Immersive Visual Analysis of Time-Dependent Multivariate Data Using Virtual Reality

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Visual Computing

Motivation
The prevention of Earth disasters like asteroid collisions is a high priority for many organizations and scientists. Studying possible asteroid deflection options and understanding the influencing factors should help domain experts create defense strategies and response plans. For exploration purposes, scientists typically use simulations that represent a real-world process over time.

Virtual Reality Environment
The environment of our virtual reality system consists of three main components:
1) 3D point cloud of the impact simulation data, illustrating an impact with an asteroid
2) 2D UI to control various properties of the point cloud
3) Two controllers to activate and use the exploration tools and also move, delete, and rescale objects

Exploration Tools
Probe tool:
- Central exploration tool
- Create 3D spheres (probes) to explore separate regions for a selected attribute
- Histogram or statistics are displayed for each probe
- Observe distributions at given areas

Analyze regions tool:
- Analyze attribute differences/similarities between several regions (probes)
- For each probe, a box plot is displayed to illustrate the probe's properties
- Visual links show the correspondence between a box plot and a probe

Analyze time tool:
- Analyze temporal changes at a given region (probe)
- A box plot is displayed for each selected frame of the animation
- One visual link for showing the explored probe

Clipping tool:
- Observe inner parts of the point cloud
- A clipping plane is attached to the main controller and can be used to clip the visualization from any direction

Rendering Modes
Transparency with Alpha Blending
We use alpha blending to make points look transparent. Each attribute value is mapped to an alpha value. The function defines how the mapping is performed. With transparency, areas with high or low attribute values can be observed while still getting an overview of the whole structure.

Impostor Rendering
To make points look three-dimensional, we use impostor rendering. The technique uses view-aligned planes, and the normal and depth at each position are recorded. This rendering technique helps users to perceive the outer structure better.

Contributions
In this work, we propose a novel Virtual Reality (VR) system for the visualization and interactive exploration of the time-dependent multivariate Impact simulation data to support domain experts in studying the features of impact events. Our contributions are as follows:
- Interactive VR system for visualizing and exploring the Impact simulation data
- Spherical probes as a central exploration tool
- Integrated 2D UI for additional settings
- Various rendering modes to improve perception
- Evaluation with a domain expert and a user study

Domain Experts Tasks
T1: Get an overview of the model at the surface and inside parts
T2: Find outliers and extreme cases in the simulation data
T3: Filter out data to reduce data and highlight relevant locations
T4: Explore separate regions to get insight into the attributes and their distribution in the given areas
T5: Compare multiple regions in terms of statistical differences and similarities to detect trends and patterns
T6: Analyze state and attribute changes in time by comparing different time-steps

Evaluation and Conclusion
We conducted a user study with 10 participants to evaluate whether the system is usable and intuitive and can support domain experts in exploring the Impact simulation data. The participants had to complete a system usability scale and a 7-point Likert scale questionnaire with 27 questions to investigate the system's effectiveness in three categories - interactions, visualizations, and general. The results show that we received mainly positive responses for each of the categories. The participants gave the most improvement recommendations for the interactions, which could be part of future work.

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