Mobile Data Visualization Techniques
Group 4 HCI Winter School

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ABSTRACT

As all kinds of mobile devices continually emerge, mobile visualization is becoming more prevalent. Mobile devices have their own convenience in mobility and input, but also usually limited in terms of display size. Therefore, it's important to reflect on what has been discovered to date on mobile visualization and to look into the future. In this review, we mainly focus on three subtopics of mobile visualization: Responsive Visualization, Glanceable Visualization, and Extended Reality Visualization. Responsive Visualization is about how to visualize data so that they can fit into different display sizes. Glanceable Visualization aims to visualize data in a way that users can easily get important information in a short glance. These two subtopics are two of the most important basics of mobile visualization. Then we look into some interesting researches about extended reality that could bring more flow experiences and interactions on mobile devices.

1 INTRODUCTION

Data visualization refers to the graphical representation of data, which allows the rapid identification of details and patterns that may indicate not only problems but also their possible causes and solutions. It's a concept present in the everyday life of professionals like data analysts and biologists, as the ability to assimilate information is essential for their research activity. In marketing, for example, it's a valuable resource to identify trends and behavior patterns. However, as discussed by Lee et al.[9] current visualization research mostly empowers data professionals but leaves out broader audiences, who can also benefit a lot from personal data visualization and data visualization on mobile devices. With the trend of mobile portables and applications flooding into everyone's life, leveraging the mobile data we produce and get would allow us to get more insights.

Though promising, there are many obstacles to overcome for achieve better mobile data visualizations. Lee et al.[9] presented that the challenges lies in design concept change, as the usage context and data manipulation methods are totally distinct. In the past, people are fixed to the PC screens with click-through buttons and menus to explore precise data for proficient analyzing in different domains. But now, designers need to consider how to minimize the interaction effort without or avoiding perception sacrifice. Another question focus on data type and corresponding visualization mode. Unlike traditional scientific data and illustrated them by pie or histogram charts, now there are countless multi-modal data which need to be processed and explored for better visual presentations.

Last but not the least, extreme using contexts also arises for challenges. Smart wearables like watches hold a tiny screen and users generally pick information instantly from them, which requires concrete designs for such unconventional usages. Thus, we need to research for what designers and scientist had done for solving the design challenges for mobile data visualization and what sub-topics they had contributed to.

2 RELATED WORK

Mobile data visualization makes data presented and perceived in a more flexible way and would contribute a lot in this Web2.0 multi-modal life. But there calls for huge effort for studying the mobile-context and application-specific challenges in designing different interfaces and interaction ways for mobile data visualization. Here we reviewed works form 3 different domains which relates to the topic and how the researchers address their challenges: *Responsive Visualization* focus on how to shift the web or large screen based visualization to the smaller sized displays. *Glanceable Visualization* talks about the extreme usage contexts for mobile data visualizations and the possible design spaces and *Extended Reality Visualization* studies how the 3D data can be presented in mobile situations with virtual realities.

2.1 Responsive Visualization

Directly mapping the traditional display's data visualization application or interface designs would encounter problems like the size restrictions. Thus, researchers explored ways to bridge the two contexts and made data visualization methods responsive for mobile devices.

Hoffswell et al.[6] presented a system that let users to preview and edit different versions of visualization based on the following guidelines: enable simultaneous cross-device edits, facilitate device-specific customization, show cross-device previews, and support propagation of edits. Their system proved to have expressiveness and flexibility for iterative design of responsive visualizations. Kister et al.[8] devised novel techniques that enable users to explore and manipulate graphs with personal mobile devices in combination with wall-sized displays. Therefore, users could not only see the overview of the large amount information on the wall, but also interact with them personally and remotely on the mobile device. Although there are works address visualization on large devices or mobile devices, there's no combination of the two size. They designed different visualization patterns for mobile and wall displays, which help user to utilize different size's advantages and interact seamlessly. The limitation of their study is that they didn't do quantitative experiment to measure the usability of their techniques, even though the qualitative feedback is good overall. Several researches had been done to utilize Machine Learning Algorithms to accelerate the data visualization adaptations for mobile devices. Wu et al.[15] introduced MobileVisFixer, a new method based on reinforcement learning to convert SVG-based visualizations into mobile-friendly designs. This method deconstructs charts into a declarative format, taking the underlying data encoding and decreasing the multi-criteria optimization issue. On the contrary, Qian et al.[12] proposed a retrieve-then-adapt infographics generation process based on example library's automatically imitating. They deconstruct the information in concrete queries to make visual elements matches and then deploy RNN to make fine adjustments until reaching a suitable stage. These methods all take text descriptions and graphic elements combinations into consideration and performs well, but they still requires much more attention for future development. As MobileVisFixer couldn't support users to input dependency relationship and Qian's application stops in proportion infographics like line charts.

2.2 Glanceable Visualization

Due to the limitation of the small size of mobile devices, the displaying information shouldn't be too complex. What's more, users often check information briefly without further interaction on their mobile devices like smartwatch. Therefore, designing glanceable visualization is important for mobile devices.

One of the most frequently used small size mobile devices is smartwatch, and most of the time, people only check information on smartwatch in a brief glance. Islam et al.[7] conducted a survey with smartwatch users to investigate the use of visualization on watch faces, which are the first screen or home screen wearers see when glancing at or turning on their watch. They are interested to know which data types people consume and in which form is the data represented currently. They found that health-fitness related data were the most commonly reported, and Icon+Text was the most common representation type. This result is corresponds to the discussion of Bongshin et al.[13], that personal data visualization would be a major research topic for the data visualization community with the development of sensors and mobile devices. In that case, people can leverage personal data to better understand their physiological status and get more insights, which helps to build a pervasive healthcare environment and contributes to what we called eHealth today.

Gouveia et al.[5] explored the design space of glanceable feedback on smartwatch interfaces for personal activity trackers. They designed 21 concepts and six design qualities, and experimented with four concepts of them. Their study shows that different interfaces can lead to different behavioral patterns, thus align feedback with the desired behavior is very important in design. Although their selection of the four concepts is reasonable, it would be better if they categorize all the concept designs and select the most typical one of each category for experiment. However, their research still outlines a rich design space for further explorations. While Rodrigues et al.[13] proposed a three-layer BSN (body sensor network) to facilitate the idea of monitoring and storing an individual's bio-data and provide meaningful information for ordinary users. In their framework, different sensors act as end-readers for various data, which are driven to the sink node and got aggregated. Later, the mobile device will perform the raw data processing and presenting by Bluetooth communication with the sink node. Although their prototype proves to be complete and low-cost for hardware, the sophisticated distribution of different layers and sensors makes it inconvenient and their visualization of data just remains the oscilloscope level. Besides, they were also aware that there was still no standard for specific visualization model for given data types[13]. As we have much more powerful wearable devices like iWatch, we are now considering how to make data presented and visualized in a user-friendly way to maximize their usability.

Except for the health-related data, scoped data like temperatures and stock values could be presented with a pair of minimum and maximum value in a chronological axis to help people better understand the periodicity and regularity. Now, we know which data worth representing but there is no guidance or principles for designers to exploit in the context of different data characteristics and their mobile devices performance. Thus, Brehmer et al.[4] conducted a crowd-sourced mobile phone experiment tasks to examine the efficiency of Linear and Radial layouts upon visualizing ranges over time. They used temperature range and sleep duration range data to test user's task completion time, error rate and subjective responses on different temporal granularity presentations. According to their result, users show a higher efficiency and confidentiality towards linear layout, which was reflected both objectively and subjectively[4]. Despite the general Week trial's higher speed in completing tasks compared to Month or Year, the proper time ranges to display on a small screen still needs more considerations, as different tasks require different effort in various time windows. Apart from that, one of their major limitation is the devices they use are individual mobile phones, which are low-cost but "rectangle" accustomed. More specifically and intuitively, radial graphs are more likely to exceed on circular devices like watches.

Facing the restriction of the limited screen size of wearables, data visualization faces two major barriers on such devices. First, elaborately but fragmentally, which means data details can be explicit but requires user's effort to interact. Second, compressively but sacrificially, user can get a condensed graph with the cost of perception ability lose. Neshati et al.[11] proposed G-Sparks, a condensed line graph to present the densest compression of a series of data. They designed 2 studies to examine the best way to shrink line graphs to limit the interactive effort while maintain the glanceability[11]. Unexpectedly, their results show that x-axis largest density (25 percentage) compression performs better than any other methods, which is counter-intuitive but prospective for future glanceable designs. Although satisfying, their researches ignored the x-axis value-read tasks and didn't test the circular screen displays, which requires more effort for generalization. Blascheck et al.[3] designed two perceptual studies with data comparison tasks, and tested three common chart types (bar, donut, and radial bar) on smartwatches with three different data sizes. Their results found that participants perceived much faster during the bar chart and donut chart condition than the radial bar chart, which means bar and donut charts should be considered first when designing quick data comparisons functionality or task on smartwatch displays.

Their study contributes a methodology of conducting staircased visualization perception study on smartwatches. However, they used a static watch during their study, neglecting the fact that people usually glance their watches while moving or engaging other activities instead of keeping steady.

2.3 Extended Reality Visualization

For traditional 2D data visualization techniques, regarding to the limited display sizes, the display ways, scope and quality of mobile data visualization are always confined, and same issues come for the interaction areas and ways. Hence, researchers have worked hard on the field of extended reality visualization, to seek new techniques to break these limitations and improve user experience.

One technique to expand the interaction way with mobile devices is to apply tactile 3D data visualization. Wang et al.[14] introduced a pressure-augmented tactile 3D data navigation technique for small devices. Their motivation was to support the interactive visualization beyond traditional workstations. They use phone-based pressure sensing with a binary mapping to separate interaction degrees of freedom and thus allow users to easily select different manipulation schemes. Although the manipulation time and finger fatigue will increase, their technique reduces the occlusion issue on small devices and improves the accuracy of interaction.

Augmented Reality (AR) can provide higher stereoscopy, degrees of freedom, and spatial proximity, especially for 3D data. It is another technique to enhance the user experience on mobile data visualization. Bach et al.[1] compared 3D data visualization in augmented-reality head-mounted display (Microsoft HoloLens) with handheld tablet and desktop setup. Their study indicates that 3D holographic visualization outperforms in time and accuracy for tasks that require coordination between perception and interaction. The results of their experiment suggest that each environment has specific strengths, but generally the desktop environment is fastest and most precise in almost all cases. However, it still gives insights in presenting 3D data in a powerful and novel way. For example, Lee et al.[10] implemented AR in their mobile outdoor application, CityViewAR, to provide geographical information and show visualizing 3D models of the buildings in the city of Christchurch. Comparing using CityViewAR with or without the AR interface, their user study showed that AR is able to improve user experience. However, the speed and accuracy of AR tracking still remains improvement.

Besides AR, mobile data visualization can also incorporate Virtual Reality (VR) and 3D printing (3DP) stuff, offering more flow experiences and interactions. Birt et al.[2] introduced a mobile mixed reality simulation system, which was launched on mobile phone incorporating 3DP, VR, and AR, for medical students to practise virtual medical training. Results showed that student used this simulation system significantly performed better on their assessment tasks, and reported more flows and preferences. However, simulation dissonance and ease of use of the system were difficulties and challenges that needed to be solved.

3 CONCLUSION

In this review, we discussed mobile data visualization techniques in three domains: Responsive Visualization, Glanceable Visualization,and Extended Reality Visualization.

Responsive Visualization focus on how to shift the web or large screen based visualization to the smaller sized displays. Techniques induced by Kister et al.[8] enable users to explore and manipulate graphs with personal mobile devices in combination with wall-sized displays. Machine Learning Algorithms could also be used to accelerate the data visualization adaptations for mobile devices. For example, MobileVisFixer, is a new method based on reinforcement learning to convert SVG-based visualizations into mobile-friendly designs. Future works should be focus on quantitative experiment to measure the usability of responsive conversion techniques and support users to input dependency relationship.

Glanceable Visualization aims to visualize data in a way that users can easily get important information in a short glance. Personal data visualization would be a major research topic for the data visualization community with the development of sensors and mobile devices. Study by Gouveia et al.[5] shows that different interfaces can lead to different behavioral patterns, thus align feedback with the desired behavior is very important in design. According to Brehmer et al. [4], users show a higher efficiency and confidentiality towards linear layout, which was reflected both objectively and subjectively. Future works should investigate how to make data presented and visualized in a user-friendly way to maximize their usability, and consider more social context when people glance their mobile devices, e.g. moving or engaging other activities instead of keeping steady

Extended Reality Visualization is implemented to bring more flow experiences and interactions on mobile devices. It has been used for pressure-augmented tactile 3D data navigation, providing geographical information and showing visualizing 3D models, and developing mobile mixed reality simulation system. Extended Reality Visualization does offer more flow experiences and expand interactions ways for mobile devices, but more studies should be conducted to solve its limitations of low accuracy of tactile interaction, low speed and accuracy of AR tracking, and simulation dissonance of mixed reality simulation system.

REFERENCES

[1] B. Bach, R. Sicat, J. Beyer, M. Cordeil, and H. Pfister. 2018. The Hologram in My Hand: How Effective is Interactive Exploration of 3D Visualizations in Immersive Tangible Augmented Reality? *IEEE Transactions on Visualization and Computer Graphics* 24, 1 (2018), 457–467. https://doi.org/10.1109/TVCG.2017.2745941
[2] James Birt, Emma Moore, and Michael Cowling. 2017. Improving paramedic distance education through mobile mixed reality simulation. *Australasian Journal of Educational Technology* 33, 6 (2017).
[3] Tanja Blascheck, Lonni Besançon, Anastasia Bezerianos, Bongshin Lee, and Petra Isenberg. 2018. Glanceable visualization: Studies of data comparison performance on smartwatches. *IEEE transactions on visualization and computer graphics* 25, 1 (2018), 630–640.
[4] Matthew Brehmer, Bongshin Lee, Petra Isenberg, and Eun Kyoung Choe. 2018. Visualizing ranges over time on mobile phones: a task-based crowdsourced evaluation. *IEEE transactions on visualization and computer graphics* 25, 1 (2018), 619–629.
[5] Rúben Gouveia, Fábio Pereira, Evangelos Karapanos, Sean A. Munson, and Marc Hassenzahl. 2016. Exploring the Design Space of Glanceable Feedback for Physical Activity Trackers. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (Heidelberg, Germany) *(UbiComp '16)*. Association for Computing Machinery, New York, NY, USA, 144–155. https://doi.org/10.1145/2971648.2971754

[6] Jane Hoffswell, Wilmot Li, and Zhicheng Liu. 2020. Techniques for flexible responsive visualization design. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems*. 1–13.

[7] Alaul Islam, Anastasia Bezerianos, Bongshin Lee, Tanja Blascheck, and Petra Isenberg. 2020. Visualizing Information on Watch Faces: A Survey with Smartwatch Users. In *IEEE VIS 2020 - Visualization Conference Short Papers (Short Papers of the IEEE Conference on Visualization (VIS))*. Los Alamitos, CA, United States. https://doi.org/10.1109/VIS47514.2020.00038

[8] U. Kister, K. Klamka, C. Tominski, and R. Dachselt. 2017. GraSp: Combining Spatially-Aware Mobile Devices and a Display Wall for Graph Visualization and Interaction. *Comput. Graph. Forum* 36, 3 (June 2017), 503–514. https://doi.org/10.1111/cgf.13206

[9] Bongshin Lee, Eun Kyoung Choe, Petra Isenberg, Kim Marriott, and John Stasko. 2020. Reaching Broader Audiences With Data Visualization. *IEEE Computer Graphics and Applications* 40, 2 (2020), 82–90.

[10] Gun A Lee, Andreas Dünser, Seungwon Kim, and Mark Billinghurst. 2012. CityViewAR: A mobile outdoor AR application for city visualization. In *2012 IEEE International Symposium on Mixed and Augmented Reality-Arts, Media, and Humanities (ISMAR-AMH)*. IEEE, 57–64.

[11] Ali Neshati, Yumiko Sakamoto, Launa Leboe-Mcgowan, Jason Leboe-McGowan, Marcos Serrano, and Pourang Irani. 2019. G-sparks: Glanceable sparklines on smartwatches. In *45th Conference on Graphics Interface (GI 2019)*. 1–9.

[12] Chunyao Qian, Shizhao Sun, Weiwei Cui, Jian-Guang Lou, Haidong Zhang, and Dongmei Zhang. 2020. Retrieve-Then-Adapt: Example-based Automatic Generation for Proportion-related Infographics. *IEEE Transactions on Visualization and Computer Graphics* (2020).

[13] Joel JPC Rodrigues, Orlando RE Pereira, and Paulo ACS Neves. 2011. Biofeedback data visualization for body sensor networks. *Journal of Network and Computer Applications* 34, 1 (2011), 151–158.

[14] Xiyao Wang, Lonni Besançon, Mehdi Ammi, and Tobias Isenberg. 2019. Augmenting Tactile 3D Data Navigation With Pressure Sensing. *Computer Graphics Forum* 38, 3 (June 2019), 635–647. https://doi.org/10.1111/cgf.13716

[15] Aoyu Wu, Wai Tong, Tim Dwyer, Bongshin Lee, Petra Isenberg, and Huamin Qu. 2020. MobileVisFixer: Tailoring Web Visualizations for Mobile Phones Leveraging an Explainable Reinforcement Learning Framework. *IEEE Transactions on Visualization and Computer Graphics* (2020).