

Transforming Graph-based Data Visualisations from Planar Displays into Augmented Reality 3D Space

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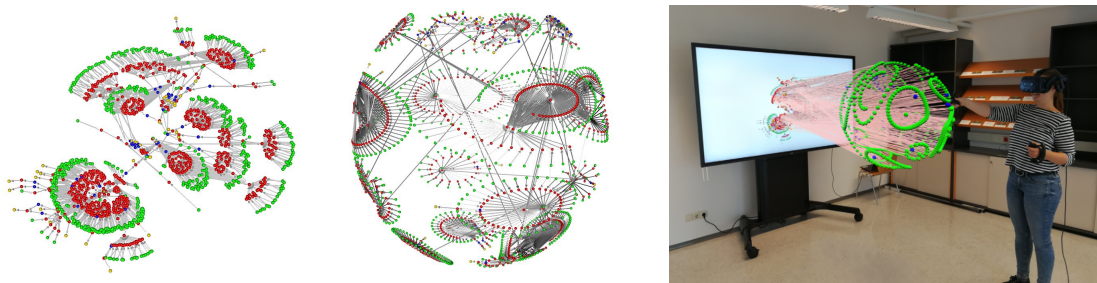


Fig. 1. Graph data as an example of transforming data visualisations from planar interfaces into 3D space for continued work in AR, outgoing from 2D (left) to target layout in 3D (middle) by gradually interpolating node positions into 3D space (right).

In this position paper we describe how graph data as an example of cross-virtuality analytics can be moved from the real environment to augmented reality by interweaving large-scale 2D displays with augmented reality head-mounted displays. With a pull gesture, 2D graph data on a large-scale display can be dragged into augmented reality 3D space and simultaneously be transformed into a 3D layout, imitating that the graph network is moving out of the screen. We outline relevant design decisions for this transformation from 2D to 3D and conclude with our assessment of the potential and future work of such data visualisation transformations.

CCS Concepts: • **Human-centered computing** → *Mixed / augmented reality*.

Additional Key Words and Phrases: cross-virtuality interaction, mixed reality, 2D/3D graph transformation

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1 INTRODUCTION

Cross-virtuality analytics (XVA) in our sense aims to use immersive analytics [4] to its full extent by interconnecting conventional 2D environments with virtual environments across the entire spectrum of the reality-virtuality (RV) continuum, ranging from the real environment over augmented reality (AR) to virtual reality (VR) [10]. With the seamless integration and transition of entities along this continuum, users are provided with optimal visual and algorithmic support that adapts to the current context of analytics tasks [14]. In particular, the use of devices located on

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different stages of the RV continuum allows for the combination of their respective advantages, such as multi-touch input, passive haptic feedback and physical navigation in front of large 2D displays [6] with the stereoscopic capabilities and unlimited workspace [12] of modern AR head-mounted displays (HMDs).

We try to exploit these benefits by developing novel user-centric methods for the exploratory analysis of supply chains that are frequently represented as graph networks. By spanning this rather complex task across real environment and AR, we believe that the users' comprehension of such networks can be improved. For this purpose, we run a graph-based interactive supply chain network visualisation on a large-scale, touch-enabled 2D display addressing also the observation that such rather complex tasks are often tackled collaboratively [16]. By performing a pull gesture with the hand controller of a stereoscopic AR HMD, users can drag the graph being shown on the planar 2D display out into AR 3D space, so that it appears that the graph is moving out of the 2D display (see also [Figure 1](#)). In addition to approaches presented at CHI 2020 [18], this transition from real environment to AR also deforms the visualisation by gradually transforming from a 2D into a 3D target layout to allow an immersive view on the data. From our experimental research we derived so far three areas influencing the degree how fluent and seamless this transformation from planar displays into 3D space is perceived by users:

- *Transformation Initialisation*: Moving data visualisations from 2D displays into 3D space for further use in AR requires often a switch between devices (i.e. from touch display to AR HMD) that is only perceived as seamless if the AR representation of the visualisation is aligned accordingly to its counterpart on the 2D display before starting the transformation into 3D space and if users can initiate the transformation in a natural way.
- *Target Layout in 3D Space*: There are various ways how a stereoscopic view and the third dimension in AR can be utilised to enhance visualisations previously only shown in 2D. While structure-preserving target layouts could help to re-establish a connection to the visualisation on the 2D display, structure-disrupting layouts potentially can improve sense-making by revealing new details depending on how the additional dimension is used.
- *Transformation Parameters*: The transformation defines how the animation from the outgoing 2D layout to the target 3D layout is performed. Speed, interpolation methods or order in which elements are transferred into 3D space potentially influence the degree to which users can follow regions of interest during transformation.

2 TRANSFORMATION INITIALISATION

Graph transformations from planar displays into AR 3D space are prone to similar problems already identified for cross-device interaction such as awkward manipulation, sharing and information display facilities on and across multiple devices [9]. This issue can be addressed by utilising the AR HMD's hand controllers to design intuitive gestures for moving content between 2D display and AR HMD. In our setup we designed a pull gesture, that enables users to drag the graph on the 2D display into AR 3D space. If the user facing the 2D display starts to pull the controller away from the display, the graph "spawns" in AR by augmenting the large-scale display with the same 2D graph shown on the large-scale display in a co-aligned way. With continuing controller movement, the AR graph moves away from the large-scale display and gradually transforms into a 3D target layout.

To maintain the illusion that the graph is moving out of the large-scale display, the AR graph must be aligned exactly with the graph being shown on the 2D display at the start of the transformation, as a large offset would let them appear as different networks. This requires a mapping of the network nodes between 2D display screen coordinates and 3D world coordinates in AR. By combining pixel coordinates with the dimensions of the large-scale display and tracking its global position in AR tracking space, this mapping can be established.

3 TARGET LAYOUT IN 3D SPACE

Unlike volumetric or geospatial data, graph data have per se no "natural" data dimension that can be applied to the z-axis in the third dimension. How the three axes are used in XVA mainly depends on the graph layout. Despite advantages such as stereoscopy and increased spatial encoding [1], work on 3D graph layout techniques is rather sparse compared with the vast amount of literature discussing graph visualisation layouts in 2D. Although most 2D layouts can be generalised for three-dimensional graphs, some were designed specifically for 3D [5].

An example of 3D graph layouts preserving graph hierarchy are *Cone Trees* that arrange child nodes evenly spaced below parent nodes in 3D space, in which root node and further parent nodes form the apex of a cone [15]. This approach was adopted in multiple derivatives such as the *H3* layout that arranges child nodes around a hemisphere in hyperbolic space allowing to display also larger graphs while keeping global structure visible [11]. *PhylloTrees* utilise a rotation pattern at each level by adding an angular constant to cone tree layouts, imitating naturally occurring phyllotactic patterns [2]. From our observations, hierarchical layouts preserve graph hierarchy and structure to a certain degree as long as nodes are not scattered too widely and can visually be linked to the graph on the planar display.

Examples of 3D layouts not projecting graph hierarchy into 3D space are spherical layouts, that map a 2D graph onto the surface of a sphere, similar to [Figure 1](#) (centre and right). This approach does not add specific semantics to the third dimension, but it delivers a clear overview over the whole graph in 3D space and enables users to see nodes without occlusion from inside the sphere [13]. Studies show that typical graph analysis tasks like finding common neighbours and paths can be performed faster and with lower error by using a spherical layout instead of a 2D graph [7]. We also observed that this layout facilitates rediscovering structures of the graph previously shown in 2D on a planar display. However, in combination with transformations out of 2D displays, spherical layouts also pose new problems, such as the need to shift global coordinates of the graph away from the 2D display to avoid occlusion with real-world objects.

Transforming only regions of interest from a 2D display into 3D space can also be an alternative. An example are exploded views where the position in 3D space for each exploded object from 2D display to AR 3D space can not only be calculated geometrically, but also based on semantics such as graph hierarchy [8].

We believe that the classification into 3D layouts preserving structure and/or hierarchy and layouts that do not is generalisable to some extent and can be applied to other semantics than graph structures.

4 TRANSFORMATION PARAMETERS

With transformation we describe the process that places and aligns the AR graph over the graph on the planar 2D display and gradually changes its shape and position from a 2D graph into a predefined 3D layout. During a fixed period, node and edge positions are updated in each frame by interpolating between their current position and the desired 3D layout, creating an animation from 2D into 3D. This process can be influenced by several parameters from which most we believe have also an impact on how seamless the transformation from 2D real environment to 3D AR is perceived.

Groupings

In our prototype, groupings are used to bundle nodes into different categories. After applying the desired criteria, those groups can be used to control the order in which graph elements are transformed from 2D into 3D space by transforming only one group after another. Exemplary grouping criteria that we used in our tests so far are:

- *None*: Nodes are not grouped and all elements are transformed simultaneously into 3D.
- *Node by Node*: All nodes are transformed sequentially into 3D, one after another.

- *Attribute*: Transformation order is determined by node attributes, such as business sector or node color.
- *Connectivity*: Nodes are grouped and transformed by their number of connected edges, i.e. their degree. Other graph metrics such as centrality measures originating from social networks analysis [17] can also be beneficial.

The order in which groupings are transformed raises an additional design question. For instance, nodes grouped by connectivity could be transformed into 3D in descending order, so that nodes with high degree move first into 3D space. From our experience during testing, finding appropriate groupings is not an easy task as it requires contextual knowledge about the task previously performed on the large-scale display. Gestalt principles such as the law of common fate might be helpful here to create transformations keeping elements together that should be perceived as one unit [3]. We believe that the discussed groupings are also applicable to other datasets, except node-specific graph metrics.

Transformation Speed

With transformation speed, i.e. how large the positional shift of nodes between each frame is, we can influence the total duration of the transformation until the graph visualisation is animated completely from 2D into 3D. So far, we experimented with different static transformation speeds and a dynamic transformation speed that is coupled with the speed of the pull gesture (see section 2) performed with the AR hand controller, allowing more user control. It appears that a trade-off must be made when choosing the optimal speed for the transformation: while a high speed might appear more efficient and playful to users, low speed makes it easier to follow certain elements during transformation.

Transformation Type

With transformation type we describe the way the position of each node changes towards the target 3D layout as the transformation proceeds. Currently, all implemented transformation types are based on interpolation, where the next node position is approximated by a function considering the final node position and the current transformation progress. Exemplary methods can for instance be based on linear, exponential, logarithmic, sinus or tangent functions.

5 CONCLUSION

During our work on transforming visualisations from 2D displays into 3D space in AR, we identified a variety of factors influencing users' perception of the seamlessness of those transformations. An appropriate choice of the discussed key parameters appears vital to us, as the cognitive capabilities of users can rather quickly be overcharged when a link to the original visualisation on the 2D display is too hard to establish. When done "right", we believe that data visualisation transitions from 2D displays to AR can leverage productivity and efficiency of data analysis tasks not only because of the combination of advantages of devices at different stages of the RV continuum, but also as it enables users to maintain a connection between 2D display and 3D AR visualisations when they can follow the transformation.

However, to draw qualified conclusions about the effects and interconnections of those parameters, further studies will have to be conducted to quantify their effect on transformations from 2D displays into 3D space. In this workshop, we discuss our current findings on how to create seamless transitions from 2D displays into AR 3D space, so that users can continue directly where they stopped in the real environment when they switch to immersive analytics in AR.

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