DDE - Dynamic Data Explorer: Dynamic data exploration in a collaborative spatial-aware environment

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Abstract

Collaborative decision-making has become an integral part of the analysis process aiming to get insight into multivariate data. To further encourage this workflow numerous co-located, multi-user systems have been developed consisting of large multi-touch screens or interactive tabletops. But such frameworks are typically expensive and unavailable outside dedicated environments as for example laboratories. Therefore we developed the Dynamic Data Explorer, short DDE, a multi-user system that enables users to join, in an ad-hoc manner, with their own mobile devices. Since forming groups should be possible in various locations, the tracking system, enabling spatial awareness of the devices, has to be light-weight and small. Near Field Communication (NFC) is a widespread transmission technology which fulfils these properties and is used in our framework to enable different side-by-side arrangements of devices. This allows users to explore multivarate data visualizations on a system where the number of devices and their set-up can be modified at all times.

CCS Concepts

• ***Human-centered computing*** → ***Mobile devices;*** • ***Computing methodologies*** → ***Tracking;*** • ***General and reference*** → *Cross-computing tools and techniques;* • ***Social and professional topics*** → *Computer supported cooperative work;*

1. Introduction

As datasets get considerably greater in size and complexity, the task of sense making becomes a group activity. Not only uncertainty and missing values but also domain specific issues lead to sophisticated problems that have to be solved by people having broad expertise and diverse perspectives. Therefore visualizations, which focus on improving cooperation in teams, have to be developed aiming to guide users towards important content and make connections visible. Supporting multiple users restricts the range of useful devices, since they need to facilitate parallel work and extend visual space when required. Furthermore devices allowing location independence and co-location encourage flexible workflows. Devices which fulfil the mentioned properties are for example tablets and smartphones. Not only are they widely used and easily available, they also support wireless connectivity and have a lot of different sensors integrated that provide information about their surrounding. Moreover, technicians as well as non-technicians are familiar with these kind of devices and most of the time have at least one with them [DGHN16]. Using a system, consisting of tablets and smartphones, makes it possible to establish a physical workspace that supports individual needs and encourages diverse forms of teamwork by just bringing a device and being able to join the analysis activity. In addition it is also possible to end the collaboration by picking the device up and leaving the group. To enable the possibility for devices to form co-located working groups, different tracking techniques have been developed. Sensors, as magnetic or acoustic, and technologies, as camera-based frameworks, were used to build such detection systems, but thereby often the real-world environment where they could be used were disregarded during the development process. Therefore these techniques are usually expensive, large or suffer from detection errors due to the environment where the system would be operated in reality [LHD18b, DAJL19, HK13, HLH*12, GO16].

One tracking technique, which until now was only mentioned as a possible alternative, is Near Field Communication (NFC) [HW14, BE19]. NFC is a widespread technique, used for detection and identification, that is integrated in nearly all smartphones. It is location independent and in order to function only small, lightweight tags are required. These can then be detected by the smartphones up to a certain distance. So this technology naturally supports close collaboration as necessary for analysis tasks in groups, which is why we decided to use this technique for our tracking system. Consequently our main contribution is a visualization system that supports ad-hoc joining of group members. It is spatially-aware, so devices close to each other will communicate with each other. Furthermore combinations and adaptions of visualizations will be possible such that an easy-to-use framework consisting of multiple coordinated views can be offered to a group of users to ease data exploration.

2. Related Work

The feature of establishing connections on the spot with adjacent smartphones or tablets, imposes the need for spatial-awareness. This can be provided by different tracking methods. The most popular technology is camera-based. In 2010, Boring et al. [BBB*10] used the camera of a smartphone to take a picture of a file, which should be dragged from one screen to another. Thereby the tracking was based solely on a pattern recognition algorithm which was able to identify different displays. The main disadvantage of this framework was its usability because of the interaction with small displays and micro-movements of the user's hands. Chung et al. [CNS*14] developed VisPorter, a system consisting of different tools, such as tablets, a tabletop and a wall display. To get the location information of each handheld device, they used a motion tracking system. Also Woźniak et al. [WLS*14], as well as Chung et al. [CN18] and Langner et al. [LHD18b] used motion tracking setups with different amounts of cameras, which were mounted on the ceiling of a room. Desolda et al. [DAJL19] used for tracking the so-called HuddleLamp. This tool is built out of a desk lamp where inside the lampshade a camera is mounted. So in a specific small area underneath the lamp different handheld devices can be tracked. Although all these systems provide a stable recognition of portable devices, they have in common that they are not location-independent, since they are bound to a specific room. Badam et al. [BE19] developed a camera-based cross-device system that can be used in various locations. To obtain one visualization from one display and show it on another, they encoded the visualization data into QR-codes and took pictures of them. A major disadvantage of this system is that it is not possible to have a mutual interaction between the devices without taking a picture every time. Further, this method's tracking ability, as well as those of all camera-based systems, is severely affected by bad camera quality, lightning conditions caused by the environment and occlusions.

But not only camera-based tracking suffers from occlusions. Also tracking through acoustic signals is highly susceptible for this problem. Although this method would make tracking possible without the need of further external sensor, the computation of the devices' positions can be quite error prone due to occlusions resulting from the users' hands. Also the movement of the devices can affect the accurate calculation, as stated by Herrera et al. [HK13]. Another method, introducing spatial-awareness between different devices, uses capacitive input provided by the users. This interaction technique is promoted in various works, as for example by Lucero et al. [LKK10], Schreiner et al. [SRJR15] and Langner et al. [LHD18a]. Each paper describes different gestures to determine how the devices are positioned to each other. Reasons for selecting this technique are various, the most important one that no external equipment is required. But it also provides location-independence. However, capacitive interaction may not be suitable in situations where dynamic reconfiguration of the devices is essential. In addition, permanently applying gestures can quickly become exhausting for the user. So automatic, gesture free techniques should be preferred, as explained by Huang et al. [HLH*12]. Another capacitive technique to locate the position of the devices to each other was proposed by Strohmeier et al. [Str15]. By placing conductive material around a smartphone and positioning the device on the tablet, the authors were able perform touch interactions and track its position on the tablet. Unfortunately, this method only provides the relative position of the smartphone, when it touches the tablet, but no position beside the tablet can be determined. A further tracking technology which supports automatic, location-independent grouping, can be provided using magnetic signals. Grønbæk et al. [GO16] developed a system which uses the built-in compass in mobile devices to facilitate co-located ad-hoc pairing. But since the compass orientation is an absolute value, users have to manually add whether the connecting device is on the left- or the right-hand side. Another approach proposed by Huang et al. [HLH*12] uses external magnets and Hall Effect sensors to determine the position and orientation to each other. This allows an automatic, location-independent determination of positions between different devices. This technique is quite similar to the ones using Near Field Communication (NFC), with the difference that NFC readers are integrated in nearly all smartphones.

In 2008, Ohta et al. [Oht08] were among the first to attach NFC tags on laptops to detect their placement at a certain time. At the same time Hardy et al. [HR08] realised an interaction technique implemented using a grid of NFC tags and a NFC phone. A projector was used to project a screen image on the NFC array. The phone could then be used to select a certain region of the image. Another approach using NFC was proposed by Fei et al. [FWK*13]. Here NFC tags were placed on the periphery of a collaborative tabletop. Smartphones could then be placed on the tags to share different information as for example photos with the table. The smartphones themselves were only used to share or store the collected data. Another system developed by Hamilton et al. [HW14] uses NFC to connect different handheld devices to a united symphony. This cross-device framework enables broadcasting of information, such that the same data can be used in different applications on diverse devices. Here the NFC function of the smartphones is only used to establish a connection between the devices, but the devices are not aware of their position to each other. In our work we extend the importance of the NFC tags, since we not only use them for establishing a connection between the devices, but we also assign them certain positions.

3. Methodology

Since our system should support efficient collaboration during data exploration, we based our framework on two main motivations: On the one hand, an easy-going and intuitive switching between tightly working in a group and experimenting on one's own, was of highest importance. On the other hand, powerful filter operations across several devices were considered to be a key feature to make close communication and a united thinking process possible.

3.1. Group Mode/ Individual Mode

As stated by Tobiasz et al. [TIC09], operating in a team undergoes different collaboration styles, which switch between tightly and loosely coupled stages. In our work, we support this change of styles by providing a position-based recognition that controls whether the current device should be used as collaboration tool or as single device required for individual examination. The integrated NFC tags can be considered as entrance and exit to the collaborative mode, which can be entered or left at any time.

Further the DDE framework also provides a Single-User Mode. In this mode the visualizations are chosen by the system according to the NFC tags on which the devices are positioned. The selection process is depends on two formulations given by Sadana et al. [SS16]. The first states that the visualization should be maximized on the device but scrolling should be kept to a minimum. The second proposes that two neighbouring visualizations should be possible to compare. By following these principles the user is further supported through the analysis process.

3.2. Filtering

To develop a highly flexible framework, we provide four different visualizations: a Bar Chart, a Choropleth Map, a Line Chart and a Scatterplot with Marginal Histograms. To get insight into the data, a detailed examination of different visualizations and data combinations is inevitable. Therefore we provide two different filtering strategies, value-filtering and view-filtering.

Value-Filtering is applied, when two visualizations, showing different datasets, act as indirect filter menus for each other. So for example with tap and drag gestures, it is possible to filter other device's visualizations.

View-Filtering is dynamically applied on the whole multivariate dataset and enables the user to work with a pre-selected part of the data. The calculation differs depending on the type of the currently computed visualization and is based on the geometrical location or time-based record. Therefore this operation emphasizes the use of handheld devices with small screens by not using Small Multiples but providing a view-dependent filtering that can be controlled with a swiping gesture.

3.3. DDE Framework

The DDE framework is realized as an Android app, since Android is a widely used platform for mobile devices. Tasks as sensor reading, as for example from NFC and the accelerator sensor, and importing datasets are implemented in Java. Datasets can be downloaded directly from Gapminder [Gap] or can be loaded from the local storage of the smartphone. All interfaces and visualizations are realised as WebViews, modelled with HTML5, CSS and JavaScript. So an extension to other operating systems and devices is easily possible.

Datasets used in the DDE framework are multivariate, consisting of different countries where their attributes are shown over various years. For example all datasets provided by the foundation Gapminder can be loaded and visualized.

For testing purposes a tablet and up to four smartphones were used. The tablet was a Samsung Tab S2 running Android Version 7. The system was mostly tested with smartphones of the type Samsung Note 8 running Android Version 9 but also a Samsung Galaxy S5 running Android Version 6 was utilized.

4. User Scenario

Our system focuses on encouraging people to work in a collaborative manner while exploring many different datasets. To show the use of our system we provide a scenario that follows a fictitious group of three data analysists, Alice, Bob and Chris. We will describe how our framework can be used by following this team through their analysis task and show how the system will support the different collaboration phases occurring during group work. In this scenario they will investigate the energy management of different countries.

4.1. Joint Examination

The three analysists start their meeting, each bringing their own devices. Alice owns a tablet, while Bob and Chris both contribute a smartphone. First Alice places her tablet in the middle of the desk and positions six NFC tags around the device. Two NFC tags above the tablet, two underneath and one on each side of it, according to their designation. This setup can be seen in Figure 1. Then she launches the DDE app on her tablet to initiate the grouping process. To quickly establish a connection between the devices and prevent the users to perform difficult interactions, the Android feature Wi-Fi-Direct was implemented. So all devices running the DDE app are connected directly to each other via Wi-Fi and are able to exchange messages.

To start their exploration Alice loads the dataset describing the total energy production of different countries. Since Alice wants to get an overview over the data, she chooses the Choropleth Map to show the energy production of different countries. For each year, which is provided in the dataset, a Choropleth Map is shown, but only one is shown at a time. To switch between the different years, Alice uses the gesture "dragging" from left to right, to increase time, or from right to left, to decrease time. Since the dataset starts with the energy values produced 1960, Alice uses a slider to jump to the year 2000. Then with a two-finger swiping gesture from right to left, she passes through the years from 2000 to 2005 to get an overview over the development of the energy production. Thereby it becomes clear, that the United States and China are the biggest energy producers.

As we can see, the team started with an exploratory data analysis phase, which was dominated by a joint examination of one shared view, where only one person, namely Alice, was interacting, while the other two team members were merely observing.

4.2. Adding Devices to the System

While closely monitoring the Choropleth Map on the tablet, it becomes apparent that the United States and China are producing the most energy. Bob therefore wants to investigate if both countries generate their energy with coal. So he plans to visualize the dataset coal consumption on two further devices to make a comparison possible. To add a new device, Bob takes his smartphone and places it on the NFC-tag left below the tablet. The device then automatically starts the DDE app. The smartphone further establishes a connection with the tablet and enters group-mode. Whether the device is in group-mode or not, can be detected according to the green or

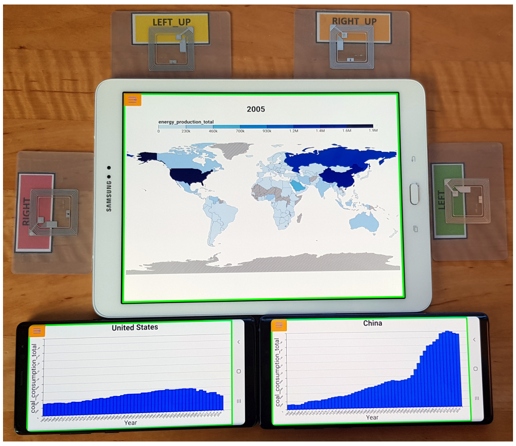

Figure 1: *This figure shows the setup of the DDE framework.*

red border around the visualization. In group-mode each filter operation can be propagated to all devices, being placed on the NFC tags, and the tablet. He then chooses a Bar Chart to visualize the data.

4.3. Value - Filtering across all Devices

The Bar Chart now visualizes the coal consumption of all countries for the year 1965. To get the data over all years only for the United States, Bob has to tap on the United States in the Choropleth Map. This gesture applies a new filter on every connected device. Therefore the smartphone then shows a Bar Chart where the coal consumption of all years is shown for the United States. To make a comparison between the United States and China possible, Bob adds a second smartphone on the NFC tag right next to the smartphone beneath the tablet.

4.4. Value - Filtering across one specific Device

To visualize the coal consumption of China on the right device, and not changing the Bar Chart on the left smartphone, Bob can use a drag gesture. When he presses China on the Choropleth Map and drags it to the right device, the filter is only applied for this respective smartphone. To facilitate the selection of the devices, a colored margin indicates, which one is currently selected as destination. Now the smartphones both show the same dataset for different countries and make a comparison possible. Bob can tell that China has a higher consumption of coal over the years then the United States, as can be seen in Figure 1. As it can be seen, the DDE tool enables users to minimize the cognitive load by increasing the screen workspace.

On the basis of this findind Alice asks herself the question, if that much coal is used for the energy production, who is the biggest polluter worldwide?

4.5. Rearrengement of Devices

To answer this question, Alice takes the device lying right below the tablet and repositions it to the NFC tag left above the tablet. The device automatically propagates its new position to all other devices and enables group-mode. So receiving input for filtering is possible from all neighbouring devices. Alice loads the dataset CO2 emission per person on this device and selects a Bar Chart for the visualization. Since she wants to examine the CO2 emission value of all countries in the year 2005, she drags the year 2005 on the Choropleth Map to this device.

4.6. Parallel Examination

Since many countries are visualized on the small screen of the smartphone, Alice wants to explore the data in more detail. To locate the country with the highest CO2 emission, she lifts the device up to disable group-mode, which can be seen by an emerging red margin around the visualization. So Alice can interact with the visualization without unintentionally propagating any filter values to the other devices. Now she zooms into the Bar Chart with a pinching gesture and explores the data by a panning gesture. She taps on the bars and a reference line visualizes the height difference of the bars. So visual support is given to the user to facilitate comparison between the bars. During the exploration it becomes apparent that the country Quatar produced the most CO2 pollution.

This scenario shows that individual exploration, where little communication occurs can be handled by the DDE system. The participants receive time to think and can investigate the data with individual devices by themselves.

4.7. Re-joining the Group

Since Alice found the biggest polluter, she re-joins the group by just placing the smartphone on the NFC tag again. After the device is successfully connected to the group again, which can be seen by the green margin around the interface, further filters can be propagated to the other devices again. The exploration that Qatar has much higher CO2 emissions than the two biggest energy producers, China and the United States, indicates that there is no direct correlation between the energy production and the emitted CO2.

Due to the DDE framework, Alice, Bob and Chris come to the conclusion that the statement claiming, a higher energy production inevitably leads to an increase of CO2 emissions, does not always hold true.

5. Conclusion

As illustrated by our prototype, the DDE framework offers a promising approach for visual analysis in practice. Since our system supports collaborative workflows, analysing multivariate datasets in groups is supported. The system also automatically adjusts to a growing or shrinking number of contributors and connected devices. Furthermore the DDE framework is inexpensive and not bound to a specific place, since it is built out of mobile devices, which are small, lightweight and universally available. But location independence is not only given through the used devices, but also the tracking system realized through NFC tags, supports this characteristic and makes spatial awareness between the devices possible.

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