Report from Dagstuhl Seminar 19292

Mobile Data Visualization

Edited by

Eun Kyoung Choe[1], Raimund Dachselt[2], Petra Isenberg[3], and Bongshin Lee[4]

1 **University of Maryland – College Park, US,** `choe@umd.edu`
2 **Technische Universität Dresden, DE,** `raimund.dachselt@tu-dresden.de`
3 **Inria Saclay – Orsay, FR,** `petra.isenberg@inria.fr`
4 **Microsoft Research – Redmond, US,** `bongshin@microsoft.com`

Abstract

Mobile visualization is becoming more prevalent, and new mobile device form factors and hardware capabilities will continually emerge in the coming years. Therefore, it is timely to reflect on what has been discovered to date and to look into the future. This Dagstuhl seminar brought together both established and junior researchers, designers, and practitioners from relevant application and research fields, including visualization, ubiquitous computing, human-computer interaction, and health informatics. Five demos and five tutorials gave participants an opportunity to share their experiences and research, and learn skills relevant to mobile data visualization. Through brainstorming and discussion in break-out sessions, along with short report back presentations, participants identified challenges and opportunities for future research on mobile data visualization.

Seminar July 14–19, 2019 – http://www.dagstuhl.de/19292
2012 ACM Subject Classification Human-centered computing → Human computer interaction (HCI), Human-centered computing → Ubiquitous and mobile computing, Human-centered computing → Visualization, Human-centered computing → Interaction design
Keywords and phrases Data visualization, Human-computer interaction, Information visualization, Mobile computing, Ubiquitous computing
Digital Object Identifier 10.4230/DagRep.9.7.78
Edited in cooperation with Ricardo Langner and Tom Horak

1 Executive Summary

Eun Kyoung Choe (University of Maryland – College Park, US, choe@umde.edu)
Raimund Dachselt (Technische Universität Dresden, DE, raimund.dachselt@tu-dresden.de)
Petra Isenberg (Inria Saclay – Orsay, FR, petra.isenberg@inria.fr)
Bongshin Lee (Microsoft Research – Redmond, US, bongshin@microsoft.com)

As pen- and/or touch-enabled mobile devices have become more powerful and ubiquitous, we see a growing demand for *mobile data visualization* to facilitate visual access to data on mobile devices (see Figure 1 for examples). Lay people increasingly access a wide range of data, including weather, finance, and personal health on their phone. Small business owners start to use business intelligence software equipped with data visualization on mobile devices to make better business decisions. In responding to these needs, practitioners have actively been designing mobile visualizations embedded in commercial systems. However,

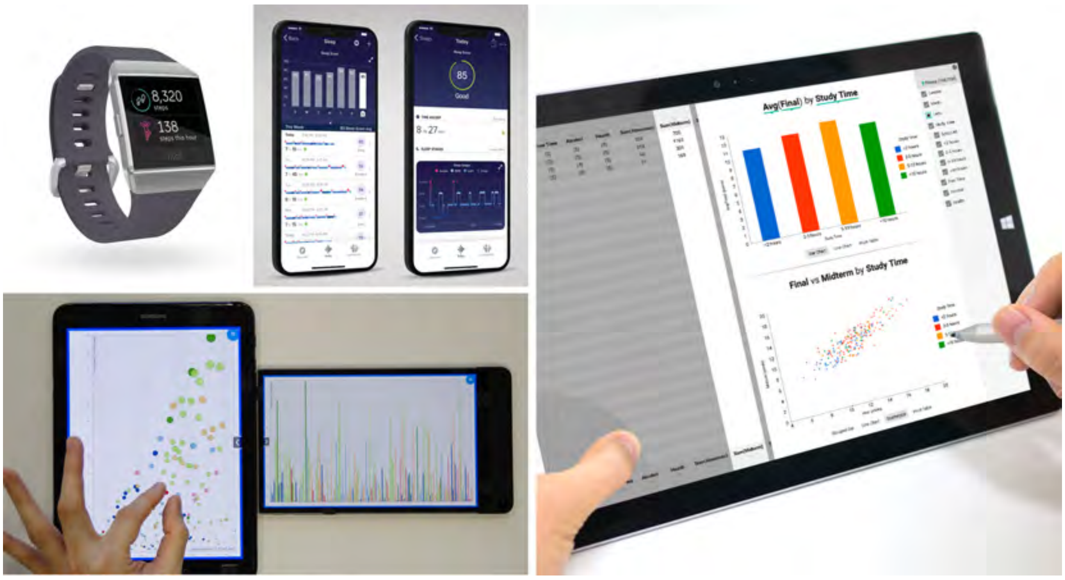

Figure 1 Examples of mobile data visualizations: step count and sleep data visualization on Fitbit Ionic and mobile app (top left); a multiple coordinated views across two mobile devices in VisTiles (bottom left); and visual data exploration on a tablet leveraging pen and touch interaction in TouchPivot (right).

research communities, such as Human-Computer Interaction (HCI), Information Visualization (InfoVis), and Ubiquitous Computing (UbiComp) have not paid enough attention to mobile data visualization.

Over the past few decades, the visualization research community has conducted extensive research, designing and developing a large number of visualization techniques and systems mostly for a desktop environment. However, the accumulated knowledge may not be readily transferable to mobile devices due to their fundamental differences in their display size, interaction, and target audience, among others. The small display on mobile devices is more vulnerable to the scalability issue and poses a well-known challenge, the fat finger problem. Mouse-over interaction, which is prevalent in interactive visualization systems in the desktop environment, is not available on mobile devices. While traditional visualizations mainly target data-savvy groups of people such as scientists and researchers, visualizations on mobile devices should account for a broader range of target audience, including lay people who might have low data and visualization literacy.

This Dagstuhl seminar follows in the footsteps of the "Data Visualization on Mobile Devices" workshop at CHI 2018, our initial effort in establishing a community around mobile data visualization. We brought researchers and practitioners from relevant application and research fields, including InfoVis, UbiComp, mobile HCI, and interaction design to exchange information and experiences, to stimulate discussion, to make new connections, and to identify novel ideas and future directions around mobile data visualization.

Unlike the CHI workshop, this five-day Dagstuhl workshop enabled us to explore mobile data visualization in depth through speedy & intense research exchanges, interactive demos & tutorials, as well as active breakout group discussions.

Figure 2 Exchange of research interest & background in a speed dating format.

The Week at a Glance

Monday. The seminar was kicked off by the organizers with an introduction to the topic of mobile data visualization and by providing organizational information. Afterwards, all participants introduced themselves and their expectations with a short two-minute slide presentation. This session was followed by a speedy research brainstorming activity (see Figure 2): In rapid five-minute sessions, two participants facing each other introduced their research activities and jointly sketched new ideas. By rotating half of the group, each session was repeated eleven times with new constellations of two people each time.

In the afternoon, five demo stations were set up and participants were split into groups to attend them in turn. Five researchers presented their latest mobile visualization demos in hands-on sessions (see Figure 3). These were:

- Tanja Blascheck: Smartwatch demo from a study comparing three representations–bar, donut, text (joint work with Lonni Besançon, Anastasia Bezerianos, Bongshin Lee, Petra Isenberg).
- Matthew Bremer: Tilting, brushing, & dialing for mobile vis (joint work with Bongshin Lee, Christopher Collins, Ken Hinckley).
- Tobias Isenberg: Personal home automation system with mobile data access and control.
- Alark Joshi: Visualization of off-screen data using summarization techniques (joint work with Martino Kuan, Alejandro Garcia, Sophie Engle).
- Jo Vermeulen: Product Fingerprints, a mobile visualization that allows people to compare nutritional information between food products (joint work with Carrie Mah, Kevin Ta, Samuel Huron, Richard Pusch, Jo Vermeulen, Lora Oehlberg, Sheelagh Carpendale).

Figure 3 One of the mobile visualization demos presented to a small group of participants.

In a second activity, 14 participants presented a design critique of an existing mobile visualization, partly commercial products, partly research results (see Figure 4). Besides evoking the spirit of a good discussion, it helped getting a broad overview about currently available solutions.

In a followup activity, to arrive at a common understanding of the state of the art in mobile data visualization, we split attendees into three groups according to their main expertise. The three groups were:

- Information Visualization–Mobile Visualization Resources
- Visualization in Ubiquitous Computing Research
- Mobile Interaction and Human Computer Interaction

Each group was tasked to collect and discuss the state of the art, with an end goal of creating a short presentation to be given to the entire audience. As a result, the collected material and insights were presented to the plenum by each group.

Through these diverse activities during the first day, participants did not only gain a good understanding of each other's background and research interests, but also established a common ground and expertise in the field of mobile data visualization

Tuesday. The second day started with a lively brainstorming and discussion of challenges and important research questions in the field of mobile data visualization. From about ten larger topics we identified, four were chosen to form parallel breakout groups:

- Group 1: Evaluating Mobile Data Visualization
- Group 2: What is Mobile Vis?
- Group 3: Responsive Visualization
- Group 4: Vis for Good & Ethics

Figure 4 Impressions from the Design Critique Session.

Using the impressive facilities of Dagstuhl in terms of rooms and places, space to think and coffee to drink, we had intense discussions within each group. We generated deeper research questions and challenges, and identified collaborative cross-disciplinary research opportunities and approaches. Section 4 provides more details on each of these working groups.

After lunch, groups reported back on what they had discussed (see Figure 5). The four groups decided to continue and deepen their discussions in the afternoon, this time focusing more on what could become a concrete research output.

Wednesday. Wednesday morning was devoted to the presentation of tutorials. Five participants had volunteered to give tutorials in two time slots, allowing other participants to attend two one-hour tutorials. Figure 6 shows the title slides of all informative and well-received tutorials, and Section 3 provides details on each of them.

Following the tradition of Dagstuhl Seminar, Wednesday afternoon was set aside for social activities. We took the bus to experience the famous Saarschleife high from the impressive treetop walk. Visiting Mettlach and having dinner in a brewery intensified personal conversations and fostered planning for joint research collaborations.

Thursday. Similar to Tuesday, the entire day was dedicated to group work (see Figure 7). The list of possible topics for breakout groups was revisited, and people assembled to form new groups on other challenging topics:

- Group 5: Starting Mobile Visualization from Scratch
- Group 6: Beyond Watch & Phone: From Mobile to Ubiquitous Visualization
- Group 7: (Discoverable) Interaction for Mobile Visualization
- Group 8: From Perception to Behavior Change: Designing and Evaluating Glanceable Mobile Vis
- Group 9: Mobile Vis for 3D Data / AR Vis

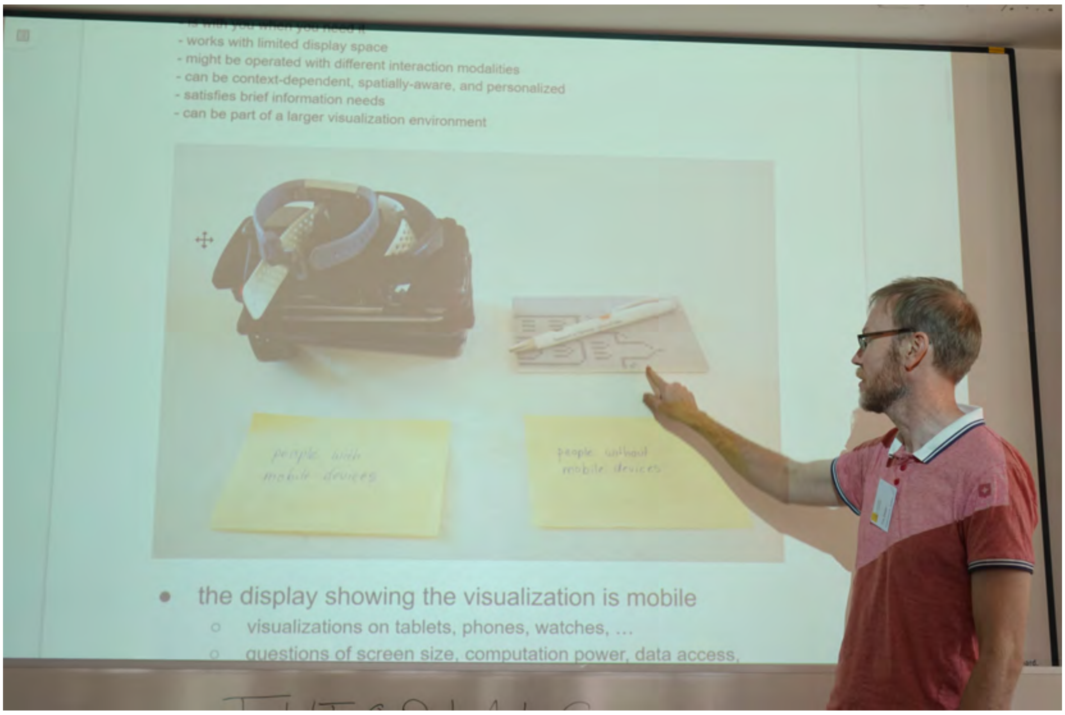

Figure 5 Report back from Group 2 on "What is Mobile Vis?"

Again, both the morning and afternoon were used for intensely discussing challenges, defining design spaces, shaping the knowledge on the given topic, and identifying opportunities for joint research. Groups also reported back to the plenum, and results were discussed openly. Section 4 provides more details on each of these working groups and their outcomes.

Friday. After interesting and enriching days of joint discussions, which considerably broadened the horizon, time had come to wrap up the seminar on Mobile Data Visualization. Most importantly, a broad range of future collaborative activities were discussed: writing a state-of-the-art report, joint grant proposals, further workshop proposals, individual papers, editing a special journal issue, and writing a book on the topic. In the end, we agreed on a book as a possible major outcome (see Section 5). Organizational details were clarified, before the seminar was concluded with thanking all participants for their great contributions and commitment during the entire week.

2 Table of Contents

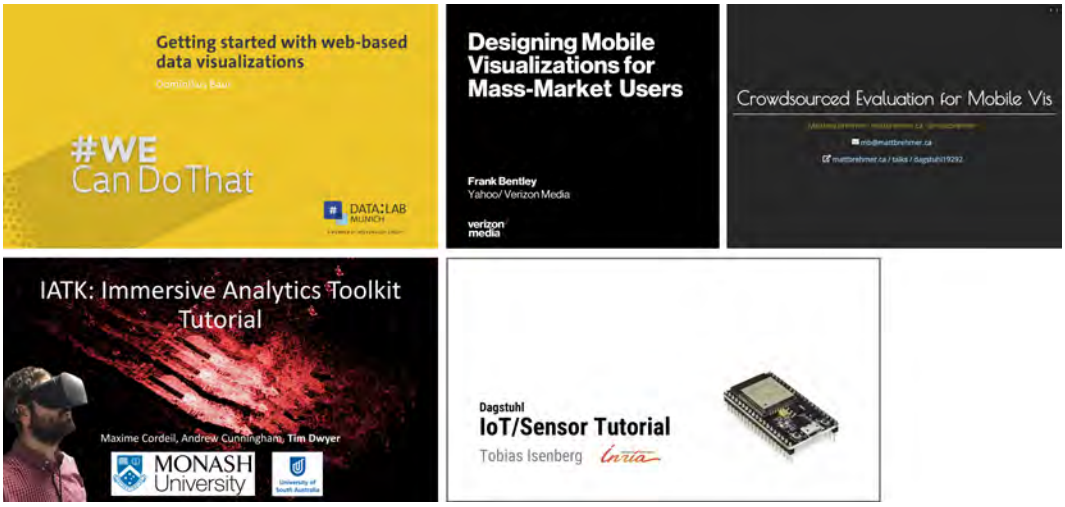

Figure 6 Title slides of all five tutorials presented at the seminar.

3 Tutorials

Before the Dagstuhl seminar, we solicited volunteers to give tutorials and demos at the seminar. Five people gave tutorials to share their research and experiences relevant to mobile data visualization. In the following, we provide the abstracts of these tutorials.

3.1 Getting Started with Web-based Visualizations

Dominikus Baur (Volkswagen Data:Lab – München, DE)

In this hands-on tutorial, we learned about the basics of creating web-based data visualizations. Initially, we looked at the basic web technologies of HTML, CSS, and JavaScript, their basic syntax, and what they're used for. We played with the technologies in a browser-based development environment to received instant feedback for our experiments. Next, we dove into d3.js, the JavaScript library commonly used for creating visualizations. We looked into the most important functions that d3.js provides to create simple visualizations. We also learned about the more idiosyncratic approaches that d3.js encompasses for mapping data to visual elements. Finally, we got into more of the real-world aspect of web development with an overview of the Node Package Manager (npm) and how bundlers like Parcel or rendering frameworks like React work.

3.2 Designing Mobile Visualizations for Mass-Market Users

Frank Bentley (Yahoo Labs – Sunnyvale, US)

When designing visualizations, it's important to consider the broader population, and their ability to interpret what is shown. Properly recruiting users that match the broader population is extremely important. In this regard, getting 2/3 of participants without a college degree, diverse ages, incomes, and races while achieving a gender balance will allow you to understand how your interface would be perceived by a larger audience. Yet many visualizations are not evaluated this way. In addition, it has been shown that many users have trouble interpreting standard InfoVis techniques, such as time series graphs or maps. Alternatives to these visualizations, using text explanations, summaries, or other ways to simplify the data are critical if systems are to be adopted and understood by broader audiences. This talk highlighted some alternatives that have been tried over the past two decades in HCI and Ubicomp research.

3.3 Crowdsourced Evaluation for Mobile Vis

Matthew Brehmer (Vancouver, CA)

In this tutorial, we reviewed the practical and methodological aspects of conducting crowd-sourced experiments about visualization on mobile devices. This tutorial followed two recently conducted experiments of this sort (in collaboration with Bongshin Lee, Petra Isenberg, and Eun Kyoung Choe). I described considerations for designing and developing mobile-only web apps for visualization experiments, as well as considerations for recruiting, piloting, and onboarding participants. I also described several ways to improve participant compliance and response quality. Finally, I pointed to other resources for crowdsourcing and mobile visualization design, and suggested some opportunities for future experimental work.

3.4 The Immersive Analytics Toolkit – IATK

Tim Dwyer (Monash University – Caulfield, AU)

Main reference Maxime Cordeil, Andrew Cunningham, Benjamin Bach, Christophe Hurter, Bruce H. Thomas, Kim Marriott, Tim Dwyer: "IATK: An Immersive Analytics Toolkit", in Proc. of the IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2019, Osaka, Japan, March 23-27, 2019, pp. 200–209, IEEE, 2019.
URL http://dx.doi.org/10.1109/VR.2019.8797978

Immersive Analytics Toolkit (IATK) is a Unity project to help you build high quality, interactive and scalable data visualisations in Immersive Environments (Virtual/Augmented Reality). This tutorial allowed participants to learn how to use the Visualisation script to create data visualisations interactively in the editor, press play and view and interact with data in V/AR. Participants could also write simple code to use the IATK core graphics components to make own interactive visualisations programmatically.

3.5 Microcontroller Programming for Sensor Data Capture & Visualization

Tobias Isenberg (INRIA Saclay – Orsay, FR)

The tutorial gave an overview of the ESP8266 and ESP32 microcontrollers and how to prototype sensor reading and data visualization with them. I showed the use of the Arduino IDE and talked about relevant electronics issues. I also covered how to manage battery operation of the microcontrollers. Finally, I covered how to collect the data using MQTT and how to prototype visualizations on e-ink displays.

4 Working Groups

The main seminar was dedicated to working in several breakout groups. From this activity, several research questions and challenging topics were identified. We first identified topics of interest by asking people to vote for the topics that they would like to discuss. All participants were part of at least two working groups, spending a day (Tuesday & Thursday) for each topic. In the following, we provide abstracts for all nine breakout groups.

4.1 What is Mobile Vis?

Tim Dwyer (Monash University – Caulfield, AU), Lonni Besancon (Linköping University, SE), Christopher Collins (Ontario Tech – Oshawa, CA), Petra Isenberg (INRIA Saclay – Orsay, FR), Tobias Isenberg (INRIA Saclay – Orsay, FR), Ricardo Langner (TU Dresden, DE), Bongshin Lee (Microsoft Research – Redmond, US), Charles Perin (University of Victoria, CA), Harald Reiterer (Universität Konstanz, DE), and Christian Tominski (Universität Rostock, DE)

There are several ways in which the term "Mobile Data Vis" may be interpreted. For example, it may describe: visualizations hosted on devices that are mobile; situations where the users of visualizations are mobile relative to the display; and visualizations that are themselves mobile across devices and screens. We focused mainly on defining visualization for mobile devices, and left deeper consideration of the latter two interpretations to future meetings. We explored the characteristics upon which visualizations can be described, focusing on those which, in their extremes, differentiate mobile visualization from other forms of data visualization. These characteristics gave rise to a first set of dimensions of a design space for mobile data visualization, in which instances of mobile data visualization may be positioned. We discussed a number of such example instances to illustrate how the definition makes it possible to describe and compare mobile visualizations. Using the dimensions, we identified gaps and opportunities for future mobile visualizations.

4.2 Evaluating Mobile Data Visualization

Lena Mamykina (Columbia University – New York, US), Frank Bentley (Yahoo Labs – Sunnyvale, US), Eun Kyoung Choe (University of Maryland – College Park, US), Pourang P. Irani (University of Manitoba – Winnipeg, CA), and John T. Stasko (Georgia Institute of Technology – Atlanta, US)

There are many different reasons to evaluate mobile visualizations with end users. Depending on the intention of the system, different methods are needed. In the mobile information visualization domain, there is a broad continuum of research questions that can be answered by a study. Some goals include validating rapid perception of differences in data, while others are interested in examining long-term use of visualizations and whether they achieve their intended impact on users. Very different methods, time-scales of research, and user recruitment strategies are needed. We began to explore the literature and different system goals and evaluation approaches, and plan to continue our work by highlighting best practices and making recommendations for future approaches to evaluating mobile data visualizations.

4.3 Responsive Visualization

Wolfgang Aigner (FH St. Pölten, AT), Dominikus Baur (Volkswagen Data:Lab – München, DE), Matthew Brehmer (Vancouver, CA), Tom Horak (TU Dresden, DE), Alark Joshi (University of San Francisco, US), Harald Reiterer (Universität Konstanz, DE), and Christian Tominski (Universität Rostock, DE)

Due to the proliferation of mobile devices like smartphones and tablets, an increasing number of data visualizations are being used not only on desktop computers but also on mobile devices. But, visualizations designed for desktop computers are often unusable on smaller mobile devices due to differences and restrictions in display size, aspect ratio, and interaction capabilities. Therefore, mobile data visualization applications need to be responsive to the specific constraints of the devices used as well as their users, environment, data, and usage contexts. In our breakout group, we discussed causes of responsiveness, how the contextual information can be sensed on devices, and what needs to be adapted based on this information. Furthermore, we worked towards a conceptual model of responsiveness by extending the simple visualization model of Van Wijk in order to capture all design aspects and data aspects.

4.4 Vis for Good & Ethics

Jo Vermeulen (Aarhus University, DK), Tanja Blascheck (Universität Stuttgart, DE), Sheelagh Carpendale (Simon Fraser University – Burnaby, CA), Raimund Dachselt (TU Dresden, DE), and Daniel Epstein (University of California – Irvine, US)

Our group discussed that visualization is neither good, bad, nor neutral. Visualization is not necessarily objective. We focused on visualization for good and for bad. Due to limited screen space, more interruptions, people are more at the mercy of the visualization designer. We attempted to characterize existing "dark patterns" for mobile visualization.

4.5 Starting Mobile Visualization from Scratch

Dominikus Baur (Volkswagen Data:Lab – München, DE), Sheelagh Carpendale (Simon Fraser University – Burnaby, CA), Daniel Epstein (University of California – Irvine, US), Lena Mamykina (Columbia University – New York, US), and Charles Perin (University of Victoria, CA)

Our group discussed what mobile visualization could be like if we shed the restrictions of existing technologies and the influence of existing (desktop) visualizations. We started from several scenarios (e.g., a lecture situation, supporting people's nutritional choices, team sports) and asked ourselves how support by a visualization system could work there. We categorized the primacy of the visualization task along a spectrum from passive awareness (via supporting the main task) to in-depth analysis and discussed corresponding considerations regarding information displays and timeliness. We also discussed "progressive visualizations" that would increase the information density depending on the amount of available attention and the viewer's involvement. As a result, we argued the inversion of Ben Shneiderman's interaction mantra to *details-first, triggering interest, and analysis/overview-on-demand.*

4.6 Beyond Watch/Phone: From Mobile to Ubiquitous Visualization

Christopher Collins (Ontario Tech – Oshawa, CA), Raimund Dachselt (TU Dresden, DE), Pourang P. Irani (University of Manitoba – Winnipeg, CA), Alark Joshi (University of San Francisco, US), Ricardo Langner (TU Dresden, DE), and Jo Vermeulen (Aarhus University, DK)

Our group talked about visualization beyond the mobile phone and smartwatch. We discussed other approaches including networked small situated displays, cheap disposable (flexible) displays, and textiles. The key characteristic is that these envisioned solutions support people's ongoing activities. We discussed several possible scenarios including crisis management, large scale communication to the public, and communication between cars, as well as several existing examples in the literature. Finally, we identified core dimensions such as personal vs. display movement; data that is mobile; public vs. private visualization; information needs; urgency; and situational context.

4.7 (Discoverable) Interaction for Mobile Visualization

Matthew Brehmer (Vancouver, CA), Bongshin Lee (Microsoft Research – Redmond, US), John T. Stasko (Georgia Institute of Technology – Atlanta, US), and Christian Tominski (Universität Rostock, DE)

Our group discussed the challenges and difficulties of interacting with mobile devices, of interacting with visualization on mobile devices, and of interaction in casual contexts. Next, we considered ways of structuring the space of interaction for visualization on mobile devices, such as around existing visualization task typologies, existing visualization interaction typologies, interaction modalities, data types, and chart types. Regardless of how we structure the space of interaction, we will catalog current approaches, gaps, and future opportunities. Finally, we distinguished mobile interaction from desktop/laptop interaction.

4.8 From Perception to Behavior Change: Designing and Evaluating Glanceable Mobile Vis

Tanja Blascheck (Universität Stuttgart, DE), Frank Bentley (Yahoo Labs – Sunnyvale, US), Eun Kyoung Choe (University of Maryland – College Park, US), Tom Horak (TU Dresden, DE), and Petra Isenberg (INRIA Saclay – Orsay, FR)

There is a continuum of uses for mobile visualizations, from solving quick information needs, through systems that provide browsing of data in more detail, to systems that afford deep analysis of larger datasets. This working group focused on systems that solve quick information needs.

Quick information needs are important components of mobile visualizations within applications such as fitness trackers, GPS displays in a car, tracking family members, or weather awareness. Visualizations that require passive interactions and are designed for quick information needs are described under a variety of terms such as glanceable visualizations, glanceable displays, peripheral displays, ambient visualizations, notification systems, or casual visualizations. In this working group, we discussed these individual terms and how they are related across the ubiquitous computing and visualization domains with a focus on how the term "glanceable" differs in the communities.

In addition, we discussed purposes for glanceable displays–from quick awareness, such as indicating to a driver or pilot that there is a serious problem, to systems meant to evoke long-term behavior change, which will be glanced at thousands of times. This working group explored different visualization scenarios, characteristics, and evaluation methodologies for these different purposes.

Figure 7 Group 8 discussing glanceable mobile visualization in the Dagstuhl garden.

4.9 Mobile Vis for 3D Data / AR Vis

Tim Dwyer (Monash University – Caulfield, AU), Wolfgang Aigner (FH St. Pölten, AT), Lonni Besancon (Linköping University, SE), Tobias Isenberg (INRIA Saclay – Orsay, FR), and Harald Reiterer (Universität Konstanz, DE)

We surveyed the space of 3D mobile visualizations (3D data on mobile 2D displays, abstract and/or 3D data in mobile (HMD) AR/VR displays). As a playful "Case Study" we used a scenario from the film "Aliens", in which a mobile, small-screen visualisation device is used to track the movements of enemy aliens around a group of space marines. In this scenario, the marines are overrun by aliens in the ceiling, as their device fails to show them the height dimension of the space around them. We used this example to illustrate how different mobile and 3D interaction techniques could have prevented the misunderstanding in the movie, using both hypothetical descriptions of the improved movie action and a scientific discussion of these scenarios and their implications.

5 Outlook and Conclusion

As an outcome of the seminar, we are working towards a joint publication that captures many of the discussed topic related to mobile data visualization. Each chapter will expand on the discussions started at Dagstuhl and will include in-depth explorations of the most of the working group topics mentioned in Section 4. We hope that our book will engage the community to further pursue this exciting topic.

In summary, we had a fruitful and engaged seminar and received positive feedback from the group. The organizers thank Dagstuhl for hosting our seminar and the great research facilities provided.

Participants

- Wolfgang Aigner
FH St. Pölten, AT
- Dominikus Baur
Volkswagen Data:Lab – München, DE
- Frank Bentley
Yahoo Labs – Sunnyvale, US
- Lonni Besancon
Linköping University, SE
- Tanja Blascheck
Universität Stuttgart, DE
- Matthew Brehmer
Vancouver, CA
- Sheelagh Carpendale
Simon Fraser University – Burnaby, CA
- Eun Kyoung Choe
University of Maryland – College Park, US
- Christopher Collins
Ontario Tech – Oshawa, CA
- Raimund Dachselt
TU Dresden, DE
- Tim Dwyer
Monash University – Caulfield, AU
- Daniel Epstein
University of California – Irvine, US
- Tom Horak
TU Dresden, DE
- Pourang P. Irani
University of Manitoba – Winnipeg, CA
- Petra Isenberg
INRIA Saclay – Orsay, FR
- Tobias Isenberg
INRIA Saclay – Orsay, FR
- Alark Joshi
University of San Francisco, US
- Ricardo Langner
TU Dresden, DE
- Bongshin Lee
Microsoft Research – Redmond, US
- Lena Mamykina
Columbia University – New York, US
- Charles Perin
University of Victoria, CA
- Harald Reiterer
Universität Konstanz, DE
- John T. Stasko
Georgia Institute of Technology – Atlanta, US
- Christian Tominski
Universität Rostock, DE
- Jo Vermeulen
Aarhus University, DK