An Immersive Virtual Paleontology Application

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Abstract. Virtual paleontology studies digital fossils through data analysis and visualization systems. The discipline is growing in relevance for the evident advantages of non-destructive imaging techniques over traditional paleontological methods, and it has made significant advancements during the last few decades. However, virtual paleontology still faces a number of technological challenges, amongst which are interaction shortcomings of image segmentation applications. Whereas automated segmentation methods are seldom applicable to fossil datasets, manual exploration of these specimens is extremely time-consuming as it impractically delves into three-dimensional data through two-dimensional visualization and interaction means. This paper presents an application that employs virtual reality and haptics to virtual paleontology in order to evolve its interaction paradigms and address some of its limitations. We provide a brief overview of the challenges faced by virtual paleontology practitioners, a description of our immersive virtual paleontology prototype, and the results of a heuristic evaluation of our design.

Keywords: Haptics · Virtual reality · Virtual paleontology

1 Introduction

Virtual paleontology is the study of digital fossils through the use of three-dimensional visualization systems, comprising a powerful tool set for the analysis of paleontological data [2]. The field is growing in relevance due to the clear advantages of non-destructive exploration of digital representations of fossils [6]. Despite its advancements, virtual paleontology still faces technological challenges that constrain it as "an expensive and time-consuming undertaking" [8]. Researchers strive to partition fossil data into meaningful regions, as automated segmentation methods are seldom applicable to paleontological datasets [2]. Virtual Paleontology currently relies on semi-automated image segmentation, which obliges researchers to perform tedious and laborious manual processes [8]. Paleontological image datasets are difficult to explore manually due to their low attenuation contrast [2]. Additionally, virtual paleontologists must segment volumes through two-dimensional slices, which is inappropriate for their tasks [3].

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2 Methodology

Application Design: We propose a novel design that aspires to evolve the virtual paleontology paradigm and overcome its limitations. Differently from the common additive image segmentation approach, our prototype enables users to subtractively carve away undesirable artifacts and formations surrounding objects of interest within volumes. We emulate some processes commonly employed by fossil preparators working with physical specimens, as we aspire to make the segmentation process more intuitive for paleontology researchers. We designed a real-time interactive visualization of a paleontological image dataset, which is presented within a virtual preparation lab scene rendered by a head-mounted display. Our prototype leverages haptics to enable researchers to establish better cognitive models of image datasets' physical structures [4]. Our simulation uses voxel intensity data to calculate the spring forces yielded by collisions between a virtual probe and the image dataset's surface. Spring forces repel the probe from voxel locations proportionally to the product of gain and distance between the positions of affected voxels and the probe using the following equation [1]:

$$F = k(P - X) \tag{1}$$

Spring force (F) is a function of gain (k) and voxel position (P) minus probe position (X). Gain assumes voxel intensity values and invokes OpenHaptics to translate these forces to a Phantom device and instruct it to produce mechanical movements opposing the forces applied by users onto the image dataset volume.
Evaluation: We assessed our prototype through Nielsen's Heuristic Evaluation [5]. This method was chosen because virtual paleontology image segmentation is a highly-specific use case, and proposing a design that aims to change its paradigms required timely feedback from subject-matter and usability experts. Following Nielsen's recommendations, three experts evaluated our prototype: E1 is a tenured professor specialized in functional morphology and biomechanics from a visual studies perspective. E2 leads a research group focused on visual and data-centric computing. E3 is a doctoral researcher specialized in virtual reality and human-computer interaction. We have chosen usability principles described in *Heuristic evaluation of virtual reality applications* [7]. The evaluation sessions involved the segmentation of a paleontological CT scan using a 3DSystems Phantom Touch force-feedback device. Sessions lasted around 60 min.

3 Results

Compatibility with the user's task and domain:
Our haptic feedback rendering was deemed inappropriate for the segmentation task. E1 suggested generating forces based on edge detection to prevent accidental segmentation of neighboring areas. E2 considered our haptic rendering too abrupt for a precision task. E3 suggested basing force calculations on gradients instead of intensity values. E1 and E2 found the haptic feedback too coarse for precise contouring.

Natural expression of movement:
This heuristic has been breached, as hand movement is restricted by our device's movement range. E1 believes that allowing users to move the dataset volume could overcome movement limitations.
Close coordination of action and representation.
E1 and E3 stated that this heuristic was breached because they experienced delays in haptic feedback rendering, which was not present in the visual representation.
Realistic feedback:
E1 and E2 considered that haptic feedback did not match real-world expectations. E2 added that our simulation is generating discrete forces, whereas continuous forces would create a stable tactile experience.
Support for learning:
E1 found it unclear that the probe's tooltip could constantly modify the volume, and he recommended linking activation to the haptic pen's button as a metaphor to the power button on an air scribe.

4 Conclusions

We developed an immersive virtual paleontology prototype that translates voxel intensity values to haptic forces. A heuristic evaluation has allowed us to detect important issues during the early stages of our user-centered design process. Most reported issues were related to incompatibility with users' tasks and domains, as our prototype aims to change an image segmentation paradigm for the virtual paleontology discipline. Evaluations have taught us valuable lessons on the discipline's workflows and how our prototype needs to be adapted to become useful to virtual paleontologists. Other heuristics covered general user interface issues in our immersive approach to image segmentation. Our next steps will be to address the issues found in our prototype and to conduct other rounds of heuristic evaluations, then we will proceed to conduct usability testing.[1]

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