Title:
Please do not write in capital letters, except abbreviations and proper nouns.**:**

construction of a three dimensional anatomical brain atlas

Abstract:
Your abstract must be: in English, 750-2000 words. Please follow this structure:
-Purpose
-Methods
-Results
-Conclusion

Purpose:
Brain is the most vital and elaborate organ of human beings. Since the last decade of the 20th century, more and more attentions have been paid to the research on brain, including the study and application of digital brain atlases.

Earlier printed brain atlases are mainly some sets of 2D pictures, such as Talairach Tournoux, Schaltenbrand Wahren etc, which have made great influence on learning and teaching of neuroanatomy, as well as on some other applications. However, there are still some deficiencies in these printed brain atlases, for example, they are always unchangeable after the creation, and doctors can hardly derive a 3D impression of inner structures of brain from 2D images. The printed atlases can not be digitized and stored for matching with the patient's down-to-earth data. Therefore, compared with traditional printed atlases, digitized brain atlases are computerized and can be stored in digital format. Modern 3D digital brain atlases are mainly constructed based on CT or MRI volume data sets, and they are flexible and convenient to be visualized in 3D space.

3D digital brain atlas is a useful tool in the education of neuroanatomy. It makes learning and teaching of neuroanatomy more easily by its rich content, flexible browsing mode and vivid 3D display. It also improves the accuracy and objectivity of anatomical location. 3D digital brain atlases can also help neurosurgeons to implement surgical planning with accurate and reliable information, and to simulate the operation in 3D space. In addition, 3D digital brain atlases can help to conduct image segmentation. It is almost impossible to segment cerebral structures automatically; however, the atlas-based segmentation method can solve this problem by non-linearly registering atlas to the patient data.

In this paper, we present the complete construction process of a digitized 3D anatomical brain atlas. A hybrid 3D segmentation algorithm and a multistage meshing method are proposed on the generation of the 3D models, where both the quality and appearance of the models are significantly improved. In addition, software for navigation of the atlas is introduced.

Methods:

A. **Material:** The MR data set of brain, which is in high-resolution (1mm isotropic voxels) and low-noise ratio, is from Montreal Neurological Institute and Hospital (MNI, http://www.bic.mni.mcgill.ca/brainweb/). It was created by registering 27 scans (T1-weighted gradient echo acquisitions with $TR/TE/FA=18ms/10ms/30deg$) of a normal individual in stereotaxic space where they were sub-sampled and intensity averaged. The volume contains $181 \times 217 \times 181$ voxels and covers the brain completely, extending from the top of scalp to the base of foramen magnum.

B. **Semi-automated segmentation:** A supervised segmentation of MR images was performed to define distinct tissue classes. Firstly, reduced the connectivity between regions of interest (ROIs) and the neighbouring tissues by recursively eroding operation. Then, a pixel was selected as the seed; the fast marching method was employed to quickly propagate the user-defined seed to a position close to the boundary. Next, taking the output of the previous step as the initial seed, morphological reconstruction was used to refine the initial contour. At last, recovered the lost data elements from first step via recursive dilation method, where the number

of iterations was the same as the times of recursive eroding operation in first step. (for a more detailed description of this algorithm see Lixu Gu et al.[1]). When an anatomical ROI was extracted, all of its pixels were marked with a unique integer. After each ROI was labelled with different grey value, a pseudo-grey-scale dataset was obtained. Also, a lookup table mapping from grey scale to RGBA space was created in order to distinguish different structures by different colours. (Fig.1)

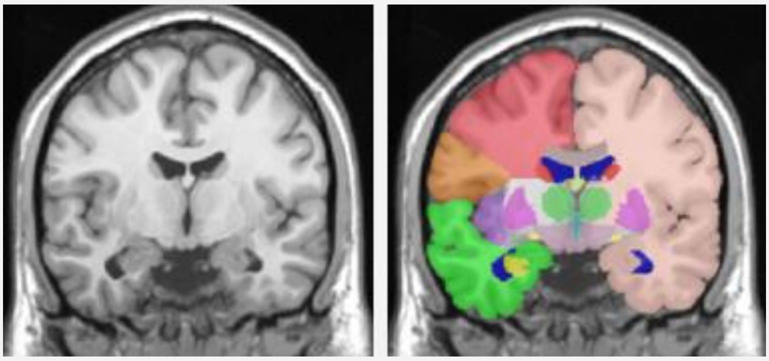

Fig. 1. Left: the original image before segmentation; Right: result of the segmentation. One hemisphere has been divided into 5 lobes, and we have attached white matter to each lobe, although anatomical textbooks define lobes as gray matter [2].

C. **Generation of 3D surface models:** In order to generate surface models with sufficient quality, the process was divided into three steps. Firstly, a 3D Gaussian smoothing was employed on the pseudo-grey-scale volume data, which was the output of segmentation. Then surface models were generated by using the marching cubes algorithm, and each ROI had a single file of its triangular mesh data. Finally, a triangle smoothing algorithm was used to improve the appearance of the models.

D. **User interface for navigation of the atlas:** The user interface of the navigator was developed using the MFC Library, and the visualization of the atlas was achieved using the Visualization Toolkit (VTK, http://www.vtk.org/).

a. *Hierarchical browser:* anatomy is organized hierarchically. For example, the right temporal lobe is part of the right telencephalon which is part of the brain, etc. Therefore, the organizational information was stored as a text file, each line of this file contained an identifier whether the item on the line was an end branch of the anatomical hierarchy or it included substructures. This file also stored the name of the item for annotation, and the location of mesh data, the RGB value and opacity value for visualization. Abrahams, P. H. et al. [2] atlas was used as the reference to the definitions of the brain structures. This file can be easily modified whenever new structures are going to be added in. The navigator had a hierarchical browser of all tissues included in the atlas, which is completely based on this text file. Every item in the hierarchical browser has a checkbox, users can check or uncheck any item in order to display or hide the corresponding structure in the view port.

b. *Property box:* there is a property box in the navigator, where users can change the color, by a color dialog, or opacity, via a slider, of a selected structure in the atlas. All these changes affect only the item and its sub-item which is selected in the hierarchical browser.

c. *Annotation:* when the atlas was constructed, labeling became an important work. An interactive mode was adopted here to label the atlas, it was friendly and flexible. If users are interested in a structure, they can stay the cursor on the structure for a moment, then the name of the structure will appear nearby the cursor, once they move the cursor, the annotation will disappear.

d. *Other interactive characters:* in our program, there are two styles to interact with the atlas, trackball and joystick. Users can choose either of these two styles as they like. Structures can be rotated, translated and scaled either as a group or by individual. After a structure is moved away from its original position, user can reset its position and orientation to the origin.

Result:
Figure 2 demonstrates the user interface for navigation of this 3D brain atlas, which is friendly and easy to use. It was developed on a PC Windows environment, and this demo was executed on a normal PC (2.6GHz, 1.0G memory).

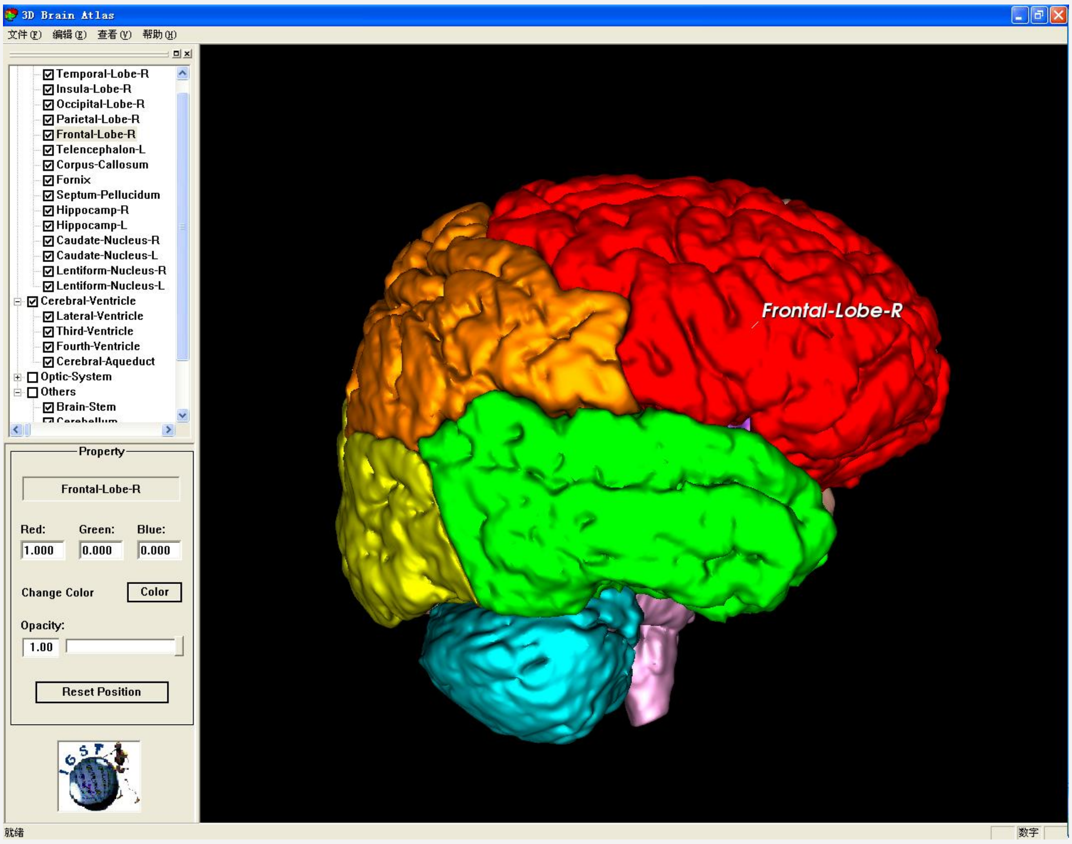

Fig. 2. The user interface for navigation of the atlas.

Figure 2 and figure 3 clearly indicate the dependencies, relationships, and positions of cortical and subcortical regions in the atlas, other elements as well. There are two types of models, surface models and triangular mesh models. The names of these structures can be illustrated interactively. Many methods are provided for users to interact with the atlas, so it is easily to be applied in neuroanatomy education.

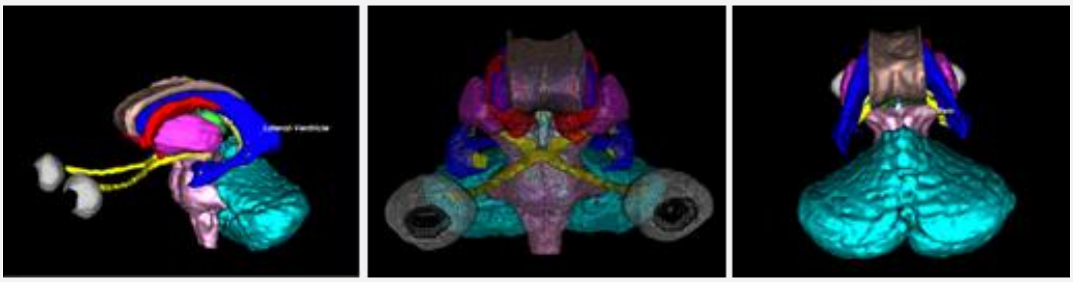
Fig. 3. Models of deep brain, optical system, brain-stem and cerebellum. The middle one employed triangular mesh models, and the others are in surface models from different view points.

Conclusion:
This digitized human brain anatomical atlas can be used as a powerful teaching tool for

medical students, since students can easily understand the spatial relationships among neuroanatomical structures when they are able to translate and rotate to view the structures in 3D space. Moreover, each element of the brain atlas is associated with a name tag, which can be shown whenever students want. This 3D brain atlas also has the potential to provide important and reliable reference information for planning and training of surgical procedures. In addition, this atlas can serve as a template for model driven segmentation.

As the future work, we plan to integrate the traditional 2D atlas into our atlas so as to improve the accuracy of details of the neuroanatomical tissues. Also, we are developing a registration tool for this program in order to implement the function of model driven segmentation based on this brain atlas.

References:

[1] Lixu Gu, and Terry Peters : 3D Segmentation of Medical Images Using a Fast Multistage Hybrid Algorithm , International Journal of Computer Assisted Radiology and Surgery, Vol.1, No.1, pp.23-31, March 2006

[2] Abrahams, P.H. Marks, S.C. and Hutchings, R.T. "McMinn's Colour Atlas of Human Anatomy", Mosby international, 4th edition, 1998.