Towards Enhancing Data Exploration with Multiple Mobile Devices

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Abstract
In a world of an increasing number of mobile devices in everyday life, people are dealing with large amounts of data every minute. It is an emerging need to create interfaces for multiple devices to support the process of data exploration and understanding. New sensors, enabling mobile devices to be spatially aware, inspire the design of context-aware adaptive interfaces. We indicate a possible direction of further research, where we treat the spatiotemporal relationships between different subsets of a given data set as part of the information communicated by the system. That give us the opportunity to create more effective visualizations to enhance perception. This approach builds on a natural human tendency to organize information spatially, as shown in previous research in cognitive science.

Author Keywords
multidevice; dual device; cross-surface; interactive visualization; multisurface environment; mobile interaction

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction
Nowadays, people are using mobile devices to explore data on the run, both in work and private life [1]. Data sets

are constantly becoming larger, so supporting effective data exploration emerges as a big challenge for Human-Computer Interaction (HCI). Finding the methods to present large amounts of information in the most effective way is required. The technology available in everyday situations should augment human's perception and sensemaking as effectively as possible. While a number of mobile devices in our homes and offices is still increasing, and those devices are getting more and more powerful, users do not benefit to the extent they could from the fact that those devices can be interconnected.

Certain research was done on possible solutions and applications for multidevice systems. MochaTop [7] and Thaddeus [6] focused on creating new methods of navigation through data sets via cross-device interaction. Rädle et al. [5] created a system where images were displayed on multiple, spatially aware displays. In Conductor [3], Hamilton and Wigdor investigated how multiple spatially-aware devices could enhance user experience and performance. Our work is also inspired by the research on collaborative scenarios for tabletops, focusing, for example, on the flow of information between users, or possible applications of tabletops in real world. This paper focuses on leveraging multidevice interaction for collaborative data exploration though visualisation. Thus, it appears to be an interesting approach to make use of space around and in-between devices. We decided to investigate it in the field of collaborative data exploration and understanding. It seems that in several years the technology enabling the device to sense its close surroundings will be embedded into commercially available devices. Past research focused mostly on creating distributed displays, like in Conductor [3] or HuddleLamp [5], or on expanding the model of control and navigation by using the relative position of devices [7].

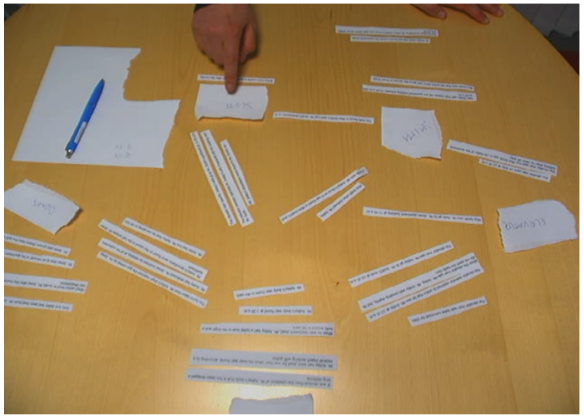

Figure 1: Users exploring data in the preliminary paper-based study. The different pieces of paper contain clues in a crime mystery game.

Preliminary inquiry

People in the course of data exploration tend to organize the information spatially, even though the information itself does not necessarily contain any spatial aspects [4]. They find relations (using temporal, person-wise or other abstract criteria) and them to a plane or space. In order to investigate how this approach may be translated into interaction design domain, a study with three participants was conducted. They were given a set of clues and asked to solve a crime mystery, as shown in Figure 1. The entire study was recorded and the video material were analyzed to find how users manipulate pieces of information on the table. This preliminary study showed that the proxemics, i.e. spatial distance, orientation and other parameters between the pieces of information is meaningful in this process. The analysis shows that objectification, i.e. connecting abstract concepts with physical object is important.

Methodology

We believe that using multiple, spatially aware mobile devices acn support collaborative sensemaking by offering more effective methods of data visualization. Sensemaking is still often performed using sheets of paper, post-it notes or other physical objects. The performance in understanding may be limited by the simplicity of the tools. Translating this process to digital world opens a wide range of possibilities to make it more effective, for example by giving the user possibility to create multiple arrangements of data simultaneously. Furthermore, managing user attention by highlighting a certain relation between pieces of information in spatial conditions can benefit sensemaking. Although we consider a set of problems where human experts are required, e.g. the data given may be partly analyzed automatically, using well-known methods and algorithms.

This scenario engages the entire space around the user and is not limited to the device displays. The space between devices becomes part of the interactive space and the spatial relations between devices become parts of the user interface. This enables examining the spatial organization of pieces of data as clues for content-related relations between information pieces. As the process of understanding consists of creating an associative network, which constitutes the multidimensional, fuzzy relations between pieces of information, it would seem that organizing the information in space and the process of understanding are closely connected. We are planning a study, in which we will observe users during the process of processing a given data set, e.g. creating a complex associative network of mutual relations between pieces of information they explore. Then, by analyzing the obtained study data, we will try to build a model of how users manage the information in space and time. Based on that we will create a system, which will be able to predict the possible relations between pieces of information based on observation of spatiotemporal parameters of data in the interactive interface.

We believe that we can create a fuzzy mathematical model for translating the spatio-temporal information to an associative network of interactions. A example of operation of such model can be a situation when two pieces of information are placed close to each other for certain period of time. By parameterizing the numerical values of distance and time, we can create a relation between two pieces of information. Based on the relations between information and data, a fuzzy inference model can be applied to transfer the spatial relations to relations between pieces of information.

An important feature of the aforementioned mathematical model is considering the history of the movement of a piece of information in the process of inference. This means that the strength of the relation does not only depend on the current position and time spent in this position, but also on the previous movements of the piece of information. One way the system could help in sensemaking would be by visualizing how strongly two objects are related if the value of the (model-inferred) relation exceeds a specific value, as shown in Figure 2. Creating such an intelligent system could open new possibilities for supporting sensemaking such as enhanced attention management. Such systems could also lower the mental demand of communicating insights between users, as they could be shared implicitly, similarly to scenario shown by Goyal et al. [2].

The advantage of implementing such solutions on mobile devices is that tablets and smartphones are physical, tangible objects. Tangibility offers additional advantages to interaction e.g. the socioconstuctivist flavor of tangible tabletops. Also, the system provides the possibility of tracking the proxemics not only on a plane, but in three (or "two and

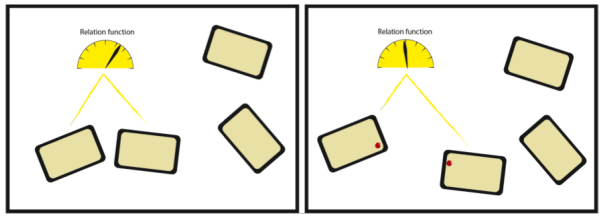

Figure 2: Illustration of a possible application of a relation function. If two devices are close, the value of relation increases. When the distance between device increases, the value of the relation slightly decreases, but the relation is still stored in the system and visualised on the screens.

a half") dimensions. Overlapping may be meaningful in this context. We believe that such enhanced systems would find applications in many fields, such as thematic or visual analysis, decision making and other areas, where human experts and their performance is crucial.

Conclusions and further work

This paper proposes a new way of designing interactive systems for mobile devices, leveraging upcoming technology. We suggest incorporating proxemics in context-aware adaptive interactive systems for multiple mobile devices, which can contribute to more effective access to information visualization, better collaboration and easier sensemaking. With this position paper, we aim to inspire further work in this area. We recommend further efforts for creating specific design methodologies and methods for examining and creating user behavior models that incorporate device proxemics in the process of sensemaking.

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