Designing for Visual Data Exploration in Multi-Device Environments

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ABSTRACT

Multi-device environments have an enormous potential to enable more flexible workflows during our daily work. At the same time, visual data exploration is characterized as a fragmented sensemaking process requiring a high degree of flexibility. In my thesis, I am aiming to bring these two worlds into symbiosis, specifically for sensemaking with multivariate data visualizations and graph visualizations. This involves three main objectives: (i) understanding the devices' roles in dynamic device ensembles and their relations to exploration patterns, (ii) identifying mechanisms for adapting visualizations for different devices while preserving a consistent perception and interaction, and, finally, (iii) supporting users and developers in designing such distributed visualization interfaces, e.g., through specific guidelines. As specific contributions, it is planned that (i) and (ii) emerge into a design space, while (iii) leads to a set of heuristics. So far, I was able to extensively work on the first objective as well as to touch on the other two.

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CCS CONCEPTS

• **Human-centered computing** → **Visualization systems and tools**; **Visual analytics**; *Interactive systems and tools*; *Ubiquitous and mobile devices*;

KEYWORDS

Visual data analysis; cross-device interaction; mobile visualization

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INTRODUCTION & BACKGROUND

In recent years, advances in hardware and interface design have spawned a multitude of devices that are notably different to traditional desktops. This multitude enables more flexible workflows, as users can easily choose a device—or a set of devices—that suits their current needs best. Although data analysis and sensemaking are typically characterized by highly flexible workflows, current practice rarely exploits the potential of the existing device multiplicity. Utilizing ad-hoc multi-device

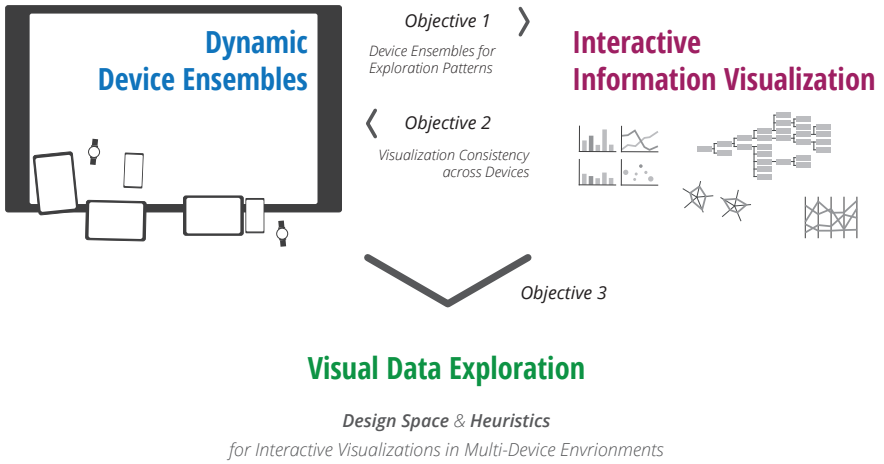

Figure 1: In my thesis, I am aiming to investigate the interplay between dynamic device ensembles and interactive information visualization to allow for a more flexible visual data exploration.

Figure 2: In modern work environments, a broad range of different working situations with different device ensemble can exists [5]. In these ensembles, devices take on different roles and, hence, offer different affordances for a data exploration.

environments would allow for continuously working on a data exploration while also seamlessly switching between different setups (Figure 2) and collaboration settings. For instance, consider a data analyst of a business consultant company: the analyst wants to get a first look at updated data during her commute (smartphone), then performs a more in-depth exploration in the office (desktop + tablet), discusses the insights further with a colleague during a coffee break (tablet + smartphone), continues the exploration while waiting at the airport (laptop + mobiles), and pitches the results to her management in a meeting room (laptops, mobiles, and large display).

In such a scenario, multiple challenges arise. First of all, it must be possible to easily incorporate multiple devices and exploit their respective strengths in the context of the data exploration. Similarly, the used visualization components must be functional on all devices as well as provide a consistency in respect to perception and interaction; this allows then users to seamlessly switch between devices while continuously performing visualization-specific tasks. Although the vision of such flexible interfaces already exists for a couple of years, e.g., as *ubiquitous analytics* [1] or information visualization *beyond mouse and keyboard* [7], the research area of data exploration in multi-device environments (MDE) is still under-explored. Based on cross-device considerations from general human-computer interaction (HCI) research as well as the few research projects for visualizations beyond desktops, I aim to better explore the underlying principles of interactive visualizations in MDEs.

RESEARCH OBJECTIVES

In a nutshell, in my thesis, I aim to answer three questions: (i) how can device combinations be utilized for data exploration, (ii) how can visualizations by optimized for diverse devices, and (iii) how can we automatize both the distribution and adaptation of visualizations across devices? Based on these rather abstract questions, I formulate my research objectives as follows:

> **Objective 1.** *Exploiting common device roles in multi-device ensembles to stimulate established visual data exploration patterns.*

When considering common device ensembles, it is often possible to consider the devices' characteristics (e.g., personal v. shared, small v. big, mobile v. stationary) and distinguish different roles, such as overview device, control device, or storage device. In visualization interfaces, specific multi-view patterns are prevalent, for instance, overview+detail, multiple coordinated views, or control panels. The goal here is to identify how the device ensembles can be used to reinforce exploration patterns and, thus, are able to promote and simplify visual exploration practice. The methodology involves a review of existing research as well as an iterative development of cross-device interface concepts involving user elicitation and feedback sessions.

Figure 3: Depending on the device ensemble (see *VisTiles* [6] and *David meets Goliath* [2]), different device roles can be applied, e.g., personal (remote) control, display extension, mutual synchronization.

Objective 2. *Preserving a consistent visualization character across devices.*

The highly diverse device characteristics also result in the need to adapt visualizations for a device, e.g., in respect to its available screen estate, aspect ratio, or input accuracy. However, the adaptation should still maintain the visualization's visual perception and interaction style in order to effectively serve the current analysis goal. For instance, for comparing two bar charts on two different devices, their appearance must still be similar in order to be able to draw any conclusions. Similarly, when moving a view to a different device, maintaining the appearance helps the users to reorient themselves and, thus, reduces the cost of device switches. In contrast to the notion of responsive design, the goal is to provide a functional instance of the visualization while maintaining its visual identity as well as interaction mechanisms. Similar to the first objective, the methodology is a mixture of literature review (here, on scalable visualizations), own design explorations, and user evaluations.

Objective 3. *Supporting users and developers in applying interactive visualization interfaces in dynamic device environments.*

Based on the first two objectives, the overall goal is to provide guidance to both analysts and programmers on how to handle and design interactive visualizations in multi-device ensembles. Specifically, I am planning to provide a set of heuristics, which are able to lead to useful visualization-to-device mappings in the context of visual data exploration. These heuristics can be used in manifold ways, e.g., for manually designing one specific setup, for proposing automatic distribution algorithms, or for fostering future research on the advantages of multi-display environments in general. All in all, this leads to a conceptual framework consisting of a design space (abstraction of objective 1 and 2), the heuristics, and a set of example implementations.

COMPLETED AND FUTURE RESEARCH

While the first objective was investigated by looking in two paradigmatic device ensembles, the two other objectives are currently addressed by on-going research.

The Roles of Mobile Devices. Besides first general considerations [4], I was able to complete two full-sized research projects. In *Vistiles* [6], we focused on the combination of multiple mobile devices, especially with respect to physical ad-hoc arrangements and how these help users during the exploration (Figure 3). We found that mobile devices can form a valid exploration setup on their own as well as enable a more physical and intuitive exploration style, similar to the way we perform sensemaking tasks with paper printouts. The second paradigmatic ensemble was explored in *When David meets Goliath* [2]. Here, the high-contrast combination of a smartwatch with a large display revealed how a

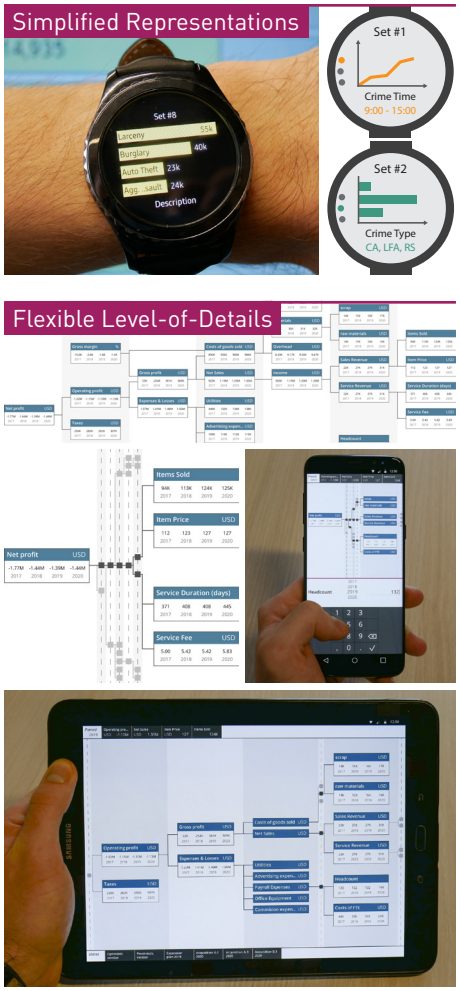

Figure 4: When visualizations must be scaled for displaying them on different devices, the goal is to maintain a consistent appearance [2, 3].

smartwatch can take on the role of a highly personal and unobtrusive toolbox (Figure 3). Specifically, the smartwatch is an always-reachable controller that can mediate the primary interaction happening on the large display. This way, users can save (and carry) selections, access preferred settings, or trigger functionalities from both close-proximity and distance—and all without interfering with other users interacting at the same time.

Recently, we also ran a user elicitation study where participants had to distribute visualizations across a given device setup [5]. Although we did not explicitly ask participants to consider device roles, we found that they are actively considering such roles. So far, the user study featured a pre-defined setups; it would be interesting to observe interaction patterns when participants can freely choose from a multitude of devices. However, this requires a stable interface that allows for a flexible and simple view distribution without requiring too much user effort. By working on the automatic distribution system for Objective 3, the first step towards such an interface was already made.

Content-aware Scaling of Visualizations. As the considered devices are highly diverse regarding their display size and resolution, visualizations must be adapted in order to maintain readability and functionality. As changing the appearance or interaction style of visualizations can temper the way they are perceived, a certain level of consistency should be guaranteed when displaying them on different devices. In *When David meets Goliath* [2], for selections, we used simplified representations of the origin, i.e., the chart where these selections were created (Figure 4). In the context of an automated view distribution (see last paragraph), we constrained the scaling of visualizations to a minimal alteration of the aspect ratio.

However, as this approach has clear limits, I also started to work on a more comprehensive exploration for the scaling. Specifically, I focus on a flexible adaptation of hierarchical graph visualizations through a lane-based approach [3]. By considering lanes for the graph layout, an additional dimension is provided, which allows for reducing details while still maintaining the overall appearance (Figure 4). However, these concepts must still be developed further and tested. Further, I plan to summarize the insights from the aforementioned projects and derive a generalized overview on how to apply these concepts to other visualization techniques.

Heuristics for an Automatic View Distribution. As a result of the two previous investigations, I aim to provide a comprehensive design space representing all relevant properties and relationships of visualizations as well as devices. This design space can then be used to derive heuristics describing the specific interplay of the prevalent dimensions and how these inform the design of distributed visualization interfaces. Within an upcoming full-paper (conditionally accepted) [5], a first version of the design space and heuristics as well as a web-based example implementation for an automatic distribution of given views across connected devices were created. For the remaining time of my PhD, the goal is to extend and improve the framework further by incorporating new insights from

Objective 2 as well as properly evaluate it by applying it to other setups and application examples. This also involves an ongoing development of the current prototypes.

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