# INTERACTIVE 3D USER INTERFACES FOR NEUROANATOMY EXPLORATION

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Abstract: Human neuroanatomy is extremely complex, and functional neuroanatomical pathways cannot be dissected and easily visualized in an anatomy lab. Teaching students to see neuro-anatomical relationships over the extent of the neuraxis is challenging. The ability to internalize a 3D map of the neuraxis with the appropriate clinically relevant neuro-pathways superimposed is critical for medical students, as it facilitates long-term retention of the information as opposed to short-term memorization. Interactive 3D simulations can play a significant role in facilitating learning through engagement, immediate feedback, and by providing real-world contexts.

## 1 INTRODUCTION

The human nervous system is the most complex achievement of the process of evolution. It is the primary mechanism in the detection of changes in the external and internal environment triggering appropriate responses in muscles, glands and organs. Neuroanatomy is the study of the brain, spinal cord, and peripheral nervous system. The understanding of neuroanatomy correlation with function and dysfunction is a cornerstone for future advances in clinical neuroscience.

Medical students historically have difficulty conceptualizing and projecting in their minds the 3D aspects of the neuro pathways and embryonic organ development from 2D text materials and electronic resources. While highly specific laboratory tests and sophisticated imaging techniques can be critical for the practice of medicine, the basis of a neurological exam relies on the physician's ability to visualize very complex neuroanatomical relationships, in order to make highly accurate diagnosis.

Interactive web-based 3D simulations play a significant role in facilitating learning through engagement, immediate feedback, and providing real-world contexts. An obvious benefit of interactive systems with 3D models is the capability to view spatial relationships among structures from a variety of viewpoints.

The maturity of Web standards and technologies has reached a point where development and deployment of interactive 3D interfaces for complex data visualization and knowledge sharing is feasible.

In this paper we present our preliminary work towards the development of an interactive Web portal and a discussion on the usability paradigms associated with this system. The project is in its early stages of development and is yet to be completed and evaluated. In Section 2 we provide a brief overview of related work. In Section 3 we present an interactive network that will simulate nervous impulse propagation. In Section 4 we discuss a few interaction design and assessment issues. We close the paper with conclusions in Section 5.

## 2 RELATED WORK

The practice of medicine relies on a clinician's ability to effectively integrate basic medical knowledge with clinical experience to arrive at the appropriate diagnosis. Laboratory tests as well as sophisticated imaging techniques can supplement the physician's diagnostic skills. However, neurology is one area of medicine which relies more on the physician's ability to use his/her knowledge of


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functional neuro-anatomical pathways to precisely identify the cause and location of the underlying medical problem (Adams et al, 2008).

Unfortunately, human neuro-anatomy is extremely complex, and functional neuro-anatomical pathways, while well described in books, cannot be dissected and easily visualized in an anatomy lab. Teaching students to "see" and understand neuro-anatomical relationships over the extent of the neuraxis *(i.e., axial part of the central nervous system)* represents another level of complexity. However, the ability to internalize a three-dimensional map of the neuraxis with the appropriate clinically relevant neuro-pathways superimposed is critical for medical students, as it facilitates long-term retention of the information as opposed to short-term memorization (Mateen and D'Eon, 2008). We hypothesize that the ability to visualize neuro-anatomical pathways in 3D significantly improves students' ability to use clinical deficits to localize discrete lesions.

While exploring the latest technology in 3D content development for the Web, we followed the VRML standard which pointed to eXtended 3D (X3D). The Web3D consortium develops X3D as an open standard for web-3D modeling and information exchange. Within the Web3D consortium, the MedX3D (Web3D, 2008) is tightly focused on medical applications that can benefit from real-time 3D visualizations. One of the MedX3D research group's focus is representation of the human anatomy in X3D.

Another research effort to represent anatomy in a Web setup is targeted at teaching anatomy (Brenton et al., 2007). A major project, focused on neuro-informatics tools for modeling the brain and stressing the importance of modeling and sharing data about the brain and its associated processes is the Human Brain Project (Sheperd et al., 1998).

Our main goal is to develop an interactive advanced learning system that will support independent exploration and experimentation through built-in features. The system will allow students to manipulate in 3D and explore the changes in the simulated process, and to visualize motor and sensory systems as well as their relationships over the neuraxis. At last but not least, they will be able to visualize neural signal traveling along the neuro-pathways from the triggered receptor. The simulation could be presented as supplementary material in the class, on the projector, or as an assignment online, and will enhance and complement the instructional material.

## 3 AN INTERACTIVE NETWORK

Primarily, two types of phenomena are involved in processing nerve signals: electrical and chemical. While electrical events propagate a signal within a neuron, the chemical processes transmit the signal from one neuron to another neuron or to a muscle cell.

To visualize neural signal propagation along the neuro-pathways, we developed an X3D anatomical model based on a male dataset, as illustrated in Figure 1.

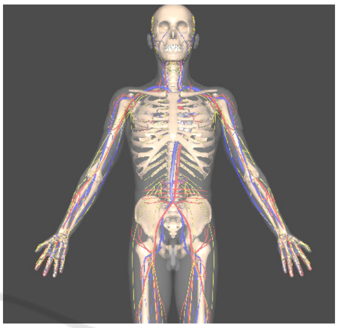

Figure 1: An X3D anatomical male model.

The anatomical model consists of the following subset: a skeletal system, a circulatory system, a nervous system, a brain model, and the skin (outer layer) model.

We decided to model the structure of the nervous system as a directed graph with vertices that follow the anatomical structures. The nodes (vertices) in this graph are nervous excitation points that can generate a nervous impulse. They correspond to the triggered receptors of the nervous system. Such a representation determines an interactive network that can simulate nervous impulse behavior at macroscopic and microscopic levels.

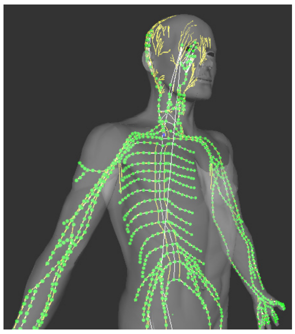

Figure 2: Interactive Network (Macro Level). A graph (tree) representation of the nervous system merged within the X3D anatomical model.

As the impulses travel along the nerves to the neuraxis and the brain, they change color and shape. The animation allows the user to visualize the path taken by the impulses and the impulse behavior as it crosses an anatomical structure. The X3D sensor-based mechanism we implemented allows addition and removal of nodes (i.e., trigger receptors) on the skin of the 3D human model. The graph is editable, and the student is able to develop its own network and test its behavior.

Two modes are available: *design* mode and *simulation* mode. In *design* mode, a student can load a default network and continue to add location sensors on the skin of the 3D model. By switching to *simulation* mode the student can explore in 3D an animation showing the propagation of the nervous impulse throughout the nervous system.

As the user zooms-in on the X3D network, after a certain threshold is reached, the "Micro Level" is activated and the chain of neurons associated with that sub-section of the nervous system is rendered. The microscopic level allows the user to visualize the signal propagation at the microscopic level (as illustrated in Figure 3, the signal represented as yellow spheres that travel along the neurons chain).

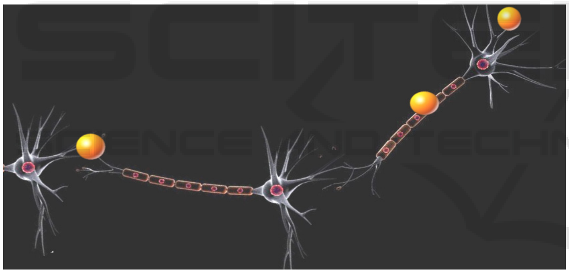

Figure 3: Interactive Network (Micro Level).

The action potentials can travel along axons at speeds of 0.1-100 m/s. This means that nerve impulses can get from one part of a body to another in a few milliseconds, which allows for fast responses to stimuli. In the microscopic simulation, the propagation speed of the signal is reduced to provide a clear visualization of the neuron components involved in the process. The level of detail (LOD) change is currently under development. To reduce the scene rendering time, we have experimented with billboards with 2D neuron textures mapped on them. The details of this module will be presented in future articles.

# 4 INTERFACE INTERACTION DESIGN

The goal of interaction design is to gain maximum usability for our interface. In what follows we explore several factors that will affect the system interactivity and usability.

## 4.1 Optimization for Interactivity

In a 3D Web-based environment the scene graph has to be loaded and cached on the client side. An X3D file usually contains large datasets representing the polygonal models in the scene. Linear transformations are applied on the polygonal models at loading time, most of the times. Such transformations will slowdown the scene loading. To speed up initial scene upload, we have investigated compression algorithms for X3D. The X3D representation of the male anatomical data set is divided into the following subsets: skeletal system, circulatory system, nervous system, the brain model, and the skin. The compression algorithm reduces, on average, three times the size of the model (as illustrated in Table 1), and hence the X3D scene loading time.

Table 1: Uncompressed and compressed X3D.

| **Body Part or Subsystem** | **Before Compression *(MB)*** | **After Compression *(MB)*** |
|---|---|---|
| Skeletal | 3.04 | 1.01 |
| Circulatory | 12.41 | 3.81 |
| Nervous | 4.87 | 1.29 |
| Brain | 9.18 | 3.08 |
| Skin | 1.85 | 0.51 |

We are in the process of exploring compressed binary encoding (ISO/IEC 19776-3, 2007) for the X3D. Compressed binary encoding uses several techniques to reduce the size of an X3D document and to increase the speed of creating and processing such documents. These techniques are primarily based on the use of vocabulary tables that allow small integer values to be used instead of character strings.

Another optimization technique, based on the initial position of the 3D models in the X3D scene, is possible. For example, the male skin polygonal model has currently around 18,000 polygons. As the 3D scene is initialized, a set of transformations will be applied on each polygon in the model. This computation done on-the-fly can significantly delay the loading time of the X3D scene at the client side. We can pre-compute the transformations in the X3D file and apply them to the "coordinate" sets beforehand. We have implemented an optimizer module that reduces the loading time in half by pre-computing the transformations for each 3D object in the scene.

### 4.2 Paradigms for Usability Support

Learnability is the ease with which new users can begin effective interaction and achieve maximal performance. Learnability is enhanced by several paradigms like predictability, synthesizability, and familiarity (Dix et al, 2004).

Predictability means that the user can easily determine the results of his/her future actions on the interface based on the interaction history. The X3D interface is a consistent 3D environment that is fully determined by the interaction history. Synthesizability of the interface is very high since the user is able to assess the effect of past operations on the current state. One of the issues that may arise is the X3D player's robustness, i.e., parsing errors may render parts of the scene invisible, having a negative effect on predictability. In terms of familiarity, the X3D interface navigation uses the mouse buttons and their well-known functionality. The 3D virtual objects have intrinsic properties that suggest how they can be manipulated. Our informal assessment shows that users familiar with the window system have no difficulty in learning and using the interface very fast. We have also deployed a small size assessment experiment on a group of 12 students. The users were explained and asked to rank the predictability of the system on a scale from 1 to 5 (1 meaning less predictable and 5 meaning very predictable). The scores average was 4.83, denoting a highly predictable system.

Another component for usability support is *flexibility*. Flexibility represents the multiplicity of ways the user and system exchange information. Currently we are working at an interactive dialogue system that will guide the user through various simulations linked to a specific topic. We are also investigating *customizability* and the transfer of control for tasks execution, between the system and the user, to support *task migratability* (i.e. the user can have a computer assistant that will provide guidance through certain parts of the simulation; the simulation control could be switched from the user to the computer at any time, to guide through difficult sections). We are in the process of developing an assessment experiment for the system migratability in conjunction with the user task and application domain.

## 5 CONCLUSIONS AND FUTURE

We have presented a few aspects of the early stages of development of an advanced learning tool for neuroanatomy. We have also discussed important aspects of interactive interface design, as interactivity is one of the main goals of the project.

Since there are different learning "speeds", and they vary from person to person, the learning tool is available online in a Web-based environment facilitating easy access anywhere and at anytime. For neuroanatomy, theory is easier to grasp than to translate into practice. In some cases, however, practical skills are quickly achieved, even without any basic understanding of the theory. In spite of these difficulties, we want to achieve the best theoretical and practical skills employing such advanced learning tools.

We are currently developing a labeling system that will allow students to visualize 3D neuro-anatomical components and their associated names. The labeling system will be accompanied by a decomposition module. This module will allow students to "virtually dissect" complex parts of the central nervous system, as illustrated in Figure 4. The figure denotes a 3D decomposition of the brain. As the user "takes apart" the components of the brain, s/he can better understand the location of the parts within the system as well as the spatial relationship among the nervous system components.

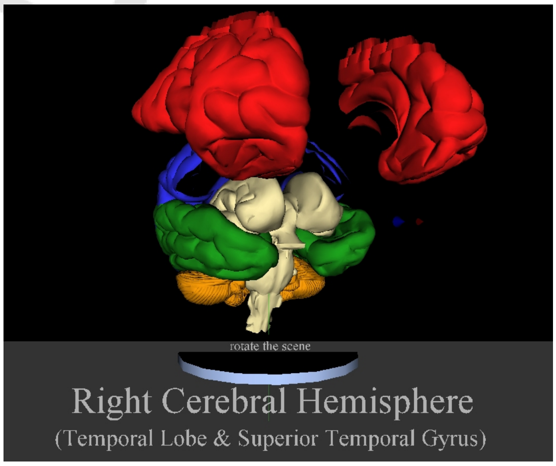


Figure 4: 3D Brain Model Decomposition.

A task of 3D model composition/decomposition based on labeling will be used as a testing tool to assess student learning performance. We will report our assessment results in future publications. The tool is available online at *www.neuro-pathways.org*.

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