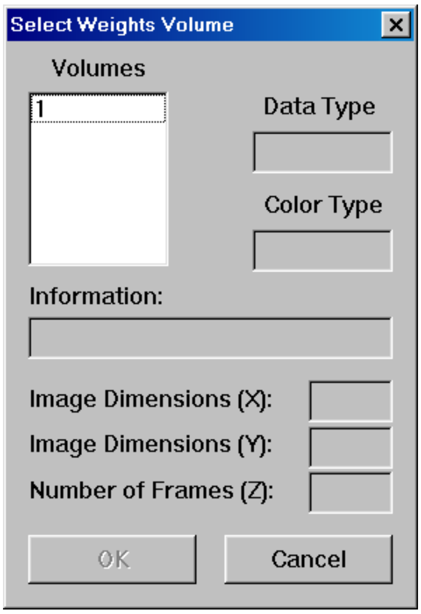


Figure 10: The Select Weights Volume dialog box.

Upon completion of the above procedure, the output volume containing the filtered image is automatically displayed on the screen. (Figure 11)

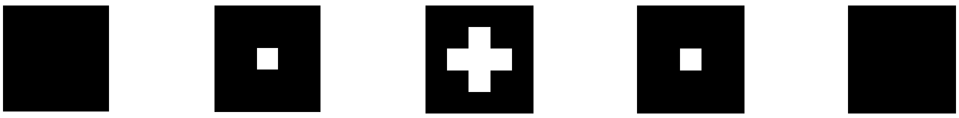
Figure 11: The 33rd frame of the 'head' image filtered by the weighted median filter.

Exercise 2.2: Morphological Operations.

In this exercise we use EIKONA3D in order to perform mathematical morphology operations on binary objects represented by binary (bi-valued, 0 and 255) volumes. In each example an operation between a binary version of the 'head' volume and a binary volume containing a structuring element is performed.

The binary version of the 'head' volume is constructed by applying thresholding (***"Operations→Region Segmentation→Threshold"***) on the original 'head' data and by choosing an appropriate threshold factor in the corresponding dialog box. For a more detailed description of thresholding please refer to chapter 5.

The structuring element that will be used in all subsequent examples, is a 3-D cross. It consists of 5 frames of dimensions 5x5 and it is illustrated in Figure 12.



(a) (b) (c) (d) (e)

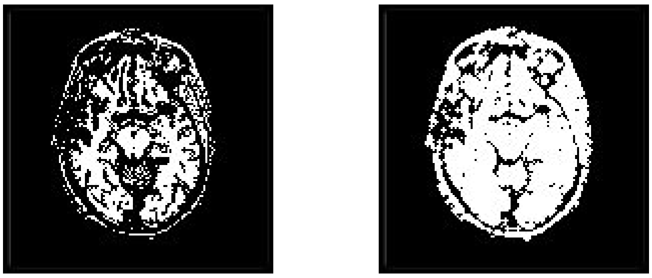
Figure 12: The five frames of the 3-D cross structuring element.

This structuring element is provided along with this file (filenames: s_element0.tif… s_element4.tif). In all sections below we will assume that the binary version of 'head' is stored in volume 0 and that the structuring element resides in volume 1.

2.2.1 Dilation

In order to perform dilation of the binary 'head' volume with the binary structuring element we have to select ***"Operations→Morphology→Dilation"*** from the main menu. In the *Select Input Volume* dialog box that appears on the screen, we choose volume 0 and in the following *Select Output Volume* dialog box we choose New[2] to be the volume in which the result will be stored. Finally, in the *Select Structuring Element Volume* dialog box we select volume 1.

In Figure 13 a frame of the binary version of the 'head' volume and the same frame after applying dilation to the entire volume with the 3-D cross structuring element are presented. Obviously, dilation is an expanding operator.



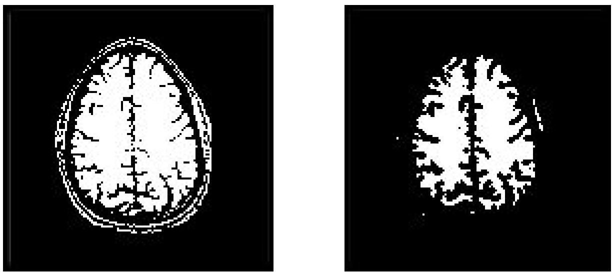
(a) (b)

Figure 13 : (a) A frame of the binary 'head' volume and (b) the same frame after applying dilation with the 3-D cross structuring element.

2.2.2 Erosion

In order to perform erosion, we have to select the menu path ***"Operations→Morphology→Erosion"***. In the *Select Input Volume* dialog box that appears, we select volume 0 and in the *Select Output Volume* dialog box we select New[2]. Finally, we select the structuring element from volume 1 and by clicking on the "OK" button the new binary volume appears.

In Figure 14 a frame of the binary version of the 'head' volume and the same frame after eroding the entire volume with the cross structuring element are depicted. It is obvious that erosion shrinks the object.

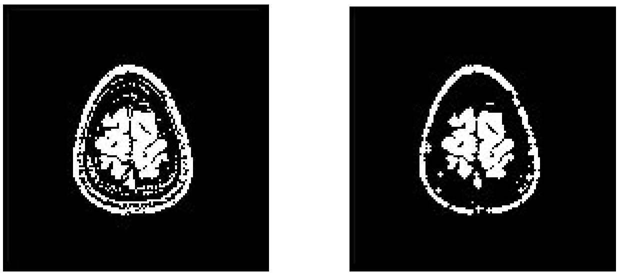


(a) (b)

Figure 14 : (a) A frame of the binary 'head' volume and (b) the same frame after applying erosion.

2.2.3 Opening

In order to perform opening of the binary 'head' volume with the given structuring element, we have to select the submenu ***"Operations→Morphology→Opening"*** and subsequently specify the input and output volumes and the structuring element volume in a way similar to the one described in the previous section. Results can be seen in Figure 15.



(a) (b)

Figure 15 : (a) A frame of the 'head' volume and (b) the same frame after applying morphological opening.

2.2.4 Closing

To perform closing of a binary volume with a structuring element we have to select ***"Operations→Morphology→Closing"*** sequentially from the main menu and repeat the volume selection operations described in the previous sections. Results can be seen in Figure 16.

(a) (b)

Figure 16 : (a) A frame of the 'head' volume and (b) the same frame after applying morphological closing with the cross structuring element.

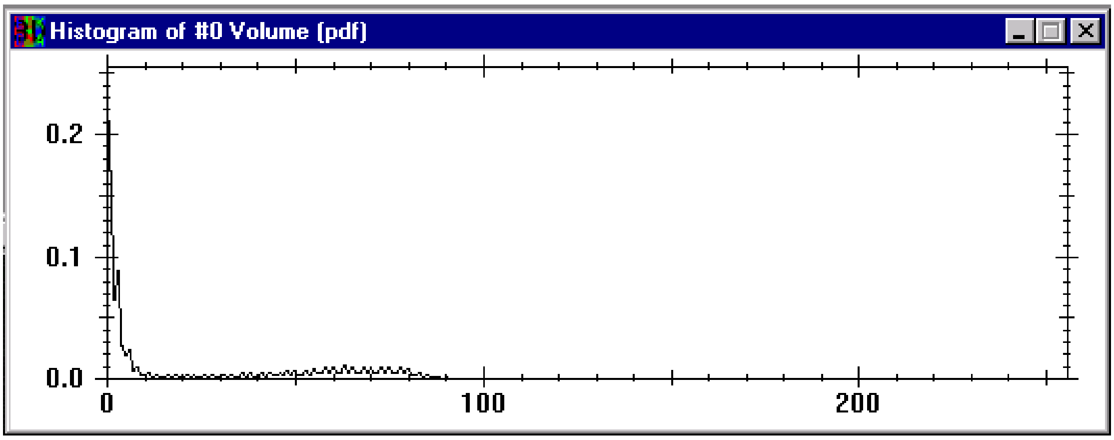
Exercise 2.3: Histogram Evaluation/Equalization.

In many cases we are interested in improving the visual quality of a 3-D image. The contrast of an image can be improved by performing histogram equalization. In this exercise we evaluate the histogram (empirical probability density function, *pdf*) and the cumulative histogram (empirical cumulative density function *cdf*) of the 'head' volume and then perform histogram equalization.

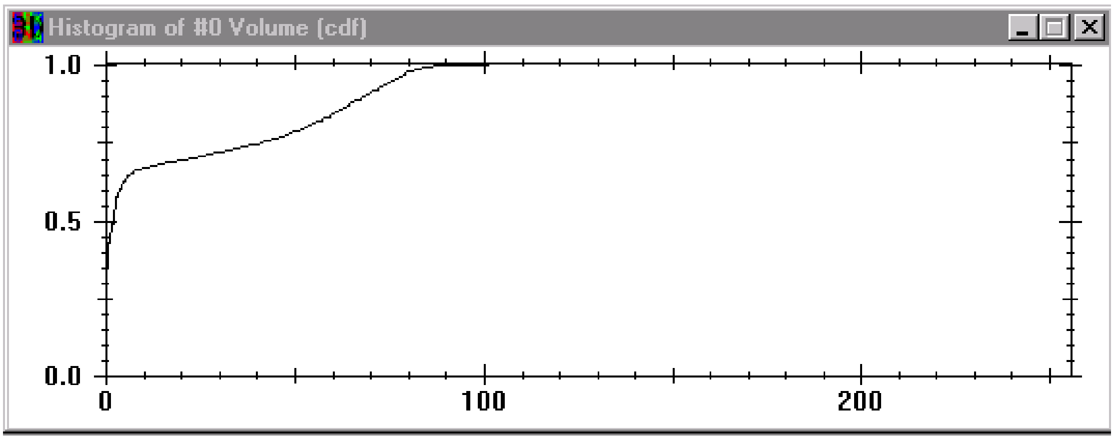
2.3.1 Histogram Evaluation

The histogram and the cumulative histogram of a 3-D image provide information about the distribution of the voxel intensity values. The histogram can be computed by selecting ***"Operations→ Analysis→Histogram→Histogram(pdf)***" whereas the cumulative histogram can be evaluated by selecting ***"Operations→ Analysis→Histogram→Histogram(cdf)"***. If the 'head' Volume is loaded in Volume 0 we choose *0* in the *Select Input Volume* box that appears. After pressing the "OK" button, the histogram is displayed in a new window.

The histogram and the cumulative histogram of the 'head' volume are presented in Figure 17.



(a)



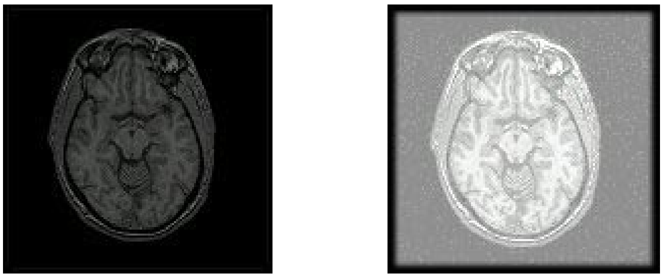
(b)

Figure 17 : (a) The histogram and (b) the cumulative histogram of the 'head' volume.

2.3.2 Histogram Equalization

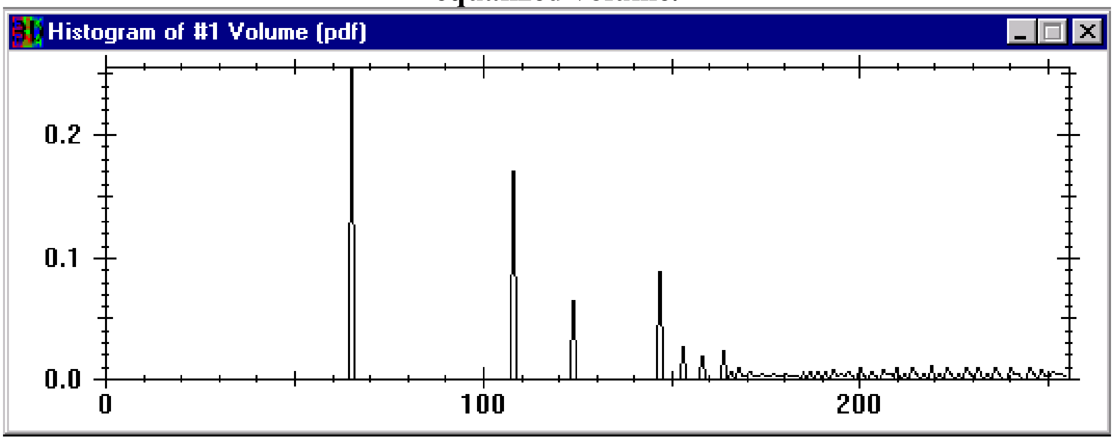
In this section we will explain how one can perform histogram equalization on the 'head' volume and store the resulting image in a new volume. Histogram equalization transforms the brightness values of the voxels in an image so that the histogram of the resulting image tends to become uniform. It can be performed by selecting the menu option ***"Operations → Filtering→Histogram Equalization"***. If the Volume 'head' is loaded in Volume 0, we choose *0* in the *Select Input Volume* dialog box and New[1] in the *Select Output Volume* dialog box. After pressing the "OK" button, the resulting volume is displayed in a new window.

A frame of the equalized volume is shown in Figure 18, while the volume histogram (pdf and cdf) is given in Figure 19. These histograms were computed by following the procedure described in the previous paragraph.

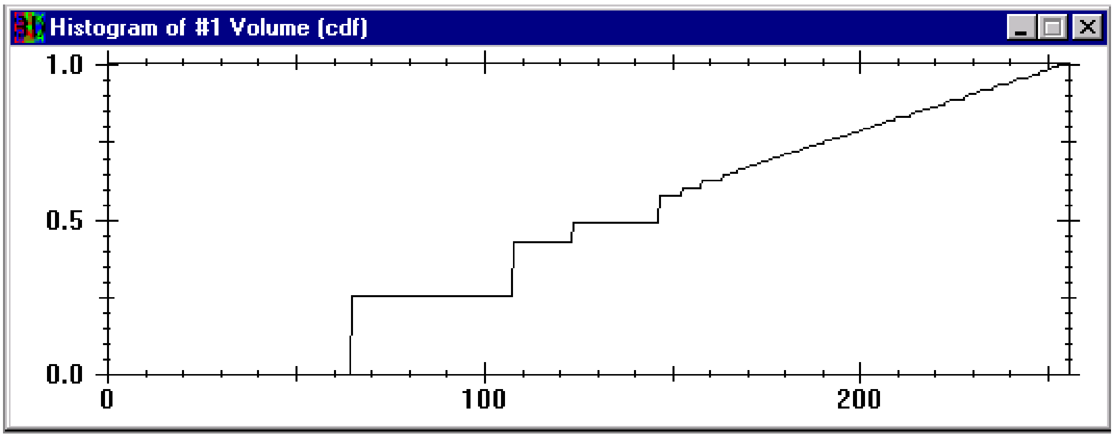


(a) (b)

Figure 18 : (a) A frame of the 'head' and (b) the same one in the histogram equalized volume.



(a)



(b)

Figure 19 :The histogram of the 'head' volume after histogram equalization; (a) pdf and (b) cdf.

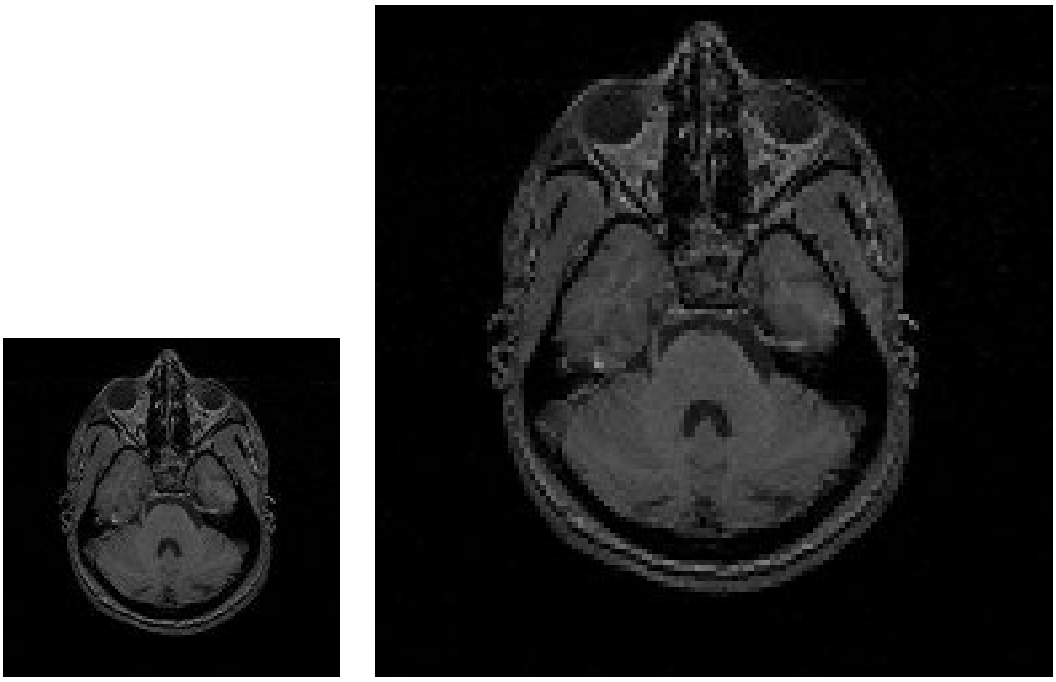
Exercise 2.4: Interpolation/Resizing.

In this exercise we use EIKONA3D in order to perform operations that change the size of a volume. We will assume that the 'head' volume is loaded in volume 0.

2.4.1 Uniform Zooming

To enlarge the volume with the same zooming factor for all three dimensions, we have to select the menu option ***"Operations→Resizing→Uniform Zooming"***. In the *Select Input Volume* dialog box we choose *0* and in the *Give Zooming Factor* dialog box we choose the desired value of the zoom factor. Note that the zooming factor should be integer. Finally, in the *Select Output Volume* dialog box we choose New[1] to be the volume in which the result will be stored. Obviously, the number of frames of the output volume is equal to the number of frames of the input volume multiplied by the selected zoom factor.

In Figure 20 a frame of the 'head' volume and the same frame after applying uniform zooming with a zoom factor equal to 2 are depicted.



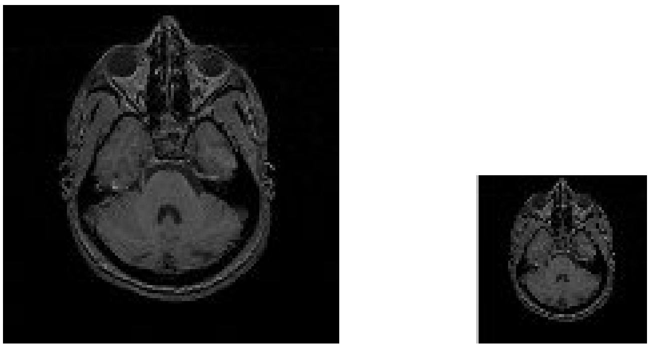
(a) (b)

Figure 20 : (a) A frame of the 'head' volume and (b) the same frame after performing uniform zooming with zoom factor equal to 2.

2.4.2 Uniform Decimation.

To decimate (zoom out) the volume with the same decimation factor for all three dimensions we have to select the menu option ***"Operations→Resizing→Uniform Decimation"***. In the *Select Input Volume* dialog box that appears, we choose 0 and in the following *Give Zoom Factor* dialog box we choose the (integer) value of the desired decimation factor. Finally in the *Select Output Volume* dialog box we select New[1] to be the volume in which the result of the procedure will be stored. The number of frames of the output volume is equal to the number of frames of the input volume divided by the decimation factor.

In Figure 21 a frame of the 'head' volume and the same one after applying uniform decimation (decimation factor: 2) are shown.



(a) (b)

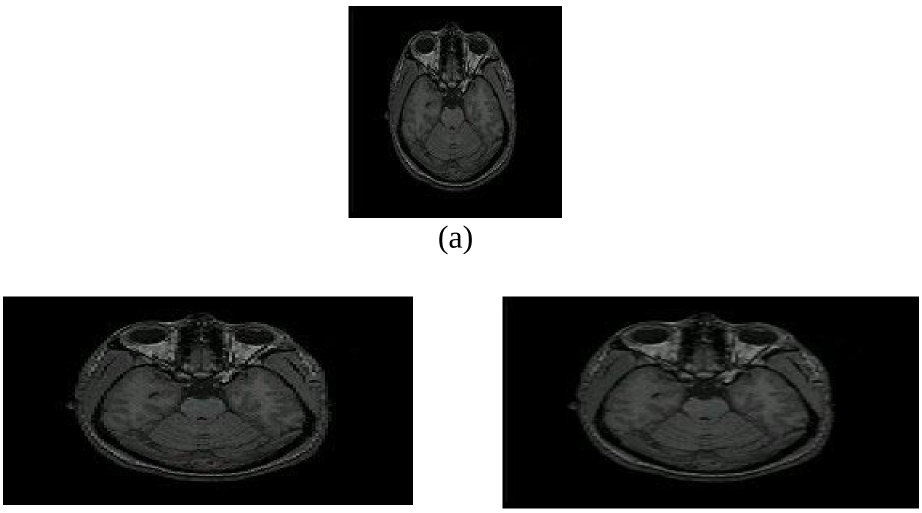
Figure 21 : (a) A frame of the 'head' volume and (b) the same frame after uniform decimation with decimation factor equal to 2.

2.4.3 3D Interpolation / Decimation.

EIKONA3D provides the functionality of resizing (interpolating/decimating) a volume using different interpolation/decimation factors for each of the three dimensions (non-uniform zooming). This can be achieved by selecting ***“Operations→Resizing→3D Interpolation/Decimation”*** from the main menu of EIKONA3D. After selecting the Input Volume to be 0, we have to select the interpolation factors for the X, Y, and Z dimensions in the dialog box that appears. Note that unlike the uniform decimation/interpolation operations described above, the ``3D Interpolation/Decimation” operation accepts decimal factors. Whether interpolation or decimation will be performed depends on the choice of the corresponding factor. In other words, a factor that is smaller than unity (e.g. 0.7) leads to decimation whereas a factor greater than unity (e.g. 2.4) leads to interpolation. We should also select the interpolation method (*Linear* or *Nearest Neighbor Interpolation)* in the same dialog box.

Finally, one should select the output volume in the ``Select Output Volume’’ dialog box. It should be noted that instead of providing the decimation/interpolation factors one can require that the resulting volume is of certain dimensions. This can be done by checking the ``*Extract factors from output volume*’’ option in the ``3-D Interpolation options’’ dialog box and select an existing volume having the desired final dimensions in the ``Select Output Volume’’ dialog box.

In Figure 22 a frame of the ‘head’ volume interpolated using linear and nearest neighbor interpolation with interpolation factors 2,1,1 in the X, Y and Z dimensions respectively is presented.



(a)

(b) (c)

Figure 22 : (a) A frame of the ‘head’ volume; the same frame after performing linear (b) and nearest neighbor (c) interpolation with interpolation factors 2,1,1 at the X, Y, and Z dimensions respectively.

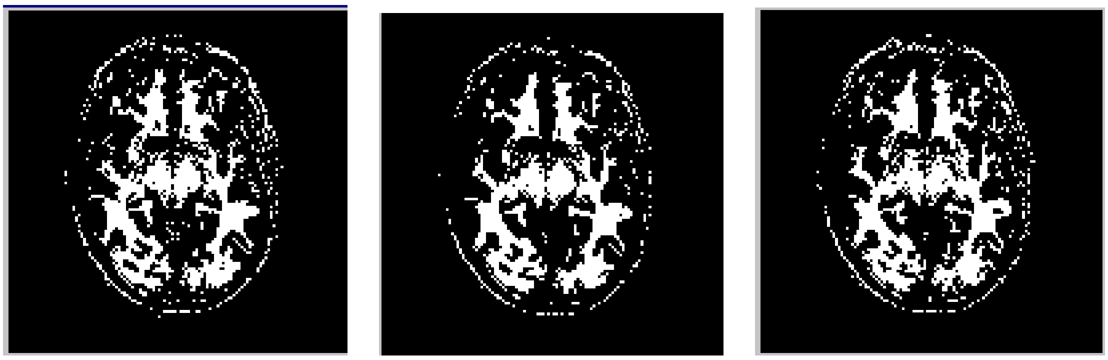
2.4.4 Frame Interpolation / Decimation.

In order to change the number of frames in a volume we should restrict Interpolation/Decimation in the Z dimension. This can be done by selecting ***"Operations → Resizing → Frame Interpolation/Decimation"***. The procedure is exactly the same with the one described in the previous section the only difference being that in the ``Interpolation options'' dialog box the user can control only the interpolation factor along the Z dimension (frames).

2.4.5 Binary Frame Interpolation

Let us suppose that we have loaded in volume 0 a binary version of the 'head' volume, which was created by applying a thresholding operation on the original 'head' volume. We can perform shape-based binary interpolation if we select ***"Operations → Resizing → Binary Frame Interpolation"*** from the main menu. In *the Select Input Volume* dialog box we choose 0 and in the *Binary Frame Interpolation Options* dialog box that follows, one can select to interpolate one or two frames between each pair of existing frames. The ``*use edge coherence*'' option is also available in the same dialog box. Finally, in the *Select Output Volume* dialog box we choose New[1]. As a result of this operation, the number of frames of the binary volume doubles or triples respectively.

In Figure 23 two frames of the binary 'head' volume and the frame that has been interpolated between these frames are illustrated.



(a) (b) (c)

Figure 23 : (a), (b) Two frames of the binary 'head' volume and (c) the frame that has been interpolated between these two frames using binary frame interpolation.