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From Data to Knowledge - the Visible Human Project® Continues

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Abstract

The U. S. National Library of Medicine (NLM) has long been a world leader in the archiving and distribution of the print-based images of biology and medicine. NLM has also been a pioneer in the use of computer systems to encode and distribute textual knowledge of the life sciences. NLM's Long Range Planning effort of 1985-86 foresaw a coming era where NLM's Bibliographic and factual database services would be complemented by libraries of digital images, distributed over high speed computer networks. The NLM Planning Panel on Electronic Imaging recommended that NLM should undertake the building a digital image library consisting of computerized tomography (CT) and magnetic resonance (MR) images, and cryosection images of a representative, carefully selected and prepared male and female cadaver -- the "Visible Human Project®." The male and female Visible Human data sets are now being made available through a license agreement with the NLM. The data sets are supporting a wide range of educational, diagnostic, treatment planning, and commercial uses. The NLM, in partnership with other U.S. government research agencies has begun a three prong effort within the Visible Human Project to address: the creation of a new online, interactive, digital head-and-neck atlas; the development of a tool kit of computational programs capable of automatically performing many of the basic data handling functions required for using Visible Human data in applications; and the improved resolution of future Visible Human data sets through the reduction of the anatomical artifacts introduced by the methods used to stabilize and section the anatomical materials and the development of staining and wide-spectrum methods for increasing tissue contrast.

Keywords:

Imaging; Anatomy; Visible Human

Introduction

Images are an important part of biomedical knowledge. Pictures facilitate the understanding of biological structure and function, and are an essential component of education, research, and health care delivery. New computer-based technologies are providing an unprecedented opportunity to supplement the traditional two dimensional images of medicine, such as pictures in textbooks and plain radiographs, with dynamic three dimensional images. These images can be viewed, rotated, and reversibly dissected in a manner analogous to the physical objects they represent, providing valuable instruction to the student, insight to the researcher, and critical treatment planning information to the practitioner.

Planning Panel on Electronic Imaging

Early in 1989, under the direction of the U.S. National Library of Medicine's (NLM) Board of Regents, an ad hoc planning panel was convened to provide the Library with in-depth guidance as to its proper role in the rapidly changing field of digital imaging. The panel recognized that much of our understanding of complicated health and disease processes actually lies in images not text. Over the centuries we have been using text to describe our view of body systems, organs, and molecules because of the difficulty and expense of creating and distributing the images. With this as a background the Panel made the following recommendation:

> "The NLM should undertake a first project, building a digital image library of volumetric data representing a complete normal adult human male and female. This "Visible Human Project®" would include digitized photographic images from cryosectioning, digital images derived from computerized tomography, and digital magnetic resonance images of cadavers." [1]

The Panel viewed this project as a cornerstone for a future set of related digital image libraries, including libraries of normal structural variation, collections of diseased and abnormal structures, embryology and pediatrics. The Visible Human Project (VHP) could serve as a test platform for developing the methods and standards necessary to acquire, maintain, distribute and efficiently use digital image libraries and as a catalyst for the development of methods to link spatial data consisting of images, and objects within images, to symbolic (text-based) data consisting of names, hierarchies, principles, and theory --

the connection of structural-anatomical knowledge to functional-physiological knowledge.

The details of how the images which make up the Visible Human data sets, figure 1, were captured are described elsewhere [2]. The male data set contains 1871 digital axial anatomical images obtained at 1.0 mm intervals and is 15 gigabytes in size. The female data set contains 5189 digital axial anatomical images obtained at 0.33 mm intervals and is 39 gigabytes in size.

Figure 1 – Visible Human Male and Female

The Visible Human Project: From Data to Knowledge

Despite the unprecedented detail in the VHP data sets and its demonstrated utility in conveying information about gross anatomy, deficiencies in the data compromise its use in the focused teaching of specific areas of human anatomy. In February 1998, a workshop sponsored jointly by NLM and U.S. National Institute of Dental and Craniofacial Research (NIDCR) explored the growing needs of the research and education community for more powerful digital tools and higher resolution models of human anatomy [3]. The workshop focused on an in-depth analysis of the existing male Visible Human data, specifically on the anatomy of the head and neck. The workshop participants recommended the development of a multi-media, web deployable head and neck atlas created from the existing male data set as a proof of educational and technical concept, the pursuit of advanced image processing software tools to accommodate future higher resolution data, and the development of better tissue fixation and staining techniques to minimize tissue artifacts. Many of these findings were confirmed through individual meetings at the Second Visible Human Conference, held at NIH in Bethesda, MD in October 1998 [4].

The NLM in partnership with NIDCR, U.S. National Eye Institute (NEI), U.S. National Institute of Deafness and Other Communication Disorders (NIDCD), U.S. National Cancer Institute (NCI), U.S. National Institute of Mental Health (NIMH), U.S. National Institute of Neurological Diseases and Stroke (NINDS) and the U.S. National Science Foundation (NSF) have begun a three prong effort within the VHP to address these new concerns. The first initiative is the creation of an online, interactive, digital head-and-neck atlas using the existing male Visible Human data set. The second is the development of a tool kit of computational programs capable of automatically performing many of the basic data handling functions required for using Visible Human data in applications, e.g., segmentation and alignment. The third seeks to reduce the anatomical artifacts introduced by the methods used to stabilize and section the anatomical materials and enhance the visibility of structures with the tissue, e.g., herniation, suppression of morphological changes in the anatomy during fixation, and staining as well as wide-spectrum methods for increasing tissue contrast.

Visible Human Project Atlas of the Head and Neck

The purpose of this project is to develop a public domain NLM hosted web site portraying human anatomy based primarily on the VHP male data set. The goal is to create a landmark functional and clinical anatomy atlas of the head and neck human body regions---a prototype for a new wave of educational applications based on the integration of the VHP data sets with other ancillary human imagery sources. The project is designed to demonstrate the utility of the existing data and will provide a platform for new directions in education and medical research. The NLM commissioned the VHP Head and Neck Atlas to the University of Colorado Health Sciences Center through a competitive, peer-reviewed contracting process.

A series of clinically relevant functional anatomy modules are being created as part of the Atlas. These educational modules are being designed to demonstrate the functional processes involved in facial expression, mastication and deglutition, phonation, hearing, and vision. The Atlas web site will allow the user to interact with the appropriate imagery in order to demonstrate functionality, for example, the function of the muscles that control and move the mandible bone during the chewing (mastication) reflex. Magnetic resonance interferometry (MRI), computerized axial tomography (CAT), and other radiology image modalities as well as conventional anatomic graphic materials will be integrated into each module. The modules will demonstrate normal musculo-skeletal system function as well as abnormal functional deficits including clinical signs and symptoms. They will illustrate neurovascular

relationships through the interactive dissection of anatomic structures and fly-through views. For example, the student will be able to experience a walking tour of the optic nerve and view of the distribution of the ophthalmic artery and its tributaries. These web accessible modules will emphasize interactivity over passivity.

Equally important to the educational success of this project is the achievement of an element of novel entertainment quality that will form a creative prototype to stimulate and encourage the interactive learning process. The Atlas web site, figure 2, is being designed to meet the needs of a wide ranging audience including: medical, dental, and nursing students with an emphasis on normal anatomic structure and function; practicing heath care professionals with an emphasis on clinical relevance; and the general public's need for reference materials to better understand a health concern.

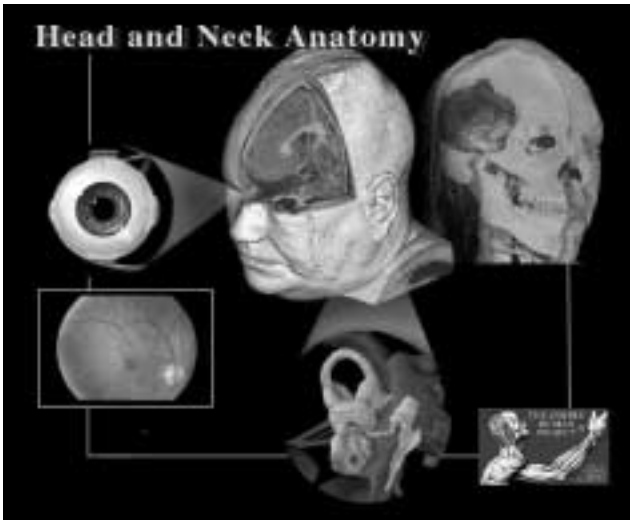

Figure 2 – Screen from the Visible Human Project Atlas of the Head and Neck

All anatomical structures are being identified by their Unified Medical Language System (UMLS) Unique Identifier. Appropriate anatomical terminology and relationships were recently added to the UMLS lexicon. The objective is to link the image library of structural-anatomical knowledge represented by the Atlas and its educational modules with the text library of functional, clinical, and physiological information at the NLM. The Atlas is being designed to give the user the option to link into NLM databases for further information. This structure, as navigated by the user, enables different levels of inquiry according to the user's educational level and need.

Visible Human Project Computational Tool Kit - "Insight"

The second initiative is a software development effort. Its purpose the creation of a self-sustaining code development consortium to support image analysis research in segmentation, classification, and deformable registration of medical images. The goal is the development of a public domain software resource that will serve as a foundation for future medical image understanding research. The intent is to leverage the investment being made through the VHP and other medical image analysis programs by reducing the re-invention of basic imaging algorithms. One result will be to empower young researchers and small research laboratories with the essential parts of a public domain image analysis system. An objective of NLM and its funding partners is to support development that will create prototypes for advanced image based applications based on the VHP data sets.

This initiative specifically does not include the development of visualization techniques or a user interface. The software toolkit is being designed to support a variety of visualization and/or rendering platforms and to be easily integrated into existing processing, visualization and presentation systems. The completed software toolkit, including all source code and extensive documentation consisting of manuals, tutorials and examples, will be made available in the public domain by the NLM through controlled Internet distribution. As with the VHP data sets, controlled access to the source code and image processing tools will be through the issuance by the NLM of a no-cost license. The license is required solely to allow NLM to track the use, distribution, and proliferation of VHP related products.

A research consortium including partners from academia and industry has been formed to carry this work forward. The members include General Electric, Inc., Kitware, Inc., MathSoft, Inc., the University of North Carolina at Chapel Hill, the University of Pennsylvania, the University of Tennessee, Harvard Brigham and Women's Hospital, the University of Pittsburgh, and Columbia University. An early goal for the consortium was the selection a common software delivery environment including the creation of a common Application Programmer's Interface (API) and the selection of target hardware architectures. All the software tools are being developed for this common environment. An algorithm validation methodology, and software performance metrics will also be provided.

An open research symposium on image segmentation and registration techniques will be held by the NLM in the 2002-2003 time frame. This symposium is being planned as a forum to present new developments in the automatic and semiautomatic segmentation of medical images. Presentations at the symposium will be based on the research and development work sponsored through the Insight initiative.

Visible Human Project Anatomical Methods

This initiative is directed at the methods that were utilized to stabilize the anatomical materials used in making the Visible Human data sets. The work is focused on three methodological areas. The first concentrates on the elimination of the freezing and embalming artifacts which

can be seen in the data set images. Methods need to be found through which tissue can be fixed without deformation, swelling or misalignment. The second will identify topical covalent histochemical markers which will enhance the contrast between nerves and their surrounding tissues. This will allow the visualization of the branching of nerves as they reach their target organs. The third involves the identification of vascular structures by the application of dye materials, or by the injection of materials for vascular luminal filling adapted to VHP cryosectioning methodology.

The enhanced anatomical methods will be used to produce new artifact-free, neurovasculature-resolved VHP data sets of specific regions within the head and neck. New MRI and CAT images of the new anatomical material will accompany these new digital anatomical data sets. They will be trans-sectioned at planar intervals appropriate to the data being captured. They will be archived at the NLM and inserted into the Visible Human Project Atlas of the Head and Neck. The goal is to obtain new higher resolution VHP data that will considered to be “normal” by all reasonable definitions of structure, virtually free from preparation and preservation artifact, and sectioned at a trans-sectional thickness sufficient to resolve functionally important and educationally relevant neurovascular structures.

Long Term Goals

One can imagine a future where an interactive anatomical atlas composed of anatomical image objects serves as the navigation device for surfing the medical literature. A database of normal structural variation [5] could be created. Each time an anatomical image is rendered from objects contained in the VHP database, the objects could be morphed according the statistics contained in the database of anatomical variation, thereby turning a single individual into the human family. These anatomical image objects can then be matched to similar patient specific MRI or CT image objects, allowing the physician to "see" the anatomy to be treated, not just the radiological representation of that anatomy. Collections of diseased and abnormal structures, in suitable object format, could be morphed and substituted for the normal object contained in the VHP database allowing for easier comparison of patient images with reference images.

The relationship of each anatomical object to the other anatomical objects in its cross-section and in the adjacent cross-sections can be catalogued. The extent of a single object which spans several cross-sections will be noted. These objects with their extents and relationships can then be projected into a lexical construct like NLM's Unified Medical Language System in order to create a truly interactive anatomical digital atlas. This is a first step in the development of methods to link such image objects to text-based data.

We do not have to limit ourselves to anatomical objects. Our interactive anatomical atlas can also contain sound objects to allow us to hear heart sounds or chest sounds. It can contain signal objects so that we can obtain an appropriate EKG as we place our virtual electrodes on different parts of the anatomy. Or how about haptic objects which define how the anatomy feels and will allow us to feel the anatomy through haptic interfaces. Interactive physiological model objects will animate the anatomy objects according to the physiological parameters which we present to the modeling object.

Standards do not currently exist for such object linkages. Basic research is needed in the description and representation of multi-media based structures, and in the connection of structural-anatomical data to text-based functional-physiological data. This is the larger, long term goal of the Visible Human Project®: to transparently link the print library of functional-physiological knowledge with the image library of structural-anatomical knowledge into one unified resource of health information. The goal is to produce a single, unified multi-medial resource for health information.

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