The LINDSAY Virtual Human Team

Overall impact of the contribution to science and medicine

Many of us might remember the movie "Fantastic Voyage", where a submarine is shrunken to miniature size and injected into the blood stream of a human. On board are medical researchers trying to save their patient. Of course, they get in trouble and a cinematic adventure unfolds. The "Fantastic Voyage" was released in 1966. How close are we to this science fiction scenario today? We still cannot shrink objects to desired sizes, whether large or small — at least not in our physical world. However, computer software is opening tremendously exciting new possibilities. We can create intricate and highly complex worlds inside our computers. Using the same approaches to build state-of-the-art computer games, we can create the illusion of diving into new and fascinating universes inside the human body: to explore systems, organs and tissues down to the level of cells, organelles and proteins.

This is the basic idea behind the **LINDSAY Virtual Human** ("LINDSAY") project, led by Dr. Christian Jacob, who has assembled a team of computer scientists, medical researchers, software developers and medical educators. The LINDSAY team's goal is to use innovative game engines to tell engaging and visually appealing stories about the human body. LINDSAY combines state-of-the-art information technology with medical expertise to complement and enhance our current resources for education, training, and research about the human body and human health. The developed LINDSAY e-learning ecosystem provides interactive visualizations of human anatomy and physiology in the form of virtual specimens, which can be distributed and shared through the internet.

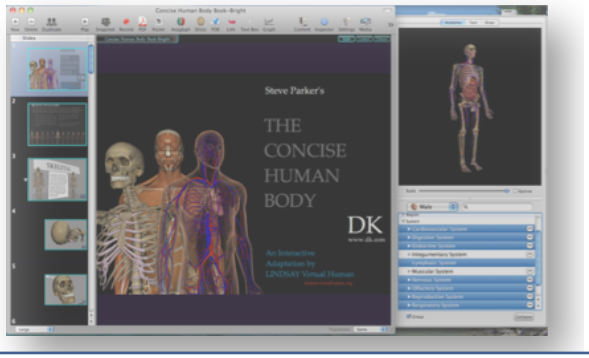


Fig. 1: LINDSAY Presenter

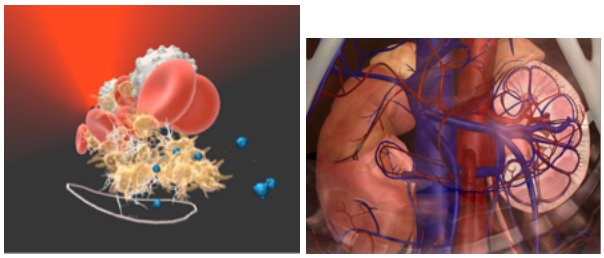


Fig. 2: Blood clotting and renal system models

General contribution to knowledge

The LINDSAY Virtual Human strives to provide integrative computer models of human **anatomy and physiology across spatial and temporal scales**. Anatomical structures are illustrated at multiple levels of scale: from the body level, to the level of systems (nervous, endocrine, muscular, immune, digestive, cardiovascular, etc), organs, tissues, cells, proteins, molecules and other sub-cellular structures. This integrative presentation across scales is not available through any other anatomy software to date. With respect to computational physiology, the same integration of models has to occur across temporal scales, as physiological processes occur in the range of nanoseconds (e.g., chemical reactions), minutes (e.g., blood clotting), days and weeks (e.g., recovery from Influenza infection) and years (e.g., tumour growth).

Anatomy teaching today still relies to a large extent on medical cadavers. This anatomical material is difficult to acquire and expensive to maintain and prepare. Furthermore, anatomical dissections are a destructive process, whereas virtual anatomical models allow any number of dissections and reassembly. Consequently, virtual human anatomy models constitute a completely new, highly flexible environment for exploring the structures and functions of our bodies.

Illustrating **physiology** is challenging on live bodies or through model organisms. Physiology illustration in a simulated environment, however, makes body functions and consequently pathophysiology (as malfunction) much more accessible. Interactive visualizations lead to a higher level of engagement (e.g., in high school classes) and increase retention of contents (e.g., in medical education). Our illustrative 3D models can also be used in health care settings, physiotherapy studios, fitness studios, or medical offices. For example, a physician can more easily illustrate a patient's case, overlay a computer simulation with patient-specific data from a CT scan, and explain the steps that will be taken during a planned surgery. The patient can then revisit this information at home on the web, including a customized patient record. Once our technology enters medical practice, it will revolutionize patient care, patient education, and truly enable personalized medicine.

Solution of novel or practical problems

Since its inception in 2009, the LINDSAY project has created integrated *eLearning* solutions for authoring, presenting and learning of human anatomy. The LINDSAY eLearning system consist of the following components.

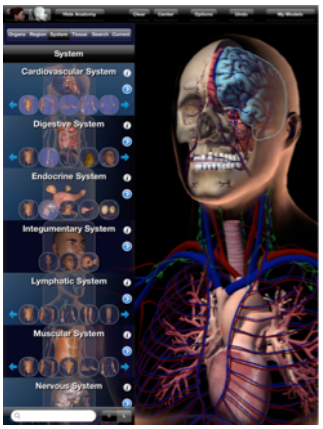
(1) **Lindsay Presenter** (LPresenter) is an innovative presentation tool for interactive, 3-dimensional anatomical contents (Fig. 1). LPresenter has a built-in anatomy database and searchable body atlas. LPresenter and its e-book derivatives have been used in courses since 2011 at the University of Calgary's Undergraduate Medical Education program (UME) as well as in anatomy courses for the Bachelor of Health Sciences program.

(2) We developed **Lindsay Composer** (LComposer), which we use in combination with game engines (e.g. Unity3D and Unreal Engine) in order to build 3-dimensional, interactive models of physiological processes within the human male and female body. Our models work across spatial and temporal scales: from systems and organs to tissues, cells, and sub-cellular structures (Fig. 2).

(3) The computer-based, virtual scenarios can be presented on mobile devices (Fig. 3), on touch tables (Fig. 4), on touch-sensitive screens (Fig. 10), and on large, high-resolution display walls (Fig. 11). Even more "futuristic", yet highly useful as an input device are the OCULUS Rift virtual reality glasses, which take the user into an immersive experience: put the glasses on and feel like hopping onto a red blood cell floating through the body.

(4) Since Fall 2013, **LINDSAY Web Atlas** has become a highly used, complementary study tool for students at the UofC's faculties of Kinesiology and Nursing as well as at the Cumming School of Medicine. Instructors and students use this Web Atlas (in combination with our iOS app (see below) to custom build and review highly annotated anatomy specimens (Figs. 3 & 5). Content retention is facilitated by quiz-type inquiry-based learning modules.

(5) The **LINDSAY Specimens Store** is a web-accessible hub to distribute and share virtual specimen assets. We have created hundreds of specimens, carefully annotated by more than 10,000 pins, which contain text, images, videos, and links that populate the anatomical structures with educational contents. The Web Atlas is equipped with user analytics capabilities, where



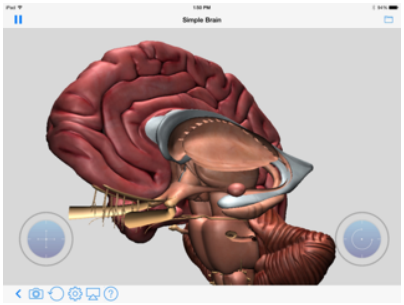


Fig. 3: iPad Apps: (a) Zygote Anatomy Atlas & Dissection Lab; (b) Brain Navigator

Fig. 4: LINDSAY Touch on SMART Table

consenting users' interactions can be tracked and form the basis for personalized training through learning analytics.

(6) With **LINDSAY Touch** we add the ability to directly interact with 3-dimensional anatomical structures by "touching them." This turns out to be of key importance for comprehending the spatial relationships in human anatomy. Our applications range from touch-based apps on mobile devices to large touch tables (Figs. 3 & 4).

Fig. 5: LINDSAY Web Atlas

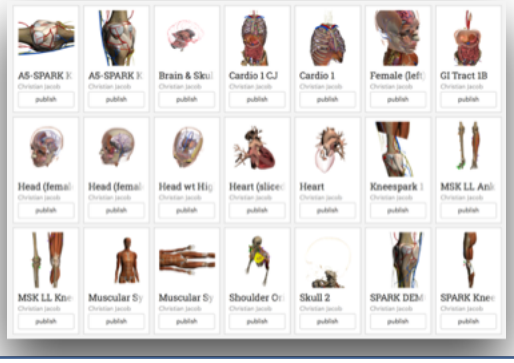


Fig. 6: LINDSAY Specimens Store

(7) Together with our industry partner Zygote Media Group, we have developed an anatomy app with unprecedented virtual dissection capabilities. This application has been available on the iTunes App Store since July 2013 as the **Zygote Anatomy Atlas & Dissection Lab**.

(8) In order to make LINDSAY technology available outside the University of Calgary, **Zygote Body University** has been implemented, replicating our LINDSAY Web Atlas and Specimens Store. Through our partnership with **Zygote**, a wide repertoire of anatomy specimens becomes accessible to any educational institution in the world. We currently test Zygote Body University with high schools (e.g., Cochrane High, West Island College), universities (e.g., the University of Calgary's Cumming School of Medicine, Faculty of Nursing, Faculty of Kinesiology), science centres (e.g., TELUS World of Science, Edmonton and TELUS SPARK, Calgary) as well as fitness and physiotherapy studios.

Overall impact of the innovation or research

The software solutions from the LINDSAY project have resulted in a close collaboration with **Zygote Media Group**, a US-based company specializing in anatomical 3D computer models. Zygote has a stellar reputation among medical illustrators and an impressive list of clients, such as Discovery Channel, Nature publishing group, Google, and a number of medical publishers (ZygoteBody.com). The iOS app Zygote 3D Anatomy Atlas & Dissection Lab has sold thousands of copies.

Fig. 9: Use of LINDSAY specimens in the Advanced Technical Skills Simulation Lab at the Cumming School of Medicine.

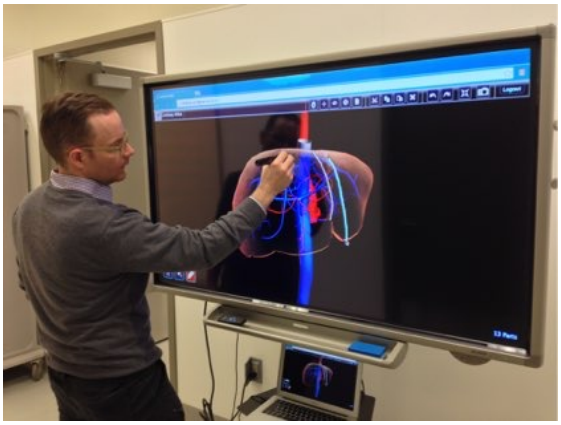


Fig. 10: E-learning manager Mike Paget demonstrating the LINDSAY Web Atlas drawing and annotation features

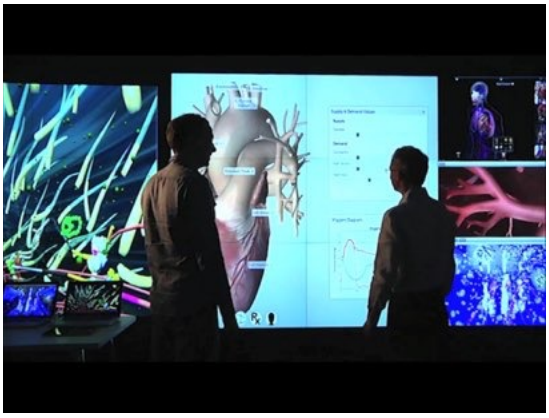


Fig. 11: High-resolution display wall in the Taylor Family Digital Library, UofC

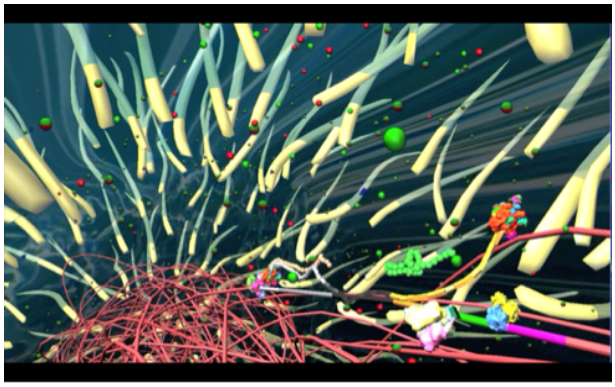


Fig. 12: Interactive 3D model of gene regulation inside an E. coli bacterium

In 2015, LINDSAY/Zygote has started a collaboration with **Thieme Medical Publishers** to enhance their learning resources with customized 3D specimens. Thieme is a key player in medical publishing in North America and Europe. For more than one year, the LINDSAY/Zygote team has been working with **Nankodo**, the second largest medical publisher in Japan. This has led to a Japanese translation of both the iOS atlas app and our web anatomy atlas, including Zygote Body University. In preparation for other key markets, the LINDSAY team is currently working on translations in German (Germany is Thieme's key market in Europe) and Spanish, both to be available this year.

The LINDSAY project has already attracted attention at **medical schools across Canada**. With Zygote Body University collaborations are currently being negotiated with research teams that had expressed their interest since we started the LINDSAY project (University of Toronto, Simon Fraser University, University of British Columbia, Memorial University, and University of Victoria). Our objective is to build a collaborative e-learning network for medical and health education and making pedagogically sound anatomy specimens and lesson plans available world wide — in close collaboration with Zygote Media Group.

The LINDSAY team is working with both science centres in Alberta: (1) with **TELUS SPARK** in Calgary we collaborate on their "Direct from the Operating Room" program by providing customized specimens to illustrate knee and eye surgeries; (2) at **TELUS World of Science** in Edmonton we develop "human body stories" for their upgraded dome theatre.

Since 2013, the LINDSAY team is working with Jay Ingram — accomplished science writer and host of Discovery Channel's *Daily Planet* — and Dr. Trevor Day, physiology professor at Mount Royal University. We created the **Giant Walk Through Brain** as a theatrical performance with live, large-scale 3-D computer simulations from LINDSAY, engaging stories about the human brain, and live original music (Figs. 13 & 14). Sold-out performances have been presented once at the Banff Centre, Banff (July 2014), twice in TELUS SPARK's dome theatre during the Beakerhead Arts & Science festival (September 2014), and twice at the Timms Centre for the Arts in Edmonton (April 2015). This project has won the **2015 Science Communication Award** from the Canadian Science Writers' Association.

Fig. 13: The Giant Walkthrough Brain workshop at TELUS SPARK, June 14, 2013.

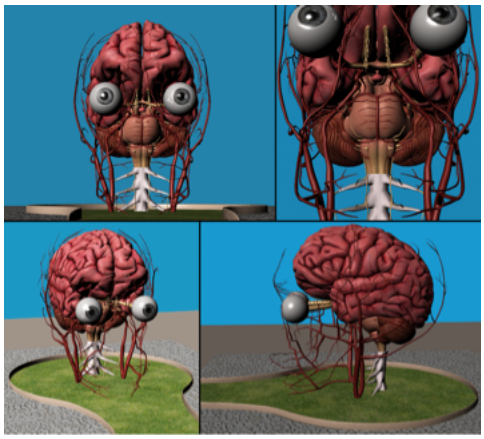


Fig. 14: Giant Walkthrough Brain example specimens

International peer recognition

Dr. Jacob was invited to present the LINDSAY project at the international symposium on ***Virtual Humans: Facilitating Break-throughs in Medicine***, at the AAAS 2014 Annual Meeting of the American Association for the Advancement of Science. The LINDSAY team was invited to present a special session at the 2013 **Information Technology in Academic Medicine** conference in Vancouver. Since 2010, our work on LINDSAY has been **published** in 4 book chapters, 4 journal articles, and 7 conference papers (see our publications on the website) and is showcased frequently (see our showcases). More information on the LINDSAY project, its current state, and its aspirations can be found at http://lindsayvirtualhuman.org