Diffusion Mapping with *FireVoxel*

Quick Start Guide

FIREVOXEL

Medical image analysis tool developed by
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FireVoxel (FV) is a MS Windows software for visualizing and analyzing medical images. The main types of data analyzed by FireVoxel are:

- 3D volumes resulting from acquisitions MRI, CT, PET, SPECT instruments
- 4D datasets, typically representing a dynamic time series of 3D volumes.
- 3D/4D ROIs linked to above data

Installation

https://wp.nyu.edu/firevoxel/ is a web page from which you can download the software, quick guides, and sample data. For the initial installation

- Download FireVoxel.zip from the link on https://wp.nyu.edu/firevoxel/downloads page
- Extract files from FireVoxel.zip to a new folder. This will include **readme.txt**
- Run vcredist_x86.exe if needed
- Launch FireVoxel.exe
- Paste your computer ID to the email addressed to hr18@nyu.edu
- The reply will include FireVoxel.key to be saved in your folder

To upgrade to the newest version, download and extract new version files, and overwrite your older files. There is no need for a new FireVoxel.key This guide was done on FV version (or build) 127. Click on **Help>About this Application** to see the build number.

Introduction

This quick Start Guide shows how to process dynamic (or 4D) datasets and generate voxel-based parametric maps. Our example is the MRI based measurement of water diffusion in renal lesions. Diffusion, or randomized microscopic movement of water molecules, can be useful to characterize the tissue. Diffusion MRI is performed using strong bipolar pulses called diffusion gradients. Their strength is measured with b-values (units of s/mm^2). While diffusion-weighted MRI is highly sensitive to motion (patient motion, breathing), with modern equipment radiologists are successful in measuring tissue diffusion even for abdominal evaluations.

MRI measurements of water diffusion coefficient are affected by temperature and magnetic properties of the tissue. We therefore use the term "apparent diffusion coefficient" or ADC (units of mm^2/s). To compute ADC we acquire a series of volumetric images, each volume at a different b-value. ADC is solved by fitting the exponsntial formula: $SI(b) = SI(0) \exp(-b \times ADC)$, where SI(b) is the signal intensity for a given b, to measured data. Please download and expand MRI diffusion files **diffusion_sample.zip** to continue this guide.

Step 1

When you start FV you will see its main window, the toolbar on the right margin and only a few menu items, including **File** and **Help**. The gray document area is initially empty. Make sure that the vertical resolution of your screen is fine enough to show the entire toolbar.
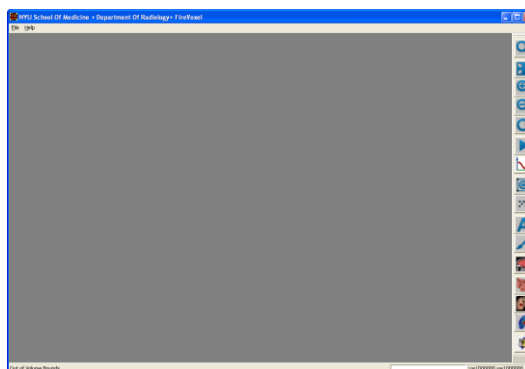
Step 2

To analyze water diffusion we will use kidney MRI dataset diffusion_sample provided in a DICOM file format. You will need to unzip the file into an empty folder before loading it into FV. Then go to **File** item of the main menu and select the **Open DICOM Single** submenu. *Browse for Folder* dialog box will now appear in order to navigate to a folder that contains your (unzipped) sample dataset. You may also select a higher-level folder, but the higher the level, the longer it will take to load.


Step 3

DICOM Tree dialog box will next appear. This is a hierarchy typically organized by PATIENTS, then by STUDIES, then SERIES. Our diffusion data is very simple, containing a single series named "AX MULTI b Diffusion". This series is marked with a green VL for volume list. When we expand it, we see a list of 8 volumes. As you click on the volume names (#0 #1 etc) you will see its middle slice previewed in the upper right. Under the preview slice you will see a summary of acquisition parameters for the current volume. The corresponding b-values are shown at the bottom of the summary table. Highlight the first volume, the one with b-value = 0, and press **Load 4D Range** button, then hit OK. This will load all 8 volumes and create a document.
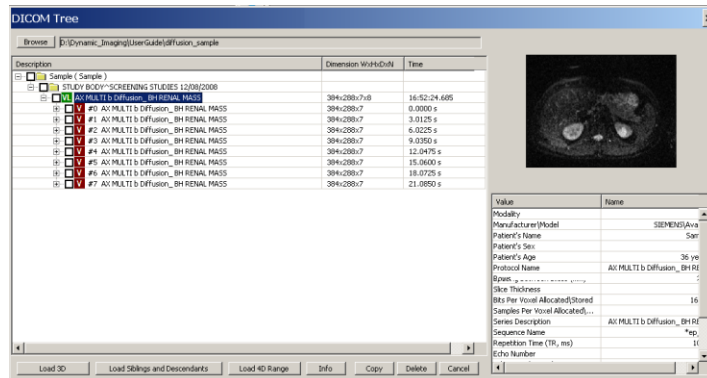
FireVoxel contains several other methods for loading dynamic (4D) datasets. For example, we can mark the desired volumes by checking the squares located at the left. We then highlight the SERIES that contains all volumes, and click **Load Siblings and Descendants** button. The squares are also used to copy part of your DICOM data to another folder or to permanently delete DICOM files. To delete images, check the corresponding squares and click on the **Delete** button located at the bottom of the *DICOM Tree* dialog box. To make a copy, make a destination folder, select the desired volumes by checking the squares, and hit **Copy** button.

Step 4

The Document window will appear inside the main window. Some new menu items (Volume, ROI, 4D Processing) will now appear. Position the mouse cursor on the first slice and right double-click to switch to a **Single Slice** view. Repeating right double-click brings you back to the **Film** View.
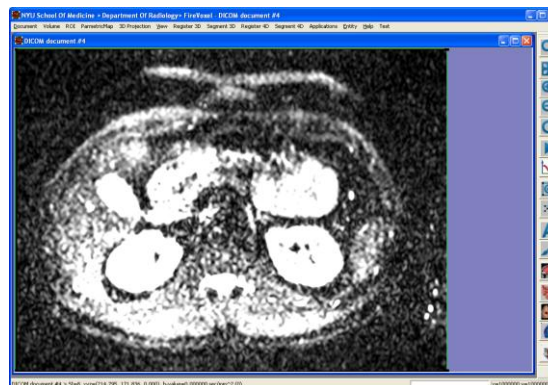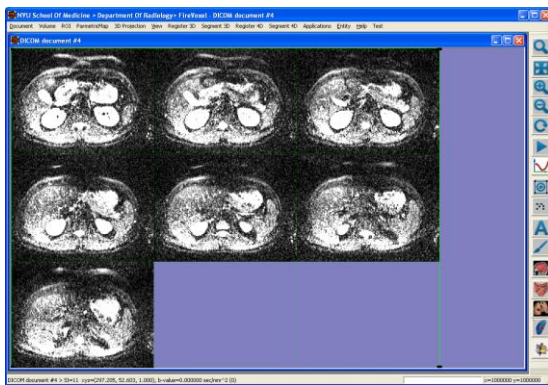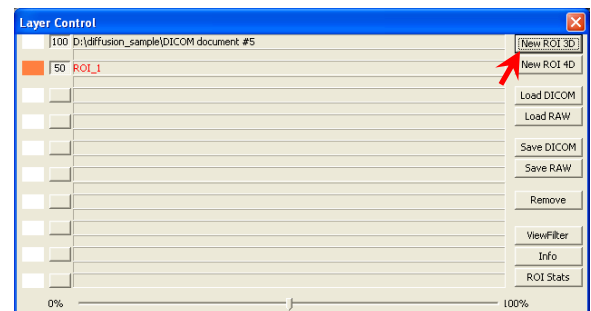

In **Single Slice** view, use the mouse scroll wheel or the keyboard up/down arrow keys to view different slices. Use left/right arrow keys to scroll across different b-values, this can be done in both **Film** view and **Single Slice** view. B-values can be read at the bottom of the summary info portion (lower right). There is a **Play 4D** triangular icon on the right toolbar to view the entire set, with **Esc** key used to stop the movie.

The signal intensity (SI) and xyz coordinates of the mouse cursor's location are indicated at the bottom of the window. These values change as the mouse cursor moves on a volume. Scroll through the 4D dataset and observe artifacts on images with b-value = 400.

Step 5: Draw 3D ROI

Regions of interest (ROIs) are often constructed to designate an organ or a lesion. ROIs can be drawn on one or more slices in the volume. (Drawing lesions on multiple slices can give a more reliable estimate of lesion signal.) To create a ROI, we first bring up the *Layer Control* dialog box by left double-clicking anywhere on the volume. We then click on **New ROI 3D** in *Layer Control*. The opacity of the ROI layer defaults to 20%. It can be changed using the horizontal slider at the bottom of the *Layer Control* box. The color of ROIs in a layer is assigned in an arbitrary fashion, but can be changed using the **ViewFilter** icon from the toolbar. The ROI layer

A 3D ROI layer is created by clicking on "New ROI 3D"

has to be *active* before changing its opacity or color. This is achieved by clicking at the desired line. The active layer is the one shown in the red font.

Painting an ROI is done by holding down the **Ctrl** key and the **left** mouse button. Holding down **Ctrl** key and the **right** mouse button will erase the ROI. Painting and erasing affects the active layer. The size of the paintbrush can be adjusted by simultaneously holding down the **Ctrl** key, clicking the **left** mouse button, and pressing and turning the mouse scroll wheel; The size of the eraser is adjusted similarly, by simultaneously holding down the **Ctrl** key, clicking the **right** mouse button, and pressing and turning the mouse scroll wheel. Paintbrush/Eraser can also be adjusted using **Paintbrush** icon from the toolbar.
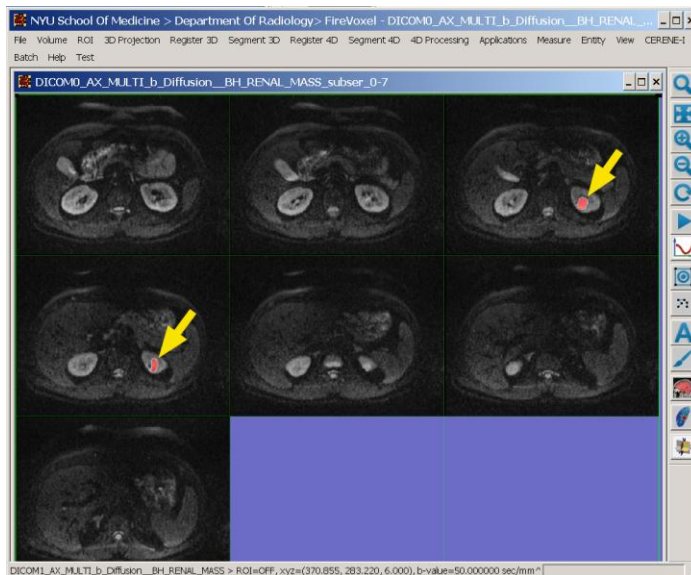
ROI for a lesion on the left kidney, drawn on b=50 volume

Try to draw a ROI for a lesion on the left kidney as shown in the figure. The lesion is well visualized on the first volume (b-value=0) by widening the gray level filter. Bring up the *Layer control*, make the first layer active (red font), click on View Filter, type Center=80, Width=160, OK, then change the active layer back to second layer. The ROI is centered at around x=247, y=196, and z(slice#)=3 and 4.

Step 6: Save, remove and load ROI

An active ROI layer can be saved by clicking **Save RAW**. We will save our ROI in a file named lesion_sample.im using a simple format we call RAW Midas.

Any active layer can be removed by clicking on **Remove** in the toolbar in *Layer Control.* Before removing a ROI, make sure it is the active layer (in red), then click **Remove.** A dialog box appears with the message "Press YES to remove Active layer", hit Yes.

To view a 3D document that was saved previously, click on **Load RAW** from the Layer Control.

## Step 7: Dynamic Activity Curves for voxels and ROI

Click on the icon with a red curve on FV right side toolbar to bring up the *Dynamic Activity Curve* dialog box. Moving the mouse cursor on a volume FV will plot the signal intensity (SI) for b-values at the voxel. The 8 plotting points in the figure below indicate the 8 b-values of the original volume. We expect these values to decrease approximately exponentially.
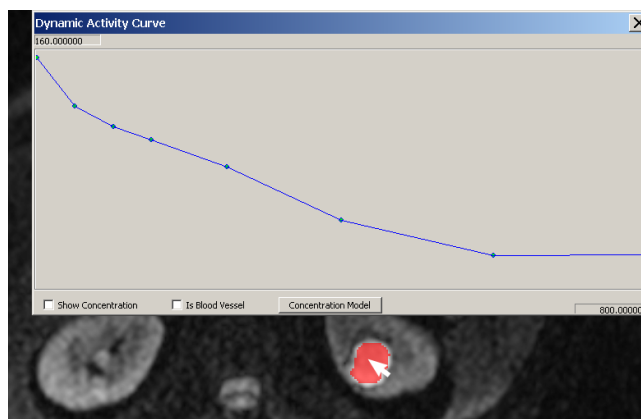
Step 8

This step involves calculation of the ADC map (see *Introduction*). First, return to film view, and left click the blue kidney icon (second to the lowest) of the toolbar on the right. A dialog box labeled "Parametric Map Calculation for Dynamic Experiment" will appear. This box is also activated through **4D Processing** -> **Calculate Parametric Map**. Switch Model to "ADC monoexponential fit S = S0*exp(-b*ADC)". Check ADC for Output and verify that ADC Upper Limit is 0.05. Press **Process ROI only** button at the bottom of the dialog box. The computer will calculate the ADC map within your ROI.
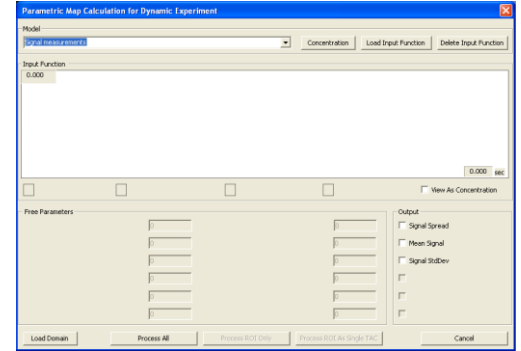
When a ROI layer is present, FireVoxel offers three modes for model-fitting.

Process ROI Only option will process only the voxels that belong to the ROI. The resulting parametric map will be computed very quickly, but regions outside the ROI will be set to void (transparent) value. The second mode, **Process ROI As a Single TAC** is even faster. All voxels within the given ROI are averaged before processing. The resulting parameter(s) are simply displayed as numbers and no new image layer(s) are constructed. The **Process All** option performs the computation on all voxels and outputs the result(s) as new layers. Even if ROIs are present, they will be ignored

Step 9

The ADC map appears in a new, third layer. The purpose of layers is to view and manipulate multiple volumes in unison. All layers have identical resolution so that they could be superimposed in the same document. The transparency of the layer is controlled with the horizontal slider at the bottom of the *Layer Control* box. Press the **Info** button to display information about the volume. Press the **ViewFilter** button to change the way voxel intensities are mapped to screen colors: gray level window and color maps. Now switch ADC to make it the active layer, make sure ADC is in red.
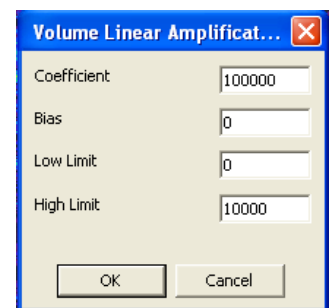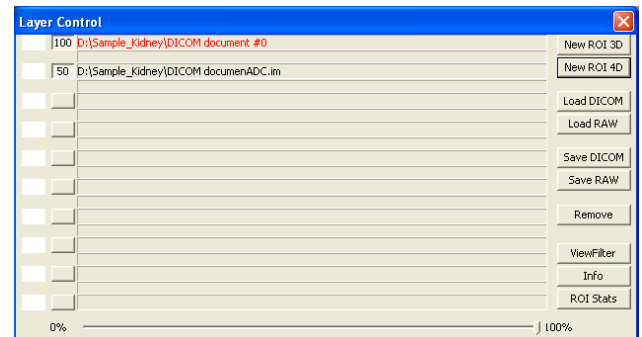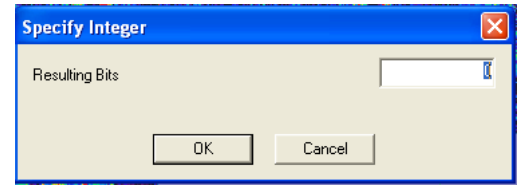
Step 10

The values of parametric maps (or PMV) will typically be in a decimal format. In contrast, Signal intensity (SI) is used to describe the values of acquired MRI data, which are almost always whole numbers. The ADC of the kidney lesion is about 0.003 mm^2/s. However, it is not customary to work with decimal numbers in imaging – most imaging software will expect voxel values to be whole numbers. In order to convert the ADC map into whole numbers, we will multiply it by 100000 and drop all digits after the decimal point.

Before proceeding, delete lesion ROI layer. Then click on **Volume** from the upper left corner of the menu, and hit *Linear Amplification over ROI*. If ROI layers are not present, the entire volume is amplified. A dialog box appears; change coefficient from 1 to 100000, then hit OK. We have changed ADC units to 10^6 mm^2/s. Notice that the voxel values (PMV= in the lower margin) in the kidney lesion change from about 0.003 to about 300.00. Linear amplification tool doesn't create a new layer, it modifies the active layer.

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Step 11

From the menu bar select **Volume** and click on "*Real to Integer Volume conversion…*". In Specify Integer box we could leave the "Resulting Bits" as 10 (default), and hit OK. A new layer pops up, in which the decimals digits are rounded off to integers and clipped to the maximum 10 bit value of 1023 (=2^{10}-1) . Verify that a kidney lesion ADC reads about 300. In the *Layer Control* dialog box, save the integer ADC map using **Save Raw** function of the toolbar on the right. Delete all layers except integer ADC map.

Step 12

In *Layer Control,* reload the lesion map that you saved in **Step 6** by clicking on **Load Raw** in the toolbar. Press *ROI Stats 3D* button to view ROI statistics. Statistics for the ADC image of kidney lesion voxels show the distribution to be a bit asymmetric, with mean of about 350 and standard deviation about 150. You may click **Save Stats** to save the histogram information for further processing.