Information Visualizations with Mobile Devices: Three Promising Aspects

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ABSTRACT
We believe that mobile devices offer great, only partly realized, potential in the context of both personal and professional information visualization. In this position paper, we outline three important and promising aspects of information visualization with mobile devices: the development of a consistent multi-touch interaction framework that can be applied to a variety of visualization techniques; the combination of common touch input with advanced spatial input techniques; and the usage of the spatial arrangement of multiple, co-located mobile devices. We explore these aspects by highlighting important questions and major challenges. Furthermore, we present several approaches and early concepts which illustrate our ongoing investigations in this field of research.

Author Keywords
Information visualization; Mobile devices; Multi-touch interaction; Spatial input; Spatial arrangement.

INTRODUCTION
We believe that mobile devices offer great, only partly realized, potential and that they will play an essential role in the future of information visualization interfaces. In the context of data visualization and exploration, today's mobile devices combine many advantages: they have become ubiquitous (familiarity) and can be used almost anywhere and at any time (availability). Due to their broad success and availability in the consumer electronics market, they provide an ideal platform to bring information visualizations techniques to even inexperienced users (non-experts). Both, their physical and technical properties make them particularly suited for collaborative work: they can be integrated into existing environments or form their own collaborative interface when multiple mobile devices are combined. Altogether, this creates a notion of the great potential which mobile devices can bring into the field of information visualization.

Of course, the idea of using mobile devices for information visualization tasks is not new. Existing research ranges from, for example, using single PDAs for simple visualization techniques [2], to investigating challenges for information visualizations when combining mobile devices with interactive tabletops (e.g., [22]), to arranging tangibles to specify search queries (e.g., [5, 7]), to designing multi-touch techniques for interactive scatterplots on tablets [17]. From recent research in this area, we can extract two major challenges: (i) re-think current visualization interfaces to utilize multi-touch input and the direct manipulation approach (e.g., [1, 3, 16, 17]); and (ii) connect and control visualizations distributed across various mobile displays (e.g., [4, 14]). Both, this and our research, is part of broader investigations bringing together two important fields of research [8]: natural user interfaces and information visualization.

In our research, we focus on three important and ***promising aspects***, which relate to the challenges mentioned above:

- ***Multi-touch interaction framework***: investigate a systematic, consistent approach that applies touch gestures to a variety of information visualization techniques,
- ***Spatial input techniques***: utilize device movements for the exploration of 2D and 3D visualizations on both small and large screens, and
- ***Device arrangement***: design new concepts that make use of the combination of multiple, co-located, spatially-aware devices.

For each aspect, we provide a motivation and a brief overview of related research, highlight important design questions, and present our approaches as well as early concepts.

MULTI-TOUCH INTERACTION FRAMEWORK
Touch-enabled mobile devices have become ubiquitous in many locations—for both personal and professional scenarios. At home, typical casual users could be interested in whether they succeeded or failed regarding their actual fitness goals. Common fitness apps provide a couple of simple visualizations (e.g., pie charts, line charts) which allow users to easily analyze their individual progress. In professional scenarios, however, interfaces are more specialized and the interactions can be more complex. For example, car mechanics regularly connect their mobile device with the car computer in order to analyze car specific data (e.g., mileage or

system warnings). As in other professional settings, such mobile apps provide task-specific visualizations. However, most visualizations (in both of the scenarios) can only be manipulated by separated, traditional UI widgets such as buttons or sliders. A more natural—and possibly more comfortable—way of interaction based on direct manipulation [3] is rarely supported.

Recent research activities mainly focused on the design of multi-touch techniques for specific visualizations, for instance, TouchWave for stacked graphs [1], TouchViz for bar charts [3], or multi-touch-enabled scatterplots [17]. All of them introduced multi-touch interfaces that allow direct interactions on elements of the visualization (e.g., axes, canvas, or data objects) and minimize the usage of traditional UI widgets. Additionally, Drucker et al. [3] compared their touch interface against a classical WIMP interface. They reported that the touch interface is faster, less error-prone, and also preferred by users. All solutions represent separated and independent sets of multi-touch interactions for individual information visualization techniques. Although many visualization systems involve multiple coordinated views [15], it is hard to apply those solutions to other visualization techniques, because of, e.g., conflicts between these interaction sets. To our knowledge, there is no general set of multi-touch interactions that guides the design of new systems.

Although different visualization techniques have individual properties, they also often share tasks or actions, such as panning and zooming, selecting objects, requesting details about an object, inverting axes, reordering axes, or specifying filters. Therefore, we investigate a more universal set of interactions. It is our goal to create a generalized interaction framework that can be applied to multiple coordinated views and systems that provide a variety of visualizations techniques.

SPATIAL INPUT TECHNIQUES

Today's mobile devices are equipped with quite a number of sensors. Among others, interaction designers can make use of motion sensors such as gyroscope, gravity sensor, or accelerometer; environmental sensors such as barometers, or photometers; or position sensors such as magnetometers. While existing sensors are getting more accurate, devices are also equipped with further sensors such as depth cameras (for, e.g., object detection, indoor navigation) or sensors for mid-air hand gestures.

The long-established position and motion sensors have already been used as an additional input channel for user interfaces—the spatial input. The sensors provide information about relative changes of the device position in space. This can be used to map device movements to certain information visualization tasks (Figure 1). While the specific combination of spatial input with mobile devices and information visualization has not been investigated in detail, Spindler et al. [20, 21] already developed basic concepts of spatial input for various use cases. For example, they found that for navigation tasks spatial input can even outperform established touch interfaces [20]. However, we need to further investigate this type of input for visualizations to learn about its limitations. We assume that spatial input can only assist certain tasks, thus making a combination with multi-touch input a promising option.

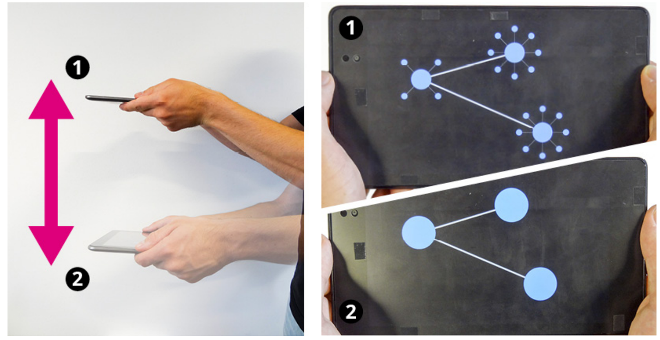

Figure 1. Mock-up of spatial input: semantic zoom based on vertical translation.

Figure 2. Different arrangements of individual visualizations during paper-based data analysis.

In this context, our research focuses on the navigation and manipulation of information spaces for two different, but interesting technical setups: a single mobile device alone and mobile devices in front of a large display. Spatial input has already been used in both setups. In particular for the usage of a single mobile device, spatial input can adequately address situations when touch input is limited (e.g., holding the device requires users to keep hands at the border) or not free of conflicts (e.g., same gesture for multiple functions, pinch zooms in/out the scene or scales an object). A setup with a large display especially supports situations when one or more users explore huge and complex data sets. Mobile devices and their spatial movement can be used to, e.g., control parameters of local, personal views.

DEVICE ARRANGEMENT

The third aspect is the spatial arrangement of a number of mobile devices [9, 10, 13, 14]. On the one hand, in situations when multiple people meet, they almost always bring their own mobile devices. On the other hand, there is actually an increasing number of people carrying more than one, sometimes even three or four devices [18]. Now, all these co-located devices can be connected to each other in order to create a combined, single user interface (cf. multiple coordinated views [15]). Similar to paper-based data analysis workflows (Figure 2), these mobile devices can form—depending on the goals of a user—various two-dimensional arrangements (e.g., positioning on a table).

The development of a system which utilizes the arrangement of spatially-aware devices must consider several general problems or questions:

- *# of devices:* How to operate an interface utilizing two or three co-located mobile devices? How does this interface change, if the setup consists of even more, i.e. plenty [12] of devices?
- *Device properties:* How to handle different device sizes? How to deal with different display qualities such as resolution (i.e., pixel density) or color fidelity? How does display bezels influence the perception (e.g., perceived unity of devices placed side-by-side) and usability?
- *Combination:* What are useful and reasonable device arrangements and what are the use cases? What role play device proximity [6], micro-mobility [11], or territoriality [19] in such a setup?

Besides the intuitive solution of simply extending the graphical context across devices, we investigate both further general and visualization-specific approaches that make use of the spatial arrangement (Figure 3). In this context, we focus on three fundamental facets of interface adjustments.

First, the individual and current *display properties* of devices can be adapted to provide a basic visual alignment of separate visualizations. This, for instance, includes smart system behaviors such as the adjustment of the basic orientation or alignment of a visualization (Figure 4). Furthermore, the system automatically scales visualizations to compensate different pixel densities.

Second, the arrangement of devices can be used to adapt the content (i.e., elements) of a *visualization*. As already mentioned, the most intuitive solution is to simply extend the graphical context to span displays of combined devices. Furthermore, device combinations can be interpreted as filter interactions [23]. For example, by combining two devices, which show different parts of a data set, the system automatically highlights objects appearing in both views (Figure 4). Alternatively, a device combination can directly adjust the way data objects are arranged (cf. reconfigure [23]). For instance, data columns of tables can be sorted, attributes of a parallel coordinate plots can be rearranged, or directions of scatterplot axes can be changed (Figure 4).

Figure 3. Mock-up of device combinations: simple extension of the graphical context (left, cf. [14]), aligned and extended parallel coordinate plot (center), two different linked visualizations (right).

Figure 4. Adapting visualizations: automatic alignment of plot and object highlight (top left), inversion of scatterplot axes (bottom right).

Third, the combination of devices can be used to control the scope of user *interactions*. If devices are combined, the visualization and thus interaction is linked. For example, selecting an object results in a highlighted appearance on all linked visualizations and panning or zooming actions are synchronized automatically across visualizations and interactive.

CONCLUSION & OUTLOOK

In this position paper, we gave first impressions of our ongoing investigations in the context of information visualization with mobile devices. We outlined three important and promising aspects: a multi-touch interaction framework, advanced spatial input techniques, and utilizing device arrangements. By developing several approaches and early concepts as well as highlighting important questions, we started to explore the characteristics of these aspects. We illustrated the usefulness and great potential of mobile devices and believe that they provide an ideal platform for usability-improved information visualization interfaces.

To further explore each of the aspects, we will specify appropriate usage scenarios and design goals that inform the future development of our concepts. Additionally, we are developing different prototype implementations, which allow the practical demonstration as well as the evaluation of our approaches.

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