Towards Combining Mobile Devices for Visual Data Exploration

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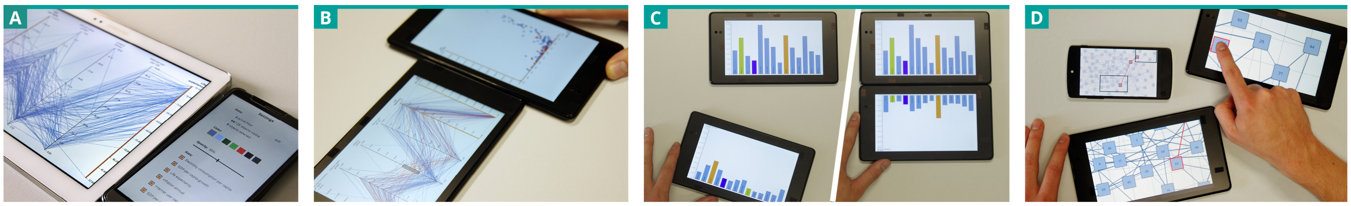

Figure 1: Implemented concept for tangible visualization views showing visualization adaptation and interaction synchronization: (a) Reduced visual clutter by UI offloading; (b & c) align and reconfigure visualizations; (d) overview & detail setup.

Abstract

We present a concept for tangible visualization views using co-located, spatially-aware mobile devices. The proposed concept takes advantage of ad-hoc device combinations and spatial arrangements, allowing users to interact with multiple coordinated visualization views distributed across mobile displays. In this work, we describe the basics of this concept and illustrate the potential of our approach by describing and implementing use cases of various visualization techniques.

1 Introduction and Background

Many visualization systems—and multiple coordinated views in particular—are created for traditional desktop environments. However, mobile devices such as smartphones and tablets represent one of the most successful product categories in the consumer electronics market. They have become ubiquitous in both personal and professional settings. Therefore, we aim to develop a visualization interface, which allows one or multiple users to visually explore data by using their mobile devices. At the core is the idea of distributing and connecting visualization views (the main components of visualization interfaces) across multiple mobile displays. For that, we need cross-device concepts for creating, manipulating, and managing those views.

In this work, we develop the basics of a concept for tangible visualization views, which provide fully-functional multiple coordinated views (MCV) distributed across a number of mobile devices. Moreover, we aim to extend the idea of MCV by taking advantage of an interaction style that is known from, e.g., paper-based visualizations (e.g., [4]): *the **dynamic** placement, spatial arrangement, and combination of visualizations*. We believe that visual data exploration will benefit from using visualization views as tiles that can be arranged in a mosaic fashion (cf. [1, 7]).

In contrast to the majority of research in the field of information visualization (InfoVis) that is mainly focused on graphical aspects, our work specifically investigates the role of interaction design (cf. [6, 9]). Related work with a similar focus mainly include research on tangibles and tangible views [8], proxemic interactions [5], and particularly multi-touch techniques for interactive surfaces [2]. However, we think that using spatially arranged mobile devices for data visualization and exploration will open up new opportunities.

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2 Concept for Tangible Visualization Views

The development of our concept for tangible visualization views is focused on supporting important InfoVis tasks (e.g., brushing, filter, compare) through the combination and spatial arrangement of mobile devices. In particular, this involves the distribution of MCV across devices, two-dimensional spatial interactions, and the adaption of visual aspects as well as interaction aspects when devices are combined.

2.1 Device Proximity and Combination

While working with physical objects on a table, people naturally use proximity [4] to, e.g., perform comparison tasks or specify group memberships between objects. We aim to utilize this behavior by allowing users to create spontaneous and dynamic device combinations. Therefore, we introduce three proximity-based coupling states (Fig. 2). Based on the distance between two devices, the states *decoupled*, *synchronized*, and *adapted* describe the type or coupling intensity of a logical connection between those devices.

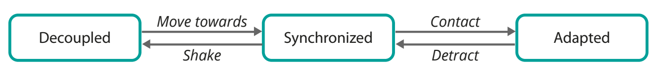

Figure 2: Coupling states are determined by device distance.

The most essential parameter determining coupling states is the distance between two devices. Initially, devices do not have a logical connection. They are *decoupled*, thus showing separated visualizations views. If distance is lower than a threshold (we empirically determined 20cm), the *synchronized* state will be assigned, resulting in shared visualization settings, such as selections, filter options, or color themes (Fig. 3a). Finally, if devices are combined side by side, their views will be *adapted* and thus aligned (Fig. 1b-c, Fig. 3b-c) or combined (Fig. 3d-e).

The specific interface synchronization and adaptation of coupled devices also depends on the views that are displayed. In our current concept, we distinguish three view categories: *vis views* provide specific visual representations, *selection views* allow choosing data sets or vis views, and *setting views* manipulate visualization parameters. Each category addresses different user tasks, such as:

Selection views load a data set, select visualization technique;

Vis views visually align views or data objects, linked brushing, zoom and pan, synchronize visual properties (e.g., colors);

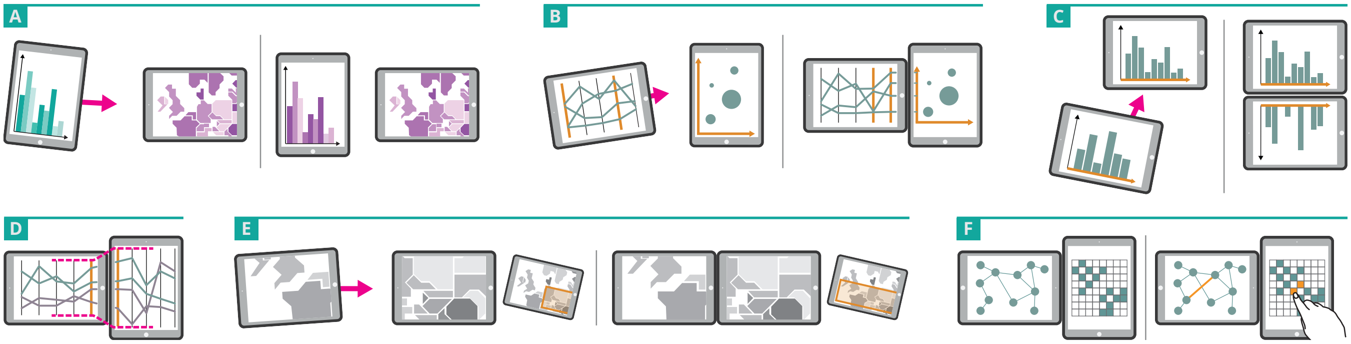

Figure 3: (a) Adapting the color scheme; (b) Combination and adaptation of parallel coordinates and scatterplot; (c) Rearranging objects; (d) Display extension; (e) Overview & detail constellations; (f) Graph manipulation through adjacency matrix.

Setting views adjust mapping data attribute to visual variable, show/hide elements of a visualization (Fig. 1a).

2.2 Visualization Use Cases

To illustrate the potential of our concept we apply it to three selected InfoVis use cases. The use cases are also implemented in a conceptual prototype (Fig. 1; see also accompanying video). We use a motion capture system[1] in order to track mobile devices that are equipped with IR-reflective markers.

Multivariate data visualization is a typical use case for multiple coordinated views. Fig. 3b shows the combination of a parallel coordinate plot with a scatterplot. At a synchronized state, linked brushing is activated and if applicable, shared axes are highlighted. When combined side by side (state adapted), the views are aligned to improve readability across them. In this example, the scatterplot is scaled and centered.

When bar charts with different y-axes are combined (Fig. 3c), data comparison can be aided by reordering objects of the attached device to match their counterparts and flipping the attached chart. In case of combining two scatterplots (Fig. 3d), the plots are unified and displayed across both devices. All axes are joined and equally distributed, but double axes are eliminated. If the polylines that are displayed in the views differ, the origin is visually encoded to support comparison.

Map-based Visualizations often involve an underlying map superimposed by specific visualizations, such as heat maps, bar charts, or lines. Critical to an efficient orientation and navigation is, e.g., support for zoom and pan as well as overview and detail. A simple overview and detail setup can be achieved by moving multiple map views close to each other (state synchronized). The view with the least magnification becomes the overview and indicates the position, orientation, and extent of all other detail views. When putting two detail views side by side, the views are joined through display extension (Fig. 3e). In addition, a map combined with another type of visualization can be used to filter objects. Objects within the map's view can be highlighted in connected views.

Network Visualizations allow the exploration and manipulation of data with relations and hierarchies between objects. This type of data is often visualized using node-link diagrams. Similar to maps, overview and detail is important to node-link visualizations. In a synchronized state, an overview device can display the location of another detail view, which shows only a sub-graph. Furthermore, the overview can also be used to visualize hidden data properties, such as the shortest path between objects of different detail views (Fig. 1d).

A node-link diagram can also be combined with an adjacency matrix [3]. Again, linked brushing is enabled when devices are moved towards each other and enter a synchronized state. However, the device proximity can also be used to explicitly distinguish exploration and manipulation. While nearby devices (state synchronized) allow exploration only, the manipulation (add, remove, or change the type) of relations requires devices to be positioned side by side (state adapted), see Fig. 3f. This might also minimizes unintended manipulations.

[1] OptiTrack (https://www.optitrack.com/)

3 Future Work and Conclusion

A challenging future aspect for our concept is the smart combination of visualizations. Avoiding unintended combinations and improving system-based decisions of how to combine or adapt views, could be solved by using knowledge of the user's attention and/or semantics. Also, the device ownership has to be considered for multi-user scenarios. Finally, there is a need to further investigate the influence of the number of devices that are involved, since there is no consensus in prior work. Moreover, more devices increase the complexity of possible combinations and spatial arrangements.

In this work, we developed the concept of tangible visualization views, which provides a multiple coordinated views interface that is distributed across mobile devices. We take advantage of the capabilities of spatially-aware mobile devices and their dynamic arrangement and apply this to the specific domain of InfoVis. We hope that our concept can form the basis for more research and discussion about this novel type of InfoVis interfaces.

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