The Image Grand Tour for Exploring Medical Images

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Abstract

The image grand tour (IGT) is a method for visualizing multi–spectral images or multiple registered images. The IGT projects a linear combination of the pixel vectors into one–dimensional space (for each pixel) and renders these projected values as a gray–scale image. We will present a JAVA–based version of the IGT with additional software enhancements such as the capability of zooming into a region of interest. Our main application of the IGT in this paper are medical images such as multiple slices obtained from magnetic resonance imaging (MRI) scans. The IGT can be used to highlight features in MRI scans taken by different scanning techniques. The zooming capability may help to focus on a region of interest, such as a tumor.

KEY WORDS: IGT, Magnetic Resonance Imaging, MRI, Multi–spectral Images, Visualization.

1. Introduction

The image grand tour is a visualization technique that is closely based on the grand tour, introduced in Asimov (1985) and Buja & Asimov (1986). The grand tour of a multi–dimensional data set is a visualization technique for examining structure of high dimensional data using dynamic graphics. The idea is to somehow capture the popular meaning of a grand tour, i.e., to look at an object from all possible angles. In a data analytic setting, Asimov (1985) and Buja & Asimov (1986) proposed projecting a d–dimensional data set into a dense set of all possible two–dimensional planes. If the sequence of projections is smooth, the visual impression is that the data points move in a continuous fashion from frame to frame of a movie. The object of the data analyst is to look for unusual projections of the data, i.e., projections that may reflect some structure. The grand tour, in this sense, shares a common objective with the projection pursuit techniques. The added motion associated with the grand tour literally adds another dimension, the time dimension, which many data analysts find very helpful.

Wegman (1992) discussed a form of the grand tour for general k–dimensional space, $k \leq d$. The algorithms for computing a grand tour are relatively computationally intensive. Wegman & Shen (1993) discussed an approximate one– and two–dimensional grand tour algorithm that was much more computationally efficient than the Asimov winding algorithm. That algorithm was motivated in part by a discussion of the Andrews multi–dimensional data plot, which can also be regarded as a highly restricted tour.

The idea of the image grand tour evolved from an initial application of one–dimensional tours to image data. Multiple registered images can be regarded as a multi–dimensional image in which each pixel location has a vector attached to it. Indeed, ordinary red, green, and blue (RGB) color images are vector–valued images. The basic idea of the image tour is to apply the same one–dimensional grand tour to each vector for all pixel locations in an image. This combines the vectors into a scalar function of time which can be rendered as a time–varying gray–scale image. Figure 1 shows a scheme of the recombination of a color photograph into a gray–scale image at a particular step of the tour. The initial discussion of the image grand tour was given by Wegman, Poston & Solka (1998). The main application consisted of six different image layers from a minefield. Additional examples where the IGT has been proven useful were discussed in Symanzik, Wegman, Braverman & Luo (2002). In that paper, the minefield data were revisited and Multi–angle Imaging SpectroRadiometer (MISR) images and rock art images were used as input for the IGT.

An application from the medical field where the IGT has been successfully used in the past deals with multiple time series data from electrocardiograms (ECGs). The specialized “HealthRx CardioView ECG Analysis Software”, developed by J. Patrick Vandersluis, HealthRx Corporation, Fairfax, Virginia, provides a framework for the visualization of electrocardiographic data using both standard signal processing and feature detection techniques, and novel computational and statistical methods. Additional details on this software can be found at `http://www.healthrx.com/patrick/`.

In this paper, we will introduce a new JAVA–based version of the IGT software in Section 2. We will revisit the rock art example from Symanzik et al. (2002) and look at a new MRI scan example in Section 3. We finish with a discussion and likely future software developments in Section 4.

2. The IGT Software

Several versions of IGT software exist. The earliest implementation was written in C++ by Qian Luo and is available for Silicon Graphics (SGI) workstations. It forms the basis for the examples from Wegman et al. (1998) and Symanzik et al. (2002). However, the limitation to SGI workstations that have a rather limited use these days and the use of SGI hardware features such as the α–channel hardware renders this version of the IGT software unsuitable for the addition of new features and general usage. Additional versions of the IGT soft-

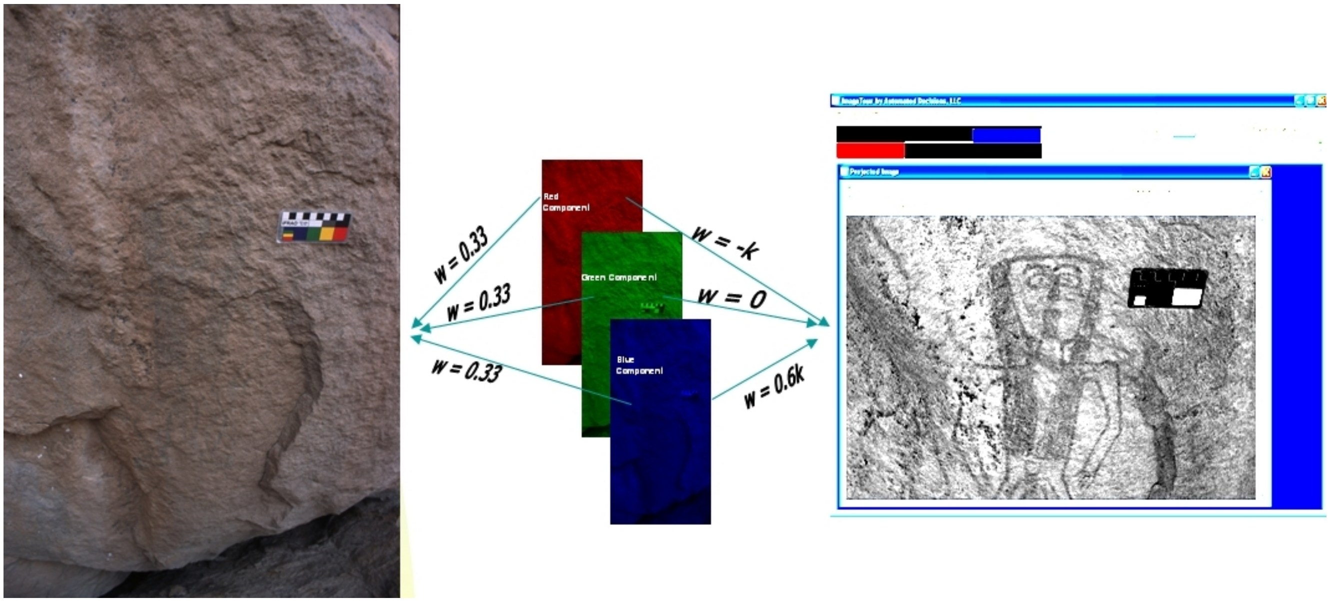

Figure 1: A photograph consists of three input layers, representing the colors red, green, and blue (middle). For the typical color rendition, these layers are equally weighted and displayed in the RGB color space (left). In the IGT, the three layers obtain different weighting at each step of the tour and are projected into a one–dimensional gray–scale color space (right).

ware were developed in MATLAB by Wendy Martinez from The Office of Naval Research, Washington, D.C., and by Amy Braverman at the Jet Propulsion Laboratory, Pasadena, California. However, these versions were developed mostly for personal use and also could not be easily extended. Therefore, it became necessary to redevelop a completely new version of the IGT software.

Our version of the IGT software is JAVA–based and therefore operates on a variety of hardware platforms. It still operates on the previously used Wegman & Shen (1993) algorithm, but it could easily be extended to a full version of the image grand tour. New features that did not exist in previous versions of the IGT software have been implemented, such as zooming into a region of interest.

The main functionality of our IGT software includes:

Multiple input formats: Current input to the software can be RGB color images in tif, jpeg, and bmp format (in a single file) and multiple single layers of at least three tif, jpeg, or bmp images.

Display of IGT tour and raw image view: The software allows to display the IGT view and any of the raw input images simultaneously. Multiple views can be opened. All windows can be fully resized and repositioned within the main application.

Zooming: It is possible to zoom into any subregion of the IGT view and the raw data view. A zoom factor of up to 6 can be chosen, thus allowing to enlarge a region of interest up to 6 times.

Time, speed, reverse, and pause: It is possible to jump to a particular view in the IGT by choosing the appropriate value on the time scale. Thus, if an interesting view has been identified during a previous run of the IGT, it is possible to jump directly to this view. The tour can be paused at any time, and its direction can be changed, i.e., we can trace back in time. The speed of the tour can be controlled, i.e., a desired frame rate (per second) can be selected. The actual speed may be slower due to hardware limitations and image size.

Flicker: The software supports a flicker capability to compare the raw input image with the current projected image. By clicking the mouse in a display window, it is possible to flicker back and forth between views. This is a common feature of remote sensing software, and it allows for examination of subtle structure differences.

Image Enhancements: The software supports on–the–fly histogram equalization to dynamically improve the viewability of the projected images. This equalization can be based upon the whole projected image or upon an identified region of interest.

Figures 2 through 5 show screen shots of the IGT software. Readers interested in obtaining a copy of the IGT software should contact the main software developer, Bradley Wallet, via e–mail to `bwallet@ou.edu`.

3. Examples

In this section, we will discuss two examples: a previously introduced rock art image from Symanzik et al. (2002) and a new application of the IGT for MRI scans.

3.1 Rock Art — Revisited

Rock art in the American Southwest may extend back eleven thousand years when Paleo–Indians hunted now extinct ani-

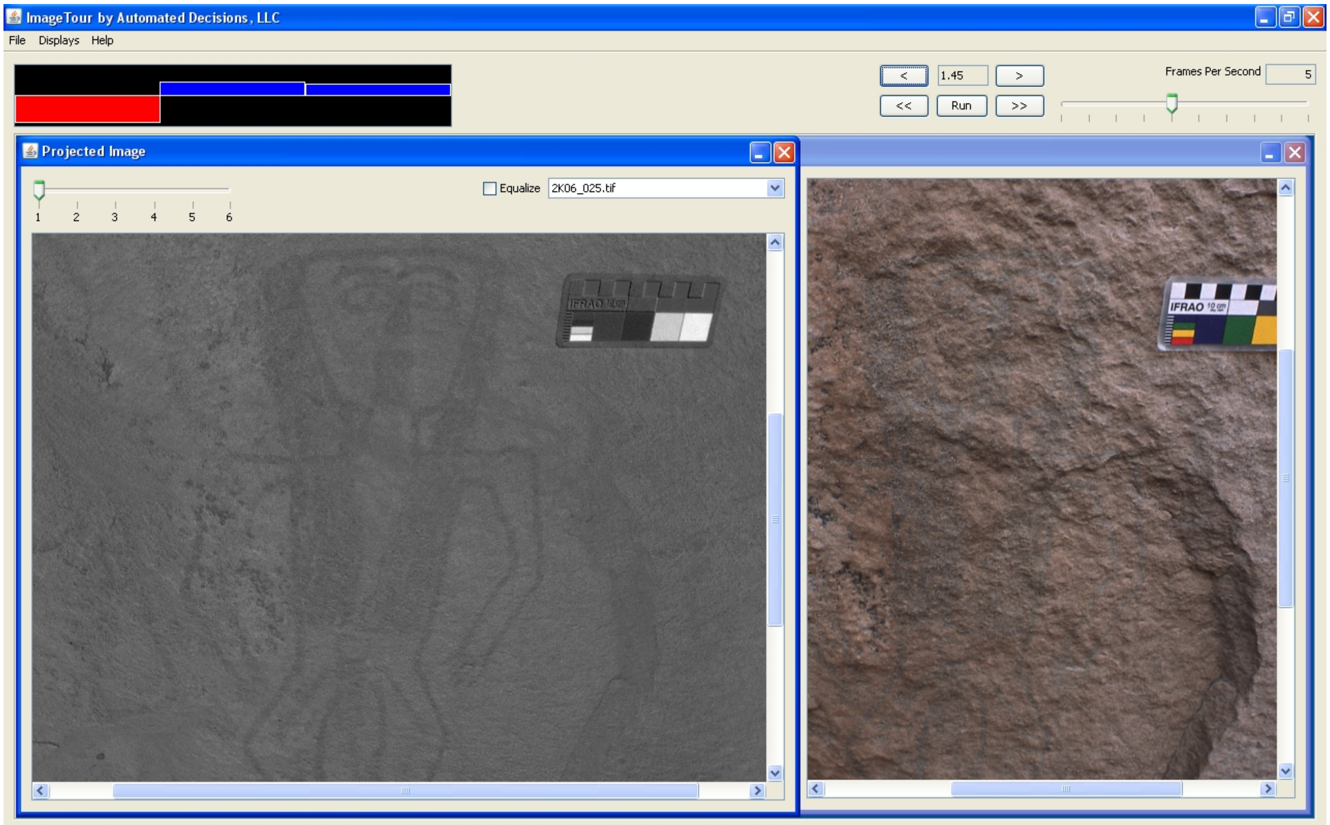

Figure 2: A rock art photograph processed with the IGT software. The large window on the right shows a part of the original photograph. The large window on the left shows about the same region of the photograph as it appears after 1.45 time units in the IGT software. The red/blue bar chart in the upper left corner represents the coefficients currently assigned to the input images. In this case, the red image has a high magnitude negative coefficient while the green and blue images have a moderate magnitude positive coefficient associated with them in the projected image. The figure that can only be anticipated in the right window now is much better visible in the left window.

mals such as mammoths. In addition to natural causes such as wind, water, and erosion that can destroy rock art, vandalism is another factor. Gunfire, the carving of names and initials, and even touching a drawing by hand (not realizing that hand oils may have a damaging effect) can all lead to the destruction of rock art images. While attempts are made to preserve images at least as watercolor renditions (Kirkland & Newcomb 1967) or in photographs (Hirschmann & Thybony 1994), unique rock art may have been lost before they could be documented.

Successful attempts to recover lost rock art images exist, e.g., the digital image enhancement technique developed by Mark & Billo (2002). Additional details on their work can be found at `http://www.rupestrian.com/`.

As an example, we revisit a photograph from the Hueco Tanks State Historical Park east of El Paso, Texas, provided by Mark and Billo. More details on the Hueco Tanks site, paintings, and photographs are featured in Kirkland & Newcomb (1967), Chapter 8, and Hirschmann & Thybony (1994), pages 14–17, respectively. Figure 2 shows both a part of the original photograph in the large right window and about the same region as it appears after 1.45 time units in the IGT software. The faded figure can only be anticipated in the right photograph but it nicely emerges in the IGT view in the left window. It appears as if the emerging figure displayed in Figure 2 relates to the "black–outlined figure of a woman", shown in Plate 147, 24–B, page 196, in Kirkland & Newcomb (1967). Keeping the tour running and turning on the "equalization" feature results in the view after 19.35 time units shown in Figure 3. Now, the "black–outlined figure of a woman" is clearly visible.

3.2 MRI Images

Wegman et al. (1998) hypothized early on that the IGT might be suitable for MRI scans:

> "A third application is to magnetic resonance imagery (MRI). In the MRI application one may combine the two–dimensional slices into three–dimensional image. MRIs may be generated at different resonant frequencies hence showing slightly different characteristics of the soft tissue. By combining these three–dimensional images taken at different resonant frequencies, one could hope to separate different biological functions, for example tumors from healthy surrounding tissue."

Unfortunately, Wegman et al. (1998) had no access to MRI data to prove their hypothesis. It is only in this paper where

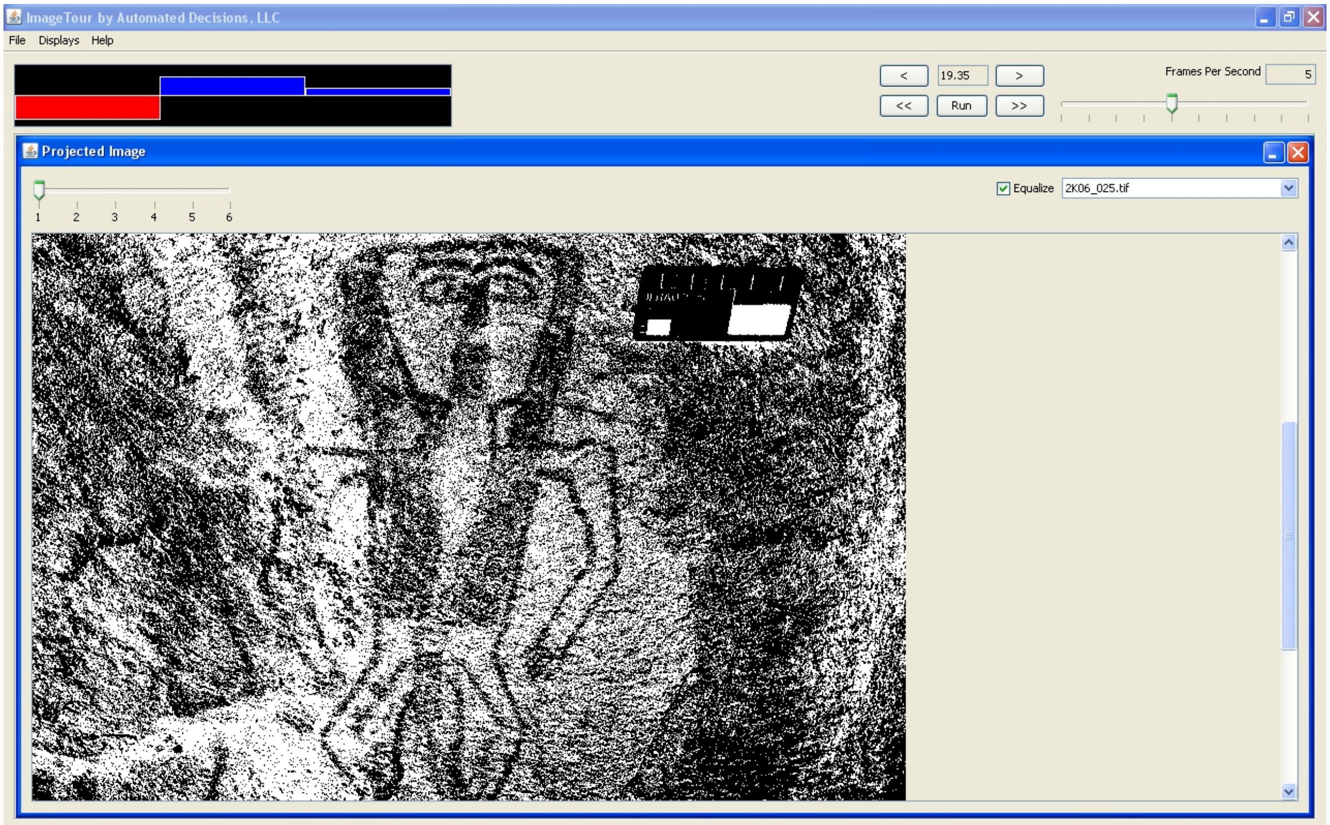

Figure 3: The same rock art photograph as in Figure 2, now processed with the IGT software with "equalization" turned on. The projected image after 19.35 time units in the IGT is shown in full width. The faded figure now is clearly visible.

we show for the first time that the IGT is highly suitable for MRI scans.

In magnetic resonance imaging, there are usually three bands of images, the so–called MRI triplet, available. These are the T1–, T2– and PD–weighted images. The three images of a MRI triplet provide complementary structure information. Therefore, it is useful for the diagnosis and subsequent analysis to combine these three–band images into one single image. Several methods for the combination of the three images exist, such as the advanced discrete wavelet transform (αDWT) described in Zheng, Elmaghraby & Frigui (2006).

The MRI scans presented in this section represent a mouse carotid region. We only use the T2– and PD– weighted images as input. The T1 image was not properly registered and therefore has been omitted as input to the IGT. Figure 4 shows the input data (right top and bottom windows) and the projection in the IGT after 0 time units (left window). Figure 5 shows the input data zoomed into the carotid region (right top and bottom windows) and the projection in the IGT after 18.7 time units (left window), also zoomed into the carotid region. As our IGT software needs at least three input image layers, but only the T2 and PD layers (but not the T1 layer) were correctly registered in the MRI data sets available to us, these two layers were duplicated and each was entered twice into the IGT software, resulting in a total of four input images. In the original images, the carotid is difficult to recognize at all in the T2 layers shown in the bottom right windows of Figures 4 and 5. The PD layer shows some more details in the top right windows of Figures 4 and 5. The projected image in the IGT in the left windows of Figures 4 and 5 that combines information from the T2 and PD layers shows more details than any of the two input layers themselves.

4. Discussion

In this paper we have presented a new version of the IGT software and we have demonstrated its usefulness for two applications: A previously discussed rock art photograph has been revisited and MRI scans were examined for the first time with the IGT. One of the huge benefits of the IGT is that it can be used immediately without any further programming for quite different applications. When demonstrating the MRI application to colleagues at the Washington University School of Medicine, St. Louis, Missouri, we received a lot of "whoas". A user can quickly find "interesting" features in an image, but it should be noted that the IGT does not necessarily produce "nice" (colorful) images. Both static views (when the IGT has been stopped) and movie views (when the IGT is running) are of interest.

Our new JAVA–based version of the IGT has proven again that this is software that should be further developed and applied to additional fields. Geophysical applications and remote sensing such as the examples presented in Symanzik et al. (2002) immediately come to mind, and the software is

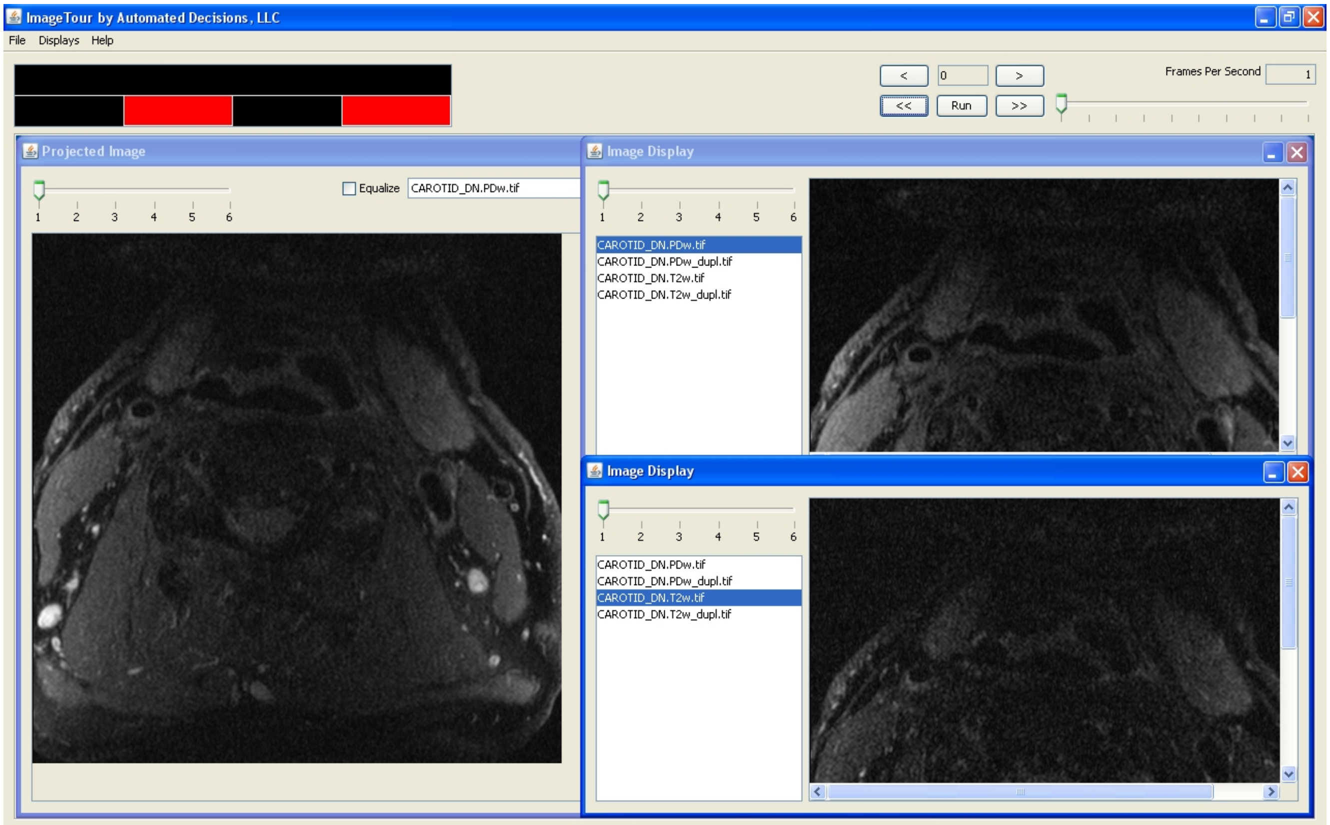

Figure 4: A MRI scan of a mouse, including the carotid region. The right top window shows the PD–weighted input image and the right bottom window shows the T2–weighted input image. The projected image after 0 time units in the IGT is shown in the left window.

currently being developed to support visualization of seismic cube data in its native 3d topology. With current hardware capabilities, the limitation to the Wegman & Shen (1993) algorithm also may be overcome easily. Finally, we have started to experiment with a color version of the IGT software that might be capable of highlighting features such as edges or unusual (small) subregions in an image in a more easily understandable way than rendering everything in gray–scale.

With respect to medical images such as MRI scans, additional features would be useful that could help to register scans taken at different points at time. Work could also be done to deal with various input formats from different scanning methods such as MRI and Computed Tomography (CT) scans. Overall, there is a huge potential how an extended version of the IGT software could be used both in the medical and the non–medical field. An ultimate goal would be the development of a convenient software platform and tool box for image management, image alignment, and applying the IGT to multi–modality image sets.

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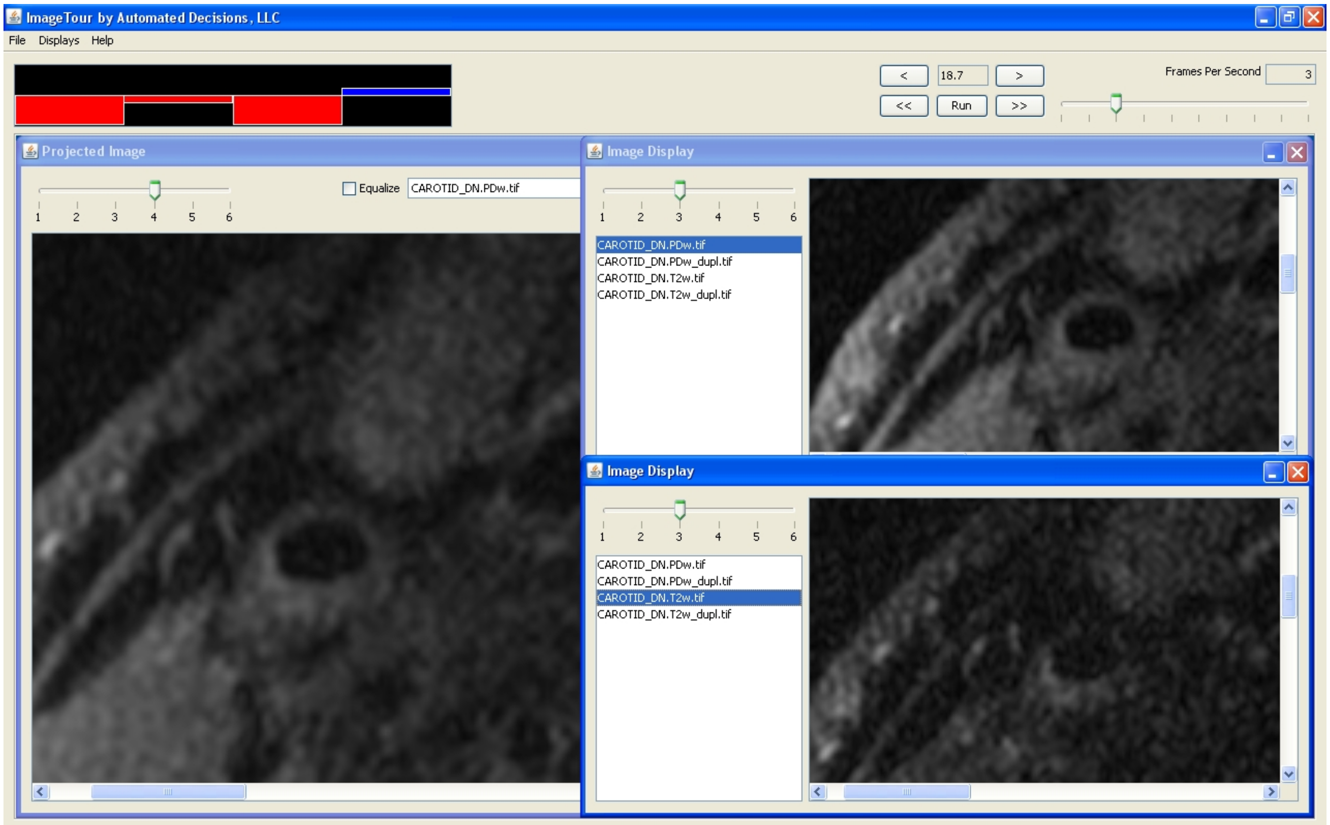

Figure 5: The same MRI scan of a mouse as in Figure 4, now zoomed into the carotid region. The right top window shows a subregion of the PD–weighted input image and the right bottom window shows a subregion of the T2–weighted input image, both zoomed into the carotid region and enlarged by a factor of 3. The projected image after 18.7 time units in the IGT is shown in the left window. This window also is zoomed into the carotid region, enlarged by a factor of 4.

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