Developing Virtual Reality Visualizations of Dinosaur Track Creation with Scientific Sketching

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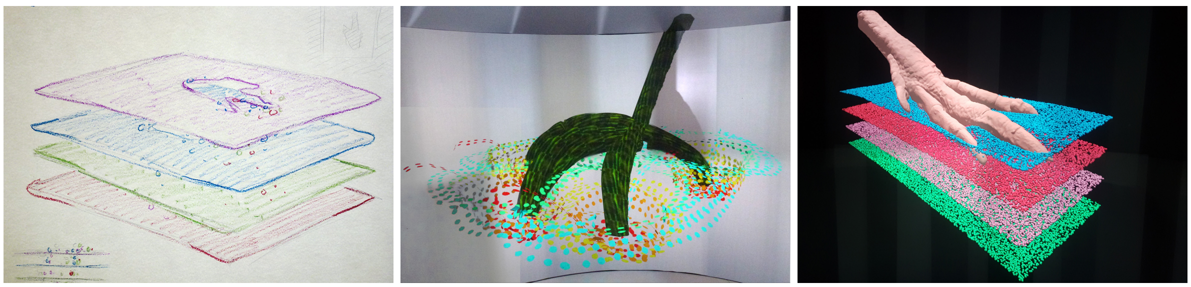

(a) Paper Sketch (b) VR Sketch (c) Implementation

Figure 1: Different stages of the Scientific Sketching design process: An example of a particle visualization concept from paper (a) and VR sketches (b) created by art students to the interactive data-driven implementation (c).

Abstract

We present a two-year design study of developing virtual reality (VR) flow visualization tools for the analysis of dinosaur track creation using the Scientific Sketching design methodology. We involved 25 art and computer science students from a VR design course in a rapid visualization sketching cycle, guided by paleontologist collaborators through multiple critique sessions. This allowed us to explore a wide range of potential visualization methods and select the most promising methods for actual implementation. We introduce the resulting set of visual metaphors and discuss how the iterative Scientific Sketching process helped to solve visualization problems of our collaborators.

Index Terms: Virtual Reality—Scientific Visualization—Flow Visualization—Design Study

1 Introduction

Large-scale simulations of substrate flow have recently been used to explore the relationship between track morphology and foot movement using data from modern birds and fossilized specimens found in the field [1]. However, the spatial complexity of these unsteady flow datasets make it difficult to analyze them using off-the-shelf visualization tools. We designed multiple VR visualizations that help paleontologists explore their simulation data with visual metaphors tailored to their specific research questions. The iterative development process spanned a period of two years with frequent progress meetings with our paleontologist collaborators. An integral part of the development was the inclusion of students in a VR visualization design course. These students sketched potential visualization and interaction techniques in VR, guided by our collaborators using the *Scientific Sketching* design methodology introduced by Keefe et al. [2].

Scientific Sketching aims to efficiently coordinate the work of artists, visualization experts and domain scientists in VR visualization projects. The development process is split into four successive stages; *(1)Paper Sketching*, *(2)VR Sketching*, *(3)VR Prototyping* and *(4)Implementation of visual specifications*. In each stage the three participating groups have a different set of responsibilities to fulfill. Domain scientists introduce their data and research questions, while artists sketch out potentially helpful visual metaphors based on the explanations. Sketches are discussed in frequent group critique sessions moderated by visualization experts. Individual visualization metaphors are developed iteratively from paper sketches, over static and animated VR drawings, to fully implemented VR visualizations.

We realized the Scientific Sketching development approach over the course of two separate semesters of the *Virtual Reality Design for Science* course offered by Brown University and the Rhode Island School of Design. A total of 11 RISD art students, 14 Brown computer science students, a graduate student TA (JN), one faculty member from each school (FD, DHL), and three paleontologists (MT, SG, PF) participated in the design of the application. During each iteration of the course students generated a large variety of visualization sketches and prototypes (Stages 1 to 3). These ideas were collected, ranked by our paleontologist collaborators based on their merit and finally implemented outside of the course by student participants (Stage 4).

2 Data and Methods

Our developed visualization aims to help with the analysis of particle flow simulations in dinosaur track creation. Our collaborators provided a time-varying dataset meant to recreate a specific fossil specimen. The LIGGGHTS simulation dataset (33 million particles,

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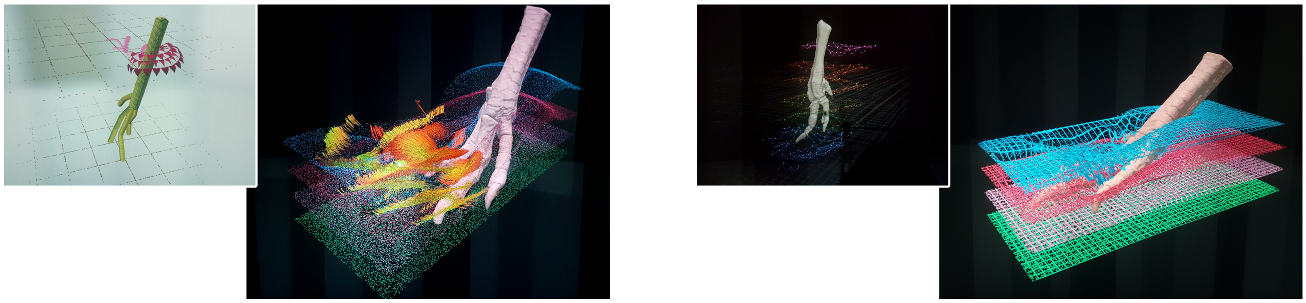

(a) Pathline Visualization (b) Time-surface Visualization

Figure 2: Examples of two different unsteady flow visualization methods implemented in our current VR dinosaur track viewer with corresponding Scientific Sketching prototypes. (a) Pathline clusters showing regions in which individual particle movements share path characteristics, (b) Time-surface visualization showing the deformation of initially flat surfaces over the course of the simulation.

174 frames) was cropped and down-sampled (70 thousand particles) to reduce occlusion problems [4] prior to its use in sketching, prototyping and implementation stages.

We developed our visualizations at the YURT (YURT Ultimate Reality Theater) VR display room located at Brown University [3]. This high-resolution CAVE-like environment is equipped with 69 high-definition stereo projectors, which cover 95% of a users field of regard at retina resolution (1 pixel per arcminute). Optically tracked 60 Hz stereo glasses and two wand tools provide users with intuitive controls within the VR environment.

Implementation of results started at the end of the 2015 course and is still an ongoing effort of a subset of course students. We implemented several promising prototypes from both courses in an interactive data-driven application for exploring fluid simulation datasets using the MinVR C++ framework[1]. This allows our application to work with a variety of different VR systems including the YURT, the HTC Vive and the Oculus Rift.

3 Results

First, we present the visualizations concepts designed and implemented based on course results, then we discuss experiences and lessons learned while using Scientific Sketching as design methodology. Our currently implemented visualization results can be categorized into three main concepts: particle, pathline and time-surface visualizations.

Particle visualization allows users to analyze raw data locations at individual time-steps. It was one of the first design concepts explored by students of the course. Fig. 1 shows snapshots of the sketching and prototyping process. We implemented multiple coloring schemes and filtering techniques to highlight particles that share specific properties. This visualization serves as baseline technique, since state of the art visualization tools often offer it.

To provide an aggregate view over multiple time-steps we implemented pathline visualizations. Users can analyze the trajectory of individual particles, or generate clusters of similarly-shaped pathlines based on an initial selection (Fig 2a). We define pathline similarity as the sum of least-squares distances between point pairs of two paths under a rigid transformation [6]. This metric was selected based on requirements and feedback of our collaborators.

Finally, We implemented time-surface visualizations that follow the deformation of initially flat surfaces of triangulated particles over the course of the simulation [5]. This visualization mimics the deformation of substrate layers found in actual fossil records. It is used by our collaborators to compare simulation results to a volumetric scans of actual fossil samples. A texture on the surface emphasizes stretching or compression of these virtual particle layers during track creation.

[1]https://github.com/MinVR/MinVR

4 Discussion and Conclusion

Based on feedback from our paleontology collaborators, we can confirm that the visualization concepts created by Scientific Sketching were effective in answering their research questions. The tight loop of prototyping and critiquing allowed them to grasp the fine details of their data, and they were able to refine their research questions to formulate their specific requirements for current and future VR visualizations. The implemented VR visualizations generated new insights into their simulation datasets. Interactive pathline clusters for example allowed common formation mechanisms to be identified among specific track features (for the first time), while still maintaining the continuum of flow within the volume. Time-surface visualizations revealed multi-scale distortions in horizontal dimensions as well as depth. As dinosaur tracks are typically found exposed across these surfaces, surface distortions reveal how observable track features are formed. Both methods furnished unparalleled detail without sacrificing the necessary spatial context to relate multiple layers and foot movements.

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