

# Into the mixed reality data sphere: mapping user's movements to data exploration tools

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## ABSTRACT

In this paper, we propose to take advantage of user movements when exploring data in a virtual reality environment. As Human-Computer Interaction (HCI) relies on a fast and accurate binding between users actions and the system's responses, we explore using the user location, as measured by the HoloLens head tracking, for data exploration, leaving the user hands free for data manipulation and selection. Since HoloLens has a very accurate measurement of user's head movements, we investigated the available design space to efficiently map data exploration actions to these user head movements. To better investigate our design space, we implemented prototypes and explored new interaction techniques thanks to different data types and data exploration tasks.

**Keywords:** Data exploration, Mixed reality, HoloLens, Multi-dimensional dataset

**Index Terms:** K.6.1 [Management of Computing and Information Systems]: Project and People Management—Life Cycle; K.7.m [The Computing Profession]: Miscellaneous—Ethics

## 1 INTRODUCTION

While Information Visualization amplifies cognition to foster insight identification using interactive visualization systems, new emerging technologies provide alternative displays with immersive or mixed reality environments. These new devices extend users ability with 360 degree screens, which are locked onto users head. Furthermore, mixed reality devices with the HoloLens<sup>1</sup> and the Meta Vision<sup>2</sup> helps to anchor virtual objects or data representation into users environment. Hence, user can freely move and the content of the augmented display is updated accordingly. This process provides the illusion that virtual objects remain at the same location as if they were anchored in the user's vicinity. New systems of Mixed Reality (MX) and Virtual Reality (VR) (such as upcoming systems from Microsoft, Google and Apple) uses high fidelity accelerometers and environment tracking systems to detect every users movements without any needs any complex room instrumentation. Such processing insuring a tight synchronization between users movements and virtual objects location adjustments on the user's head mounted screen in a large varieties of spaces, of different dimensions and content, thus opens new interaction paradigms.

In this paper, we propose to take advantage of this high-fidelity user motion tracking system. As Human-Computer Interaction relies on a fast and accurate binding between users actions and the system's responses. We will retrieve user movements and use them to interact with our data exploration system. We investigated the available design space to efficiently map data exploration actions to measure user's head movements measured by the head mounted device. Hand movements, which can currently measured when the hands lie in front of the user, and sensed by the HMD, may be used to manipulate and select the data, while the user stands in a static place. In this

paper we will focus on the user motion in space, used for changing the entire data settings.

To better investigate our design space, we have implemented different prototypes and explored new interaction techniques using different data types and data exploration tasks.

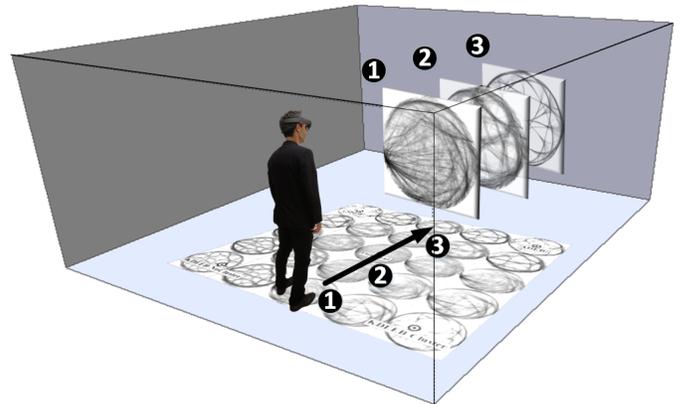


Figure 1: When exploring multi-dimensional datasets, the user can explore many possible data dimensions. In this scenario, a given set of visual representation of a given multidimensional dataset is provided thanks to small multiple which shows different scatterplots of data dimensions mapped to its axis. When the user hovers over one of these scatterplots, the corresponding visualization is displayed in front of her.

## 2 STATE OF THE ART AND DESIGN RATIONALE

Despite its long history, visual data exploration has not gone much beyond the mouse, keyboard, and flat-screen paradigm [14]. Post-Wimp interaction has been investigated but few investigations have been done to support binding of user movement with the data exploration process. In this section, we provide relevant works in this direction and discuss how our conducted investigation contributes to this effort. Immersive environments have proven to support data exploration and collaborative work [6]. Data exploration in immersive environments and so-called immersive analytics provides unique opportunities to leverage user actions [3]. Graph exploration and collaboration system have proven to be efficient and accurate [5].

Our design rationale takes its roots from the proximity interaction [1] [12] provided by objects, user's vicinity [7] and user's movements [11]. We extend this concept leveraging the mixed reality environment where manifold interactions are possible between virtual and physical world. Physical world can also embed and anchor information and helps users explore them [17].

MR environments provide interesting innovative usages to explore multi-dimensional datasets. As such, the user can take advantage of the room and use it as a data container. Every object can also be used to support data interaction by mapping object movement to data exploration interactions. This paper reflects upon such possibilities and reports our initial work in this direction. In particular, we will focus on the mapping of the user movement can be mapped to

<sup>1</sup><https://www.microsoft.com/en-us/hololens>

<sup>2</sup><https://www.metavision.com/>

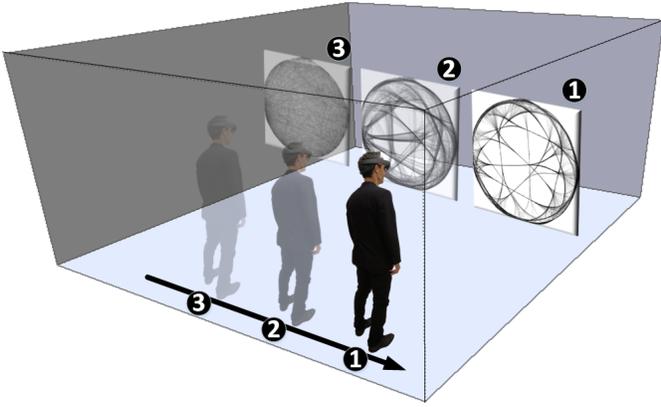


Figure 2: In this example, the user is exploring a dual graph layout with its original setting and its bundled (e.g., visual aggregation) version [15]. The user can freely move sideways and the graph layout dynamically evolves between its two layout. This graph modification is also called graph relaxation and helps to better understand how the graph simplification was computed and helps to links the two graph layouts.

data exploration interactions. How accurate can user movement to support data exploration? How to efficiently map user movement to data interactions? How MR environments better perform compared to standard screen based data exploration? We believe this paper is an initial step in answering such questions.

### 3 SCENARIOS

In this section, we describe example usage scenarios where the user's movements are mapped to interactions to support data exploration. These scenarios are not limited by the datasets used but provide evidence of potential assets of these kinds of mixed reality interaction tools. The supplemental website<sup>3</sup> provides videos and additional information.

#### 3.1 Multi-dimensional data exploration

Fig. 1 shows an exploration of two parameters (one in the left-right direction and the other on the front-back direction). This is a very simple and natural arrangement. However, the use of the space can enable more options. Suppose we have a set of  $N$  samples, that present  $N$  different views of the data. The user can now explore the space between the samples in the following way: as the user is getting closer to one of the samples, she sees a visualization generated by weighted linear averaging of all  $N$  samples weighted by their relative inverse distances.  $current - vis = \sum_{i=1}^N \frac{1}{distance-to-exemplar_i + c} * exemplar_i$  where  $C$  is a constant that prevents an infinite weight once the user reached one exemplar location. Other weighting scheme for the interpolation may include Gaussian weighting of the distances. When the user reaches the location of one exemplar she sees a that exemplar visualization. Moving to the location of another exemplar will show a gradual transition toward that visualization. A common arrangement of the exemplar may be in a circle around the center of the room to allow easy approach to all of them, however the user of AR allows the location of each exemplar to be aligned with landmarks in the room, so they will be easily located by the user. Another possible modification may fit the interpolation paths between the exemplars to existing paths in a populated room, rather than to direct linear paths.

<sup>3</sup><http://recherche.enac.fr/%7ehurter/HololensMapping>

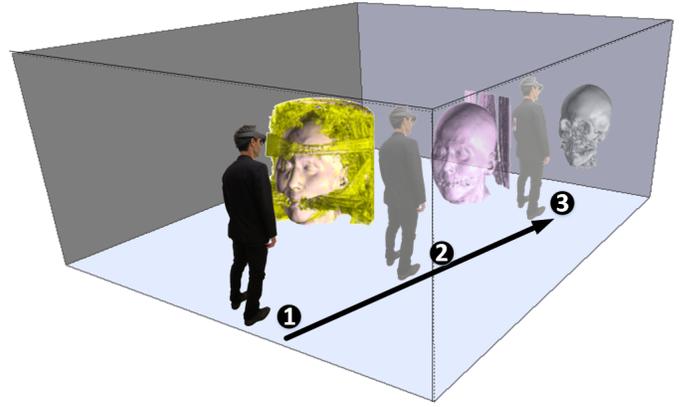


Figure 3: In this scenario the user explores a 3D scan. This data is composed of voxels (3D location of a discrete element) which corresponds to the density of the tissue it referees too [8]. The user moves forward or backward and the system adjusts the filtering level of the tissue density accordingly. A such, the user can explore the the skull of the 3D model when exploring the model in the back of the room, while the model surrounding is visible in the front of the room.

Compared to standard data exploration with small multiples [13], AR provides additional assets: The user may position physical landmarks (and not just digital ones) to mark interesting view points. These physical landmarks are easy to follow in the real world, and their location can symbolize the interpolation area, even without an AR HMD.

#### 3.2 Graph bundling

Edge bundling is a technique to visually simplify a path or graph in dense visualization. Many techniques are today available [15]. With this deluge of possible visual simplification, it remains difficult to choose the appropriate technique. One solution is to display every technique and to visually assess the bundled result of the a dense dataset. This can take time and also many manipulation to display all of them. As a simple solution, we developed a prototype which displays many bundled results which are laid down on the floor (figure 1). In this sense, we take advantage of the available space to display many techniques. The user can then step on a technique to display it full size result. Edge bundling techniques also produce path or edge distortions. These can produce inaccuracy and relaxation techniques (i.e., investigating the correspondence between the original graph layout and its bundled version) can help address this issue [10]. We also developed such interaction in an MR environment, where user movements are mapped to the level of relaxation (figure 2).

#### 3.3 Volumetric data exploration

In this example, one explores a volumetric dataset composed of voxel (i.e., 3D location of a unit volume) with a given density corresponding to the tissue density. In figure 3, the user faces a 3D holographic visualization of the volumetric dataset representing the head of a human scan. High density voxels correspond to dense tissue like bones and teeth, while low density voxels correspond to tissue like skin or noise. One of the major limitations when exploring such dataset is to address occlusion issue where many peripheral voxels prevent the user to visualization inner model voxels. As a solution, adequate transfer function [16] can be defined or direct volume manipulation can be applied [9]. As a simple interaction mapping paradigm, we mapped user location to the density filtering threshold. As such, the 3D scan model gets peeled (removal of voxels with a given density) when the user moves toward it. When

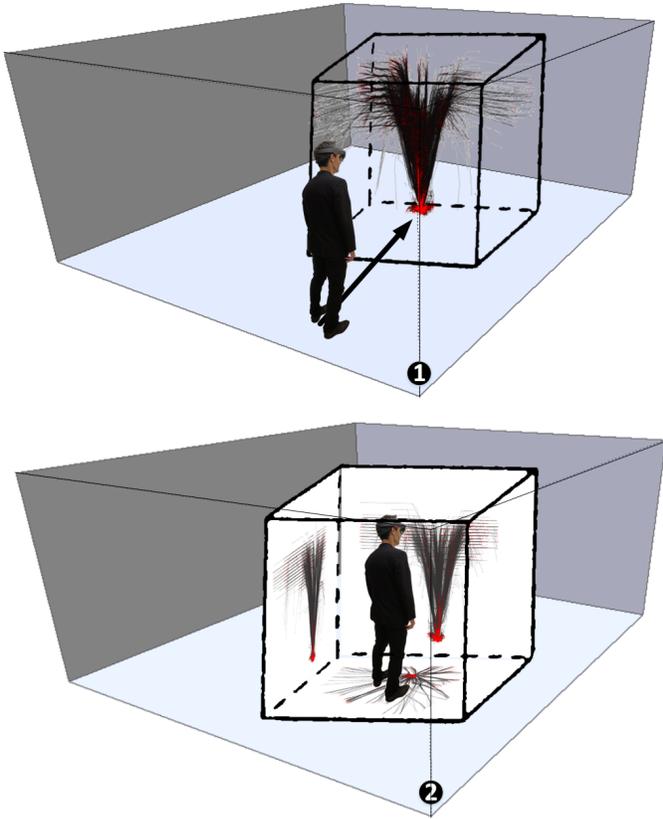


Figure 4: In this example, the user investigates 3D trails visualization (recorded aircraft trajectories). The user can freely explore this set of trails by looking around but when entering the bounding box of this dataset, every trail is projected onto the face of the cube boxing the data. As such the user can have another point of view to the investigated dataset with 6 additional visual mapping (6 faces of the cube and thus 6 scatterplots where two data dimensions are mapped to the corresponding axis).

the user gets too close to the model, only the denser voxels remain visible and thus unveil the bones of the 3D scan. Thanks to this interaction paradigm, the user can control the density of the peeled voxels (figure 3).

#### 4 IMPLEMENTATION DETAILS

Our scenario uses a large dataset with more than 100k multidimensional data records with the trails visualization. The volumetric dataset uses a volume of a 500x500x500 cube. Both of these datasets are considered large and a special care has to be taken to allow interactive visualization with such number of displayed items. As such, we built our own rendering system using GP-GPU techniques. Our prototype uses c# and direct X API with hlsl shaders (graphic card programming language). Furthermore, the computation power of the HoloLens device is not able to handle the visualization of such large datasets. Therefore, we use the remote processing where all the computation (CPU and GPU) is done on a more powerful computer and the HoloLens device is only used as a display and interaction input/output device. This technique helps to render time demanding visualization on a remote computer (with high computational power and big memory size) and then send the result to the HoloLens. This process trades off the rendering issue with the available network bandwidth.

#### 5 DISCUSSION

In this section, we discuss assets and potential limitation of the developed interactions.

**Interaction paradigm/Mode switching:** In our implementation, we had to take a special care for the change of interaction modes: In one mode, the user changes location in the room to control the display representation. In another 'viewing' mode, the user is moving around a data without changing the representation. The user may move between the modes using a button press on a controller (i.e. HoloLens clicker), or by speech control. However, when the user is leaving 'viewing' mode, she may be standing in a location that dictates different representation than the one is currently displayed, which may cause a sudden change of the display. We may show this transition gradually.

**Movement fatigue:** User movement can produce some fatigue and may not be the best option to support data exploration. Freely moving in the room while standing natural, may produce less fatigue than holding hands in the air, either in the room space or even while sitting. Further investigations are requested with a user study to compare the different modalities. Nevertheless, when dealing with 3D representations, holographic environment provides two additional assets to consider: depth perception with the binocular visualization, and kinetic depth perception with the user movement. The latter one is very interesting and reinforces the depth perception thanks to user movements (far objects move slower than close one).

**User natural spatial understanding and memory:** Users have the ability to know their location in space. This is especially true when assigning a given semantic to a special location. The back of the room shows the 3D model skull, while the front of the room shows the flesh. This asset is of great interest and needs deeper investigation to define its boundaries in terms of interaction potential.

**Single and multi users:** When the user moves in the room to change the point of view, the user also interacts with the visualization. To address this issue, a simple hysteresis filtering is computed so that small user movement only changes user point of view. Another solution is to use a modal interaction to define when the user wants to change his point of view or when he wants to adjust on visual parameter. This may also be an issue with multi-users - on one hand, each user can see a different view based on her independent motion, on the other hand, we may need to apply a modality that will synchronize the status of the display for all viewers. Also a single user may be assigned the controller of the visualization condition, and other users may only change their viewing condition. The assignment may be moved between users.

**User displacement and user movement:** When moving in a room, the user has a continuous displacement. In our prototypes, we mainly used 1D (figure 3, figure 2) or 2D (figure 1) interaction path. More complex path can be considered where the user climbs few steps, performs circular movement or navigates in a nD polar coordinate system.

**Movement mapping:** User movement can be mapped to a given visual variable [2]. The question remains to correctly assign such mapping and find the suitable ones. Since user movement is continuous, it is advisable to assign continuous interaction like data filtering, animation or color gradient change. Animation [4] provides interesting opportunities to map user movements. This is especially the case with transition between views [9].

#### 6 CONCLUSION

In this paper, we investigated simple interactions to support multidimensional data exploration thanks to the mapping of user movements with data exploration tools. To qualitatively assess the potential of such interactions, we built a set of prototypes. They all allow one to interact with different datasets and to perform the requested data exploration feature.

As a future agenda, we envision that technological improvements will provide even more accurate user movement tracking. New devices will also provide more computational power to deal with larger datasets and allow more complex movement mapping (i.e., hand gestures). For instance, the ability of the user to step into the data enables the use of the user's natural gestures to define complex selection; a user may trace a separating non planar surface, by moving her palms. Although the accuracy of positioning the hand maybe coarser than using supported devices such as a mouse, the user can express arbitrary geometries, which can later be refined automatically by optimization, or even using supported 2D tools, such as a mouse, defined to work on the 3D surface defined by the user, and need only to modify it in the local 1D orthogonal direction. This example shows the diversity and the potential of extend mapping between user movement and data exploration tools.

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