PhD Project Proposal “Collaborative Data Exploration and Discussion supported by Augmented Reality”

The traditional way to explore, analyze, and discuss 3D datasets is to use a dedicated workstation with its associated software and hardware, typically by a single person. In practice, however, such data analysis often needs to be discussed collaboratively, such as in team meetings in which several stakeholders join to analyze the data. For this purpose, people often prepare visualizations in form of renderings and graphs/plots to be analyzed in the meeting, with the problem that these presentations are (a) static and (b) do not provide the immersion that dedicated visualization environments afford. In this project we thus want to investigate the use of augmented reality (AR) technology to allow people in traditional meeting settings to perceive stereoscopic visualizations of 3D datasets, explore them individually and collaboratively, and thus are enabled to make decisions without the need of repeated sessions in which the presentations are updated based on previous results. AR is interesting in this context because, even if visualization of 3D dataset can be important, practical work situations often involve discussions about other types of data (tables, documents, slides) and manipulation of other tools: AR is a convenient way to integrate advanced intuitive 3D visualization in a meeting situations while preserving these possibilities. Moreover, recently released AR systems (e.g, Microsoft Hololens) have overcome several technological limitations (real and virtual world registration, reliable user head tracking in an unprepared environment, increase in the 3D rendering capabilities of mobile devices, high-definition head-worn displays) while remaining easily operable and lightweight. These advances create favorable conditions for the adoption of AR in the context of office meetings with non-expert users. In particular, we want to investigate the needed interaction support, both with respect to capturing the necessary input as well as to supporting the needed data and view manipulations, coordinating between collaborators, and sharing and discussing the results of the analysis. For this project, we are collaborating with the “Virtual Reality and Scientific Visualization” group of EDF Lab Paris-Saclay whose interest in the data analysis of flow data drives the research questions of this proposal.

Scenario and Vision

The specific scenario in which we are interested comprises a traditional meeting room setting, in which a small group of people (3–4 people) come together to discuss 3D datasets. This data is time-dependent flow data in the specific spatial context (i.e., a river bed) with its associated simulation results which are created offline. All people in the room are equipped with AR glasses (e.g., Microsoft Hololens) to allow them to see both the data as well as all people participating in the meeting. Each person sees the 3D data displayed stereoscopically on or above the table surface in a way that a specific 3D data point is shown at the same 3D spatial location for all participants. This setup allows the participants to refer to specific parts in the dataset using their hands or other tools. Alternatively, some parts of the visualization may also be viewer-specific, such that personal spaces and analyses are possible.

Specifically, EDF Lab is interested in numerical finite element simulation scenarios involving free surface flow hydraulics. These simulations produce scalar or vector fields varying over time. They depend on parameters whose relative influence needs to be determined and is often difficult to understand, such as bathymetry, bed friction, inflow discharge, tidal parameters, or initial states. In this type of study, engineers and researchers at EDF typically run multiple simulations with varying values of these parameters. The data to be analyzed comprises multiple simulation results, corresponding to a sampling of the simulation parameter space. We want to explore typical applications such as a schematic river (fluvial configuration) and a coastal site (maritime configuration):

- *Fluvial configuration.* In 2D hydraulic solvers such as TELEMAC-2D, the nature of the bottom of a waterway is modeled by a roughness coefficient. In some occasion, this coefficient also takes into account the friction of the walls as well as other phenomena such as turbulence. This kind of simulation produces 2D meshes as well as vector and scalar fields that vary over time.
- *Maritime configuration.* Understanding hydrodynamic models for tidal changes is typically an engaged and difficult process due to the tidal flow interaction between shoreline, islands, meteorological conditions and the lack of a reliable tidal observation stations. This kind of simulation also produces 3D meshes as well as vector and scalar fields that very over time.

For these scenarios we need to allow people to analyze the data by changing the global view (e.g., rotations around *y*, uniform scaling), changing visualization parameters (e.g., type of data being displayed, temporal animations, selection of simulation parameters, etc.), probing local data values by manual input, creating and then showing personal or shared views of abstract data analysis results, providing localized input such as seed streamlines or moving cutting planes using manual input, calling up different simulation scenarios, showing other data on shared screens such as external monitors/projectors, and recording specific results/situations for later analysis.

Challenges and Research Questions

Within the context of this scenario, we want to investigate a number of research questions.

1. **What types of input should/can be used?**
   Essential for a successful environment is that adequate input techniques are available. Beyond the gestures that are supported by the API of the AR headset (e.g., two gestures for MS Hololens), we need to be able to support pointing, object manipulation, use of external non-digital devices such as pens, phones, objects, etc. to serve as proxies for object manipulation techniques. Here we need to investigate what happens to physical items if the virtual data context changes, for example due to a global re-orientation of the dataset. We also need to determine if precise input using such devices is directly possible, how precise and reliable it is, and whether external tracking technology is needed. We also plan to investigate the support of the tracking using techniques such as fiducial markers. An essential question, however, is how we deal with the issue that we need to distinguish between a simple object motion and a desired input action—potentially by making use of bi-manual interaction. We also need to investigate the difference between the initiation of actions (e.g., play the temporal animation) and direct-manipulation input (e.g., select this region). We also want to investigate the augmentation of the input through haptic feedback devices to provide a higher level of immersion and control during the interaction.
2. **What types of input are best used for the interaction, 3D input or 2D input?**
   We need to investigate the best way of capturing input, either in the whole 3D space, only based on 2D locations on the table, or combinations of both. We may take inspiration from previous work which investigated the interaction with stereoscopic visualizations of ocean flows, yet also hybrid forms of input or both 3D and 2D input may be possible.
3. **Types of interaction: What types of control are needed?**
   At the start of the project we need to get an understanding of the types of control that are needed in the described data analysis context. For example, we can safely assume that we need the control of data navigation, data selection, data filtering, exploration of temporal aspects,

and combined 3D and abstract views. However, to be able to provide an effective data exploration environment we may need additional, data-dependent techniques. We will thus conduct an initial investigation together with the stakeholders to understand their current work practices, and extract the needs for the AR-supported system.

4. **What are challenges and opportunities of the specific data types?**
   The described scenario exhibits a number of unique properties that make it different from traditional 3D dataset exploration. In particular, the dataset is shallow, in contrast to the more compact form of traditional data investigated by flow visualization tools. Moreover, the natural "surface" of the dataset is on top of the dataset, so that it is necessary to visually "raise" the data to above the table to be able to physically access all points in the simulation. Finally, the data is typically quite elongated (i.e., rivers are much longer than they are wide), even when considering that only a part of the river is simulated and that a river contains bents. Nonetheless, these qualities seem to fit quite well with the envisioned physical layout (meeting table) of data analysis scenario.
5. **How do we solve the challenges of collaborative work/collaborative visualization?**
   In this collaborative data exploration scenario we share many challenges of other collaborative work environments. In particular, we need to be able to deal with global changes without disturbing collaborators, or, alternatively, need to find a way such that global changes are disallowed or can only be initiated by a single person. Another challenge is to coordinate the use of personal views as well as shared views. The setting with personal AR headsets facilitates the use of personal data analysis views, which is a benefit. However, we also need to allow people to share such views, but in a way that other collaborators are not negatively affected; e.g., how can we enable or switch between different types of visualizations that reside within the same spatial context? We may need to find ways to deal with such different personal views as people refer to a specific physical location. For example, we could initiate interaction-specific local visualization changes so that locally all collaborators see the same information, and then each collaborator could locally initiate a change to the visualization used by the person who started the interaction.
6. **How do we solve the challenge of physical reach?**
   Participants man also need to reach distant parts of the dataset, which may be difficult to do for parts at the opposite part of the table. At the same time, we may want to avoid global changes that would disturb other collaborators such as rotations. For this research question we may make use of virtual extensions of hands and arms as previously investigated in the HCI literature.
7. **How can we handle personal abstract data analysis views in a shared VR context?**
   Essential is also the support of abstract data analysis views such as data plots for a given location or selected range of data. The AR-based environment would allow us to display such views in a way that they are well oriented toward the person using it, and for other collaborators they can also be appropriately oriented. However, we may need to resolve conflicts with other displayed data items and/or with physical objects on the table that represent interaction elements.
8. **How do we solve the challenges of shared views?**
   Connected to the previous research question we also need to support shared data views. Here we cannot make use of different placements and/or orientations as all collaborators need to be able to refer to the same physical location when discussing shared data. Unfortunately, this may lead to situations where not all collaborators have ideal views, so we may need to find ways to restrict such views to locations where a good view is possible for all collaborators, for example on external displays.
9. **How can we enable people to transition between 2D vs. 3D data display?**
   With the table-based scenario we have a natural 2D surface that could serve as a projection for

the dataset (enabled by the AR headset). We may thus start an exploration session in this setting using a map-like display, before later transitioning to a 3D view by "raising" the 3D dataset out of the surface, enabling all collaborators to interact with the 3D-spatial aspects of the data. Both settings have their advantages and disadvantages: the 2D setting has a natural interaction surface and no 3D input ambiguities exists, yet the 3D view provides a more immersive view and provides easier access to all spatial locations in the dataset. One may thus use ways to transition between the two views, or participants could each have their personal 3D views in front of them, and could link them/share them to the central common view through interaction techniques.

10. **How can we integrate traditional WIMP interaction paradigms?**
    Despite the benefits of the described novel interaction environments, expert participants in the data exploration meetings are likely familiar with their traditional tools, and will also continue to use such tools when they explore and analyze the data themselves. Furthermore, in-depth analysis is usually carried on desktop workstation, and this process will likely be similarly important in the future. We thus would like to explore ways to replicate some of this established data analysis functionality in our shared meeting context, potentially by integrating these tools into the personal work area. Alternatively, we need to figure out how to support/embed the traditionally used software packages in this AR-context or enable ways to easily transition between both analysis paradigms.
11. **What are the limitations of the AR devices?**
    The current AR technology is still quite limited in what it can support. In particular, existing headsets have limits with respect to their display resolution, their field of view, their processing capabilities, their physical weight, etc. We need to analyze in which way these current limitations impact the envisioned interactive scenario and to what degree we can safely assume that future technology developments can address these issues.

Research environment

This project will be carried out as a collaboration between the AVIZ research team (supervised by Dr. Tobias Isenberg) at Inria and "Virtual Reality and Scientific Visualization" group of EDF Lab Paris-Saclay. The prospective student is expected to spend time both at the Inria and the EDF labs. We also expect excellent programming skills, specifically with a background in computer graphics and VR/AR and, ideally, experiences with visualization and human-computer interaction. The prospective student is expected to be fluent in English in order to be able to communicate with other international team members as well as to communicate research results in written and oral form. Past experience in a research environment with scientific publications would strengthen an application.