Investigating Link Attributes of Graph Visualizations in Mobile Augmented Reality

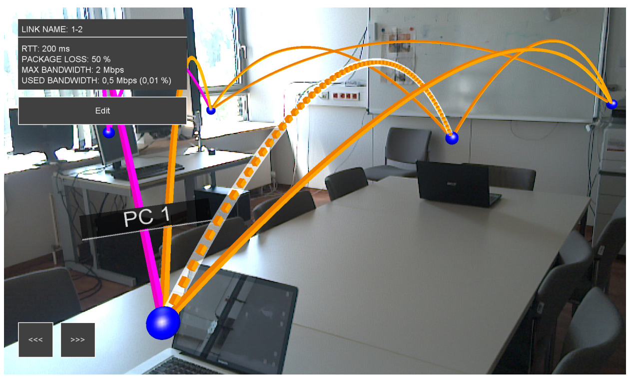

Figure 1: Screenshot of the prototype. The picture shows the graph used in the study with different edge variants, a labeled node, and link details for a selected link.

Wolfgang Büschel
Interactive Media Lab
Technische Universität Dresden
Dresden, Germany
bueschel@acm.org

Stefan Vogt
Interactive Media Lab
Technische Universität Dresden
Dresden, Germany

Raimund Dachselt
Interactive Media Lab
Technische Universität Dresden
Dresden, Germany
dachselt@acm.org

MobileVis '18 Workshop at CHI 2018, April 21, 2018, Montreal, QC, Canada.
https://mobilevis.github.io/

Abstract
Current mobile devices have the necessary technological capabilities to support situated, augmented reality (AR) visualizations. Especially when dealing with data that is inherently spatial in nature or has a strong connection to the physical environment, 3D data visualizations may be suitable. One specific use case is the node-link visualization of network connections and their edge attributes, e. g., to show link capacity or connectivity in LAN or IoT networks. So far, however, there has been very little research on which visual variables to use. We implemented eight link variants and report on the findings of an initial study in which we compared these different visual variables for edge attributes in 3D AR node-link diagrams.

Author Keywords
Augmented Reality, Node-link Diagrams, Mobile Visualization, Immersive Analytics

ACM Classification Keywords
H.5.1 [Multimedia Information Systems]: Artificial, augmented, and virtual realities

Introduction & Background
New classes of mobile devices such as AR headsets and current smartphones support Augmented Reality appli-

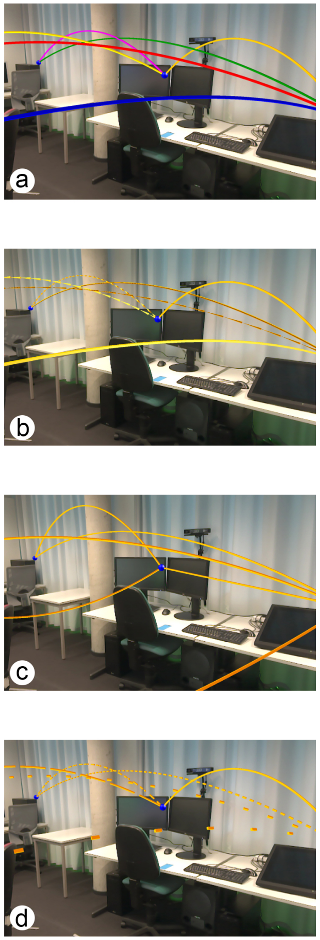

Figure 2: The four static techniques that we used in our study, from top to bottom: color, different primitives, curvature, and stippling patterns.

cations and allow to go beyond classic 2D visualizations. In-situ visualizations have the potential to support ad-hoc analysis processes [4, 5]. They may support serendipity [2] and spatial interaction has been shown to improve performance in navigation tasks for 3D visualizations [3]. They suffer from the well-known, general problems of 3D visualizations such as occlusion, misleading perspective, and readability. Still, they are useful when dealing with data that is either spatial in nature, e. g., volumetric data, or has a strong connection to physical locations, e. g., data linked to objects. One particular example for this class of visualizations are 3D node-link diagrams of networks between real-world objects or locations, e. g., computer networks. AR link visualizations could also be used to show semantic connections between both virtual and real-world objects, e. g., to differentiate between types of labels or annotations attached to physical objects.

Node-link diagrams have extensively been used to visualize graph data. However, there is surprisingly little research specifically on how to visualize link attributes. Notable research in this area includes the work by Holten et al. [7] on techniques for directed edges, Guo et al.'s detailed examination of uncertainty visualization [6], and, very recently, the design space for animated edge textures presented by Romat et al. [8]. For 3D graph visualizations, past research has often focused on the potential of stereoscopic representations, examining the influence of stereo cues in comparison to 2D representations (e. g., [9, 10]) and also considering AR representations [1]. To our knowledge, however, the question which visual variables are best suited to encode link attributes in 3D AR graph visualizations has not been directly addressed yet.

In this paper, we present our current work towards answering this research question. We conducted an initial user study comparing eight different, basic visual encodings for link attributes regarding their usefulness regarding both nominal data (i. e., labels) and ordinal data (i. e., ranked/ordered values).

Prototype

Given the lack of conclusive, prior research in this area, we were particularly interested to get a general idea of which visual variables to use to encode link attributes, informing future, more specific research. To this end, we built a prototype AR application for Google's Project Tango tablet. We chose this platform because we wanted to focus on a form factor close to current generation, hand-held mobile devices. The design of our prototype was influenced by the use case of the management and maintenance of small-scale local computer networks, typically found, e. g., in the offices of small and medium-sized businesses. Accordingly, the prototype shows a set of network devices and connections between them as a 3D AR node-link diagram (Figure 1). For the study, we manually placed the nodes at the location of devices such as laptop computers, PCs, and a printer. We implemented eight variants to map attributes on links using different visual encodings shown in Figure 2 and Figure 3:

(a) Color In this variant, an attribute is mapped to different colors (hues). When using color, one should consider that cluttered, colorful environments may affect the user's ability to distinguish different color tones in an AR application.

(b) Primitives Different (nominal) values can be mapped by constructing the edges from different basic geometric primitives, e. g., pyramids, cones or cylinders. Scale or shape could also encode specific values but 3D perspective does not necessarily allow an easy comparison between

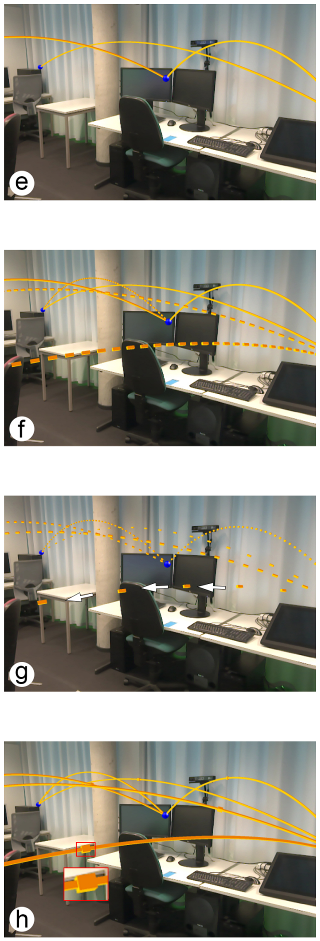

Figure 3: The four dynamic variants, from top to bottom: blinking, alternating stippling, animated stippling, and animated segments

edges.

(c) Curvature For curvature, the edges are implemented as quadratic Bézier curves. By defining the distance of the control point, the curvature of the curve can easily be controlled to encode different values.

(d) Stippling patterns Different stippling patterns and also their animations (see below) are often used to encode link data [8]. Not only can different patterns encode different nominal values, but the distance between segments or their size can also be used to visualize ordinal data.

(e) Blinking Blinking edges can be easily perceived, in many cases even pre-attentively. By controlling the frequency, values can be encoded. However, visual overload should be considered.

(f) Alternating stippling A “softer” form of blinking is to periodically change between different stippling patterns, e. g., between a solid line and simple pattern. Again, the frequency but also the patterns itself can be used to visualize attributes.

(g) Animated stippling In this variant, a a stippling pattern is animated to simulate a flow. Besides showing a direction, this technique can also be used to encode data by changing the animation speed, i. e., the velocity of the flow.

(h) Animated segments In what we call animated segments, an enlarged segment (e. g., a cube or cylinder) is moving along the edge, again showing the direction of the edge and visualizing an attribute as the speed of its movement.

The prototype allows the user to select an edge to get additional, detailed information. The currently selected link is highlighted with a half-transparent hull (Figure 1). The structure of the graph and all attributes are stored in a database and can easily be modified to quickly test different configurations.

Tasks & Procedure

We conducted our study in a controlled lab setting. Eight participants took part in the study (four male, four female, avg. age 30). All participants had normal or corrected to normal vision and all successfully completed the study.

After signing informed consent and filling out a short entry survey, each participant was given the opportunity to train the handling of the Tango tablet and the application. Afterwards, they were shown the eight variants in a counterbalanced order. Each variant was using the (structurally) same graph consisting of five nodes and six edges but with different values for the edges, resulting in, e. g., different colors in the color variant or different frequencies of the animations. During the study, participants were asked to freely explore each variant. No time limit was imposed.

After exploring all eight variants, the participants were asked to subjectively judge each variant regarding its perceived suitability to show nominal attributes, its perceived suitability for ordinal attributes, and its aesthetics. All ratings were based on 5-point Likert-scale items from 1 = not suitable/low to 5 = very suitable/high.

Results & Discussion

We were primarily interested to get a general idea of user acceptance for different, basic encoding strategies for link attributes. Due to the limited number of participants, we opted against a deep statistical analysis for the results of

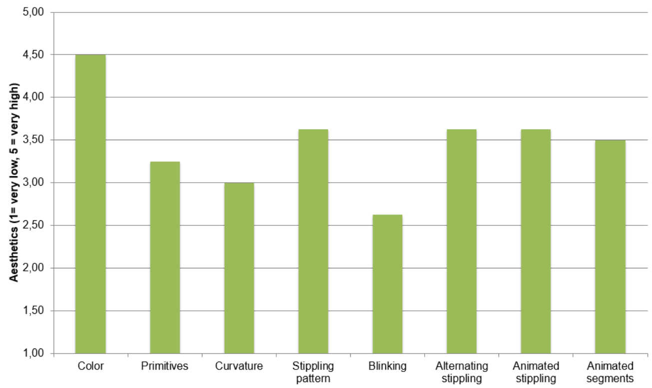

Figure 4: Average aesthetics rating for the different variants

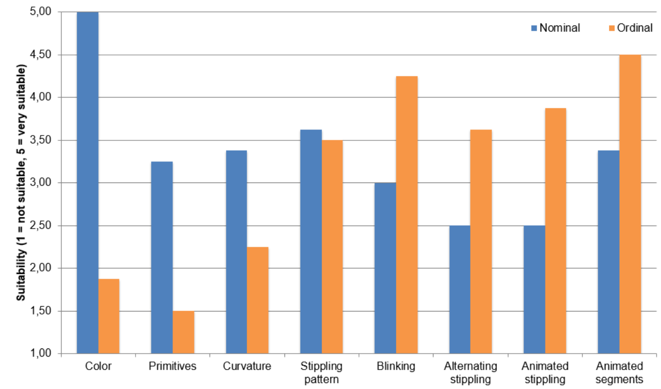

Figure 5: Average suitability rating for the different variants for both nominal and ordinal data

this initial study. Instead, we only report on the means, believing that this suffices to inform future studies. One should note that the data consists of subjective ratings by the participants, not, e. g., measured performance data. The results are shown in Figure 4 (aesthetics) and Figure 5 (suitability for nominal and ordinal data).

In terms of aesthetics, most variants achieved similar results. Our participants rated color the highest, while blinking edges were rated lowest. There, specifically, participants voiced concerns regarding visual clutter.

Regarding the suitability for nominal data, color was rated highest; every participant gave the highest rating of 5. Even with the somewhat cluttered backgrounds of an AR application, participants seem to feel confident in discerning different colors. Most of the animated variants were rated lower than the geometric techniques, with alternating and animated segments being least preferred for nominal data. For ordinal data, the results differ: Our participants clearly preferred the variants making use of animation, with static stippling patterns being the only non-animated variant coming close.

Two interesting points arise from these observations: First, and not surprisingly, no single variant seems adequate for all kinds of data. The highest combined rating for both types of data was given to the animated segments technique but even there, the reported suitability for nominal data was only slightly above average. We believe that for any real-world application, different techniques need to be combined, depending on the data. Second, there appears to be a dichotomy between static variants and animated variants: The static variants were always preferred for nominal data rather than ordinal data and vice versa for the animated variants. While the individual differences between the techniques may be small, the results seem to support the notion of animation speed or frequency being suitable indicators of ordinal data. We believe that the use of appropriate color scales would greatly increase the perceived suitability of color for ordinal data. Though not tested in this early experiment, it would be interesting to examine how such scales should be selected, and how to present them to the user in an immersive AR application.

Conclusion

In this paper we presented the current results of our ongoing investigation into visualizing 3D node link diagrams in Augmented Reality. We conducted an initial user study to assess the suitability of different basic variants for data encoding on links. In the future, we aim to run more in-depth studies, also taking into account specific user tasks related to graph visualization. We also believe that AR glasses are a form factor that will become more important with affordable devices becoming available. Thus, we have already ported our framework to the HoloLens and are looking into comparing hand-held mobile AR with head-worn devices.

Acknowledgments

This work was funded in part by grant no. 03ZZ0514C of the German Federal Ministry of Education and Research (measure Twenty20 – Partnership for Innovation, project Fast).

REFERENCES

1. Daniel Belcher, Mark Billinghurst, SE Hayes, and Randy Stiles. 2003. Using Augmented Reality for Visualizing Complex Graphs in Three Dimensions. In *Proceedings of the 2Nd IEEE/ACM International Symposium on Mixed and Augmented Reality (ISMAR '03)*. IEEE Computer Society, Washington, DC, USA, 84–. `http://dl.acm.org/citation.cfm?id=946248.946799`
2. Wolfgang Büschel, Annett Mitschick, and Raimund Dachselt. 2018. Here and Now: Reality-Based Information Retrieval. In *Proc. CHIIR '18*. ACM, New York, NY, USA, to appear. DOI: `http://dx.doi.org/10.1145/3176349.3176384`
3. Wolfgang Büschel, Patrick Reipschläger, Ricardo Langner, and Raimund Dachselt. 2017. Investigating the Use of Spatial Interaction for 3D Data Visualization on Mobile Devices. In *Proceedings of the 2017 ACM International Conference on Interactive Surfaces and Spaces (ISS '17)*. ACM, New York, NY, USA, 62–71. `https://doi.org/10.1145/3132272.3134125`
4. Neven ElSayed, Bruce Thomas, Kim Marriott, Julia Piantadosi, and Ross Smith. 2015. Situated Analytics. In *2015 Big Data Visual Analytics (BDVA)*. 1–8. DOI: `http://dx.doi.org/10.1109/BDVA.2015.7314302`
5. Barrett Ens and Pourang Irani. 2017. Spatial Analytic Interfaces: Spatial User Interfaces for In Situ Visual Analytics. *IEEE Comp. Graph. Appl.* 37, 2 (2017), 66–79. DOI: `http://dx.doi.org/10.1109/MCG.2016.38`
6. Hua Guo, Jeff Huang, and David H. Laidlaw. 2015. Representing Uncertainty in Graph Edges: An Evaluation of Paired Visual Variables. *IEEE Transactions on Visualization and Computer Graphics* 21, 10 (Oct. 2015), 1173–1186. DOI: `http://dx.doi.org/10.1109/TVCG.2015.2424872`
7. Danny Holten, Petra Isenberg, Jarke J. van Wijk, and Jean-Daniel Fekete. 2011. An Extended Evaluation of the Readability of Tapered, Animated, and Textured Directed-edge Representations in Node-link Graphs. In *Proceedings of the 2011 IEEE Pacific Visualization Symposium (PACIFICVIS '11)*. IEEE Computer Society, Washington, DC, USA, 195–202. `http://dl.acm.org/citation.cfm?id=2015551.2015652`

8. Hugo Romat, Caroline Appert, Benjamin Bach, Nathalie Henry-Riche, and Emmanuel Pietriga. 2018. Animated Edge Textures in Node-Link Diagrams: a Design Space and Initial Evaluation. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems (CHI '18)*. ACM, New York, NY, USA, 13.

9. Colin Ware and Glenn Franck. 1996. Evaluating Stereo and Motion Cues for Visualizing Information Nets in Three Dimensions. *ACM Trans. Graph.* 15, 2 (April 1996), 121–140. DOI: http://dx.doi.org/10.1145/234972.234975

10. Colin Ware and Peter Mitchell. 2008. Visualizing Graphs in Three Dimensions. *ACM Trans. Appl. Percept.* 5, 1, Article 2 (Jan. 2008), 15 pages. DOI: http://dx.doi.org/10.1145/1279640.1279642