Visualization and Interaction in the Atlas of the Human Brain, Head and Neck

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Abstract. Our ultimate objective is to create a holistic and reference atlas of the whole adult human brain along with the head and neck. Several techniques have been employed to create atlases. Here we discuss the atlas design and use from a point of view of two key techniques, visualization and interaction. For visualization, surface rendering of a geometrical model of the brain, head and neck is employed. Geometrical model ensures anatomic parcellability, high (sub-pixel) resolution, editibility, extendibility, structure separability, structure-to-structure conflict detection, and integration a knowledge-based content with the atlas. Interaction allows the user to create and explore any region of interest along with its surroundings just with a few clicks, taking into account that the atlas provides a rich set of functions and the number of atlas components is about 3,000. There are seven types of interaction enabling to: select and deselect tissue classes/groups/individual structures, do real-time manipulation, do virtual dissections, select and scroll the original scans, query a structure to get its label or location, get stereotactic coordinates and measure distances, and support other functionality. This design of visualization and interaction provides a fast and easy to use solution, and allows the atlas to run on desktop and mobile iPad and Android-based platforms.

Key words: atlas, brain, head, neck, visualization, interaction, geometrical model, integration, knowledge base, desktop platform, mobile platform.

1. Introduction

As the XXIst century is considered the century of the brain, numerous projects address modeling, mapping, and atlasing of the human brain. Our contribution to these efforts is to create adult human brain atlases and develop atlas-based applications. So far, we have developed 35 brain atlases licensed to 63 companies and institutions, and made available to medical societies, organizations, medical schools, and individuals.

Our ultimate objective is to create a holistic atlas of the whole adult human brain along with the head and neck. The atlas is three-dimensional (3D), advanced, detailed, reference, interactive, accurate, realistic, high resolution, fully parcellated, completely labeled, spatially consistent, stereotactic, user friendly, extendable (scalable), composable, dissectible, explorable, and modular. To date, we have constructed a 3D atlas from multiple 3 and 7 Tesla MR (Magnetic Resonance) and high resolution CT (Computed Tomography) in vivo scans of a single brain specimen to ensure spatial consistency and extendibility. The virtual model in the atlas contains structure [3], intracranial vasculature [4], white matter tracts [5], cranial nerves with nuclei [6], head muscles and glands [7], extracranial vasculature [8], and a complete skull added recently reconstructed

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from a CT scan (Nowinski et al., Three-dimensional stereotactic atlas of the adult human skull correlated with the brain, cranial nerves and intracranial vasculature, submitted to Journal of Neuroscience Methods 2014). The atlas design criteria and tools for atlas construction have been addressed earlier [10].

Several techniques are required to create atlases, including image processing, computer graphics, modeling, registration, and image and model editing. The key techniques employed for the atlas use are visualization and interaction. The goal of this work is to discuss the atlas design and use from a point of view of visualization and interaction.

2. Visualization

Two main visualization techniques are volume rendering and surface rendering. Volume rendering handles a volumetric representation of data and surface rending a polygonal data representation. An advantage of the volumetric representation is that the scans used for atlas creation were originally acquired as volumetric data (sometimes with prior resampling). However, the parcellability of volume rendered images is limited as image intensities are translated to (R,G,B) color and opacity by means of transfer functions. Despite the use of various extensions of the standard transfer functions, such as [11], [14], anatomic parcellation of a scan is practically not feasible. For instance, if each pixel in the scan would be labeled (colored) individually, and assuming that a single pixel is processed within 30 seconds (to perform pixel reading, making decision about what tissue it belongs to, assigning label or color, and saving it), the main structural MR scan with 20 million voxels would be handled for about 100 years.

Anatomic parcellability is feasible by means of geometric modeling. Prior to forming a geometric model, the acquired scan has to be accurately parcellated (for instance contoured) which is a tedious and time consuming process. From the parcellated scan, its 3D polygonal model can be created by applying, e.g., the Marching cubes algorithm [2]. When multiple scans are used (as is in our case), they must be spatially registered first and their segmented models merged. The polygonal representation enables a high (subpixel) parcellation of the scans and provides control over editing of data (i.e., images and models), resulting in a more accurate and realistic model. It also has additional advantages as listed and compared in Tab. 1. Therefore in our atlas, the brain, head and neck are represented as polygonal models visualized by surface rendering.

3. Interaction

The key interaction requirement was to allow the user to create and explore any region of interest along with its surroundings just with a few clicks, taking into account that the number of atlas components is about 3,000. Moreover, the atlas provides a rich

Tab. 1. Volumetric versus polygonal representation

Feature	**Volumetric representation**	**Polygonal representation**
Data representation	Originally acquired or resampled	Must be created
Spatial resolution	Voxel size bounded	Sub-voxel
Parcellation	Fast but of low resolution and anatomically inaccurate; anatomic parcellation infeasible	Time consuming and accurate; anatomic parcellation feasible
Integration of knowledge-based content	Very difficult, if possible at all	Possible; requires dedicated tools
Extendibility	Easy (by image fusion)	Easy (by object import)
Editibility	Easy but extremely time consuming (by editing individual voxels)	Easy (by editing polygonal objects); requires dedicated tools
Structure separability	Low (fuzzy borders)	Very high, as borders are defined, enhanced by structure color coding
Structure-to-structure conflict detection	Non existent	Requires manual or automatic handling

set of functions [10] enabling component selection, 3D model display and real-time manipulation, brain/head/neck compositing (assembly) and decompositing (disassembly), structure labeling, virtual dissections, scan scrolling, 3D stereotactic coordinate readout, 3D distance measure, and highlighting of individual components. Therefore, the main challenge was to design interaction to be fast and easy to use.

There are seven types of interaction in the atlas, which enable to: 1) select and deselect tissue classes, groups and individual structures (during 3D scene compositing and/or decompositing); 2) do real-time manipulation of the composed 3D scene (rotate, zoom, pan, and set views); 3) do virtual dissections by means of 3D cutting of the cerebrum, cerebellum, brainstem, spinal cord, white matter and skull in order to expose structures lying inside; 4) select and scroll the original scan in axial, coronal, and sagittal planes displayed in 3D; 5) query a structure to get either its label (and diameter for the vessels) or location in the composed 3D scene; 6) get stereotactic coordinates and measure distances; and 7) support other functionality (namely, image saving to an external file, starting/stopping 3D scene auto rotation, clearing labels, and getting information and help). Typically during brain exploration, the user may perform all seven types of interactions.

In order to facilitate interaction as well as to expedite structure selection and 3D scene compositing and/or decompositing, the atlas components have been grouped at multiple levels. The atlas content has been divided into tissue classes (modules), groups within each tissue class, and individual components within each group. A component may be single or composed. There are at present 17 modules containing the central nervous system (CNS), deep structures, ventricles, white matter, white matter tracts, intracranial arterial system, intracranial venous system, head muscles, glands, extracranial arteries, extracranial veins, skull, skin, neck, visual system, and auditory system. The CNS is available permanently and the remaining modules are selectable by the user from a (4×4) module matrix. Examples of groups include 12 pairs of the cranial nerves (CN I – CN XII) within the cranial nerve tissue class or ICA (internal carotid arteries), ACA (anterior cerebral arteries), MCA (middle cerebral arteries) and PCA (posterior cerebral arteries) within the intracranial arterial system tissue class. An example of an individual component is the basilar artery (BA) which can be handled as a single component or a composed component (i.e., the BA itself along with its tributaries). The de/selection operations can be performed at 5 levels supporting the paradigm "from blocks to brain"; namely, at the level of all tissue classes (components), tissue class cluster (brain, head, neck or systems), tissue class, group within a class, and individual component within a class (with or without its sub-components).

4. Results and discussion

The first edition of the atlas of the human brain, head and neck has been developed and made available [9]. Figure 1 shows surface rendered images of the brain (along with the intracranial vasculature) and the head (with the skull, muscles, extracranial vasculature, cranial nerves, and visual system). Figure 2 presents the user interface with the controls for interaction, including the module matrix for selection of all the tissue classes, tissue class cluster and/or individual classes; actually selected modules with their panels enabling group selection; anatomical indices for individual component selection; and functional buttons.

This design of visualization and interaction provides a fast and easy to use solution. Moreover, one of the requirements of the atlas design was affordability. At present, the atlas runs on a standard PC and MAC equipped with a graphics card supporting OpenGL 2.1 or higher library. The current design of visualization and interaction has allowed porting the atlas to mobile platforms, including iPad [12] and Android-based [13].

This work in a long-term effort aiming to create a holistic atlas of the human brain, head and neck. Visualization and interaction are two key techniques enabling atlas use. Future atlas development may require more advanced visualization and interaction. Developing a hybrid volume and surface renderer would facilitate to display any scans imported to the atlas by the user. Stereoscopic viewing (especially to visualize tubular

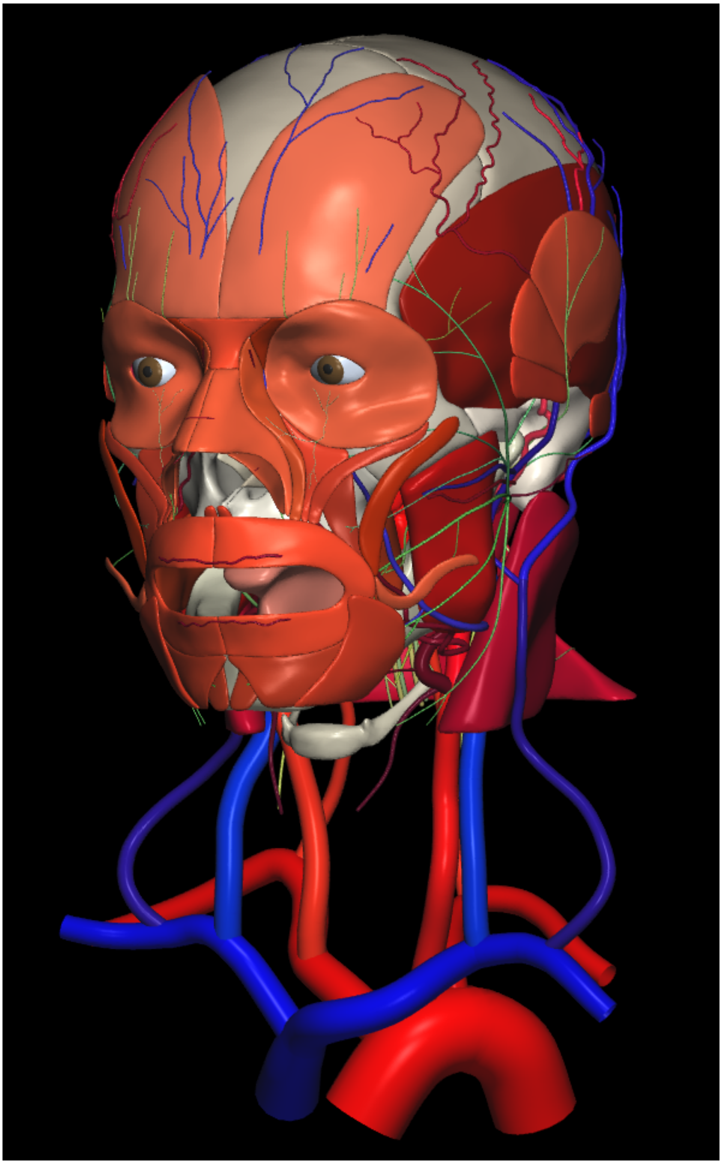

Fig. 1. Surface rendered images of the brain and the head.

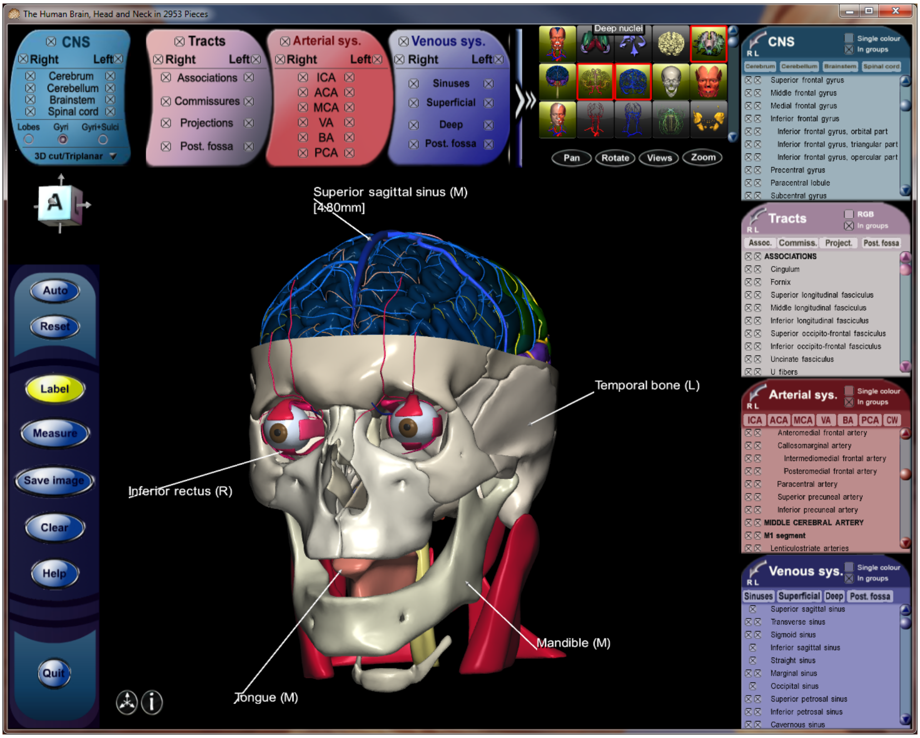

Fig. 2. User interface with the controls for interaction.

structures, such as vessels and cranial nerves) and 3D two-hand intuitive interaction, as applied earlier in our neurosurgery planning system [1], would further enhance visualization and interaction (though this approach may reduce affordability of the atlas).

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