CHAPTER 1

Challenges in Everyday Use of Mobile Visualizations

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As visualizations become more widely incorporated into mobile devices such as phones, smartwatches, or fitness bracelets, they become more ingrained in everyday life. The contexts in which they are used introduce a range of challenges caused by the small form factor, screen space, temporal limits of viewing, and increased integration of personal data. In this chapter, we illustrate challenges resulting from the everyday use of mobile visualizations in three categories: logistical challenges relating to situated use, privacy challenges involved with potential data disclosures, and ethical challenges surrounding increased access and decreased evidence. In spite of these challenges, introducing visualizations in everyday life can lead to positive experiences viewing and reflecting on data in their natural contexts. Using scenarios to depict use opportunities, we introduce a set of considerations for designers and researchers looking to develop mobile visualizations for everyday contexts.

1.1 INTRODUCTION

As will be discussed in Chapter **??**, the increasingly ubiquitous nature of mobile visualizations introduces a variety of contexts and circumstances which influence how people interact with the visualizations and derive value from them. While early visualization work envisioned controlled environments viewed by a relatively homogeneous group of experts, the move towards Casual Information Visualization [51] and Narrative Visualization [55] highlights the ongoing increase in access and circumstances. The evolution into Mobile Visualization even further increases access and circumstances, as illustrated by examples of mobile visualization shown in Chapter **??**. We would now expect people to encounter and interact with visualizations as they are living their lives.

The move towards increased use of visualization in everyday life caused by mobile visualization introduces significant benefits and opportunities. Mobile visualizations offer the ability to review and react to data in the circumstances people need to make informed decisions, such as learning about bus arrival times when waiting [35] or about nutrition when choosing what to eat [11]. They also increase access to visualizations, as mobile devices are the only resource that many adults have for accessing information online. People often interact with mobile visualizations in the presence of others, introducing opportunities for people to share knowledge they have gained about themselves or the world.

However, the integration of mobile visualization into everyday life also introduces significant challenges. Today, people view and interact with visualization environments that are often removed from the context from which they were created. Visualizations of personal data are often expected to be private, however, the contexts in which they are viewed undermine that expectation. For example, someone is commuting on a bus, and looking at personal data, while the person behind them might be shoulder surfing and following along. The devices and modalities people use to view these visualizations can limit people's ability to make sense of or interact with their data. Due to limited screen space, data may be only partially represented, aggregated, or specific aspects of the data might be highlighted. People also use mobile visualization with quick interactions, while on the go, or to pass time while waiting in queue (see Chapter **??** on details about glanceability of mobile visualizations). As a result, the assumptions we make about careful analysis or consideration of visualized data are unlikely to hold up for many people in many circumstances.

In this chapter, we unpack some of the everyday challenges people currently encounter or may encounter when interacting with mobile visualizations in their everyday lives. We discuss challenges under three categories: (1) *logistical challenges*, relating to certain interactions or observations becoming more challenging or impossible in mobile visualization; (2) *privacy challenges*, caused by the social circumstances where mobile visualizations are often viewed; and (3) *ethical challenges*, impacted by more frequent access to visualizations by more people at the mercy of what visualization designers create. For each category, we introduce scenarios to illustrate key challenges and discuss potential considerations those challenges illustrate for visualization practitioners and researchers.

Our chapter primarily focuses on current and near-term mobile visualizations to allow us to understand the challenges involved with integration into everyday life. Future mobile visualizations, such as those discussed in Chapter **??** could introduce further everyday challenges. We also focus on the challenges caused by viewing and interacting with visualizations, ignoring technical challenges around data leakage or theft caused by deeper entanglement of data, often personal data, with devices people are using in everyday life. Finally, we acknowledge that mobile visualizations introduce additional sociocultural and societal challenges, such as datafication [24] and using visualizations of data to reinforce societal health ideals [43].

1.2 EVERYDAY INTERACTION CHALLENGES OF MOBILE VISUALIZATIONS

Mobile visualization provides increased opportunity for viewing and interacting with visualizations in the context under which the data is collected or can be used to inform decisions. But the form factors that mobile visualizations are viewed on can lead to more frequent or unintended viewing of visualizations than in desktop environments, which can cause challenging or even stressful interactions.

1.2.1 From being Informed to Information Overload

Data is becoming increasingly collected digitally,[1] driven by the ubiquity of mobile devices and proliferation of smartwatches and fitness bracelets that allow people to track themselves constantly. The research literature often refers to this phenomenon as the Quantified Self [43] or personal informatics [42], with people reflecting on data collected about themselves for self-knowledge or self-understanding.

As displays proliferate beyond desktop computers, visualizations will become even more ubiquitous. We often think of visualizations in terms of opportunities for smartwatches, fitness bands, mobile phones, data jewelry, and augmented clothing, but also e-ink displays, billboards, drones, and robots are and will be used in the future to depict data in the form of visualizations. This increase in available information as well as the number of different channels and the often historical or contradictory information can help people to be more informed, but also lead to information overload.

[1] https://www.statista.com/chart/17723/the-data-created-last-year-is-equal-to/

Figure 1.1: An example of app showing different kinds of environmental information using different types of visualizations and different color scales. The visualization's complexity can lead to information overload for a person looking to answer a specific question, such as whether or not it is currently raining.

Scenarios

Unimportant weather information. Thomas is going to meet up with friends. He recently installed a new weather app so he can check if he needs to take an umbrella or not. He is about to leave the house and wants to quickly check his new app to find the weather forecast for the next couple of hours. When he opens his new app he is confronted with a complicated looking interface, depicting all kinds of environment related data, such as the current threat of pollen, the current UV index (UVI), an air quality index (AQI) representing air pollution, the temperature, current weather, the moon phase and wind speed (cf. Figure 1.1) all shown with different colorful visualizations. Although he knows where the forecast is located on the watch face and can quickly see that it will rain today, he is reminded that most of the information is irrelevant to him most of the time. He is frustrated that he cannot customize the interface to his needs, highlighting other information or more prominently displaying the forecast.

Hyper reality visualization. Decades from now, Sara is leaving the house to go grocery shopping after a busy day at work. Her augmented reality headset shows her world as a hyper reality[2] and she is exposed to advertisements, information about her surroundings, gamified performance scores, and suggestions on how to improve herself. She hops on the bus, eager to use her headset to help her formulate a shopping list as she travels. While in transit, her headset displays visualizations relevant to the buildings she's passing. As she looks out the bus window at a gas station, the headset shows a line graph highlighting how the price of gas has reached an all-time low. Glancing nextdoor at a phone store, Sara sees a bar chart advertising a 20% reduction in phone plan rates, personalized to her current phone plan. Distracted by

[2]http://hyper-reality.co/

this information and the use of visualizations to make persuasive arguments, Sara arrives at her bus stop having not written her shopping list.

Problem Description

Advances in personal sensing and capabilities of mobile devices have increased the amount of data people are able to collect about themselves for self-reflection. For example, the Android platform offers 13 different sensor types[3] that a mobile phone or smartwatch can use, such as accelerometer, temperature, gravity, gyroscope, light, acceleration, pressure, and proximity. People are also increasingly using these devices to manually journal their daily activities and experiences, such as what they eat and how they are feeling. Therefore, people can nowadays not only track where they are, but they can now track many different aspects of their lives from sleep duration and quality, to calorie and water intake, step count, distance walked, floors climbed, heart rate, electrocardiography, and much more. These high volumes of collected data can be visualized and shown to people for self improvement, for example, leading to healthier and more active lives.

Modern watch faces nowadays depict this collected personal information together with the time. For example, a person using an Apple Watch can choose between many watch faces[4] that can depict up to eight different data types at the same time. Although, people usually learn where which type of data is located and can quickly glance at the relevant information they are interested in, often such interfaces cannot be customized as described in the scenario above. For example, the way a data type is represented—often step count is depicted as a number with an icon—cannot be chosen. In some cases, interfaces do not allow people to choose which data types are presented at all. This lack of customization can lead to people being frustrated or ultimately stopping to use an interface.

In addition to the amount of data one device collect, the ubiquity of devices (e.g., billboards, data jewelry, ambient clothing, robots) visualizing data can lead to an increase of channels to receive information and thus cause distractions. Although such ubiquitous devices can help people to make informed decisions and live healthier lives, having many visualizations around oneself can distract people from their current task or make it difficult to determine what data to focus on.

Potential Considerations

Allowing customization. Most watches enable people to customize the layout of their watchfaces choosing which data types to represent and how prominently to present them. Other devices often enable similar customizations, such as allowing people to select modules with visualizations for the homescreens of their mobile phones. The inclusion or exclusion of visualization modules may be helpful to reduce distractions or allow people to better match their homescreens to their intended goals, such as by enlarging visualizations with the data they are primarily interested in.

[3]https://developer.android.com/guide/topics/sensors/sensors_overview
[4]https://support.apple.com/guide/watch/apde9218b440/watchos

However, relatively fewer devices and tools support customization of the construction of the visualizations themselves. Gouveia et al. [31] suggest that tools offer multiple or customizable encodings, to allow people to choose a visualization which represents their personality. As one example, Kim et al.'s [36] DataSelfie contributes techniques for allowing people to customize visual mappings of their self-tracked data either automatically or manually.

Visualizing sparingly and at-a-glance. It is worth considering whether the displayed content benefits from being a visualization or being visualized. Text, icons, or other less cognitively-demanding representations are often sufficient for showing many kinds of data. For example, many fitness bracelets show the collected data as numbers with icons to represent the data type, which is sufficient if a person wants to see how many steps they have taken today [15].

The usage context of mobile visualizations is often different from traditional visualization on desktops or other large displays. Mobile visualizations are viewed while in motion, and the devices they are visualized on are mostly used to satisfy quick information needs. Visualizations either are not needed or can be designed in a way that makes them easy to comprehend even when focusing only for a few seconds at it. For a detailed discussion on glanceable mobile visualizations, we refer to Chapter **??**.

1.2.2 Fewer Opportunities for Interaction

We mostly use mobile devices for passive consumption of information and media, and value the possibility of interacting with data while on the go without the need for external input devices. It can be helpful to interact with a map visualization, a stock chart, or personal health data while on the go with a few touch gestures. However, not having keyboard or precise mouse input available in mobile settings also significantly reduces the possible interactions. While the limited output capability of mobile devices (i.e., their reduced screen estate) seems immediately obvious in the context of visualization, its influence is perhaps less clear for interaction and its implications. Although the resolution and pixel density of mobile devices and smartwatches might be high, the smaller physical dimensions introduce dilemmas for designers of interactive visualizations. Being able to show less information than on desktop computers requires adapting well-known interaction techniques such as distributing the information onto multiple coordinated views [54], zoomable interfaces, overview and detail approaches, and focus+context techniques [32, 14]. However, all these solutions require extensive interaction like flipping through pages, scrolling, zooming and panning, scaling lenses, filtering, brushing data etc., which in turn are harder to accomplish on mobile devices due to the lack of precise pointing as well as limited input space and lack of haptic feedback, especially for multitouch input.

Of course, not all mobile visualizations require the same level of interaction. The scenarios described in this chapter range in scope from passive consumption of glanceable visualizations (e.g., detailed weather information) to simple and shorter interaction with less complex information (e.g., personal fitness data) up to more direct and involved interaction with more complicated data (e.g., comparison of several stock quotes for making investment decisions). With increasing interaction complexity, mobile devices are less suited for some tasks, especially under time pressure and in in-the-wild situations, as the following scenarios further exemplify.

Scenarios

Wrong choice caused by inaccurate touch. Alicia is a government researcher who analyzes patterns of disease spread over time. Sitting in the bus on her way back home, she received an urgent email from a news reporter asking whether this year's seasonal flu is spreading more rapidly than last year's. For that, she opens a chart of this year's cases and zooms to the the current time span using two fingers. This is necessary, because the display is too small to show her the entire disease spread at once. While she is opening last year's chart in a different view below for comparison, she has to leave the bus, but wants to quickly finish her action. Due to the shaking of the mobile phone while getting off the bus and the inaccuracy in touch interaction, she accidentally chooses the wrong time span in the zoom view provided by the app. Because the curves look similar to her, she does not realize that she is comparing disease spread at different levels of time granularity; this year's chart shows days while last year's shows weeks. Still on her walk home she decides to call the reporter and state there is no cause for concern.

Inconvenient to impossible interaction. Fred is in his mid-fifties and loves to go running regularly to stay healthy and reduce weight. He uses a running app on his smartwatch, which also provides a desktop version he uses on his computer at home. To track his progress over time, he loves to use the time-oriented charts on his desktop app which require mouse interactions to understand how the length, duration, heart rate, pulse etc. have changed over time. While again going running on a sunny day, he gets ambitious and tries to set a new record on his usual track. He, therefore, looks at his watch to request data on previous runs, but struggles with the bright sunlight and reflections on the watch surface. In his attempt to request the speed distribution along the track for his best attempt so far, he misses touching the tiny data mark he intended to click on and gets the wrong details shown. When he tries to overcome the problem by using the digital crown, his sweaty fingers prevent an easy selection of the correct data set. Having to interrupt his run and eventually missing his ambitious daily goal makes him angry.

Too cool to be controlled reliably. Mercedes is a young fashion aficionado and bought herself the latest interactive wearable: a touch-enabled jacket based on smart e-textiles. The cloth includes interesting woven-in displays which allow her to communicate either her mood or any personal information to others by means of some simple multi-color segment displays. She can control this information not only using her connected smartphone, but also via touch- and pressure-sensitive areas on the sleeve and cuff. Before going out in the evening, she has agreed with her close friends on a visual code to represent the number of compliments and/or drinks they each receive in the club. Using her smartphone app, she loads the initial design to the segment displays on her jacket and is now able to increase or decrease numbers by pressing the respective textile touch-buttons on her sleeve. Later in the evening, she forgets to switch to the passive mode which should prevent involuntary input. While dancing, she touches other dancers with her sleeves, who accidentally change her e-textile displays several times. She does not notice, but wonders about the comments of a group of people making fun of her and the rapidly changing light ("like Christmas tree lighting") and later on about the laughter of her friends who comment on her rather unrealistic numbers accidentally shown on her jacket. Mercedes feels slightly embarrassed on what she thought would be a cool dernier cri accessory.

Problem Description

These scenarios exemplify how input challenges on mobile devices and wearables can impact visualization interactivity. The output space is often insufficient to show and compare data for longer time periods at once. Further details of visualized data sets, like a previous run, may need to be explicitly requested on mobile devices because they might not fit on the screen alongside other visualizations. Even the rather simple interactions mentioned in the examples highlight some of the interaction limits of mobile visualizations. There exists a trade-off on mobile devices between the advice to show less data at once (cf. Section 1.2.1) and the additional interaction required by this reduction. This is even amplified if people desire supporting more advanced exploration, comparison, and filtering tasks on mobile devices.

Many visualization tasks require interaction such as a pinch to zoom in on an information space, dragging to move a visualization lens, or just a simple tap for requesting details for a data mark. The opportunities for interaction are, however, limited on mobile devices (cf. Chapter **??**). Issues like the fat finger problem on small touchscreens [4, 57], limited input precision, missing hover state, or missing implicit mode switches (like pressing a mouse button and dragging on desktop computers) severely reduce the interaction repertoire well-known from desktop solutions. Therefore, it is important to decouple interaction steps and apply them one after the other.

On the one hand, mobile devices are the only way of accessing data for many people worldwide with limited or no access to different computing devices. With this in mind, the example of numerous complex interactive dashboards showing important information about the COVID-19 pandemic, most of which are almost challenging to be seen or interacted with on smaller devices, is a cautionary tale. Therefore, interfaces should be as simple as possible for everyday people, and visualization designers should neither assume sophisticated devices nor specialized knowledge and skills of their users. On the other hand, people also have expectations from using high-bandwidth desktop applications, which they might want to transfer to the mobile world. These constraints require careful balance.

Looking into the future of mobile visualization head-mounted displays or interactive wearables (e.g., clothing-based displays described in [18]) have the great advantage of overcoming the boundaries of the flat and stiff screens of today's mobile devices. They also offer ability to integrate visualizations naturally into the environment or relate them to our bodies. Such novel devices lose the comfort and familiarity of established input methods, and interaction can be severely constrained. However, more natural means of (perhaps casually) interacting with mobile data visualizations open up new opportunities. Hand gestures in mid-air or gentle touches and movements on personal clothes like in the Mercedes' scenario can be subtle means of interacting with visualizations. However, more advanced or complex interactions may not be not well-supported with such techniques, if they are possible at all. In addition, the involuntary activation like in Mercedes' case or the possible embarrassment of performing mid-air gestures in certain environments are novel problems designers need to be aware of, which might prevent social acceptance and widespread use.

People typically have limited interaction time with mobile devices, which is another important problem pertaining to all mobile devices and scenarios. Like in the first two scenarios, people often do not have the time to leverage more complex interactions with visualizations while on the go, and the display surface for interaction might be moving or shaking. Touch interaction as the dominant way of using mobile devices, while per se already less accurate, becomes even more problematic on small *moving* surfaces. For example, selecting items in a scatterplot might cause severe problems on a smartphone and potentially lead to subsequent errors or wrong decisions. This is less noteworthy for tablets and larger devices.

Design Considerations

The aforementioned problems related to interaction with mobile visualizations are being examined not only in research, but also by mobile device manufacturers, because companies are interested in selling their mobile units along with well-designed and usable apps. However, while interface guidelines like Apple's Human Interface Guidelines for iOS and WatchOS [5] address mobile interface design in detail, there exist only few recommendations for mobile visualizations—beyond simple charts—yet. In the following, some thoughts and recommendations are outlined with regard to limited opportunities for interacting with mobile visualizations.

Considering adapting existing visualization solutions. When transforming desktop visualization solutions to mobile devices, it should be considered how to adapt both the visualization views *and* the interaction, as well as how the two interplay. This often means reducing complexity and capabilities that cannot be achieved on smaller mobile devices such as brushing and linking in multiple coordinated views. For other techniques like zoomable interfaces or focus+context techniques, mobile variants have been developed [9, 10, 50]. Because the mobile phone is the primary means of information access for many people, carefully adapting visualizations to mobile devices also with regard to interaction becomes crucial.

Reducing interaction complexity. Connected to the previous recommendation, mobile visualizations should ideally rely on interactions that people already use on mobile devices for other applications. Avoiding complex gestures, bimanual interaction, asymmetric interaction techniques, or incomprehensible mode switches can help remedy this. High dexterity should not be required and may not be possible in on-the-go mobile contexts, in which it is hard to hold the device in a stable manner. When designing for lay people, a pitfall could be designing for the lowest common denominator. Instead, providing alternative techniques or introducing advanced techniques for experts could

[5] https://developer.apple.com/design/human-interface-guidelines/

be a viable solution like known from traditional computers, for which one size also does not fit all.

Considering novel interaction principles. Another solution is to provide novel interaction capabilities which go beyond what has been known from the desktop computer or is currently used on larger mobile devices like tablets. These might include pure software solutions. Examples for this are popular text entry methods like SwiftKey, based on the ShapeWriter and SHARK approaches [61], or the pointing technique Shift [60]—in which a callout shows a copy of the mobile screen area occluded by the finger and places it in a non-occluded location. These are just inspiring examples for approaches to overcome the fat finger problem, for example, by means of gesture-based shortcuts for interacting with visualizations.

Novel interaction techniques could also be designed, which might employ different sensing technology beyond multitouch. Examples for the latter are back-of-device interaction approaches (e.g., Vogel et al. [60]) or physical input sensors like digital crowns or rotatable bezels on current smartwatches. While rarely being used in current mobile visualizations, more physical approaches like squeezing or bending a mobile phone [30] could provide interesting means of data exploration. Multimodal approaches can also become interesting solutions, like physical smartwatch interaction combined with additional touch-enabled wristbands [39], the combination of touch and spatial movements [50, 58] or the usage of speech in combination with touch [38, 59]. However, though promising, such solutions might contradict with the previous design consideration.

Towards mobile visualization guidelines. The already-existing guidelines of mobile device manufacturers on how to design mobile apps could be further extended to include recommendations on mobile visualization and interaction. Guidelines on chart design could, for example, be incorporated into Apple's HealthKit Human Interface Guidelines.[6] While interaction standards for working with mobile visualizations will be difficult to establish (if at all), such guidelines might help ensuring consistency across visualizations. Perceptual studies on mobile visualizations (e.g., Blascheck et al. [6]) can help lay the foundations for and expand these design considerations.

1.3 EVERYDAY PRIVACY CHALLENGES OF MOBILE VISUALIZATIONS

Being able to access visualizations on more displays, from public displays to phones or watches, naturally has implications when personal data is being visualized. One clear upside is that visualizations can be shared for sensemaking or reporting of information. However, visualizations being more available naturally open up access opportunities for people other than the intended party or parties, whether accidental or intentional.

1.3.1 Violating Privacy Expectations

When people are using mobile devices to visualize and review data about themselves, such as data sensed about them or from personal accounts, they might assume that

[6]https://developer.apple.com/design/human-interface-guidelines/carekit/overview/views/

they are the only ones who are able to view the data. However, the personal and social contexts under which mobile visualizations are used can challenge this assumption.

Scenarios

Shoulder surfing. Jackson is an executive at a pharmaceutical company, and he recently started using a financial planning app to manage his children's inheritances. While Jackson commutes home by train after a long and tiring day at work, he receives a notification about some changes his financial planner made, which prompts him to check his app. The graph breaking down how his earnings are getting divided draws the attention of the passenger next to him, who strikes up a conversation and asks for career advice. Although there is no further fallout, Jackson wonders whether future passerbys might see him as a potential target for identity theft.

Unwanted advertisement. Natalie and her partner are trying to have a child, and have been using an app to monitor and review her basal body temperature and potential conception windows. At lunch, she goes out for a hilly run with a coworker at her small company. After the run, Natalie and her coworker use their smartwatches to compare how the elevation impacted each of their heart rates. Natalie scrolls slightly too far, revealing a graph of her temperature readings to her coworker and prompting an awkward discussion about the impact of a potential pregnancy on the long-term goals of the company.

Problem Description

The varied circumstances in which data is viewed can lead to many positive sharing circumstances, but also unintentional disclosures. Compared to desktop environments, the portability and convenience of mobile visualizations make people more likely look at visualizations in the presence of others. As a plus, this can promote shared reviewing and reflecting on visualized information. For example, prior work has highlighted opportunities for shared sensemaking around visualized patient data in hospitals and other clinical settings [13, 44, 45]. Although there remain many interaction and sociotechnical challenges (e.g., collaborative browsing, finding time to look at data during a clinical consultation), mobile visualization increases opportunities for patients to collaboratively review data with their healthcare providers.

As the scenarios illustrate, the ease of bringing up visualizations in daily life can also lead to less positive disclosures. Peeking at a person's screen on a bus or a train, whether intentional or not, is prevalent in today's society. This experience is common in more private spaces as well, such as seeing what a colleague is doing on their phone during a meeting. We often hold interpretability and glanceability as ideals in the design of visualizations, but these principles can also enable others around us to easily perceive and interpret the data.

Prior work has shown that people express concern about how mobile visualizations can accidentally disclose their personal data in social settings. For example, people frequently use mobile apps to keep track of and visualize where they are in their menstrual cycle (cf. Figure 1.2 left). These mobile apps often have obvious names (e.g., Period Tracker) or use gendered color schemes (e.g., pink, cf. Figure 1.2 right),

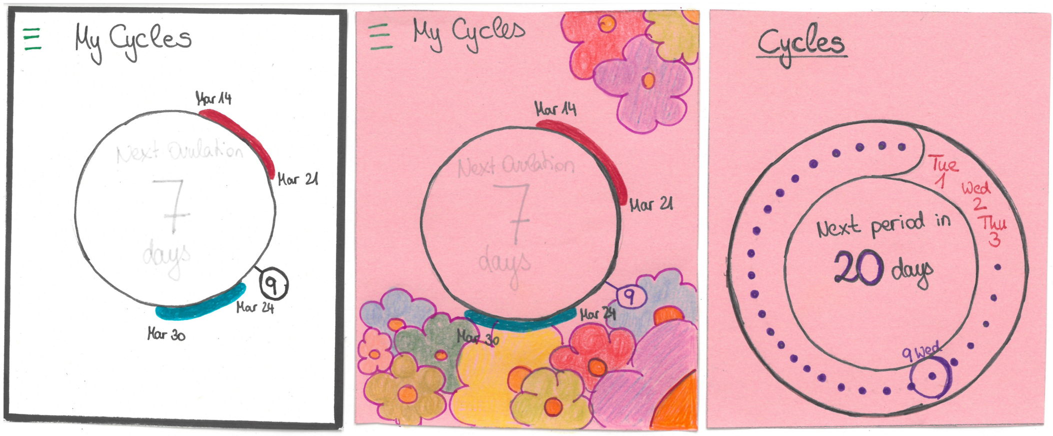

Figure 1.2: Left/Middle: Some apps include the ability to adjust the app's theme to use more neutral colors. However, rarely is the visualization itself adjustable. Right: Gendered color draws attention to menstrual cycle information.

Figure 1.3: Gardy [31] represented progress towards physical activity goals as growth in a garden. *Republished with permission of the ACM, from [31]; permission conveyed through Copyright Clearance Center, Inc..*

drawing attention to data that people might view as sensitive. People describe taking precautionary measures to avoid disclosure, such as by changing the app's default color scheme or avoiding use of the app in public spaces [23].

In another example, Gouveia et al. [31] explored design opportunities for representing physical activity on the home screen of a smartwatch. One of their design approaches, Gardy (cf. Figure 1.3), implemented an abstract representation of physical activity as flowers growing in a garden. In their field deployment of the interface, some participants appreciated how the abstract display instigated rewarding conversations with children and their parents who happened to see their watch. However, other participants felt the display was too vibrant, fearing that it would invite unwanted attention or would result in others judging their interests and goals. They instead chose to hide the display in public. Overall, Gardy was the least preferred and least motivating of the different interfaces considered in their study.

Related literature often exposes these risks in explicit data sharing scenarios, such as disclosing physical activity or location. These overt disclosures of information can lead to exposing more information than a person is comfortable sharing. For example, Epstein et al. [22] describe scenarios for what sharing fine-grained physical activity data (e.g., minute- or hour-level) could expose in an effort to examine how aggregating, truncating, or manipulating the data could help avoid these risks. They describe a scenario in which an employee decides to go for a run in the middle of the workday, but worries that sharing his run on a site on which he is friends with his co-workers might reflect poorly on his work performance. These same challenges persist in-person as well when others nearby have the opportunity to look at a person's data.

Design Considerations

As the field continues to explore ideas around glanceable displays, this risk of unexpected or unwanted viewers increases. Unfortunately, potential strategies for addressing these unwanted views are often directly in tension with the benefits people derive from the visualizations being ubiquitous.

Making visualizations abstract. Abstract visualizations of data, such as in Gardy or in UbiFit Garden [16], are typically used to provide metaphors to motivate further behavioral change. However, they have the additional advantage of not being easily read or interpreted for people not privy to the encoding scheme, such as that the presence of a butterfly in the abstract display represents goal achievement [15].

However, as Gouveia et al. [31] point out, the public nature of these abstract visualizations need to align with people's self-presentation desires. As discussed in Section 1.2.1, customization can enable people to choose how bold they want to display what they are visualizing, responding to their personal perspectives on privacy and the sensitivity of the data being visualized.

Ensuring viewing intentionality. To preserve privacy, a system can aim to better understand who is looking at the visualization and assess whether their access to it is reasonable or expected. One strategy would be to ensure that a person is comfortable with their current surroundings prior to displaying a visualization. For example, people could configure visualizations of information they find sensitive behind confirmation screens or passwords, rather than prominently displaying when an app is first opened or a device is first glanced at.

However, this strategy comes into tension with principles around supporting glanceability and passive pick-up of information. For example, much of the value people find in seeing their physical activity data visualized on a phone or watch involves being able to quickly check in on how they are doing relative to their goals. When that information is displayed on a phone or watch home screen, it promotes quick check-ins even when the device is being viewed for other reasons (e.g., seeing step activity while responding to a notification). However, it also provides frequent opportunities for passersby to see and interpret that data.

Measures taken to protect privacy in mobile visualizations have the potential to challenge other aspects of usability or utility. When deciding what privacy measures, if any, to put into place, designers of mobile visualizations should consider the sensitivity of the data displayed and the circumstances under which it will often be viewed.

1.4 EVERYDAY ETHICAL CHALLENGES OF MOBILE VISUALIZATIONS

The visualization research community is increasingly aware of changing issues with regards to people, data, and visualization. For example, Dörk et al. [20] discussed ethics in the context of data representation for *Critical Information Visualization*. Kong et al. [40] have pointed out how even the words we choose to entitle a visualization with may change its interpretation. Correll [17] broadened this discussion to include more ethical dimensions to consider, including whose data is being incorporated into data sources and the rhetorical impact of visualizations.

For many people, mobile devices are the primary or only means of accessing online content. A Pew study in the United States shows that smartphone ownership exceeds desktop, laptop, and tablet ownership, particularly among people with lower levels of education, incomes, and those who do not have internet connections at home[7]. In studying visualization attitudes by primarily low-income individuals living in rural Pennsylvania, Peck et al. [49] argue that visualization has the opportunity to make data more accessible and democratic. However, the individuals most at risk may not have access to displays any larger than mobile devices, and therefore not facilitate deep exploration of data.

1.4.1 Low visualization literacy

Visualization literacy has been a longstanding focus of study and concern in the visualization community [7, 8]. We illustrate a few potential challenges which can arise from a lack of visualization literacy in mobile contexts.

Scenarios

Misleading climate impact. Tonya is browsing Facebook, and quickly scrolls past an ad with the caption “CLIMATE CHANGE IS A HOAX.” The ad shows a relatively flat line of average yearly temperature from 1900 to present in her native city, citing data from a National Weather Service report. Puzzled, Tonya scrolls back up to the ad to look at it further. Remembering what she learned about visualization from high school, she goes to check the chart axes, noticing that there is no label on the Y-axis. She suspects if you were to calculate the bounds, they would be from -1000°F to 1000°F. She reports the ad and returns to looking at her friend’s pets.

Interpretable metaphors. Oliver was recently diagnosed with Type 1 Diabetes, and his doctor suggested using a mobile app to help him monitor his glucose level. The app includes a few different line, area, and bar charts for monitoring glucose. While the app looks sophisticated, he isn’t able to make sense of the graphs, and instead guesses when he should be taking insulin. After explaining this confusion in his next visit, Oliver’s doctor recommends a different app which uses a hot-air balloon hovering

[7] https://www.pewresearch.org/internet/fact-sheet/mobile/

at different levels (too high, too low, just right) to indicate glucose levels and whether to take more insulin. Oliver finds the balloon much easier to understand than the graph, and uses the new app to better manage his diabetes.

Problem Description

There are numerous examples of articles and advertisements leveraging misleading visualization strategies just like what Tonya experienced, from promoting the competitiveness of political campaigns to raise interest and donations[8] to aiming to suggest a stronger impact of governmental policies than reality.[9] In these cases, the designer often aims to use the visualization to convey objectivity in order to persuade people towards their cause [17].

While Tonya is careful to investigate and question the data being visualized and the sources of information, the mobile nature of the visualization makes the kind of misleading content present in the scenario more problematic. Although Tonya looked back to consider and reflect on the visualization, people's tendency towards quick interactions with mobile visualizations suggests that many others would not, though they may still interpret the overall message. The limited screen space also potentially enables the visualization designer to take shortcuts they otherwise would not have, choosing not to label axes or cite data sources to reduce data-ink and make the trend being visualized more immediately comprehensible.

While a mobile visualization might enable someone to monitor and address chronic conditions as they go about their daily life, Oliver's example highlights that for many, the graphs are not interpretable and may lead people to discount the advice they give. Research literature have suggested that visual metaphors can be used to educate people about graph interpretability alongside disseminating health information [19, 52].

Tonya's and Oliver's examples sit in a context where developing curricula around visualization comprehension is an ongoing goal and area for improvement. Challenges around visualization literacy are more societal than related to the design of visualizations, and thus have an impact on people's ability to interpret traditional desktop visualizations as well as mobile ones. However, the increased access to visualizations via mobile devices, particularly among people who may not have had as many educational opportunities, makes more people susceptible to the rhetoric surrounding the mobile visualization rather than critical examination of the data being shown.

Design Considerations

Creating Visualizations Responsibly. Ultimately, the decision around what to visualize and how relies on creators being benevolent and advocating for truth. Correll argues that visualization designers have a moral obligation to challenge unethical uses of data visualization [17]. This obligation is particularly important in mobile contexts, where

[8] https://www.washingtonpost.com/graphics/politics/2016-election/trump-charts/
[9] https://www.independent.co.uk/news/health/coronavirus-charts-trump-axios-interview-cases-deaths-us-tests-data-a9652631.html

quick interactions lead people to be more reliant on the gestalt of a visualization or rhetoric surrounding it, and when viewed by people who may not be predisposed to put the visualization under as much scrutiny. The constraints of mobile visualization put people more at the mercy of the designer's assumptions around data literacy and their desires for what information they choose to convey on a small screen with limited interaction potential.

Improving Education. At a societal level, there continues to be a need to study and improve how we teach data visualization concepts to enable more people to critically consider the data being visualized and their sources. Mobile data visualization only increases the need for further work on improving visualization education and literacy.

Pertaining to the design of mobile visualizations, designers can consider whether there are ways to incorporate teaching visualization principles into the design of mobile tools. Past work has highlighted how rhetorical descriptions can be made based on the data to aid people in interpreting it [5, 21]. Such descriptions could further connect back to the mobile visualization to teach people how to interpret similar visualizations in the future. Additionally, mobile platforms where visualizations are often shared could flag misleading or untrustworthy visualizations similar to other misinformation content.

1.4.2 Limited Resources Lead to Missing Context

Although desktop visualizations might enable interactive exploration or questioning the data being presented, quick interactions and limited screen real estate also introduce challenges surrounding interpreting data when missing context. The limited resources of mobile devices (e.g., display space, interaction capabilities, processing power) and their use on the go with typically limited duration of interaction [33] mean that people are more at the mercy of the visualization designer to avoid misleading or misinforming them about the data that is being visualized. Due to the limited display space, it is common practice to only show certain aspects of the data. However, it is often unclear to a person how the choice of what data to show has been made, and people tend to lack options to control or configure which data attributes are visualized and how.

Scenarios

Incomplete Jobs Report. Horace is reading a news article on his phone with the latest unemployment numbers in his country. The article presents a graph showing that unemployment has decreased by about 1% each month over the past 6 months, suggesting a strong economy. Because the graph is relatively small, it does not show the impact of a global crisis which occurred 8 months earlier, resulting in an unemployment spike 3x the improvement of the last 6 months. While Horace is well aware of the global crisis, the graph and article's focus on improvement leads him to think that the economy is already back on track.

Case Numbers. Estelle is a ranch owner in a geographically-small, low-population, rural county in Texas in the United States. In the midst of the global COVID-19 pandemic, Estelle uses her phone to look at an interactive national map of case counts colored on a gradient, zooming in on Texas. She cannot locate her county due to its size, and it does not appear near the top on the nearby table highlighting what counties have the most cases, like Dallas County (Dallas) and Harris County (Houston). She instead finds a few larger, neighboring counties on the map and table, noting that they are colored "green" and have only a few daily cases. She decides to proceed to hold a 300-person wedding for a local couple on her ranch, only later learning that cases in her county were actually quite high at the time. However, this fact was not visible on the map due to the size of her county, nor the table due to the focus on raw case counts versus per-capita.

Problem Description

Similar to the previous scenarios, Horace and Estelle's experiences highlight that the limited space for displaying and interacting with visualizations on mobile devices put people more at the mercy of the visualization designer's choices, whether those choices are intentional or not. For Horace, the missing contextual information leads him to make inaccurate assumptions about the state of the economy, while Estelle's case points to a reasonable, but inaccurate assumptions in the absence of being able to find her county and a less desirable method of aggregating data.

In desktop environments, a well-intentioned visualization designer might implement a jobs report as interactive to enable a person to better understand the full context. For many desktop visualization tasks, a person may also spend more time researching the topic, such as looking up alternate data sources. But the barriers to doing further research on mobile devices, and challenges creating effective interactions (see section 1.2.2), again leave people reliant on the visualization designer. Estelle's case highlights that even a well-intentioned visualization designer can make choices which mislead people about risks when limited by the mobile context.

Visualizations are often simplified for mobile consumption and, as a result, have to aggregate or leave out certain parts of the data (see also discussions on responsive visualization in **??**). An important issue with incomplete information—and particularly visualizations that leave out information about uncertainty—is that these may lead to more misinterpretations and may cast doubt on the credibility of the data and its sources. For instance, during the COVID-19 pandemic, there were many discussions on social media about the inherent uncertainty in certain measures such as the number of new cases compared to the number of deaths. When mobile visualizations on such a high-profile and heavily debated topic lack nuances on how new cases are influenced by changing testing strategies or how the number of deaths may lag behind new case numbers, it could lead to mistrust in the institutions that release the data.

With the rise of misinformation and conspiracy theories on social media, people may be compelled to believe that these visualizations were deliberately designed to hide this uncertainty. When viewing visualizations on a desktop, it is more possible to provide additional details such as links to additional sources, elaborate details on the data collection methodology, further explanations and additional aspects of the data in the visualization. On a desktop, a person may be more likely to open multiple browser tabs and follow hyperlinks to find additional background information, or

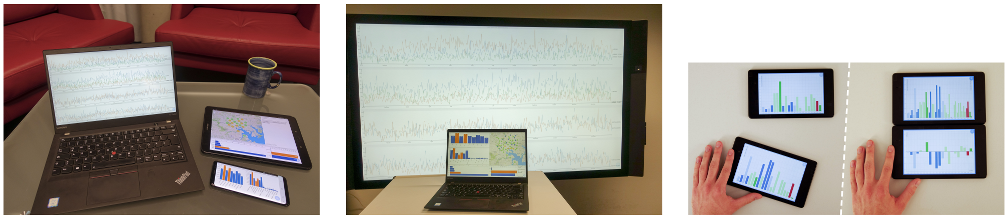

Figure 1.4: Left/Middle: Vistribute by Horak et al. [34]. Right: Vistiles by Langner et al. [41]. All images show cross-device interaction between visualizations. *Figures courtesy of Tom Horak, used with permission.*

even compare visualizations side by side. With the majority of people consuming their news—and the accompanying data visualizations—on mobile devices, simplified mobile visualizations combined with the increasing spread of misinformation could lead to mistrust in scientific institutions and governments.

Design Considerations

Both scenarios again highlight the importance of responsible visualization creation and improving education around interpreting visualizations. They additionally highlight a need to imagine the audience and emphasize uncertainty when appropriate.

Imagining the Audience. Getting feedback from people who might potentially use a visualization is central to visualization design principles. Estelle's case points out a need to ensure that visualizations are not only speaking to the largest audiences, but can also answer the questions of smaller or less-privileged groups. Estelle's example points out that mobile visualizations can strengthen the correlation between size and importance often made in visualizations, particularly when they aim to reflect real-world characteristics like maps. Ensuring that potential use cases like Estelle's are considered in the design of visualizations can help increase the utility for a broader group of people, and serve as a model for creating more equitable visualizations.

Supporting exploration and interaction. As previously discussed, limited real-estate and interaction techniques make supporting exploration of data a challenge. But when possible, it should be considered whether designs can support people in exploring data beyond what the visualization designer chose to present, such as through a details on demand paradigm[56]. While doing so can be difficult from an interaction design perspective, it can help alleviate limitations of missing context. Cross-device interactions can assist by extending the screen space on which a visualization can be interacted with, and thus supporting further context. Figure 1.4) demonstrates some cross-device interaction examples from past literature.

Emphasizing Uncertainty. Given the increased reliance on choices made by designers in mobile visualization contexts, it is worth considering whether a mobile visualization can present when measures are uncertain, and how they are uncertain. Kay et al.'s approach [35] to displaying uncertainty around traffic prediction could serve as one model, using potential outcomes to help people understand a potential data distribution.

1.4.3 Persuasive Mobile Visualizations can Foster Behavior Change, but not Always for the Better

With persuasive technologies, it is possible to influence people's behavior and to change their attitude. Increasingly, computer technologies are being used to support this [25, 26, 47]. As described as far back as 2007 [27], mobile devices have become a powerful channel for digital persuasion. Only in recent years have researchers started to investigate, how visualization can contribute to influencing people or in making a message more persuasive. The power of persuasive visualization [48] can be particularly unleashed on mobile devices, which people have on them almost every day, in almost any environment.

Like with any persuasive technology, persuasive visualizations can function as a tool (e.g., supporting peoples' goals), medium (e.g., creating persuasive experiences), or social actor (e.g., creating social relationships) [25]. Many modern health or fitness apps, for example, have the functional role of a *tool*, because they support the people's ability to follow a goal they want to achieve. People might want to walk 10,000 steps, get 2 hours of REM sleep, get 30 minutes of activity, drink at least 3 liters of water, etc. to live a better and healthier life. Visualizations can also work as a *medium* if they facilitate data-driven *persuasive storytelling* [53]. If they, for example, include characters (animals, cartoon figures, avatars), they might even take over the role of a *social actor* and companion.

Therefore, the spectrum ranges from rather ambient or casual information visualizations [51] triggering or nudging people to sophisticated analysis tools monitoring personal behavior. Regarding the scope of change, there is a range from personal behavior change to societal impact. The following examples illustrate this bandwidth.

Scenarios

Cheating to reach a goal. Paul is sitting in the train on his way home from work. For him, the visualization of the daily steps on his fitness bracelet is an important motivation to stay in motion and healthy. This time, the bracelet shows him that he is still far from reaching his daily step goal because he did not have time to walk enough during the day (cf. Figure 1.5 left). However, if he fails to achieve his goal again, his company will not give him the monthly reward of 50 € extra pay, which he desperately needs to pay for his rent. Therefore, he starts to beat his fist wearing the fitness bracelet against his chest to simulate walking. When he arrives at home he receives a notification from his fitness bracelet that congratulates him of having walked 10,000 steps today even though he has been sitting all day.

The impact of food choices. Katy is buying groceries for the weekend. When she has sufficient time and energy for shopping and cooking, she sometimes appreciates the mobile traffic light visualization of the nutritional value of any food in the store, which helps her making the right purchase decisions. Today, however, she knows she will not have time to cook a proper meal due to her taking care of her mother who has dementia. She walks up to the frozen food section and picks a frozen pizza and lasagna that she can just quickly warm up in the oven. As always she pays with her online cash system, which immediately depicts information about the types of foods

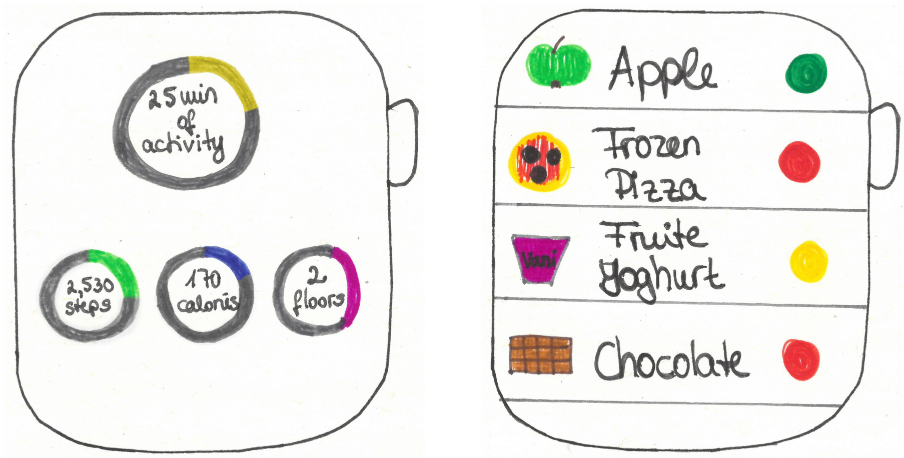

Figure 1.5: Visualizations of activity or of nutrition can be persuasive, but also create feelings of guilt or judgment. Left: showing progress towards activity goals on a smartwatch. Right: highlighting the healthiness of food with "stoplight" indicators.

she has bought (cf. Figure 1.5 right). She notices from the red food traffic light next to each item that she has only bought foods that have a high calorie count and she feels bad that she again is eating something unhealthy. Moreover, she is afraid of receiving a message from her insurance company that she needs to start eating more vegetables and healthy food to avoid an increase in her insurance fee, as she has heard happened to others already.

Visualization for good. The Adam family has three kids, and together they try to live an environmentally-friendly and climate-protecting life. When they received their electricity bill from last year, they were astonished to see in a static comparison chart that their energy consumption was even lower than that of an average four-person family. They installed an energy tracking app, eager to reduce their consumption even further and to make a comparison to the families in their neighbourhood. Besides tracking energy consumption for all means of transport the app uses GPS to surface the Adam's family energy consumption relative to those in their neighbourhood. They discover that they are only doing slightly better compared to families around them, and decide to improve on that. They install another app on their ethically produced and fair-traded mobile phone, allowing all family members to see the production methods and supply chains of products they want to buy. While going shopping for clothes, they can easily trace the origin of the product, its transport paths, and the estimated energy footprint associated with it.

Problem Description

There are many benefits to setting goals for oneself and persuasive mobile visualizations assisting in those goals, including following a healthier lifestyle, improving work performance and outcomes, or even contributing to solve societal problems. However, the first example also illustrates that reaching personal goals can sometimes become problematic and lead to personal pressure or even immoral personal decisions. Often visualizations such as the ones shown in Figure 1.5 left depict how far off a person is from reaching a goal. For example, the more color a radial chart contains, the closer one is to reaching a set goal.

If a person like Paul notices that all goals are still far off (their circles are mostly gray, cf. Figure 1.5 left), they might take immediate action, which can be a good motivation and help them lead healthier lives. However, it can also lead to people electing to reach their measured goals through means which do not support the overall, high-level goal. For simulating walking, there are even gadgets like phone cradles[10] to help people reach a specified step count, which can be used to get discounts in a personal health insurance or premium services as a reward. With health insurance companies potentially demanding similar information or goal-setting from their clients in the future, what is currently a private goal and moral dilemma can have more far reaching consequences.

The second example also shows a personal dilemma when buying (un)healthy food. When a visualization depicts such health information during shopping like with Katy's example, people might start to feel stressed over what they are eating. While it is beneficial and effective to classify food into easy to distinguish categories such as green (healthy), yellow (neutral), red (unhealthy) (cf. Figure 1.5 right), people suddenly have to make moral decisions about their lives and perhaps feel guilty about their choices. Again, these are private matters at first, but are subject to abuse by insurance companies, employers, fitness studios etc.

Less far reaching, the fact that other people might simply observe visualizations meant to be rather personal can have an impact. On the negative side, people might find it embarrassing to take some visibly unhealthy food from the shelf or that bypassers observe the visual feedback provided on a personal mobile phone indicating that they have not achieved their goal. On the positive side, if several people have access to a mobile visualization, this might trigger a positive behavior change. As an example, the GenderEQ app [11] provides a simple line graph swinging in the male or female direction over time to indicate speech distribution during a meeting and allowing a team to reflect on whether some members are talking more or less than others. Therefore, raising awareness can be an important goal of mobile visualizations.

The third example highlights that mobile visualizations have the great opportunity to make people aware of more than the nutritional value of the food they buy. Individual behavior changes in choosing personal transportation or consuming energy can eventually influence larger problem contexts on a societal or even global scale. For example, the UbiGreen transportation display prototype is an application that semi-automatically senses and reveals information about transportation behavior [29]. People partly considered it to be game-like, engaged with it and saw a great potential for behavior change, but also highlighted the potential for cheating. For a comprehensive overview of persuasive technology for inducing sustainable mobility behaviors, see the state of the art report by Anagnostopoulou et al. [3].

[10] https://twitter.com/mbrennanchina/status/1128201958962032641?lang=en

[11] https://www.fastcompany.com/3068794/this-app-uses-ai-to-track-mansplaining-during-your-meetings

It is both an important opportunity and challenge to design mobile visualizations so that they can help foster personal behavior change and even mitigate global problems like CO_2 emissions and climate change. In the long run, visualizations might even contribute to let what started as personal behavior change potentially result in societal impact. On the downside, people could become socially excluded if they did not use such tools or ignore what is suggested, or governments could abuse such visualizations to influence people in their interest.

Design considerations

Many techniques for developing persuasive visualizations have been proposed in research literature, often including some type of visualization or at least visual display [25, 27]. For a deeper analysis, guidelines for identifying and classifying persuasive elements of interfaces [46] may prove helpful. While not directly targeted at visualizations, criteria like credibility, privacy, personalization, attractiveness, solicitation, priming, commitment, and ascendency might help in developing own persuasive mobile visualizations.

Prior literature has surveyed persuasive techniques in particular application domains, like sustainable mobility behavior [3] or gamified systems for energy and water sustainability [1], which also discuss incentive mechanisms for inducing behavior change and design guidelines. In addition, hundreds of apps promising support for changing habits, attitude, mental and body state, etc. are available for mobile devices and demonstrate the big commercial interest in the behavior change domain.

Balancing information and persuasion. It is worth considering how a visualization can strike a balance between informing people and patronizing them or pushing them into a certain direction. Nudging people's behavior might be in conflict with the idea of an informed society, in which people are able to have access to substantial information and several opinions or arguments and empowered to make their own decisions. Mobile visualizations can offer assistance, but we suggest that people be able to decide how much, when, and in which way they want to leverage these techniques to help change their behavior. For example, in the case of saving the environment and preventing further climate change, mobile visualizations can help trigger behavior change, but should be mindful to avoid crossing the line to get a person's nerves or exhibit an attitude dictatorship.

Considering the impact of framing effects. How data in mobile visualization is framed has been shown to impact people's behaviors. For example, in TimeAware Kim et al. [37] show that a visualization showing how far off a person is from reaching their goal had a greater impact on productivity behavior than highlighting what they have achieved so far (cf. Figure 1.6). However, this framing also introduced stress. As a result of another study investigating the effect of framing on self-efficacy [12], Choe et al. recommend positive framing (highlighting what has already been achieved compared to still remaining). They also found text-only framing led to higher self-efficacy than a text with visual (colored progress bar) framing. Therefore, depending on the design goal, one framing may be preferable over the other, but they should not be treated as equivalent. Other framing choices such as colors and iconography

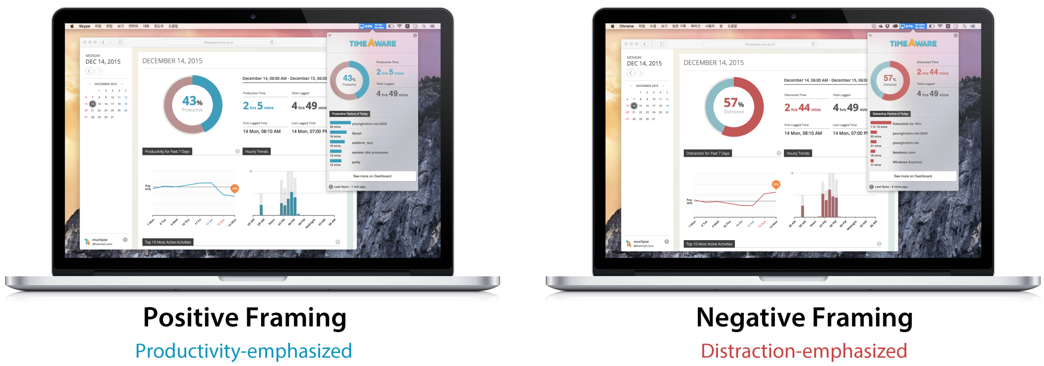

Figure 1.6: Time Aware by Kim et al. [37] shows a visualization to indicate how far off a person is from reaching their goal. *Figure courtesy of and © Young-Ho Kim, used with permission.*

can influence the persuasiveness of mobile visualizations while also generating other emotional responses such as strong sense of drive, stress, or even guilt.

Letting people decide. When possible, it is important to give people control over the type of information they want to be shown, at which frequency, and even the level of detail. Often it is not good to surface as much objective data as possible. Again, data aggregation might help people to focus on the information they consider relevant to reach a goal. However, people should always have the opportunity to request more details, to compare, even to see other views or arguments. This also includes the visibility to others. In the data physicalization domain, for example, solutions have been proposed which show data significant for a single person or a group of initiated persons in physical form.[12] A knitted blanket (cf. Figure 1.7) or a knitted scarf, for example, could show individuals data encoded in colored stripes, resulting in a pattern that can only be deciphered by the wearer. It is also important to consider that especially for persuasive mobile visualizations one size does not fit all. Persuasive interventions can be personalized with regard to messages and visualizations, and the intensity of such persuasive interventions can be adapted to peoples' goals and contexts, thereby increasing the effects of persuasive mobile applications [2].

Balancing personal freedom and societal needs. Some application cases involving mobile visualizations present challenges balancing individual freedom versus societal benefit, which again presents ethical challenges. The example of the world-wide COVID-19 pandemic has demonstrated how the temporal restriction of individual freedom and rights has had a positive impact on the health within the society. As described in many scenarios across the chapter, mobile visualizations played a crucial role in that regard to inform the public. One could argue that visualizations for good could follow a similar path and thereby, even though less drastically, contribute to a better society and world, for example, with regard to the prevalent climate change.

[12]See the website `http://dataphys.org/` for an overview on physical representations of data.

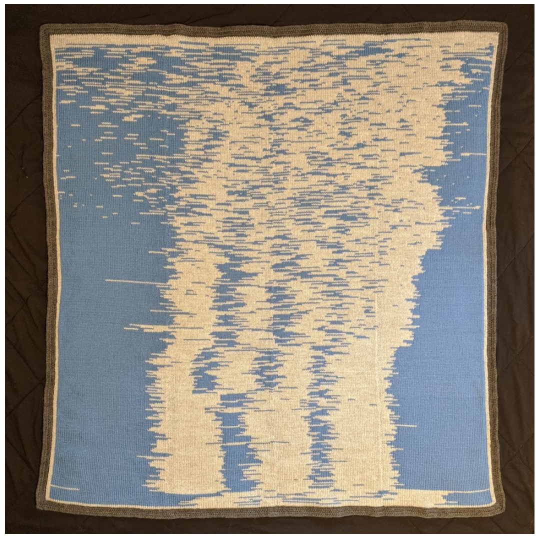

Figure 1.7: Knitted sleep pattern. Each stitch represents 6 minutes of time spent awake or asleep. *Photo courtesy of and © Seung Lee, used with permission.*

1.5 DISCUSSION

Many of the mobile visualizations scenarios we discussed in this chapter can be addressed with better understanding the people and use cases, careful design, and development of standards. Improving interaction techniques to enable people to further explore data and supporting customization of visualizations on a range of devices are important steps towards improving everyday use of mobile visualizations. But ultimately, well-intentioned designers can avoid many of these pitfalls, and we can collectively build up and develop an interaction language for supporting common mobile visualization tasks.

Other scenarios demonstrate how mobile visualization designers can use the lack of context, interaction, and education to deliberately mislead or misinform people. Others use mobile visualizations to persuade, which can promote help as well as harm. With mobile devices and varied contexts enabling visualizations to become more prevalent, these challenges pose serious concerns. Further understanding how designers are using mobile visualizations to mislead or nudge, and developing techniques and curricula to help address these challenges, we can aim to ensure that mobile visualizations are used to inform and improve society rather than undermine or cause undue stress.

In spite of the presented challenges, the scenarios and considerations we describe still demonstrate the immense opportunity for mobile visualizations to better help people understand and connect with their world and themselves. Increased access and glanceability supports people in understanding and interpreting data closer to the environments under which they need to make decisions, and can support increased passive reflection. Mobile contexts promote an opportunity to share knowledge gained with others. Increased visualization access can help people question and challenge their assumptions and enable deeper access to scientific knowledge and evidence.

We primarily ask future researchers, designers, and developers to consider the potential challenges their mobile visualizations or tools for creating mobile visualizations could promote alongside the benefits. Although we outline specific considerations when addressing the challenges we have surfaced, a more general approach is to integrate conversations around people's interaction, privacy, and ethical concerns into their design process, such as through *value-sensitive design* [28] or involving more stakeholders in the design process.

1.6 CONCLUSION

The ubiquity of mobile devices introduce tremendous opportunities for personal and societal understanding driven by visualization. However, the situational and physical realities of use influence how the data is able to be interpreted and interacted with. Through offering scenarios of use, we have illustrated the complexity of designing effective interactive, ethical, and privacy-conscious mobile visualizations. Although we offer a few considerations for future design based on research systems and commercial tools, there is a need to further study and report on challenges integrating mobile visualizations into everyday life.

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