The BioImage Suite Datatree Tool: Enabling Flexible Realtime Surgical Visualizations

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Abstract

This paper describes the Datatree module of BioImage Suite, that allows for rapid and flexible reslicing of images based on a user-defined tree structure that organizes image and transformation data as well as electrode localizations, image landmarks, and surface objects. This Datatree tool provides abstracted file loading, allowing for interface with databases, as well as multisubject capabilities, other plugins designed for specific image modalities, and an incr Tcl based API, allowing users to extend its functionality with their own plugins.

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1 Overview

In recent years, a variety of specialized algorithms have been developed for processing and analysis of medical images. This has opened the door for clinical applications of image analysis software in guiding diagnoses and interventions, as well as new clinical research techniques. In order to be maximally useful, however, these applications must be accessible to the non-specilist. Practical application of cutting edge image processing and visualization techniques in operating room situations requires a user-friendly interface between experimental software and the commercial systems that are presently in place in hospitals. Specifically, software designed for surgical planning and guidance must implement an interface that is straightforward and quickly navigated. This interface must be simple enough that a person without a strong engineering or image analysis background can operate it effectively, but flexible enough so that it can accommodate changes in the experimental modules to which it is attached.

BioImage Suite [5] and the Datatree tool provide an extensible software package for processing and displaying a variety of modalities of brain images, which can then, via an interface with the BrainLAB VectorVision system, be displayed and interacted with in the space of the operating room during surgical procedures. Specifically, the Datatree tool, built as a front-end user interface to BioImage Suite's image processing algorithms, provides a necessary user interface that allows for utilization in an operating room setting.

BioImage Suite is a collection of programs that use and extend underlying code and visualization tools based on VTK[9] and ITK[1], but are specially tailored to specific image analysis applications, including preprocessing, voxel classification, deformable surface segmentation, conjugate gradient optimized registration schemes that can be used to register mutimodal image data, diffusion weighted MR image (DTI) image analysis including fiber tracking, cardiac image analysis, and fMRI activation detection. It is developed using a combination of C++ and Tcl/Tk. BioImage Suite consists of a set of graphical applications, as well as a toolkit of command line utilities. The Datatree tool serves to link these features together in order to provide a non-specialist with an easily usable platform.

2 Features

Transformation Organization and Concatenation: The central feature of the Datatree tool is the tree hierarchy, which is a visual representation of available images for a particular patient or group of patients. Each node in the tree represents an image, electrode location set, landmark set, or surface object. Each node is connected to its parent via one or a pair of transformations (forward and/or inverse). The user is able to select any combination of up to three images to set as "Reference Space", "Anatomical", and "Functional" images. Based on the tree structure, all transformations along the shortest paths between the Reference Space image and the other images are then concatenated, and the images are resliced into the space of this image based on the result of this concatenation. Electrode, surface, and landmark data can also be transformed to the space of the Reference Space image by this method. Hence, only the original image data and appropriate transformation matrices need to be saved; all images do not need to be resliced and saved before generating specific visualizations. This allows for in-place verification of all registrations and minimal interpolation error associated with increasing numbers of reslicing operations. Thus, the core function of the Datatree tool is a powerful utility with which to quickly create a variety of functional overlays and show electrode locations "on the fly".

File Input/Output Abstraction: The input and output to the Datatree tool are handled by a parent class that is currently extended by a class offering basic Load/Save functionality, but which can be extended to merge with an existing database system. This offers the potential to link the BioImage Suite software into a networked database of patient data, allowing for easy sharing of image data between researchers or potential secure connection to clinical data servers. This is especially useful in the context of the Datatree's multisubject capabilities, and statistical processing abilities.

Graphical Interface: The strength of the Datatree tool lies in its user interface, which was developed with [incr Tcl/Tk][10, 2], and is completely graphics-based and platform-independent. The left panel houses a visual representation of the data tree itself, giving the user a quick summary of which images are available, and which transformations have been loaded for them. The transformation lines are color-coded: a yellow line indicates the presence of the transformation to the parent; a purple line represents the inverse transformation (from the parent); and a green line indicates the presence of both forward and inverse

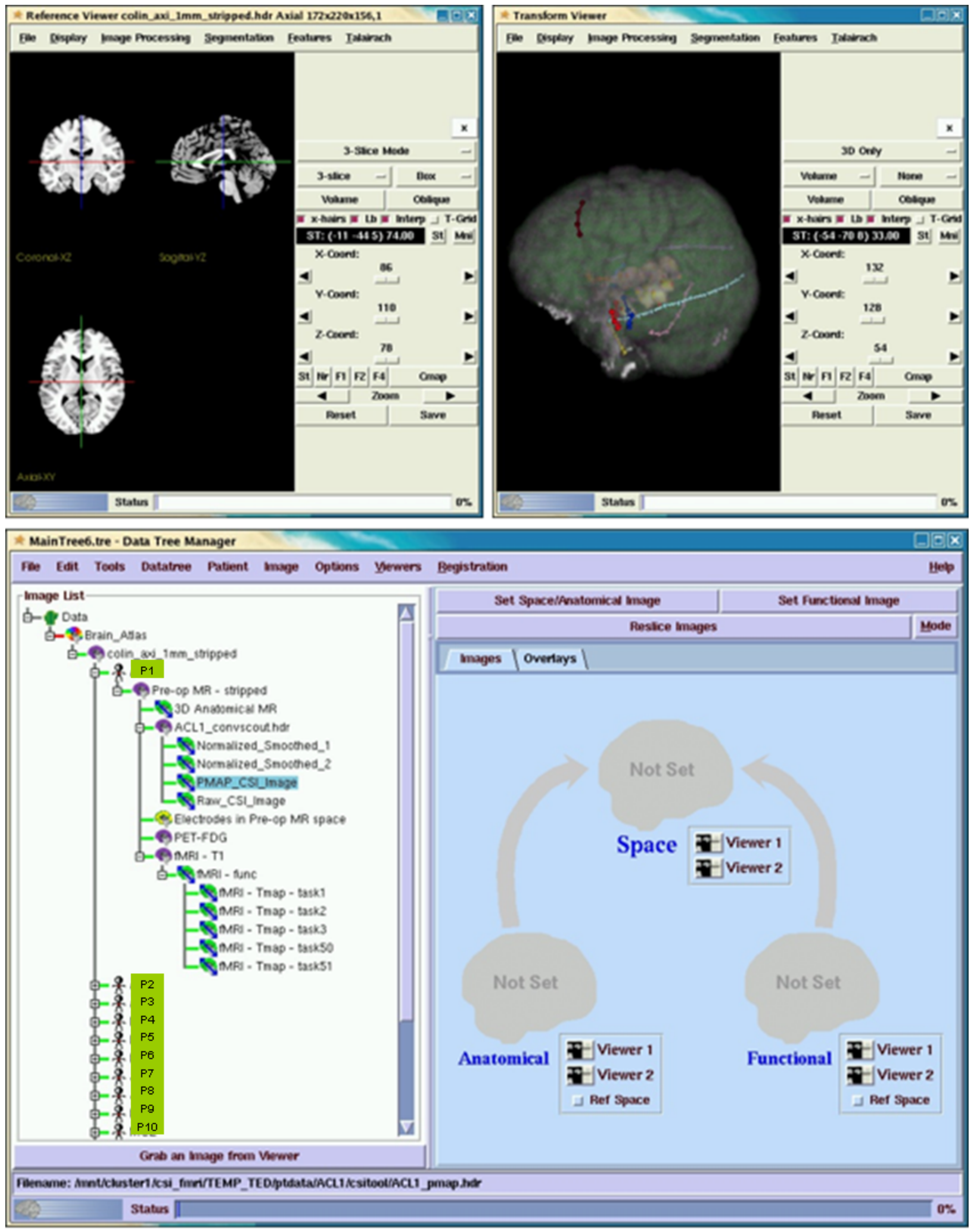

Figure 1: The Datatree tool (bottom window) provides the user with a quick tree hierarchy view of available images and transformations on the left, along with a reslicing scheme on the right that determines which images will be resliced and potentially combined into overlays, and sent to the viewers. The viewers (middle two panes) are showing examples of the types of image views that can be generated using the Datatree tool, and offer a variety of visualization options, including 3-slice mode (left, showing a common anatomical space) and 3-D volume rendering (right, showing an overlay of MRSI data inside an anatomical MRI with intracranial electrode locations displayed). We are generating images such as the one on the right for use in epilepsy surgery navigation. More snapshots can be found in the Data Tree manual[3] *The lower figure has been slightly edited by the addition of the small green boxes P1–P10 to eliminate potentially subject identifying information.*

transformations. A red line indicates no transformation present. The right panel contains a visual framework the reference space, anatomical, and functional images, where the user can select images to be sent to the reslice control. The large arrows in the right panel indicate whether all necessary transformations for the operation defined by the visual scheme are loaded. Thus, the user is given immediate feedback on whether the desired operation can proceed. If not, a quick inspection of the tree will tell which transformations need to be calculated.

A facility for searching the tree is included, allowing the user to search by node title, image modality, or within selected folders. The output of the search can be piped into any of a group of functions that can operate on any reference space chosen including:

- Save a copy of all images in the reference space
- Generate average, standard deviation images, and t-statitcs images in reference space
- Given an Region of Interest (ROI) input image, generate statistics for each ROI in each image

This is very useful for multisubject studies, and eliminates the need for large numbers of setup files and command line utilities for reslicing large numbers of files into a common space or generating group statistics.

The API and Plugins: We use [Incr Tcl] objects to wrap VTK objects that provide additional storage (e.g. pxitclimage is a wrapper around vtkImageData which adds a filename and an orientation parameter). Similarly, wrappers exist for vtkPolyData and custom intra-cranial Electrode and Landmark objects.

The basic functionality of the Datatree is expanded upon by a number of plug-in modules for specific image processing and display jobs, such as image math or comparison with standard images. An API incr Tcl class is also provided that allows users to leverage the tree's abilities in building their own plugins by providing get and set methods for the selected image in the tree, the currently selected reference space image, and the result of concatenation of transformations between them, as well as other relevant image information. The incr Tcl base class, which any plugins should extend, provides methods such as these examples:

- `GetSelectionObject` { } - Get the object associated with the selection in the tree
- `GetSpaceImage` { } - Get the image object currently set as "Space"
- `GetAnatomicalImage` { } - Get the image object currently set as "Anatomical"
- `GetFunctionalImage` { } - Get the image object currently set as "Functional"
- `GetReslicedImage` { } - Get the image object that results from reslicing the Anatomical And Functional images into the space defined by the Space image and creating an overlay
- `GetTransformationToSpace` { } - Get the result of concatenation of all transformations between the selected image and the Space image

We have already developed a plugin to perform ictal-interictal analysis of SPECT images of patients with epilepsy that identifies brain regions with most significantly abnormal hyperperfusion. It requires only that the user builds a tree that contains an interictal SPECT scan, an ictal SPECT scan, and two images provided with the software that were generated from a standard database: an mean and a standard deviation image derived from healthy normal SPECT scans

3 Application to Neurosurgery

Navigation with VVLink: The Datatree is a utility for managing and working with whole sets of images, spaces, surfaces, and other data relevant to both clinical and research applications. Connecting this organizing and processing utility to a pair of VTK viewers, which are the central feature in BioImage Suite, allows for real-time visualization of surgical tool locations within experimental images during surgery. These viewers can be connected to the BrainLAB VectorVision Cranial image-guided neurosurgery system via

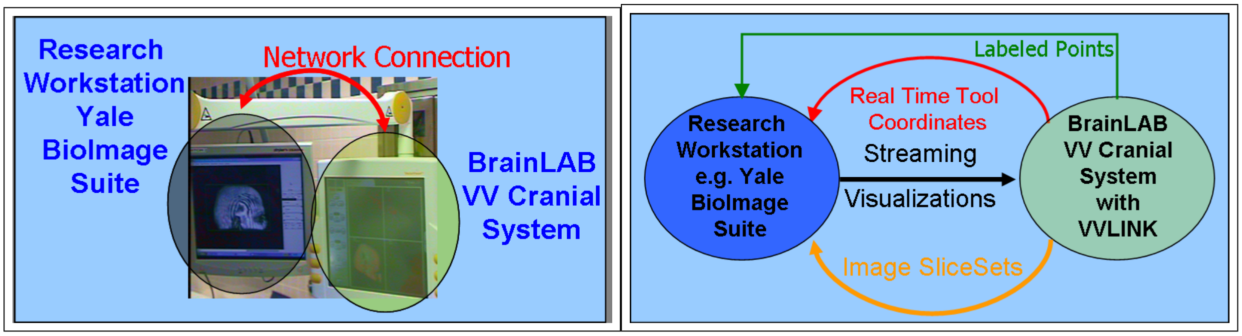

Figure 2: Integration of BioImage Suite with the BrainLAB VV Cranial environment using the VV Link Interface.

VectorVison Link (VVLink), a custom designed client/server architecture [6, 4], which extends functionality from the Visualization Toolkit. VVLink enables bi-directional data transfer of image data sets and visualizations and tool positions in real time. Thus, as the commercial VectorVision system tracks infrared markers on a pointer tool and outputs its location in space, the BioImage Suite viewers are able to continuously update their display to reflect the pointer location, as well as draw the pointer in 3D-rendered images to help the surgeons navigate based on cutting-edge functional image data. This is made possible by registration of the operating room space (defined by scanning a laser pointer over the face of the subject) to the previously acquire anatomical MR image, to which all experimental data is connected via the tree.

Research Images in Epilepsy Surgery: Rapid access to multiple image types has particular application to epilepsy neurosurgery, which employs various state-of-the-art imaging techniques, such as functional MRI, Magnetic Spectroscopic Resonance Imaging (MRSI) of metabolites such as N-acyl-aspartate and choline, spike-related fMRI, and SPECT/PET imaging. These and other experimental image techniques are acquired via non-standardized protocols and require nonstandardized image processing procedures to properly orient them and visualize them in the context of anatomical images. These tasks require a relatively large number of transformations to be calculated, managed, and applied. The short interval between registration between the MR image and the operating room space and beginning of the surgical procedure would normally preclude the use of such an array experimental data in the space of the operating room, due to all the transformations that would have to be loaded and verified. The Datatree makes accurate, rapidly interchangeable visualizations of electrodes and various modes of functional data possible by automatically keeping track of available data sets and the transformations necessary to view them in any given space.

Navigation Based on Intracranial Electrode Location: Additionally, epilepsy surgery navigation is often based on location of intracranial electrodes, which also must be visualized. Sub-dural EEG electrodes are placed on the surface of the brain during the initial intervention, followed by a period of a few days in which the patient is continuously monitored, and locations of electrical abnormality associated with epiliptogenesis are identified. This relies on matching EEG channels showing such abnormalities with the precise location of the electrode. The electrodes are removed, and their positions are then used to guide a resection in a second surgical intervention. Performing this procedure accurately requires an ability to identify locations of electrodes in the brain even after they have been removed. Previously, the surgeons relied only on drawings, their memory, and their knowledge of anatomy. With the Datatree tool, however, electrode locations identified on a CT scan acquired before the surgery can be included in the tree, and displayed in the space of the operating room on top of an anatomical MR image. They can even be shown over an overlay image of functional or spectroscopic data on an anatomical image, yielding a more complete picture of the pathology [6]. Any of these visualizations can be linked with the surgeons' tools, allowing them to accurately revisit sites previously identified as abnormal.

These same tools are also being used to analyze multimodal data in the study of epilepsy [7, 8].

4 Current Status and Future Work

BioImage Suite is currently available for download from `www.bioimagesuite.org` – it is currently in final beta mode. The datatree tool will be integrated into the main BioImage Suite distribution in the next release candidate version to be made available in early July 2006. We anticipate a first official release under the GNU General Public License a few weeks later, at which point source code will also be made publicly available. Support for users is available at the BioImage Suite forum (accessible from the main webpage). An early version of the Data Tree manual is also available [3].

The Datatree tool currently stores all informations using its own setup file format. The setup file contains primarily the filenames of images and other objects (e.g. transformations) as well as the topology of the tree. However, all input/output operations in the Datatree tool are abstracted, and the hope is to be able to provide a proper database client interface that will enable such data to be stored on a database server as as mySQL.

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