Data Visualization on Mobile Devices

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***Abstract*—Even though the use of mobile devices is widely spread and data visualization is becoming available for larger audiences, there still is a lack of concrete research and approaches to implementing visualizations on mobile devices. This paper deals with presenting the importance of mobile visualization, the challenges coming with it and existing approaches to solve these problems. It should bring awareness to the need for further research in this field to ensure usable and appropriate visualizations for mobile devices.**

I. Introduction

Since mobile devices are commonly used in everyday life, there is a need for adapting data visualizations for smaller devices to make the communication and exploration of data possible, not only on desktops and laptops, but also on the go [1]. The global development of accessing the web more via mobile devices than via desktops supports the importance of prioritizing mobile development in all areas, including data visualization [2]. There are many use cases which exclusively call for visualization on smartphones, tablets, and other mobile devices, like tracking one's health [3], second screen applications [4], electric vehicle maintenance [5] or casual information visualization [6]. Even though there has been the need and opportunity for providing visualization content specifically on mobile devices, there still is a lack of proper research regarding problems when it comes to mobile visualization. Efforts have been made to enhance usable, mobile-friendly websites and content, e.g. the trend towards mobile-first design, but all these solutions focus on layout and design, while visualization in particular is left unaddressed [2].

II. Significance of Data Visualization

Data is becoming more and more valuable, even though it's becoming easier and more affordable to collect large amounts of it rapidly. However, a large number of raw data only result in an overload of information, which is overwhelming rather than useful. Thus, it is vital to use collected data in a way to gain insights that, in consequence, can be used further to develop and advance all kinds of processes or investigations [7].

To achieve the goal of gaining insights, visual channels can be used to facilitate better and faster understanding. It's extremely difficult for humans to detect patterns in tables full of numbers and words, but visual representations, like bar charts or other visualizations, can be easily interpreted [7], [8]. Thereby, the goal of information visualization is not replacing people in the process of data analyzing and interpreting, but rather supporting them in fulfilling their tasks. Visualizations should enhance the ability of understanding information and foster methods of exploring and investigating [9].

III. Why Visualize Data on Mobile Devices?

Even though data visualization started out as a way of understanding data mostly targeted towards researchers and experts, the usage of visualization technology is becoming more and more integrated into everyday life. It can be used in fields of communication, entertainment and productivity [10], health [3], or for mundane things such as emails, music and photo collections [6]. Along with this development, mobile devices and their functionalities are advancing even more rapidly. This has caused mobile devices to become more affordable, which in turn means they are a medium that can be used to reach large amounts of people [1], [3], [4], [11]. Moreover, using mobile devices offers the opportunity of accessing information visualization anywhere and at any time, therefore making it more accessible and flexible than using desktops [10], [12], [13].

With increasingly better hardware and performance in smartphones, it is possible to fulfill more complex tasks, enabling more effective visualizations [12], [14]. This also includes the possibility of using them for a wide variety of applications, e.g. all kinds of use cases where the current location of the user is crucial [15]. Another added value of visualizing data on mobile devices is the option of using integrated features like sound, touch interaction and feedback via vibrations [10].

IV. Challenges in Mobile Visualization

Even though visualizing data on mobile devices is becoming more and more significant, there are still unsolved problems when it comes to displaying visualizations on them. There are several conflicts with the hardware of mobile devices, in comparison to desktops or laptops, as well as a lack of standardized and tested methods directed towards mobile visualization specifically.

A. Limited Displays

The biggest problem when it comes to displaying data visualizations on mobile devices, is the screen size. Mobile devices, especially smartphones, have significantly smaller screens and lower resolutions compared to desktops [4], [10], [13]–[19]. Not only are the screens smaller, but they additionally have a different height to width ratio, making the layout completely different to that of desktop screens [13].

B. Hardware Restrictions

Although mobile devices are developing at a high speed and their hardware is improving steadily, they still cannot be compared to the performance of a desktop. Processing, battery power, graphic hardware, bandwidth, memory and storage are some of the components that get in the way of implementing as powerful visualizations as for desktops [13]–[15], [18].

C. Difficulty of Transfer from Desktop

There are many problems concerning the layout that especially arise when visualizations are simply transferred from desktop applications to mobile ones. Visual encodings are broken, elements are out of the viewport and therefore not visible. Other elements can be overlapping and cluttered or texts too small to read. Oftentimes the layout gets completely distorted or unwanted white space can appear. Especially when SVGs are used, which are mostly present in web applications, scaling items down is not as easy as it is when working with HTML alone [2].

D. Variety of Devices

A similar problem persists for desktop applications, but the difference in devices is even larger when it comes to mobile devices. Not only is there a bigger variety of screen sizes, there are many different operating systems as well. Each device has different levels of performance and computational capability as well, which are hard to factor into development. But the biggest problem is the different forms of input often specific to each device [13], [15], [20].

E. Different Types of Input

While desktops usually have mouses and keyboards as fixed input devices, mobile devices do not have those and therefore make it more difficult to properly include interaction in visualizations, especially on smaller screens [13], [15], [17]. Virtual keyboards or hand-writing mechanisms usually do not include the full range of inputs and the lack of mouses, track pads or similar components makes it difficult to clearly point or click on a data point. Usually users only interact with their mobile devices by using one hand's thumb and apart from clicking and dragging, there are only some rather unfamiliar options for input like cameras or microjoysticks [13], [15].

F. Unpredictable Environment

Even though the mobility and flexibility of mobile devices is an advantage, it also has some downsides. Because mobile devices can be taken and used anywhere, it can not be foreseen in which environments data visualizations will be displayed. That includes the auditory environment, which can limit the use of audio in applications, as well as the lighting conditions, which need to be taken into consideration when checking a graph's visibility. But most of all, because mobile devices can be taken anywhere, they can also be used while doing something else, as a form of multi-tasking. So there are not only physical distractions but also distractions in the user's thoughts when switching between tasks. Thus, their attention span is influenced and limited, resulting in a need for more guidance and support [13]–[15].

G. Lack of Visualization Resources

Since data visualization has mostly been focused on desktop applications, it is difficult to find suitable tools and resources for mobile device development. Available tools and libraries oftentimes are not free and/or accessible to other developers and are very limited in their functionalities. Although there are some techniques that are provided, they usually do not cover all eventualities and due to that are oftentimes not a viable option for a full-fledged mobile visualization [13], [15].

V. Approaches to Solving the Problems

To solve the stated challenges when it comes to visualizing on mobile devices, several different approaches in existing research can be found. They range from trial and error to completely automated mechanisms and try to tackle the problems from different perspectives.

A. Manually Trying to Adapt

Many techniques proposed in research deal with manually adapting visualizations for mobile devices. However, there are different methods within this approach.

1) Cross-Platform Solutions: Some of the solutions deal with making visualizations that should work cross-platform, for example by using D3.js to dynamically adapt displayed content. Using Responsive Web Design with media queries, flexbox or Adaptive Web Design with multiple curated alternatives for different screens are also options [2], [11].

2) Mobile-Specific Solutions: Other methods focus solely on mobile visualization and the already mentioned challenges specifically concerning mobile devices. Some typical solutions used on desktop, like overview and detail or focus and context, may not perform as effectively on mobile devices. Thus, there need to be other solutions for mobile devices. One problem with smaller screens is the limitations of the viewport which leads to loss of context. To preserve the context, relevant information can be indicated in other ways, like indicating some hidden points on a map at the edge or having a miniature version of the map to navigate through the zoomed in version [13].

Another essential point is putting more focus on interactions. Since the screen space is limited, interaction can be used to balance this problem out. Further, one-handed interactions are quite intuitive for users who are used to smartphones [4], [13]. Some interactions include scrolling, panning or zooming by touching, tapping, dragging or pinching, but need to be handled carefully to avoid losing the overview [12], [14], [16].

Lastly, it is difficult to foresee the environment in which mobile devices will be used, but some effort can be made to adapt for different circumstances. Analyzing different contexts and thinking about the user during the design process, can assure the avoidance of errors [14].

B. Making a Prototype and Evaluating It

Another approach that seems to be used oftentimes when the focus isn't necessarily on good mobile adaptation, but rather on a specific use case, a prototype is implemented and simply evaluated with users. This method usually includes much trial and error [2]. Some examples can be found in [3], [5] and [19].

C. Automated Adaptation

To properly transfer visualizations from desktops to mobile devices or to avoid overcluttering, there are different tools that were developed to tackle these issues. While some techniques can use machine learning [2], other methods are more rule-based and try to use generalized rules to adapt visualizations [18], [20].

Tools that focus on adjusting from desktops should help avoiding the time-consuming process of manually tailoring the visualizations for mobile devices. However, since there are several problems that need to be solved in the process, some may be left not optimally solved. These methods appear to be a promising option but require further development to be seamlessly integrated into normal workflows [2].

D. Other Approaches

Apart from these more frequently seen solutions, there are some other more rare approaches that can be found.

1) Evaluating Existing Methods: One method focuses on evaluating existing research and products. For example Blumenstein et al. [1] deal with finding suitable evaluation methods for mobile visualization and comparing them to find existing, tested methods that could be used. Paelke et al. [15] focus on creating a repository for different visualization techniques suitable for use in mobile devices. Although they started by focusing on static visualizations, the plan would be to expand the repository to include interaction techniques as well. To achieve that goal, they collected, analyzed and categorized different visualization methods and evaluated them based on functional capabilities as well as usability.

2) Remote Rendering: Another solution by Krone et al. [12] explores the possibilities of rendering visualizations remotely on a desktop before transferring the finished render to the mobile devices. This approach solves the problem of worse graphic hardware, but has the disadvantage of needing large amounts of data transfer.

3) Workshops: Brainstorming with a group of domain experts and trying to work on new solutions is another method, explored by Lee et al. [17]. The goal here would be to tackle specific challenges in a group of capable people.

VI. Conclusion

Based on the presented existing research and approaches concerning mobile devices, it can be said that there is a definite need for data visualization on mobile devices. Solely due to the widespread availability of mobile devices and their significant advantage of enabling use anywhere at any time, there needs to be a focus on developing solutions for mobile devices. Apart from that, visualization is moving into the direction of being used in all forms of contexts and is beginning to be broadly used by laypeople and larger audiences.

However, there are many challenges that come with developing visualizations for mobile devices. The small screens, as well as other hardware and software limitations prevent the use of proven approaches used in desktop visualizations. The addition of unpredictable environments of use and lack of user attention bring even more problems.

To solve these challenges, there are some existing approaches to try and find suitable solutions for easier and more appropriate design options. Although there are many different perspectives involved, no definite universal solution can be found yet. There is a lack of widely tested solutions and a need for more research in the field of mobile visualization to encourage more wide-spread access to visualizations.

References

[1] K. Blumenstein, C. Niederer, M. Wagner, G. Schmiedl, A. Rind, and W. Aigner, "Evaluating Information Visualization on Mobile Devices: Gaps and Challenges in the Empirical Evaluation Design Space," in *Proceedings of the Sixth Workshop on Beyond Time and Errors on Novel Evaluation Methods for Visualization*, (Baltimore MD USA), pp. 125–132, ACM, Oct. 2016.

[2] A. Wu, W. Tong, T. Dwyer, B. Lee, P. Isenberg, and H. Qu, "MobileVisFixer: Tailoring Web Visualizations for Mobile Phones Leveraging an Explainable Reinforcement Learning Framework," *IEEE Transactions on Visualization and Computer Graphics*, vol. 27, pp. 464–474, Feb. 2021.

[3] J. Meyer, A. Kazakova, M. Büsing, and S. Boll, "Visualization of Complex Health Data on Mobile Devices," in *Proceedings of the 2016 ACM Workshop on Multimedia for Personal Health and Health Care*, (Amsterdam The Netherlands), pp. 31–34, ACM, Oct. 2016.

[4] K. Blumenstein, M. Wagner, and W. Aigner, "Interactive Data Visualization for Second Screen Applications: State of the Art and Technical Challenges," Aug. 2015.

[5] N. I. L. Ibrahim, M. M. Ariffin, and A. Zakariya, "Mobile Application of Data Visualization for Electric Vehicle," in *2022 6th International Conference On Computing, Communication, Control And Automation (ICCUBEA*, (Pune, India), pp. 1–5, IEEE, Aug. 2022.

[6] Z. Pousman, J. Stasko, and M. Mateas, "Casual Information Visualization: Depictions of Data in Everyday Life," *IEEE Transactions on Visualization and Computer Graphics*, vol. 13, pp. 1145–1152, Nov. 2007.

[7] S. Murray, *Interactive data visualization for the web: an introduction to designing with D3*. Beijing Boston Farnham Sebastopol Tokyo: O'Reilly, second edition ed., 2017.

[8] A. Cairo, *The functional art: an introduction to information graphics and visualization*. Berkeley, Calif.: New Riders, 2013.

[9] T. Munzner, *Visualization analysis & design*. Boca Raton, FL: CRC Press/Taylor & Francis Group, 2015.

[10] J. C. Roberts, P. D. Ritsos, S. K. Badam, D. Brodbeck, J. Kennedy, and N. Elmqvist, "Visualization beyond the Desktop–the Next Big Thing," *IEEE Computer Graphics and Applications*, vol. 34, pp. 26–34, Nov. 2014.

[11] J. Gu, S. Mackin, and Y. Zheng, "Making Sense: An Innovative Data Visualization Application Utilized Via Mobile Platform," in *2018 IEEE 20th International Conference on High Performance Computing and Communications; IEEE 16th International Conference on Smart City; IEEE 4th International Conference on Data Science and Systems (HPCC/SmartCity/DSS)*, (Exeter, United Kingdom), pp. 1105–1109, IEEE, June 2018.

[12] M. Krone, C. Müller, and T. Ertl, "Remote Rendering and User Interaction on Mobile Devices for Scientific Visualization," in *Proceedings of the 8th International Symposium on Visual Information Communication and Interaction*, (Tokyo AA Japan), pp. 21–26, ACM, Aug. 2015.

[13] L. Chittaro, "Visualizing Information on Mobile Devices," *Computer*, vol. 39, pp. 40–45, Mar. 2006.

[14] M. Lebusa, H. Thinyane, and I. Sieborger, "Mobile visualisation techniques for large datasets," in *2015 IST-Africa Conference*, (Lilongwe, Malawi), pp. 1–9, IEEE, May 2015.

[15] V. Paelke, C. Reimann, and W. Rosenbach, "A Visualization Design Repository for Mobile Devices," Feb. 2003.

[16] S. Burigat, L. Chittaro, and E. Parlato, "Map, Diagram, and Web Page Navigation on Mobile Devices: the Effectiveness of Zoomable User Interfaces with Overviews," Sept. 2008.

[17] B. Lee, M. Brehmer, P. Isenberg, E. K. Choe, R. Langner, and R. Dachselt, "Data Visualization on Mobile Devices," in *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*, (Montreal QC Canada), pp. 1–8, ACM, Apr. 2018.

[18] P. M. Pombinho, M. B. Carmo, and A. P. Afonso, "Evaluation of Overcluttering Prevention Techniques for Mobile Devices," in *2009 13th International Conference Information Visualisation*, (Barcelona, Spain), pp. 127–134, IEEE, July 2009.

[19] T. Buering, J. Gerken, and H. Reiterer, "User Interaction with Scatterplots on Small Screens - A Comparative Evaluation of Geometric-Semantic Zoom and Fisheye Distortion," *IEEE Transactions on Visualization and Computer Graphics*, vol. 12, pp. 829–836, Sept. 2006.

[20] B. Gillick, H. AlTaiar, S. Krishnaswamy, J. Liono, N. Nicoloudis, A. Sinha, A. Zaslavsky, and M. M. Gaber, "Clutter-Adaptive Visualization for Mobile Data Mining," in *2010 IEEE International Conference on Data Mining Workshops*, (Sydney, TBD, Australia), pp. 1381–1384, IEEE, Dec. 2010.