

The Online Anatomical Human: Web-based Anatomy Education

Noeska Smit¹, Cees-Willem Hofstede¹, Annelot Kraima², Daniel Jansma², Marco deRuiter², Elmar Eisemann¹, and Anna Vilanova¹

¹Delft University of Technology, The Netherlands
²Leiden University Medical Center, The Netherlands

Abstract

The Online Anatomical Human (OAH) is a web-based viewer for studying anatomy. It is based on real human anatomy and incorporates medical image data in linked 2D and 3D views that students can freely interact with. Our application is the only to support 2D and 3D views based on real medical imaging data. The main goal of this anatomical online resource is to serve as an educational platform available to anyone with access to a modern web browser. Users can annotate regions, add comments, and provide hyperlinks to additional media. By making our work accessible to medical experts, we can ensure an increasing amount of information, leading to an ever-growing gain in educational value. The OAH will be used in an upcoming Massive Open Online Course (MOOC) to teach anatomy of the pelvis and will be made available to students worldwide via the web.

Categories and Subject Descriptors (according to ACM CCS): K.3.1 [Computers and Education]: Computer Uses in Education—Distance learning

1. Introduction

Human anatomy is the science of shape and structure of the human body. One of the oldest known papers on human anatomy, known as the Edwin Smith Papyrus, dates back to approximately 1700 BC. Still today, most education on anatomy is based on books [Nun02] and even though software exists, the presented anatomical models are often idealized and only an artistic rendition of the real anatomy.

In this paper, we present the Online Anatomical Human (OAH), an online viewer and annotation system for anatomical information developed for educational purposes. It is based on real human anatomy and incorporates medical image data in linked 2D orthogonal slice-based views and 3D views, but runs entirely in a web browser. This property makes our OAH solution a good choice for educational purposes, as it is basically available to anyone with an internet-enabled device. A screenshot is shown in Figure 1. Within OAH, a user can interact with the 3D model and 2D slices of a real data set to gain a better understanding and improve the mental mapping between the two domains. The latter is a critical skill since medical imagining has been introduced in clinical practice; while interpreting medical scans, such as MRI and CT, used to be done mainly in radiology departments, nowadays scans are available in digital form throughout the hospital and many specialists examine the images directly. Consequently, for medical students, it is important (but challenging) to mentally reconstruct a 3D model based on 2D images, as well as to relate 3D anatomy to 2D medical imaging data.

Additionally, by allowing medical experts to share their knowledge via annotations and hyperlinks, our representation becomes an online database, able to keep track of a variety of information and the most recent developments. The 3D annotation system has several additional purposes; it can be used by teachers to indicate anatomical landmarks, lines and regions, or to acquire different expert opinions on, e.g., optimal incision lines for surgical procedures. The annotation can also be used by students, to verify their understanding of the presented material or to ask questions. In consequence, our solution is highly valuable for educational purposes. Finally, our approach can be interacted with by using a Leap Motion such that the application can be controlled via hand and finger gestures. Besides a general ease of use, this possibility is of advantage when using the OAH during a anatomical dissection classes.

Specifically, our contributions are as follows: (1) A prototype tool, the Online Anatomical Human, capable of providing the user with linked 2D and 3D anatomical information for educational purposes via a web browser; (2) An open platform to enable users to annotate anatomical structures in 3D, leading to an ever-growing wealth of information; (3) 3D interaction techniques via hand and finger gestures.

2. Related Work

Estevez et al. evaluated the use of 3D visualization in teaching neuroanatomy and concluded that 3D physical modeling is

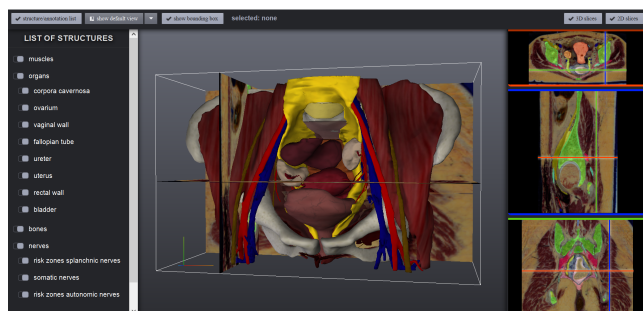


Figure 1: Main window of OAH: The structure list is available on the left for selection and showing or hiding (groups of) structures. In the center, the 3D model is shown. On the right, orthogonal 2D sliceviewers are available.

an effective method for teaching spatial relationships of brain anatomy [ELB10]. Web interfaces for anatomy atlases have been around for over ten years. In the beginning, these interfaces did not work well enough in terms of interaction speed to replace existing atlases in books [BRB95]. Only recently, using new techniques, such as WebGL, full 3D applications are feasible in the browser. Zygote Body was introduced by Blume et al. [BCK*11] in 2011, at the time under the name Google Body. The shown anatomy stems from a model designed by artists and not from medical imaging data, in consequence, it is not always representative of real patient anatomy. Qualter et al. introduced the Biodigital Human [QSO*11]. This WebGL anatomy platform supports pinpoint annotations. The model is again not created from real anatomical data, but a manually-modeled artistic generalization. 2D medical images are therefore not available. InnerBody [Tay97], in contrast, does not feature a 3D model, but a collection of illustrations. The tool offers various anatomical systems, such as the vascular or lymphatic system, to be explored in detail. In the Anatomography project, anatomical polygonal surfaces are made freely available via the dataBodyParts3D website for educational purposes [The]. Acland's video atlas of human anatomy provides videos of dissections online via a subscription service [Rob]. 4D Anatomy Online is a subscription-based online education platform that provides dissection-simulation resources based on dissection images [4D]. Furthermore, apps have been developed aimed at mobile phones and tablets such as Anatomy 4D by DAQRI and the Human Anatomy Atlas by Visible Body. Our application is the only freely available web-application that supports both 2D and 3D views using real anatomical imaging data.

When looking at depictions of anatomy in books, such as the works by Platzer et al. [PSF*07] and Attene et al. [ARSF09], several types of annotations are used. For larger regions, an internal label is shown directly on top of the depicted structure, whereas interesting landmarks can be labeled externally with a connecting line [RPRH07]. In the work by Platzer et al., color is used to distinguish different tissue types, whereas Attene et al. use color to label sub-parts in a larger structure. To allow users to make similar annotations, we examine several methods and systems for the annotation of surface meshes. A digital example of interactive direct painting on a mesh, within a web-browser, is DeathPaint [Sla]. In principle, this technique could be used to annotate regions on anatomical structures. Due to the restriction to WebGL, Deathpaint uses

a color-picking technique to choose a drawing location. Our approach uses a similar technique, but does not require pre-rendered textures and works even for new models without any preprocessing. Other tools, such as Space Pen [JGD02] allow users to annotate 3D models in 3D space by directly drawing on a model. It is web-based, but requires external plugins. Gorgan et al. [GSG07] also aimed at medical education and support a pen-based annotation in 2D and 3D, but the software is not web-based. Furthermore, all these solutions only support freehand annotation.

An elaborate survey of 3D web graphics techniques can be found in the survey by Evans et al. [ERB*14]. In order to reduce the stress on client computers, Blazona and Mihajlovic [MB07] proposed a method of in-server rendering. In this approach, the rendering process is performed by the server and only the resulting imagery is sent to the client. This solution increases the workload on the server when many clients are present. The release of WebGL made rendering complex 3D medical data within the browser feasible [CSK*11]. Since our models are relatively lightweight, and we expect many clients in a Massive Open Online Course (MOOC) context, WebGL suits our needs best.

A thorough overview of several input devices for 3D interaction can be found in the survey by Chris Hand. [Han97]. Standard interaction is based on a computer mouse and keyboard. The mouse is essentially a 2D device and in case a 3D scene is rendered, interaction can become counter-intuitive. Gallo et al. [GDPM08] proposed a method for model interaction with a Wiimote, which can be controlled in the air, such that the user is not limited to 2D mouse interaction. 3D devices usually map motion more intuitively on 3D interaction. The Leap Motion captures hand gestures in the air. Unlike when using the Wiimote, there is no need to hold anything in your hands. Weichert et al. [WBRF13] concluded that the device is robust enough to use in applications requiring a high level of accuracy for in-the-air movement with an average measured accuracy of 0.7 mm.

OAH was inspired by the research and tools described above, but none of the mentioned tools use real anatomical data. The OAH features a 3D model combined with the 2D medical image data from which it was created. It is also the first such system to allow region and line annotations on anatomical 3D models in a standard web browser. Besides keyboard and mouse, our application also supports the Leap Motion to enable interaction without touching a device, which is useful during anatomical dissection practicals.

3. The Online Anatomical Human

OAH uses the same models as in The Unified Anatomical Human by Smit et al. [SKJ*12]. The models were derived from the Visible Korean Dataset, which was chosen due to its high quality; cross-sectional intervals of 0.2 mm, with 4,368 x 2,912 pixels resolution. The dataset is considered to be qualitatively one of the best Visible Human Datasets available. A medical expert made detailed manual segmentations, from which 3D models were reconstructed.

The OAH interface can be seen in Figure 1. Users are able to interact with the 3D model and browse through the linked 2D cryosectional and segmentation slices on which the 3D model is based. Structures can be selected directly in the 3D view or by

choosing them from a nested list of all available elements. Whenever a structure is selected, the non-selected elements become semi-transparent to prevent occlusion, while preserving anatomical context. Further, query results from the UAH database, such as literature associated to the selection, become available to the user. Additionally, the user can decide to hide or reveal selected structures. Once a user finds an interesting view of the 3D model, it is possible to store the camera position. Such camera views can also be retrieved and make the camera move from its current view to the selected one via a tweening animation. These interactions help students familiarize themselves with the anatomical structures and their relations.

To ensure that students understand the link between 2D medical imaging and 3D anatomy, the 2D cryosectional images, which were used to create our 3D model, as well as the corresponding segmentation labels, are made available in the OAH in transversal, coronal and sagittal directions. For each of these three directions, a 'sliceviewer' is available. Each view is linked, hence, updates in one view are automatically propagated to all other views. One update relates to the movement of a cross-haired marker shown in each 2D sliceviewer and the 3D view. The axes of these markers are color-coded according to corresponding global directions. In each sliceviewer, one axis is invisible and represented by the stack of images associated to it. The user can scroll through the image stack using the mousewheel.

Annotation Our system also supports annotations. Teachers can use these to provide details regarding the structures, such as landmark names. Additionally, the annotation system can be used to evaluate student performance, by asking them for instance to indicate certain landmarks on a blank model. The same system is also suitable for the students to indicate relevant areas when asking questions about structure details.

At the core of our annotation functionality is the selection of a point on the 3D surface. Raycasting is the most-commonly used technique. Although accurate, a ray test against all primitives is too slow. While octrees or spatial indexing methods [Mea82] are standard, they increase memory usage for larger models and lead to increased preprocessing times, which makes it a suboptimal choice for mobile devices. Instead, we use an offscreen render target into which the model is rendered with a distinct color for each face. The color of the pixel underneath the cursor then directly reveals the selected face. Although this technique requires an extra render pass, the buffer is only a single pixel in size, making it highly efficient.

Examples of different annotations made in the OAH are shown in Figure 2. We offer three solutions to place annotations directly on the 3D mesh: landmark, region and line annotations. Landmarks are single points on the surface of an anatomical structure, used to either label an exact point, or to sub-label a structure without a specific region. We illustrate such landmarks with a small sphere at the selected point, so that it is visible from both sides of the surface.

Regions are used to coarsely annotate areas of structures. It can be useful when, for example, two parts of a structure need to be distinguishable, but the actual border is not evident. The method uses a brush, which makes annotations of large areas simple and quick. In our brush metaphor, all vertices within the brush diameter

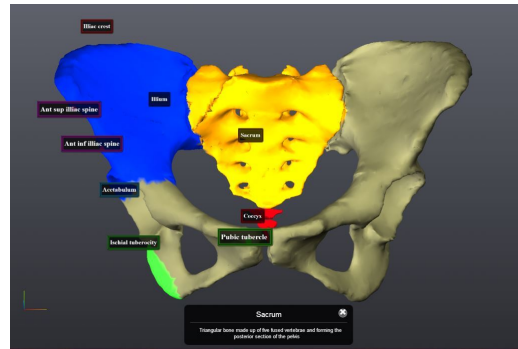


Figure 2: In this annotation view, pelvic bones are shown with landmark, region and line annotations.

are colored and a fadeout can be defined to indicate the precision of the annotation. When two parts of the model are close together, we ensure that our brushing method does not overflow into the disconnected region.

Line annotations are used when precision is needed. While regions have a fuzzy fadeout, lines are accurate. They can be set to form a region contour by connecting start and endpoints. Line segments can be drawn in two modes. The first mode, only uses a line segment drawn by the user. Our approach finds a path on the surface, whose projection matches the user input, while handling surface discontinuities. For this, we first project the two endpoints of the segment on the surface. We then virtually cut the entire model by the plane defined by camera center and the drawn segment. Hereafter, we launch a shortest path algorithm from the first to the second projected endpoint, traveling only on the newly created intersection edges. The second mode adds such line segments continuously, while the pointer is moving over the model.

Interaction Our system can be used entirely with a mouse to navigate and define annotations. However, one particularity of the OAH is its support of the Leap Motion. It is a sensor capturing input via hand and finger gestures, which can also be used alongside the keyboard and mouse. It registers full 3D positioning, making it particularly suitable for 3D interaction. The fact that the device works touchless, is particularly useful if OAH is used during anatomical dissection classes because students do not need to clean their hands, as is the case for standard input devices. Additionally, the Leap Motion provides a playful way for students to interact with the models and can be used for demonstration purposes.

Course Setup The OAH system will be used in an upcoming Massive Open Online Course (MOOC) as an interactive part of a Coursera course on human anatomy. This online course is aimed at large-scale participation and open access via the internet to students worldwide. Instructors provide questions on the anatomy of the pelvis, which students need to answer by interacting with the OAH. Through these questions, which can have different goals, mutual relations between organs and their clinical relevance are interactively explored by students.

A first goal is to focus on important organs in order to better illustrate their shape, extent, and location. For example, 'Show in three cross-sections that the Douglas Pouch is the deepest part of

the peritoneal cavity'. Another type of questions deals with relations between organs. For example, 'Explain what peritonitis is and what symptoms it causes'. Besides abdominal pain, also vaginal pain can occur, due to the close proximity of the peritoneum to the vagina. Questions can also be oriented towards risk investigations, which can lead to awareness of typical pathologies in certain organs. For example, 'A small kidney-stone is able to travel through the ureter to the bladder. Where can it get stuck along the way?'. Here, the students will find that the most critical point is crossing of the ureter and the Arteria Iliaca. Further, the students can be trained in communication. For this purpose, they can be asked to first identify all possible illustrations from the data set and present the finding to a colleague or patient. For example, 'Show the potential problem points for a kidney-stone in the 3D model, as well as on all cross-sections revealing these points and present it to a patient.' Through interaction with the OAH, these questions can lead students to gain a deeper insight into anatomy. They will not only be familiarized with the organs themselves, but also develop an understanding of their relationships and the symptoms caused by various pathologies.

4. Conclusion and Future Work

We presented the Online Anatomical Human (OAH), an online viewer and annotation system that is of interest to both students and experts. It makes 2D and 3D anatomy based on imaging data available to anyone with an internet connection, as it runs entirely inside of a web-browser and avoids any kind of installation procedure. Besides interactive exploration, users can annotate the model directly in 3D by adding landmark, region and/or line annotations. We support the use of the Leap Motion, enabling an intuitive and playful way to interact with the system. The OAH will be used in an upcoming Massive Open Online Course (MOOC) to allow students to learn about the relation between 2D and 3D pelvic anatomy in an interactive environment. In the future, we intend to use our OAH system to perform large-scale user studies with students from the MOOC.

References

- [4D] 4D ANATOMY INC.: 4D Anatomy Online. <https://www.4danatomy.com/>. [Online; accessed 10-March-2016]. 2
- [ARSF09] ATTENE M., ROBBIANO F., SPAGNUOLO M., FALCIDIENO B.: Characterization of 3d shape parts for semantic annotation. *Computer-Aided Design* 41, 10 (2009), 756–763. 2
- [BCK*11] BLUME A., CHUN W., KOGAN D., KOKKEVIS V., WEBER N., PETERSON R. W., ZEIGER R.: Google body: 3d human anatomy in the browser. In *ACM SIGGRAPH 2011 Talks* (2011), ACM, p. 19. 2
- [BRB95] BRADLEY S., ROSSE C., BRINKLEY J. F.: Web-based access to an online atlas of anatomy: the digital anatomist common gateway interface. In *Proceedings of the Annual Symposium on Computer Application in Medical Care* (1995), American Medical Informatics Association, p. 512. 2
- [CSK*11] CONGOTE J., SEGURA A., KABONGO L., MORENO A., POSADA J., RUIZ O.: Interactive visualization of volumetric data with WebGL in real-time. In *Proceedings of 3D Web Technology* (2011), ACM, pp. 137–146. 2
- [ELB10] ESTEVEZ M. E., LINDGREN K. A., BERGETHON P. R.: A novel three-dimensional tool for teaching human neuroanatomy. *Anatomical sciences education* 3, 6 (2010), 309–317. 2
- [ERB*14] EVANS A., ROMEO M., BAHREHMANN A., AGENJO J., BLAT J.: 3d graphics on the web: A survey. *Computers & Graphics* 41 (2014), 43–61. 2
- [GDPM08] GALLO L., DE PIETRO G., MARRA I.: 3d interaction with volumetric medical data: experiencing the wiimote. In *Proceedings of Ambient media and systems* (2008), ICST, p. 14. 2
- [GSG07] GORGAN D., STEFANUT T., GAVREA B.: Pen based graphical annotation in medical education. In *null* (2007), IEEE, pp. 681–686. 2
- [Han97] HAND C.: A survey of 3d interaction techniques. In *Computer graphics forum* (1997), vol. 16, Wiley Online Library, pp. 269–281. 2
- [JGD02] JUNG T., GROSS M. D., DO E. Y.-L.: Annotating and sketching on 3d web models. In *Proceedings of the 7th international conference on Intelligent user interfaces* (2002), ACM, pp. 95–102. 2
- [MB07] MIHAJLOVIĆ Ž., BLAZONA B.: Visualization service based on web services. *CIT. Journal of Computing and Information Technology* 15, 4 (2007), 339–345. 2
- [Mea82] MEAGHER D.: Geometric modeling using octree encoding. *Computer graphics and image processing* 19, 2 (1982), 129–147. 3
- [Nun02] NUNN J. F.: *Ancient egyptian medicine*. University of Oklahoma Press, 2002. 1
- [PSF*07] PLATZER W., SPITZER G., FRITSCH H., KÜHNEL W., LEONHARDT H., KAHLE W., FROTSCHER M.: *Sesam atlas van de anatomie*. Sesam, 2007. 2
- [QSO*11] QUALTER J., SCULLI F., OLIKER A., NAPIER Z., LEE S., GARCIA J., FRENKEL S., HARNIK V., TRIOLA M.: The biodigital human: a web-based 3d platform for medical visualization and education. *Studies in health technology and informatics* 173 (2011), 359–361. 2
- [Rob] ROBERT ACLAND: Acland's Video Atlas of Human Anatomy. <http://aclandanatomy.com/>. [Online; accessed 10-March-2016]. 2
- [RPRH07] ROPINSKI T., PRASSNI J.-S., ROTERS J., HINRICHS K.: Internal labels as shape cues for medical illustration. In *VMV* (2007), vol. 7, Citeseer, pp. 203–212. 2
- [SKJ*12] SMIT N. N., KRAIMA A. C., JANSMA D., DERUITER M. C., BOTHA C. P.: The unified anatomical human (beta): model-based representation of heterogeneous anatomical data. In *Proceedings of the 3D Physiological Human (3DPH) Workshop, CASA* (2012). 2
- [Sla] SLACK J.: Cartelle deathpaint study. <http://www.cartelle.nl/deathpaint/study/>. [Online; accessed 10-March-2016]. 2
- [Tay97] TAYLOR T.: InnerBody. <http://www.innerbody.com>, 1997. [Online; accessed 10-March-2016]. 2
- [The] THE DATABASE CENTER FOR LIFE SCIENCE: Anatomography - BodyParts3D. <http://lifesciencedb.jp/bp3d/>. [Online; accessed 10-March-2016]. 2
- [WBRF13] WEICHERT F., BACHMANN D., RUDAK B., FISSELER D.: Analysis of the accuracy and robustness of the leap motion controller. *Sensors* 13, 5 (2013), 6380–6393. 2