Editors: Bruce Campbell and Francesca Samsel

Immersive Visualization to Support Scientific Insight

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What do you get when you bring together a seasoned popular art school illustrator, an accomplished computer graphics scientist with a new virtual reality surround theater, a respected scientist with a compelling field of study, and 21 eager participants in a semester-long course focused on how to support science through design in virtual reality? You get plenty of material for a Art on Graphics article, at a minimum.

The Virtual Reality Design for Science course explores the visual and human-computer interaction design process for scientific applications in immersive virtual reality. The class has run on occasion for 14 years. As a past participant, Dan Keefe wrote a Visualization Viewpoints department article about the course for *CG&A* in 2005.[1] In that article, Dan hypothesized that VR is "one of the technologies that can most benefit from artistic insight, since guidelines for good visual depiction are far less developed in the unconventional visual space of VR than in more traditional media."

The course feeds upon both artistic and scientific perspectives in considering the design of science-support tool prototypes. By inviting scientists to experience perspectives that resonate with the artists, discussions across art and science attempt to guide iterations on design with the aim of awakening scientific insights. Utilizing a next-generation shared VR space—the Yurt Ultimate Reality Theatre (YURT), Brown University's state-of-the-art immersive 3D VR room—artists gain a perspective on how they can assist scientists through their work. Art students are taught how to consider a VR space as a material, as they would consider a new type of paper or clay. Scientists are taught how collaboration with an artist could advise hypothesis generation and insight support. The ultimate goal is to immerse scientists in high-fidelity data representations supported by visual scaffolding to engage human cognition.

Editors' Note

As Art on Graphics department editors for CG&A, we investigated many immersive visualization demonstrations in 2015 during our conference rounds (SIGGRAPH, SIGCHI, and VIS). Emerging technologies demonstrated to us that yet another round of higher fidelity experiences are available for innovation, which suggests opportunities for another iteration of art-science collaborations to contribute useful results. Brown University's state-of-the-art immersive 3D VR room, YURT, is fascinating because it has approached the retinal fidelity limit of human visual physiology.

The Class

The fall 2015 version of the Virtual Reality Design for Science course was cross-listed at Brown University and the Rhode Island School of Design (RISD) and was co-taught by David Laidlaw from Brown's computer science department, Fritz Drury from RISD's illustration department, Steve Gatesy from Brown's ecology and evolutionary biology department, and Joseph Crisco from Brown's orthopedics and engineering department. Johannes Novotny, a PhD student at Brown, performed teaching assistant duties.

Fritz Drury believes that the course has always been enormously complex to teach because of its hybrid nature. It is focused on visualization design for a unique and demanding medium, an immersive Cave Automatic Virtual Environment (CAVE). Most of the design lessons proceed from an artistic aesthetic, intensively investigating colors, textures, and spatial relationships from the

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physical world and traditional practices in art and design. In addition, the subject matter is drawn from actual scientific research, especially involving biology and physics, which requires the students to acquire at least some knowledge of rather complex, ongoing investigations. Furthermore, the student body is exceptionally heterogeneous, consisting of roughly half Brown University students, mostly in the sciences, and half RISD art and design students. A large burden descends on the shoulders of the teaching assistant, who must facilitate the students' use of the sometimes temperamental CAVE and the CavePainting program, which is the primary software application used in this course.[2]

By having experts and emerging experts in these subjects co-present in a shared studio, the most recent class provided an ideal configuration for distributed cognition: tangible objects for interaction (casts of dinosaur tracks and bird anatomy), artifacts of embedded cognition (diagrams and multimedia exhibits), and rich social processes for creating new objects and artifacts to support a scientific pursuit (as a well-designed studio class readily provides).

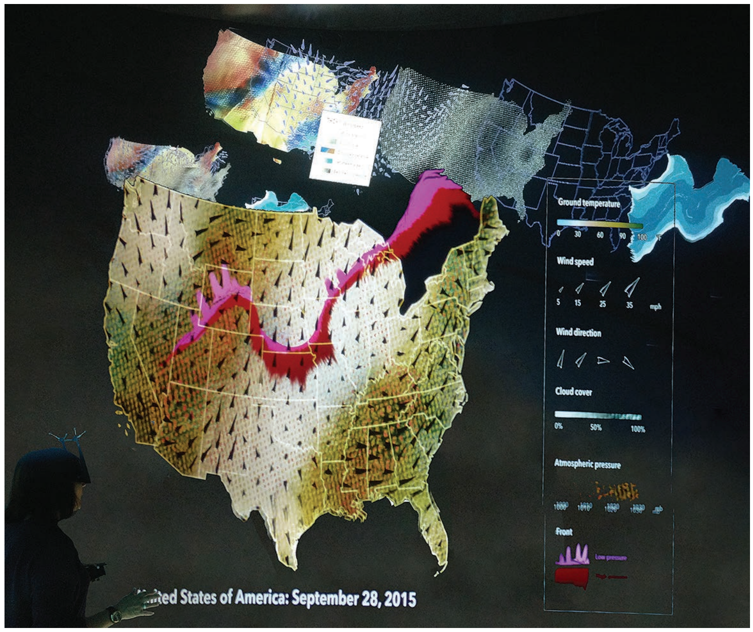

Figure 1. Example student map visualization. In this example, Timothy Blaine-Kuklo represents temperature, wind, cloud cover, pressure, and front delineation on a single map. The artist explored intermediate steps and stacked them to experiment with encoding combinations while also discussing them interactively during critique sessions. (Courtesy of Johannes Novotny)

Course Setup and Materials

To prepare for twice-a-week studio time, students were required to master a reading list that included historical perspectives on visualization from art,[3,4] science,[5,6] and computer science.[7] To weave those themes together, students read and discussed publications on human perception,[8] human-computer interaction,[9] and the unique capabilities of the YURT VR environment as a medium for artistic expression. In addition to that background, students were required to read science publications with perspectives relevant to dinosaur science and related bird science[10,11] in order to understand the work of the professional scientist participating in the collaboration.

Visualization Exercise

To help develop their own personal process for digesting the reading materials and making visual trade-offs, students first grappled with a popular visualization opportunity: weather map generation. Specifically, students were required to create weather maps to explore multivariate data representations (see Figure 1).

To help students prepare for this initial exercise, course discussions about scope and relevance shed light on the various weather characteristics the students might consider including in a visualization. In addition, the instructors discussed human perception and cultural implications to show how the students might represent those characteristics visually and texturally.

The YURT

After sketching with physical materials and desktop drawing programs, students learned to sketch immersively in Brown's 3D VR room. Named the YURT because the room's shape resembles the traditional shelters, the VR theater is an upgrade of Brown's previous CAVE. The YURT has a 100-million-pixel surround display and utilizes devices that allow software to track the position of a user's hand, head, and wand. It has a highly responsive 360-degree retinal resolution provided by 69 high-resolution, high-luminosity projectors. The YURT technology and the software that runs within it are not readily found outside of the class.

Project Domain

Steve Gatesy's contribution to the course, as a professional scientist participating in the class studio, provided a realistic expectation for the students so they could envision how they would work with scientists to further scientific study. While many paleontologists uncover and describe new fossil skeletons, Steve's work involves the tracks dinosaurs of varying anatomy made in varying substrates using different kinematics. Steve studies modern day birds, such as turkeys and guinea fowl, and sets up experimental environments where they walk

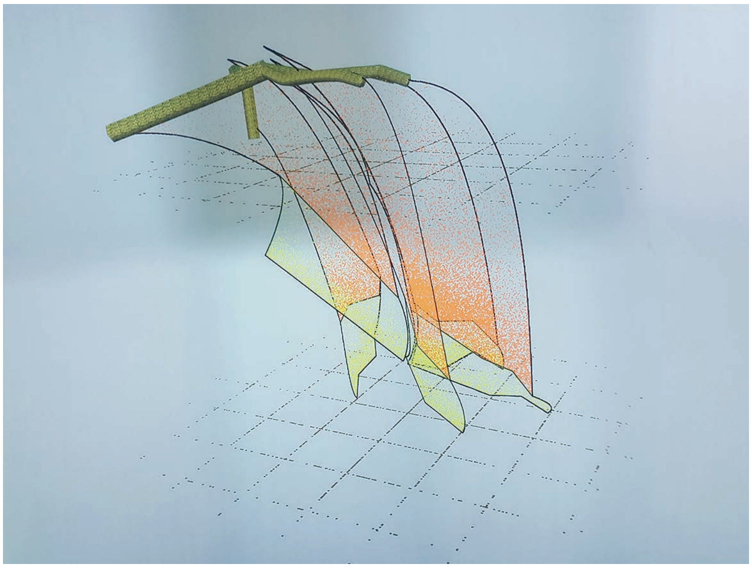

Figure 2. Example student visualization. Here, Johannes Novotny traced points of foot anatomy through a walk cycle and used color to represent displacement of the substrate. Orange represents displacement of the substrate at one point in a foot down motion, and yellow represents displacement slightly later. Red and purple were added later to illustrate upward motion. As in many cases, the resulting visualization appeared as an attractive sculpture floating in the YURT'S 3D projection space. (Courtesy of Johannes Novotny)

through designed substrates. Many iterations on using different ground materials eventually paid off so foot movement could be videoed underground with x-rays. Track simulations that can be generated from reconstructed foot motion involve a large number of variables. Visualizing the data involves choosing among the variables and encoding them to coexist in a meaningful perceptive presentation. Steve shared his attempts at such visualizations as a starting point for student visualization work.

Injecting Art

In another class assignment, students were asked to use the lessons they learned from weather visualization to create hypothetical dinosaur foot movement visualizations. The goal was to provide useful science support and help scientists rethink their hypotheses, clarify their experimental goals, and even alter the way they collect data. The potential for support became evident through the diversity of solutions participants suggested, sketched, created in the Yurt, and then critiqued over many weeks. Research for the design work included watching bird walking movies and data simulation videos that demonstrated foot movement and substrate deformation. Incorporating those hints, some students created visualizations that focused on structure, while some focused on motion and others on representing the forces involved in the interaction of both.

In all cases, participants created visualizations that honed in on an aspect of foot movement in order to verify their understanding of what active bird footprint generation data should provide for visualization. Figure 2 shows an example student visualization.

During most studio sessions, class participants filled the YURT during critique sessions. Being inside the YURT is a powerful experience due to retinal visual fidelity, bold color representation, and a sense of being immersed inside the data and narrative representations. Some students demonstrated tremendous eye-hand coordination while creating detailed immersive visualizations. Others used language to articulate observations regarding missing or deformed features. Still others utilized their inherent abilities to sketch ideas out quickly, describe fuller implementations verbally, and then readjust their sketches to incorporate feedback. Often students would catch themselves mid-statement to consider a new train of thought springing from the collaborative communications.

Over time, students improved their abilities to dynamically manipulate the point of view, scale, and orientation of their creations. With that, the students' abilities to promote ideas that required manipulation with VR peripherals (such as a wand, tracker, or button-based devices) improved significantly.

Fritz Drury has repeatedly observed that the materials involved in illustration offer strengths and weaknesses and that an artist needs first-hand experience exploring materials in order to find the strengths that best support an effective presentation of his or her ideas. During their course work, the students were able to do just that by gaining a sense of the YURT and its software as materials worth exploring in depth.

Final Student Projects

The final project assignment required students to expand their artistic visualization ideas into science-support tool prototypes. Students created storyboards to explain the tool user's experience, identified virtual menus and objects that would allow the user to make meaningful choices, and then built a visual representation of a practical state of their tool in action in the YURT.

Figure 3 shows one example project in which a student's prototype includes a visualization of a hypothetical running guinea fowl's footprint sequence. Before reaching this state in tool use, the user had to review the different bird anatomy options, create a substrate shape and ensure consistency, choose a locomotion speed, and suggest a tile density for data collection purposes.

Reflections from Participants

After the course ended, participants were asked to share thoughts regarding their experience in the course. There was no formal survey and most questions were left open-ended, so much of the commentary was anecdotal. Students found the constraints in the CavePainting software a relief at times given the enormity of design choices available and the course's time constraints. Students also found the fidelity of the experience supportive of a wide range of design genres that they were able to create in the YURT. They reported that the YURT'S ability to simulate the look and even suggest the feel of a variety of materials was critical to their success.

Fritz Drury believes that the photorealistic background objects that students included in their project work helped to focus the viewer on the relevance of the data being explored. For example, Figure 4 shows how a student immersed her data visualization in a photorealistic dinosaur habitat. *Jurassic Park* and other dinosaur films had provided the students with previous experience with dinosaur environments, but the freedom to independently choose a visual experience through such an environment evokes a different type of emotional engagement, one perhaps hard to put into words and perhaps more valuable in the artist's domain.

Fritz also reported that the new YURT significantly improves the illusion of immersion provided by a color range, making the results far beyond what he had to work with in the older CAVE. In addition, the YURT is big enough for all the course participants to comfortably fit inside for the critique sessions. This became an essential component of the collaborative design process. The improvements provided an increased sense of engagement and helped support context, metaphor, and narrative. .

Fritz and David Laidlaw acknowledged that they were fortunate to have some computer science graduate students enrolled in the course who approached the technicalities of scientific visualization in a substantive way, but also some illustration students who pushed the boundaries of using the virtual space to create elaborate immersive environments. Another group of particularly cogent thinkers were able to construct clean designs that facilitated usability and visual clarity. This variety reflects the potential applications of the skill set that the students can acquire in this class: visualization for scientific research, creation of immersive displays for public use, interactive interface design, and pure entertainment. Although Fritz and David stressed the importance of designing for the scientist user, the course embraced all these corollary skills and interests.

Steve was fascinated to see the object of his research through the eyes of bright, creative students. Sometimes a key point that he thought was obvious from his papers and presentation was not communicated well enough as he became aware of students' confusion from their reading and listening.

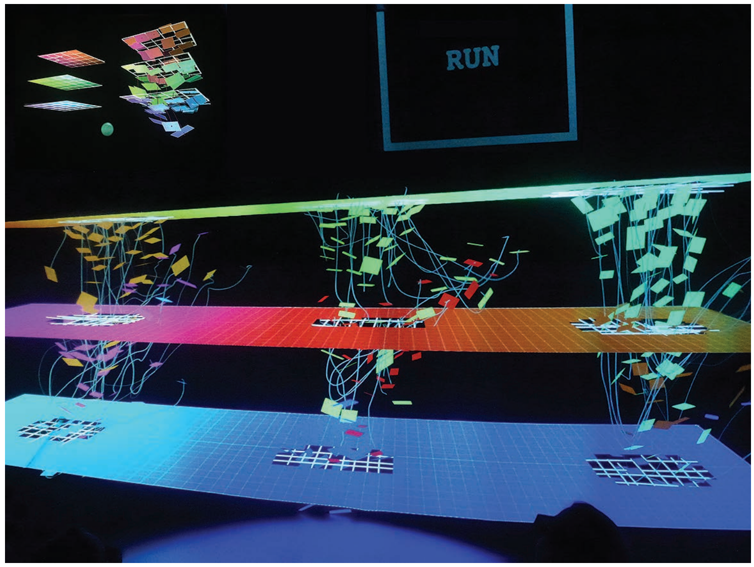

Figure 3. Example final project. This student's scientific-support tool prototype includes a visualization of a hypothetical running guinea fowl's footprint sequence. Three depths of substrate are disrupted by foot interaction, and uniquely colored tiles are displaced to represent their final resting spot. Visual filaments show the paths taken by each tile, and tile orientation identifies the direction of last movement. The initial concept offered for critique is inset in the upper left. (Courtesy of Johannes Novotny)

Figure 4. Example final project. Student Emily Schnall took advantage of the YURT's high fidelity to immerse her data visualization in a photorealistic dinosaur habitat. (Courtesy of Johannes Novotny)

In other cases, an extremely subtle aspect that he never expected anyone to understand was picked up perfectly. He explained that, although it's always instructive to get feedback from nonscientific audiences, such feedback is typically verbal. Artists creating images and material in the YURT during this course provided uniquely visual feedback that was extremely powerful.

At an intermediate level, Steve was repeatedly struck by how art students were comfortable working with approximations and caricatures of real data. Sketches, cartoons, and inexact representations usually conveyed relationships just as well, and often even better, than perfectly scaled and anatomically accurate objects. The freedom to exaggerate or ignore certain elements made him see his data differently. He especially appreciated the students' attention to color, line, and perceptual cues, and they varied their approaches far more than he expected.

Steve added,

> Seeing our project in the YURT was invigorating. 2D sketches and concept drawings that looked promising did not always pan out in 3D. Yet other examples that I thought might go nowhere shocked me in the YURT. Sometimes the impact was simply a novel perspective (standing above a lifesize trackway or plunging down and into the depths of a magnified track). The stereo and textures often combined to offer visual overlap that I've never had before, seeing through multiple layers without losing spatial context.

David echoed the demonstrated success of many objectives he had in mind when creating the YURT, and he is still integrating the feedback provided by the class experience. As the YURT's talented support staff looks forward to support new and improved methods for getting applications running in the VR theater, they are considering many candidate approaches. David wonders about the metrics to use in pursuing a promising best solution compared with an ecosystem of marginally improved solutions. The pursuit is complicated because many applications benefit from specialized trade-offs in data size and format considerations, messaging strategies, performance considerations, and interaction facilities.

The supportive demeanor of the career-accomplished scientists, artists, and computer scientists who taught and collaborated through the course created a positive environment in which the undergraduate students could evolve their styles. Student commentary both implicitly and explicitly suggested, "The class gave participants a lot to think about." Newfound confidence and artistic effectiveness allowed students to grow and taught them to work together within the YURT technology, rather than in isolation with personal gadgets (smartphones, music players, and other social media applications) as buffers to collaboration.

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