Proceedings of the Workshop on Data Exploration for Interactive Surfaces (DEXIS 2015)

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Proceedings of the Workshop on Data Exploration for Interactive Surfaces DEXIS 2015

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Abstract: By design, interactive tabletops and surfaces provide numerous opportunities for data visualization and analysis. In information visualization, scientific visualization, and visual analytics, useful insights primarily emerge from *interactive* data exploration. Nevertheless, interaction research in these domains has largely focused on mouse-based interactions in the past, with little research on how interactive data exploration can benefit from interactive surfaces. These proceedings represent the results of the DEXIS 2015 Workshop on Data Exploration for Interactive Surfaces. It was held in conjunction with the ACM International Conference on Tabletops and Interactive Surfaces (ITS) in Funchal on the island of Madeira, Portugal, on November 15, 2015.

Key-words: interactive tabletops and surfaces, visualization, data exploration

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Résumé : Les tables et surfaces interactives sont conçues pour offrir de nombreuses possibilités en termes de visualisation des données et leur analyse. Dans la visualisation d'information, la visualisation scientifique et la visualisation analytique, une bonne compréhension émerge principalement d'une exploration *interactive* des données. Néanmoins, dans le passé, la recherche en interaction dans ces domaines a surtout porté sur des interactions basées sur la souris, avec peu de recherches sur les avantages des surfaces interactives. Ce rapport de recherche comprend les résultats du DEXIS 2015, un atelier de travail portant sur l'exploration de données avec des surfaces interactives. Il a été tenu en conjonction avec la Conférence Internationale de l'ACM sur Tabletops and Interactive Surfaces (ITS) à Funchal sur l'île de Madère, au Portugal, le 15 Novembre 2015.

Mots-clés : tables et surfaces interactives, visualisation, exploration de données

Contents

1 Preface by the Organizers

By design, interactive tabletops and surfaces (ITS) provide numerous opportunities for data visualization and analysis. In information visualization, scientific visualization, and visual analytics, useful insights primarily emerge from an interactive data exploration. Nevertheless, interaction research in these domains has largely focused on mouse-based interactions in the past, with little research on how interactive data exploration can benefit from interactive surfaces. We assert five apparent benefits of interactive surfaces for visualization systems:

1. As interactive surfaces become part of our everyday environments, they provide new ubiquitous data analysis platforms in which data can be accessed and analyzed anywhere and at any time (e. g., on mobile phones and tablets, in meeting rooms, or on public surfaces);
2. Interactive surfaces offer research opportunities on novel interaction paradigms that can improve data exploration experiences or encourage alternative forms of data exploration;
3. Novel visualization designs and interactions promote the use of visualizations by a broad range of people;
4. In particular, large interactive surfaces offer the possibility of depicting and interacting with much larger visualization spaces than possible previously; and
5. As data analysis is increasingly turning into a collaborative process, interactive surfaces offer novel research possibilities on dedicated collaborative visualization platforms.

While the combination of interactive surface technology and visualization research promises rich benefits, much remains to be learned about the effects of supporting a visual data exploration experience on interactive surfaces. For instance, we need to learn more about (a) how to re-design desktop- and mouse-based systems for alternative forms of input, (b) what motivates people to explore data using novel vs. traditional interfaces, and (c) how novel input modalities change the ability of people to understand data and draw insights from it. In addition, interactive surfaces often come in the forms of larger or screens, more screens, higher resolutions, sometimes less accurate inputs, and multiple simultaneous inputs, all of which create additional challenges for visualization designers.

At DEXIS 2015, we brought together researchers and practitioners from all sub-fields of visualization including scientific visualization (SciVis), information visualization (InfoVis), and visual analytics (VAST) as well as the related field of human-computer-interaction (HCI) to discuss and shape the field of visualization and analysis on interactive surfaces. We discussed ongoing research, exchanged experiences about challenges and best practices, and identified open research questions. In these proceedings we collate the knowledge gathered during and after the workshop in order to contribute to the future research in the field.

1.1 Keynote – Sheelagh Carpendale

Sheelagh Carpendale from the University of Calgary, Canada, was the invited keynote speaker for the workshop. Her talk was entitled “InfoVis on Large Displays” and was an experience report of her past research that set the stage for the rest of the workshop. In her talk, Sheelagh discussed three topics that are at the forefront of her thinking when she is considering visualizing information on large displays. One is the importance of the combination of size plus resolution that matters for these displays. To make this point, she discussed one of her initial inspirations: how David Hockney’s great wall (a whole wall in his studio that he covered with a timeline of reproductions of great art), led re-discovery of the use camera-lucida in renaissance painting, and how he has talked about how immersion in this large display led to his inspiration. In confirmation of this, Sheelagh and her team's recent study on the use of a high resolution large display led to similar findings. People from a great variety of disciplines were finding inspiration from immersion in their data. The second point she made was about how we use sketched externalizations to help ourselves during problem solving, particularly collaborative problem solving. The important point here is that the fluid combination of gestures, diagrams, and words are not yet supported with software and may hold much promise for effective use of large displays. Sheelagh closed with the third point, which is about the importance of a more holistic approach. Sheelagh argued that we need to consider the individual discoveries in combination. She stated that we, as a research community, are making lots of specific detailed discoveries in regards to large displays; however, we need to think about how they can be integrated, how they can work together. This more holistic approach, Sheelagh closed her talk, might help us formulate a paradigm for large display interaction.

1.2 Workshop Sessions

We organized discussions at DEXIS along five main topics for which representative papers are collected in the main part of this proceedings compilation:

1. InfoVis frameworks for multi-user, multi-screen, and multi-device environments,
2. situational awareness using large displays,
3. responsive visualization for touch-enabled devices,
4. information visualization for mobile devices, and
5. casual geo-visualization on interactive surfaces.

The authors of each paper were asked to set their work in relation to the topics in a brief position statement. After these presentations, we discussed the topic in break-out groups and then summarized the discussion in the plenary.

Blumenstein (see the paper on page 7) brought up various challenges related to the design and implementation of frameworks for InfoVis and SciVis that could support multi-user and multi-device collaboration. In an open brainstorming exercise we collected technical challenges surrounding multi-user and multi-device collaboration as well as various domains that such frameworks could help with. Other breakout group discussions focused on what kind of interactions could be performed between multiple devices for interactive exploration and visualization.

Onorati (see the paper on page 12) provided an overview of an emergency response scenario with challenges for interactive data visualization on large displays. Participants were asked to identify strengths, weaknesses, opportunities, and threats when designing interactive visualizations for emergency response scenarios using a SWOT analysis technique.

Tabard (see the paper on page 16) presented R3S.js, a toolkit that addresses responsive visualization for tactile interfaces such as tablets and large screen displays. For his group activity, the workshop participants were split into three groups to explore the design of surface visualizations: (a) sketching/envisioning surface viz (including with lay people in a participatory way), (b) prototyping surface viz (i. e., rapidly test ideas, scenarios), and (c) developing surface viz applications.

Langner (see the paper on page 20) motivated the need to have a consistent multi-touch interaction framework that is useful for multiple domains as well as for multiple visualization techniques. The discussions were focused on various challenges with such a unifying framework and breakout discussions were focused on InfoVis, SciVis, and interaction challenges.

Nagel (see the paper on page 24) presented his group's work on interactive geo-visualization in casual settings such as museums and libraries. His session focused on reflection: He provided a handout to each participant and asked them to reflect on a personal project and list the inspirations, other work that emerged from it, and trajectory/impact of the project. Examples of these sketches were then presented and discussed in front of the workshop participants.

In the discussions following these papers we identified a number of challenges for research at the intersection of ITS and visualization. These include different types of users and their domain-specific tasks, interactions, and visualization requirements as well as different types of collaboration settings. For example, the use of a touch-enabled mobile surface as a remote interaction tool for visualization was discussed, for several application domains and tasks as well as the resulting implications for how the interaction on the mobile device needs to be realized. These challenges had been specifically mentioned in the presented papers.

1.3 Acknowledgements

We would like to thank all paper authors and participants of DEXIS 2015 for their excellent contributions and lively discussions. The exchange showed that data exploration on interactive surfaces is an exciting area of research that offers great potential.

Petra Isenberg, Bongshin Lee, Alark Joshi, and Tobias Isenberg
DEXIS 2015 Organizers

1.4 Copyright Notice

Cross-Platform InfoVis Frameworks for Multiple Users, Screens and Devices: Requirements and Challenges

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ABSTRACT
To improve the interactive visualization and exploration of the fast growing amounts of data, collaborative and multi platform systems will get increasingly important. To focus on future challenges of Information Visualization and Visual Analytics, we describe three prospective data exploration scenarios: 'Multi User', 'Multi Screen' and 'Multi Device'. In relation to these scenarios, we define a basic set of requirements to design and build such systems in the future. Finally, we elaborate on a set of challenges in this context which have to be solved for such data exploration systems in the future.

ACM Classification Keywords
H.5.3 Group and Organization Interfaces: Collaborative computing, Computer-supported cooperative work, Synchronous interaction; H.1.2 User/Machine Systems: Human factors, Human information processing

Author Keywords
Information visualization, cross-platform, framework, future scenarios, multi user, multi screen, multi device

INTRODUCTION
Visual interfaces, especially Information Visualizations (InfoVis), are high bandwidth gateways for perception of structures, patterns or connections hidden in the data. Interaction is the heart of InfoVis [19] and allows the analytical reasoning process to be flexible and react to unexpected insights.

In recent years, InfoVis takes essential steps towards the mass market (e.g., through infographic websites like Daily Infographic[1] or Infographics collected on Pinterest by mashable.com[2]).

However, the main target group in information visualization research has been expert users for a long time. But InfoVis is as much of importance for the informed citizens as it is for expert users. Pousman et al. [13] introduced the term Casual Information Visualization which complements traditional research in InfoVis with a focus on less task driven activities and a wider set of audience. As pioneers in the field, Wattenberg and Viégas developed the web portal Many Eyes[3]. With this project a broader public receives access to visualization tools [14].

In contrast, especially this broader audience uses a wide range of devices. Screen resolution differs from 320 x 240 pixels to 1920 x 1080 pixels (HDTV resolution) up to 4640 x 1920 pixels (powerwall resolution) [14]. However, target devices for traditional expert visualization research were mainly desktop computers.

To be prepared for the future, cross-platform frameworks become increasingly important. With these frameworks it should be possible to build interactive InfoVis for different devices, different screen resolutions (sizes) and different operating systems.

Based on established Beyond Desktop initiatives and workshop (e.g., [10, 17]) as well as the found challenges for Visual Analytics (VA) by Thomas & Kielman [20] (Collaborative analytics, Scale independence, Information sharing, Lightweight software architecture) we describe future scenarios for interactive visual data exploration.

RELATED WORK
A lot of frameworks and toolkits are offered for developing InfoVis applications (e.g., D3.js[4], Prefuse [4], TimeBench [16]. They provide data import/storage solutions and often a variety of widely used visualization techniques. However, none of them handle touch gestures which are needed for mobile devices or cross-platform deployment out of the box.

The Tulip 3 Framework by Auber et al. [2] comes with Tulip Graphics, a complete OpenGL rendering engine which was "tailored for abstract data visualization". The framework is "efficient for research prototyping as well as the development of end-user applications" [2].

In 2013 Isenberg & Isenberg [7] published a survey article for visualization on interactive surfaces. They have systematically

[1] http://www.dailyinfographic.com, accessed August 06, 2015.
[2] https://www.pinterest.com/mashable/infographics/, accessed August 06, 2015.
[3] http://www.ibm.com/software/analytics/many-eyes/, accessed August 06, 2015.
[4] http://d3js.org, accessed August 06, 2015.

analyzed 100 interactive systems and tools for small and big displays. The overview shows that most research projects work with Multi Touch Table Top devices. They found "displays ranging from 3.7" in the diagonal up to 283"" [7] which shows the wide range of different screen sizes.

Jokela et al. [8] concentrated on collaborative interaction and the connection between devices for this propose which is a "complex technical procedure".

Based on the afore mentioned tools and papers we found out that there is a need for frameworks which supports cross-platform compilation and touch gestures, although currently such frameworks are not commonly used in the InfoVis community.

DATA EXPLORATION SCENARIOS

This section presents three different usage scenarios of future interactive visual data exploration. Each scenario gives the user various opportunities to interact with the data on different devices, to collaborate with other users or both. Additionally, these three scenarios can be combined and/or adapted to other working areas.

Multi User

In many business cases or in science, it is very helpful to cooperate during data exploration. This opens the possibilities to share the expert knowledge and to learn from each other.

Let's think about the managing board of a company. Normally, the members receive reports from different departments which show productivity, sales, profit, maybe the cash flow and many more. One major problem is, that users can not dig deeper into the data to gain more insights. In the case of a paper (or simple presentation), interesting and helpful insights for the creation of new business strategies could be lost or overlooked.

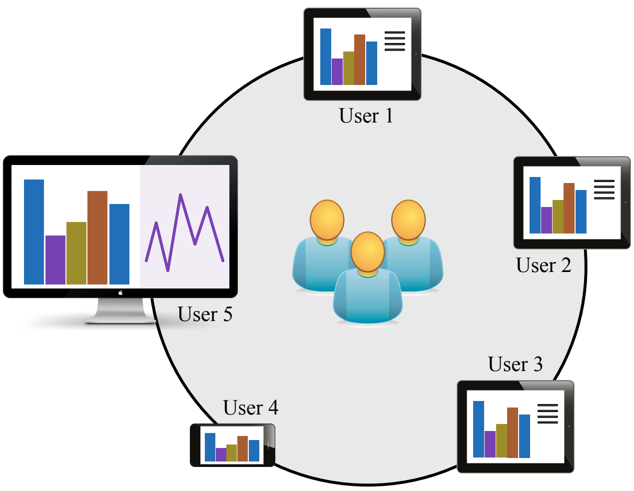

Figure 1. Shows a 'Multi User' scenario for collaborative data exploration working on the same dataset with combined expert knowledge.

In this future scenario, we present a new cooperative setting which supports 'Multi User' data exploration. Each member of the management board of the company has the same data set on his mobile device or notebook. On the one hand, they only have to share the interaction commands to each other which lowers the needed bandwidth for a faster immediate feedback. On the other hand, each device which is used in this setting has to have enough power to prepare the data fast enough. Therefore, all the devices should be connected by a server-client or peer-to-peer network architecture for the data transfer, whereby it is not necessary that all users are at the same place (see Figure 1). If a user filters the data on his/her own device, the other users could see this on their own device too, however they have the ability to accept, to ignore or to follow the changes of each other. This way, the users can share and combine their different expert knowledge for the data analysis.

Multi Screen

In the situation of live presentation of results or data in business or science, it can be very helpful to use more than one screen for the visualization of the exploration results.

Let's think about the (internal or external) presentation of the results of a research group. Each researcher presents his/her results in front of his/her colleagues or an expert group. Therefore, most of the time the presenting researcher uses a simple presentation or shows the data directly on a research prototype.

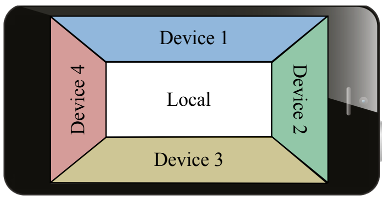

Figure 2. Provides an example for the configuration of the active edges for the 'Multi Screen' setting.

This future scenario indicates a novel presentation approach for the interaction with the data on more than one screen. Therefore, we introduce the active edges technology. Based on this new idea, it will be possible to connect up to four additional screens (of other devices) to your own presenter device. Each screen will be connected to one edge of the 'main' device (see Figure 2), so it will be possible to move visualizations onto a screen by using a swipe gesture into its assigned edge (see Figure 3) nearly similar to the Pick-and-Drop operation which was described by Rekimoto [15] in relation to interactive whiteboards.

Figure 3. Shows an example for the swipe gesture in combination with the active edges for a 'Multi Screen' setting.

In the first step, the presenter has to link the screens which have to be connected to his/her device. This connection will be established via a server-client or a peer-to-peer network architecture which is similar to the 'Multi User' scenario. In the second step, the presenter has the ability to swipe different explored datasets to the connected screens. This way, it will be easy to show the audience the results and to interact with them if there are questions which need detailed explanation of the presented datasets. Additionally, it will be possible to include linking & brushing between screens, use them like small multiples or focus & context [9, 14].

Multi Devices

Nowadays, most of the people are working on more than one device (e.g., smart watch, mobile phone, tablet, notebook) at a time, to get their work done (see Figure 4). In this case, it could be very helpful to keep the data and the included filtering and zooming settings synchronized between these devices (basically similar to iCloud Tabs[5]).

Let's take a closer look on the workflow of a data analyst in this future scenario. If the analyst works in his/her office, he/she has a desktop computer or a notebook to do the analysis. But, if the analyst will go to a meeting, it would be very convenient to use only a tablet which contains (or has access to) the same data exploration state as the other device in the office. This way, it will be possible for the analyst to bring the current results with him/her and to present these results to the colleagues.

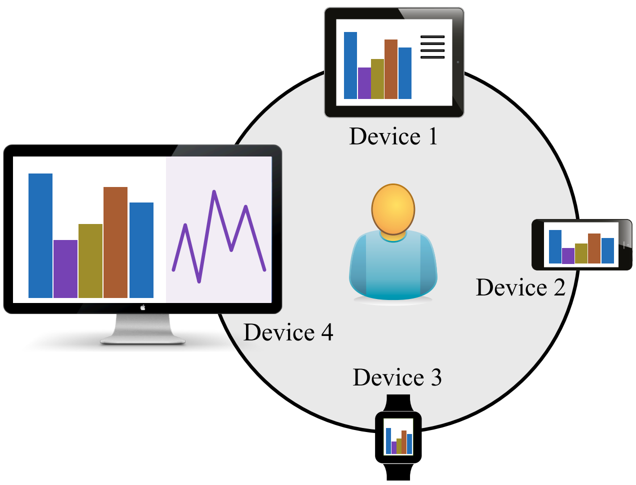

Figure 4. Gives an overview of the different devices which can be used for interactive data exploration together by a single user.

To get this setting done, it will be necessary to be online with all devices or at least with the current device which will be used at that time. This will be used to synchronize the data and the settings (exploration history) with a server or directly with the other devices depending on the network architecture. Additionally, in this setting, it will be very easy to work remotely when necessary in order to improve the work-life-balance. So it will be possible to explore and analyze the data during the travel per bus or train. If there is a beautiful day, it is also possible to work in the park for some hours and if you go back to your office, all the results are 1:1 transferred to your desktop computer.

[5]https://support.apple.com/en-us/HT202530, accessed August 06, 2015.

REQUIREMENTS

In 2011, Landesberger et al. [21] stated that "the development of collaborative visual analytics systems has received attention". Nowadays, there are many different devices (e.g., notebooks, tablets, mobile phones, smart watches) available which have different operating systems, screen sizes or screen resolutions. In our former presented scenarios, all these different devices could be used for InfoVis. Therefore, it is important to build a cross-platform environment and to think about two major issues in relation to the framework. First, the framework should be based on the well established InfoVis reference model for a better understanding in the InfoVis community (see Figure 5) [3] including an adaption for the support of cooperative data exploration. Second, the framework has to be based on an cross-platform engine which supports the building for different devices and operating systems. To increase the effectiveness of such a future framework, it might be a good choice to use a render- or game-engine like Unity3D[6], Cry Engine[7], Unreal Engine[8] or OGRE[9]. All these engines supports cross-platform compilation (to several devices) which opens up new possibilities for the future. To grant the ability to use all provided features of the devices, it is important to point out that we do not focus on web based solutions.

To increase the user experience the following multi screen pattern should be implemented [6, 12]:

- **Screen Sharing** addresses the way to combine multiple screens to a larger one.
- **Complementary Views** for collaboration between different devices whereby every device gets a specific role to fulfill an InfoVis task.
- **Device Shifting** depends on the collaboration between different devices which are close together. Devices can communicate with each other (e.g., switching the screen).
- **Coherence** contains the finding of suitable use cases for every device. Therefore, design and usability has to fit to the device and has to be consistent over different screen sizes.
- **Synchronization** should provide the possibility for changing work from one device to another conveniently.

CHALLENGES

The creation of such mentioned systems for interactive visual data exploration opens up some interesting challenges in relation to interaction and collaboration, new frameworks, system architecture and data synchronization. In relation to

[6]http://unity3d.com/, accessed August 06, 2015.
[7]http://cryengine.com/, accessed August 06, 2015.
[8]https://www.unrealengine.com/what-is-unreal-engine-4, accessed August 06, 2015.
[9]http://www.ogre3d.org/, accessed August 06, 2015.

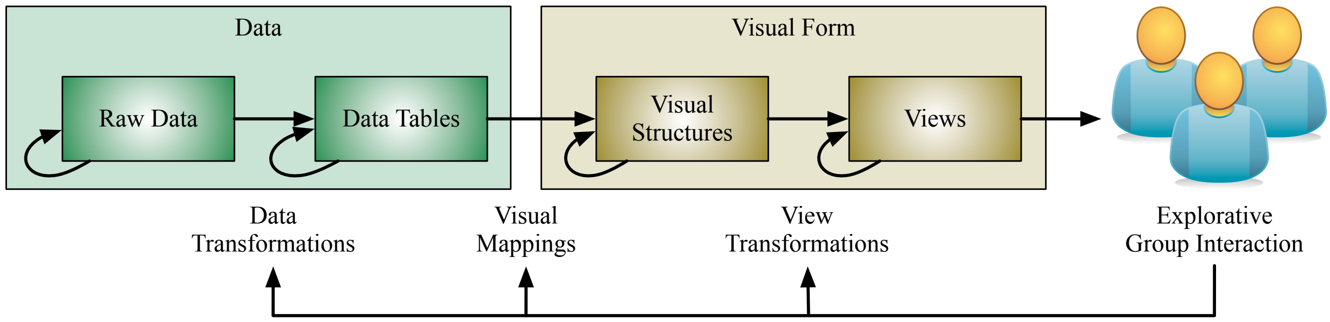

Figure 5. InfoVis Reference Model. Adapted from [3] including an extension for group interaction in relation to the interactive data exploration process.

the described three different scenarios, we defined the major challenges which have to be solved for the creation of such cross-platform environments.

- **Collaboration:** "For solving complex analysis tasks" the "development of collaborative visual analysis systems" becomes more and more important [21]. Based on such systems, it will become easy for the users to share their knowledge and to cooperate during their work to find the best solutions for their problems/tasks [11].
- **Different platforms:** From the view of different available systems, it is important to create new development frameworks which include the possibility for cross-platform compilation (e.g., mobile devices and desktop solutions) and different operating systems (e.g., Mac OS, Linux, Windows). This way, it will be possible for the user to choose the preferred device to solve his/her problem [1, 5].
- **Synchronization:** Most of the time, InfoVis deals with a huge amount of data whereby a permanent transfer of the analysis data would not be efficient. To overcome this limitation, an initial data synchronization with all the devices followed by interaction synchronizations could be used. Therefore, each interaction should have a time-stamp, a user-id and an interaction type. The major benefit of this synchronization would be that devices with bad network connections could be used in spite of the mentioned limitation (e.g. [12]).
- **History:** Based on the previously described synchronization approach, it will be possible that every device which is connected to the 'network group' has the same history in the backlog. Thus, it will be easy for the analyst to change his device during the work. Additionally, it will be possible to support undo and redo actions on each device which is synchronized [18].

CONCLUSION

In this paper we presented three different combinable scenarios for 'Multi User', 'Multi Screen' and 'Multi Device' settings in the future and we roughly outlined the requirements for these systems. These requirements include examples for future cross-platform frameworks and patterns which will be needed for the native deployment of InfoVis systems. According to the requirements, we identified four challenges which have to be solved in combination for such interactive data exploration systems. Similar challenges were identified by Thomas & Kielman [20] in 2009 which have however not been solved yet.

ACKNOWLEDGEMENT

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WallTweet: A Knowledge Ecosystem for Supporting Situation Awareness

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ABSTRACT
We present WallTweet, a tweet visualization designed for wall displays and aimed at improving the situation awareness of users monitoring a crisis event utilizing tweets. Tweets are an important source of information during large-scale events, like tornados or terrorist attacks. Citizens in affected areas are often direct witnesses of the situation, and can be aware of certain details useful to, e.g., news channels and emergency response organizations. Yet, tweets are hard to visualize and put in a geographical context: large quantities of tweets get sent in a short period, that vary greatly in content and relevance with respect to the crisis at hand. Our visualization tool is currently a work in progress: it addresses these challenges by performing a semantic analysis of the tweets' content and displaying them on a ultra-high-resolution wall display. The goal of our tool is to create an inclusive experience that enhances users' situation awareness during a crisis event, by displaying geo-referenced tweets in detail, embedded into the more global geographic context of the event.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

Author Keywords
Tweet visualization; wall displays; crisis monitoring.

INTRODUCTION
We are currently working on a geographic visualization tool called WallTweet that visualizes a knowledge ecosystem built from the analysis of information collected from Twitter during a large-scale event. WallTweet's goal is to improve the situation awareness of people involved in crisis monitoring through

Figure 1. Clusters of tweets labeled by the most relevant words.

integrated details and overview visualizations for ultra-high-resolution wall displays (see Figure 1).

The datasets underlying WallTweet are tweets (brief textual messages) collected from Twitter during a crisis event and then analyzed. These datasets are becoming more prevalent as the wide availability of modern smartphones with photo, GPS, and video capabilities has led citizens to actively report on crisis events [15]. It is now very common that, when an emergency occurs, citizens start to share information about the situation, not only as witnesses, but also driven by curiosity. For example, YouTube lists more than 1 million amateur videos for the search terms *tsunami* and *Japan*. Another prominent example is the use of social networks during Hurricane Sandy. As published by the official @*twitter* account on November 2nd, 2012: *"people sent more than 20 million tweets about the storm between Oct 27 and Nov 1."* This in turn means that tweets have become an interesting source of information for various people involved in crisis monitoring, such as journalists or crisis operators [6].

As data generated by citizens become more and more useful during emergencies, it is increasingly important to support the active tracking and analysis of these data. With WallTweet, we aim to contribute a tool that is useful and effective during real-time crisis monitoring. The tool relies on a geographic map of the monitored crisis event. Several visualization techniques are used to provide local detail in a global geographic context, in order to support situation awareness. All tweets are analyzed according to their semantic context. Figure 1 shows one of the visualizations we are currently developing: tweets are geographically included into clusters and semantically analyzed to identify the most relevant topic. In its current stage of development, WallTweet works on offline data, and as such is useful for understanding and analyzing – in retrospect – how emergencies have unfolded. Our test dataset contains about 500,000 tweets collected during one of the most critical days of the Hurricane Sandy crisis. Our goal is to first finalize the main visualizations, perform a user study, and then extend the tool to enable live updates during a crisis event.

INFORMATION VISUALIZATION FOR TWITTER

Twitter is a micro-blogging platform created and launched in 2006. Official statics published on June 30, 2015 on `about.twitter.com/company`, indicate that this social network has reached 316 millions active users per month and that 500 million tweets are sent each day. Tweets focus on different topics, including personal feelings, events of general interest, and daily news [5]. Shared information can be seen as an interesting source for discovering what is going on and what the opinions of involved witnesses are.

Considering the amount of generated data on Twitter, a question arises: is it possible to efficiently access and analyze tweets? Different visual analytic tools have been described in the literature, that take advantage of data collected from streams of information, like social networks or blogs.

The Visual Backchannel [3] is an innovative tool for monitoring micro-blogging platforms during large-scale events using different visualization techniques. Each technique aims at emphasizing a particular aspect of the data: a streamgraph for visualizing topic evolution over time; a helical graph of the most active users participating in the discussion; a list of tweets; a cloud of all published images.

Steed et al. [12] proposed a system called Matisse for automatically extracting emotions from the text messages and relating them with other measures, such as frequency of contained terms, time range and geographical coordinates. All these data are combined through three visualization techniques: a timeline, a streamgraph, and a map. With this system, it is possible to have a general understanding of how people feel about a specific event and from where they are posting.

Based on the same idea, Zimmerman and Vatrapu [16] built a prototype that combines information from different social media channels into six different dashboards. Three of them present general offline statistics about most relevant topics, sharing activities, *likes* from other users, and most active contributors in the networks. The other three dashboards are about the real-time evolution of the same information. Following the same direction, Hao et al. have focused on identifying customer opinions and possible useful patterns from tweets as influences on the market [4].

In order to understand the current experience of emergency managers and practitioners with social media, authors in literature have been contributing with the design of several user studies. This is the case of SensePlace2 of MacEachren et al. in [7] and ScatterBlogs of Thom et al. in [13]. In both contributions, participants involved in the evaluation agree on the relevance that social media have in today's crisis, suggesting also several issues to take into account for designing a tool for analyzing them, as for example the privacy or the adaptability to a specific situation.

All of the above systems are aimed at better supporting the understanding of how information propagates, and peoples' sentiments, when a large-scale event occurs. We are not aware of any visualization of tweets for high-resolution wall-sized displays. However, researchers have worked on the design of multi-surface interactive environments for crisis management centers, involving multiple devices such as tablets, smartphones, and both horizontal and vertical large displays [2]. In particular, the wall display's purpose is to give an overview of collected data from Twitter about the incident. The visualization relies on the Folding View technique, that distorts the information space depending on where the user's attention is directed. If users need more detailed information, a tablet or a smaller device is required.

THE KNOWLEDGE ECOSYSTEM

A Knowledge Ecosystem is defined by Thomson as a *"complex and many-faceted system of people, institutions, organizations, technologies and processes by which knowledge is created, interpreted, distributed, absorbed and utilized"* [14]. The Knowledge Ecosystem used within WallTweet is the result of a semantic similarity-based approach for analyzing text, already presented by Onorati and Diaz [10]. It consists of four different steps: (i) query Twitter for one or more keywords; (ii) perform a syntactic analysis of collected tweets for extracting nouns, where nouns are considered the most meaningful elements in a speech; (iii) filter extracted nouns, identifying the relevant ones by comparing their frequencies with a domain ontology about emergency; (iv) perform a semantic analysis of filtered terms, associating each one with a fixed category. Categories have a semantic value; they help in organizing the tweets depending on their correlation with *Emergency*, *Evacuation*, *Media*, *Hashtag*, *Place*, *Time* and *General*. All these data, including tweets, extracted terms, frequencies and categories, are visualized in WallTweet using different techniques, as described in the next section.

In this work, we have applied this mechanism for collecting information from the Hurricane Sandy dataset. While at the end of the hurricane crisis more than 20 million tweets were published, we currently work with a subset consisting of almost 500,000 tweets. These tweets are the result of querying keywords *hurricane* and *Sandy*, as well as hashtags *#hurricane* and *#sandy* during the first 24 hours of the hurricane hitting New York bay on October 29. During the semantic analysis, almost 24,000 nouns were extracted, successively filtered and reduced to 5,500.

WALLTWEET

Emergency operation centers usually work with a large display showing a map visualizing the current position of officers on duty, temperature, traffic information, etc. Inspired by this setup, we use a wall displays that shows a geographic map

Figure 2. The three proposed views: (a) *Global View*, (b) *Semantic View*, (c) *Time Sequence*.

of the hurricane twitter data. Our goal is to explore different options for helping operators in finding an answer to questions about the most affected areas, the number of people involved, the range of damages, or the effects of the rescue activities.

The Knowledge Ecosystem described above runs on the WILDER ultra-high-resolution wall, that consists of 75 narrow-bezel LED tiles (960x960 pixels each, 60ppi) laid out in a 15x5 matrix, 6 meters wide and 2 meters high for a total resolution of 14,400 × 4,800 pixels. WILDER is driven by a cluster of 10 computers, each equipped with high-end graphics cards, and a master workstation. The platform also features multiple input capabilities, including a multi-touch frame, real-time motion tracking, and handheld devices. WallTweet is built upon jBricks [11], a Java toolkit for rapidly prototyping multi-scale interfaces on cluster-driven wall displays.

Ultra-walls (short for *ultra-high-resolution wall displays* [9]) make it possible to visualize much larger volumes of data compared to earlier projector-based wall displays, whose pixel density is lower. Ultra-walls support the display of large datasets with a high level of detail while retaining context. They afford multi-scale interaction through physical navigation [1]: users can move from an overview of the data, to the fine details of a specific area simply by walking in front of the wall.

WallTweet offers three main views: *Global View*, *Semantic View* and *Time Sequence*. In the *Global View*, geo-located tweets are represented by geographical points over a map. Each point gets assigned a background color depending on the semantic category of the terms contained in the tweet (Figure 2-a). This view also includes a bubble chart representing the most relevant terms extracted from the dataset. Analyzing this view, we can see that the most discussed topics are related to the emergency description, and the majority of the tweets are distributed around big cities, like New York City, Baltimore, Washington and Boston. This can indicate densely populated areas, and areas that have been impacted most by the hurricane. Knowing where these areas are located is a crucial information for emergency operators in charge of making decisions about where to allocate resources.

The *Semantic View* combines two different visualizations (Figure 2-b): a geographical clustering and a tag cloud. The clustering consists of groups of tweets that are geographically close. To identify these clusters, we apply the *concave hull* algorithm [8], that associates each point with its neighbors at a distance that has been determined empirically. For each cluster, tweets are semantically analyzed based on the Knowledge Ecosystem described earlier, in order to identify the most relevant terms and use them as labels. As in tag clouds, the labels' font size depends on their relevance with respect to the defined Knowledge Ecosystem. This view thus gives an idea of the semantic distribution of terms with respect to their geographical position.

The last view, *Time Sequence*, is an animated visualization in which each tweet falls from the top of the display and is added to the map at the time of its posting on the social network. Clusters are updated once the tweet reaches its geographical position. Figure 2-c illustrates the visualization after new tweets have fallen on the map, showing that both the labels' font size and the clusters have changed. Each cluster has its own label (indicating the topic) and is painted with a specific color to make it easier to distinguish. If used in real-time, this dynamic visualization of how published content evolves over time can help emergency operators or media centers to get an idea of how people are reacting to the emergency, and taking these reactions into account to inform future decisions.

DEVELOPING VISUALIZATIONS FOR WALL DISPLAYS

The benefit of using a large surface with a ultra-high resolution is twofold. First, its large size enables multiple users to work together in a shared workspace, thus making the monitoring exercise and the collaboration among them easier. Second, as mentioned earlier, the very-high pixel density enables users to look at the data at different levels of detail simply by physically moving in front of the display. Developing multi-scale collaborative visualizations that take advantage of these properties is not trivial, but we have started to make progress. For example, in our Semantic View, clusters can be seen at a distance from the wall, indicating pockets of activity, while when stepping closer users can also read details about the most discussed topics of each cluster. The map can also be smoothly zoomed in and out, in which case clusters get recomputed as the distance used by the concave hull algorithm to compute point neighborhoods is adapted to the new zoom factor. Interacting with the display, it is also possible to read tweets and compare them with the performed semantic analysis.

Walltweet can be seen as part of a more complex ecology of devices aiming at surrounding users – who have to handle crisis situations – with data, helping them explore those data and extract meaningful information from them in an efficient and timely manner. We believe that using wall displays in such an ecology can significantly improve users' situation awareness, and we are very interested in further discussing the associated challenges in this workshop.

CONCLUSIONS AND FUTURE WORKS

Social networks and other messaging services have drawn the attention of researchers and practitioners in media and crisis management. In social networks like Twitter, people share their opinions and experiences, generating vast quantities of data about a wide range of topics, including real-time information on crises that impact them. Visualizing this data in order to better understand and use it for decision making is a challenging topic in visual analytics and information visualization.

In this paper, we introduced a prototype system for analyzing and visualizing tweets generated during a large-scale critical situation, in order to support the monitoring activities of emergency operation and media centers. The main contributions of our approach so far are the combination of the semantic analysis of tweets and the use of a ultra-high-resolution wall display for visualizing its results. We are still at an early stage of this on-going project, called WallTweet. So far it consists of three different views: a generic view showing the semantic categorization of tweets on the map; a semantic view with geographical clusters of tweets, tagged with the most relevant terms associated with them; a time sequence that simulates the real-time posting of tweets on the map, the definition and evolution of clusters, and the varying relevance of terms.

Future work will focus on two different directions. First, we are going to evaluate WallTweet and its visualizations from both a domain and a usability point of view. We are currently planning a usability test as well as an expert evaluation with emergency practitioners. Second, we are going to make the system run in real-time, integrating it in an ecology of devices for achieving better collaborative sense making and higher situation awareness: including additional data sources such as digital sensors for tracking information about, e.g., pressure, temperature or traffic, and providing users with more elaborate capabilities for interacting with the wall display using devices such as smartphones and tablets.

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R3S.js – Towards Responsive Visualizations

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ABSTRACT
We present our preliminary work on R3S.js, a Javascript library supporting the development of Responsive Visualizations, i.e., Web visualizations adapted to the device they are displayed on. R3S.js is based on D3.js and brings the following contributions: 1. Handling of tooltips and especially their triggering on tactile devices; 2. Abstraction of input events to avoid dealing with mouse, touch or styluses separately; 3. Pre-defined media-queries to automatically control the size of graphical elements depending on the device size and resolution. And 4. Automated resizing of specific visualizations. We show how basic D3 line-chart and treemap could benefit from more responsiveness. And we conclude with a discussion on automated adaption of visualizations to devices' properties, and whether Responsive Web Design principles provide good adaptation strategies.

Author Keywords
Visualisation; adaptation; plasticity; Responsive Web Design; mobile; d3js.

ACM Classification Keywords
D.2.2. Design Tools and Techniques; H.5.2 User Interfaces.

INTRODUCTION
Since the beginning of the 1990's, digital devices of varied form factors and supporting various interaction modalities have emerged. User Interface (UI) adaptation mechanisms are an interesting strategy to avoid device-specific development [6]. Besides the devices themselves, adaption efforts started to also consider the environment and the users, i.e. the context of use, for instance with plastic UI [13].

More recently, with the commercial success of smartphones and tablets, Responsive Web Design (RWD) emerged as a simple approach to adaptation. Unlike richer adaptive approaches, RWD does not take into account the specificities of users or the environment but only devices' properties. RWD principles center mostly around fluid layout of Web pages on mobile devices, tablets, and computers screens. We can summarize the responsive approach to the following points[1]:

- Adapt the spatial layout to the screen size.
- Adapt images to the screen resolution (especially with ultra high fidelity displays).
- Simplify pages for mobile devices with low bandwidth.
- Make links and buttons clickable and touchable.

These principles are widely used for Web pages today and are starting to be adopted for images[2] and videos. Although they have been taken into account in Web-based information visualization, it is often in an ad-hoc manner. For example, the New York Times visualizations are often designed to handle touch. The approach consisting in designing first for devices with a small screen size and then extending to larger and more capable devices has been described in practioner conferences, for example by Gabriel Florit from the Boston Globe at OpenVizConf 2013[3] or Dominikus Baur at JSConfEU 2014[4].

Building on this previous work, we present our preliminary work on R3S.js, a library based on D3.js that facilitates the development of responsive visualizations. R3S.js helps developers to incorporate adaptation mechanisms in their visualizations. More specifically we bring four contributions:

1. Abstraction of input events to avoid dealing separately with mice, touch or styluses.
2. Management of tooltips, especially by providing means to have them pop-up on touch devices.
3. Predefined media-queries to automatically adjust the size of the main graphical elements (font, tooltips, and label size) to the size and resolution of the device.
4. Automated resizing of the visualization itself.

[1] Responsive Web Design Demystified, 2011, Matt Doyle, http://www.elated.com/articles/responsive-web-design-demystified

[2] https://www.w3.org/community/respimg/

[3] Gabriel Florit, 2013, On Responsive Design and Data Visualization, OpenVis Conf, https://youtu.be/BrmwjVdaxMM

[4] Dominikus Baur, 2014, Web-based data visualization on mobile devices, JSConfEU, https://youtu.be/X2ZlDrx6dAw

We discuss the challenges of making responsive visualizations, based on the case of a simple Treemap and a line-chart, and show how R3S.js could help. We conclude on whether Responsive Web Design mechanisms are suited for visualization.

RELATED WORK

While Responsive Web Design gained a lot of popularity, research on adaptation also proposed to leverage Web standards and emerging HTML standards, for instance using columns to let content flow on screens of various sizes [8], or to handle touch in a generic manner [9].

Mobile visualizations

Several examples of visualizations for phones [2] or large interactive displays [7] have demonstrated the relevance of touch devices to visualize and explore data. Regarding interaction, recent work such as TouchWave [1] or Kinetica [10], demonstrated that touch input could support understanding and create engaging experiences of data exploration. However, most visualization toolkits are still geared towards interaction with a mouse and keyboard. Zoomable visualizations lend themselves particularly well to adaption [5], but they nonetheless require specific adjustments.

In their survey of mobile visualizations, Sadowski and Heidmann [11] note that "*Tablets and smartphones are not only varying in size but are also providing new interaction methods or sensors which enable new design possibilities*", which suggests that adaptation could be about retargeting input and output modalities to other ones depending of their availability on different devices.

D3.js

D3.js[5] is a Javascript library sometimes referred to as a visualization kernel [4], in the sense that it provides the core functionalities to create novel Web based visualizations. D3 is based on the browser's Document Object Model (DOM), which enables developers to apply transformations to data Since D3 is based on Scalable Vector Graphics (SVG) and the DOM, scaling to different screen size is relatively straightforward. And the use of Web standards such as CSS makes it possible to modify graphical properties of visualizations. Nonetheless adaptation mechanisms are not offered by D3.js. This can be explained by D3 focus on offering rich control on the basic elements of interactive visualizations, rather than offering a library of ready to use visualizations. This motivates our work to offer alongside D3.js a library supporting the development of adaptive visualizations.

[5] http://d3js.org/

CHALLENGES IN DESIGNING RESPONSIVE VISUALIZATIONS

Based on the related work and our experience adapting a line-graph and a Treemap to various devices, we have identified the following challenges.

Variations in input modalities across devices

Touch devices have different input modalities than laptop or desktop computers. For instance, while a mouse scroll often controls zoom levels on computers, a pinch gesture is generally preferred on touch devices. Although the correspondence is well accepted for zooming, there is rarely a generic correspondence between a touch-based and a mouse-based interaction technique. For example, hovering with a mouse, is difficult to translate to touch devices. Different applications and operating systems handle this differently, either through a long touch, or quick tap or a gesture.

Besides interaction modalities, the form of the devices has an impact on possible interactions. Finger size is rarely a problem on large screens, but can become one on small mobile devices [3], where the hand or even a single finger can easily hide the points of interests.

Variations in displays

The main motivation behind RWD is to manage screens of various sizes and resolutions, i.e., the available display space. We separate display sizes into five broad categories: Large screens with a diagonal size larger than 27", desktop computers with a size of 19" to 27", laptops with screens ranging from 11" to 17", tablets between 8" and 11", and smartphone between 5" and 8".

Screen resolution can vary a lot and smartphones may have more pixels than a 55" touch screens. So relying on either screen resolution or screen size, or even a mix of the two such as pixels per inch (ppi), may not be satisfying. Text at a small size on a large screen with low resolution may become sharp but unreadable of a small screen with high resolution if proportions are preserved. For a given resolution, the smaller the screen, the smaller graphical elements will become. Some high-resolution devices (e.g. Retina devices) already offer a lower "virtual" resolution to simplify display management.

Finally, besides screen size and resolution, the width-height ratio of a smartphone, a tablet and a computer screen are often different.

Use cases

We studied two simple visualizations offered alongside the D3.js library to better understand the challenges of developing responsive visualizations. First, a line chart, presented the following challenges (see figure 1):

- The size of the line and the axes are not updated when the window is resized.
- The quantity of information displayed does not depend of the available screen space and its resolution. A line with lots of variations can

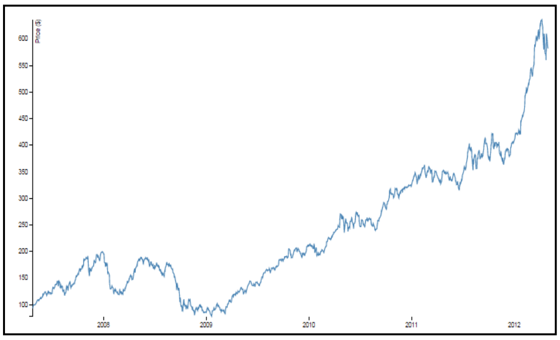

Figure 1. Timeline visualization offered with d3.js

become unreadable as they become squeezed horizontally.
- It is difficult to explore specific zones or points on the line.
- When adding interaction capabilities to the visualization, the "fat finger" problems appears.

Second, a Treemap visualization revealed several problems when displayed on different devices :

- Labels were displayed as the visualization loaded, and when no space was available they were not displayed. This is not a problem on large displays but quickly becomes one when most labels are not displayed.
- The layout of the rectangles is not adapted to the screen size.

R3S.JS

Based on the challenges and issues identified above, we have started to develop R3S.js[6] (figure 2), a library to ease the development of responsive visualizations. We present here our preliminary work on the library.

Event management

R3S.js offers a `ResponsiveEvent` class to bind callback functions to objects when an event is triggered. By default, `ResponsiveEvent` establishes a correspondence between mouse events and touch events. Since the default correspondence may not always be the most appropriate, it can be changed by extending the object. Depending on the use case, it can be better to use specific events rather than others, e.g. mouseover event can be associated to a touchenter in some cases, a touchmove in other cases or even a simple tap depending on the action triggered by the event.

Tooltip Management

Tooltips are a classical method to display extra information about points of interests while keeping the context visible. Mouse hovering often triggers Tooltips. But very few touch devices have the ability to detect finger moving over the surface. The `Tooltip` object makes tooltip use more

Figure 2. Adaptation of a Treemap visualization with R3S.js

straightforward by removing the need to handle different input event listeners. At the moment, developers still have to handle callbacks and dynamically assign the content of the tooltip related to the hovered object. This could probably be improved in future versions of R3S.js, so that the content of tooltips is defined with the object.

Media queries

Media queries enable developers to specify rules that change the CSS style of a page based on some conditions. Although media queries were originally designed to link a specific style to a specific medium (e.g. printouts or screens), media queries now support the activation of styles when some criteria are met, for example a device or window having a given width, this is called a breakpoint.

Breakpoints

We have defined a series of breakpoints adapted to visualizations, especially on small devices, while taking into account portrait and landscape orientation (see Table 1). Besides size and orientation R3S media queries also consider the type of devices. Further work would involve dealing with "real" displayed sizes using ppi instead of pixels.

Min-width	Max-width	Orientation	Device
X	320	X	Phone
321	768	X	Phone-landscape
1024	X	X	Desktop
1824	X	X	Large screen
768	1024	X	Tablet
321	768	landscape	Phone-landscape-strict
321	768	portrait	Phone-portrait-strict
768	1024	landscape	Tablet-landscape-strict
768	1024	portrait	Tablet-portrait-strict

Table 1. Media queries.

Media queries configuration with Less

Less[7] is a CSS pre-processor. It enables developers to generate style sheets using variables, functions or inheritance. Default values for media queries breakpoints

[6] http://juliana23.github.io/responsiveVisualisations/

[7] http://lesscss.org/

and textual elements such as fonts, labels and tooltips size are defined in a less file. A JavaScript utility class is dedicated to setting less variables and adjust them if needed. It generates getters and setters for all the variables defined in less files. Developers can then change dynamically the style of their visualizations.

Axes management

Finally, R3S.js offers an `Axis` objects that handles visualization resizing. Whenever a resizing happens (on load or later on), `Axis` will recompute and redraw its axis automatically. Developers only set an initial container size; the object will then compute the initial ratio and marks and will maintain the ratio and adjust the marks whenever the object is redrawn.

CONCLUSION AND FUTURE WORK

We have presented our preliminary work on R3S.js a library for responsive visualizations. Further work is required to make the library more in line with D3 philosophy and to better work alongside it. D3 being low level, it also means that we only tackled a very limited set of visualizations in our work, and that more efforts are needed to make a library like R3S.js really generic and reusable.

An alternative to working with D3, would be to explore if toolkits of more ready to use visualizations wouldn't be a better place to offer responsive facilities in a totally transparent manner. Or also in the spirit of reducing the amount of code required, another possibility would be to incorporate responsive elements in a declarative visualization format such as Vega[8] [12].

Our work only touches on one aspect of adaptation; we mostly ignored how visualizations would be explored differently on a smartphone and a computer. We can imagine that in many cases the questions asked while interacting with a tablet on a sofa would be different from the ones asked while sitting on a desk in font of a dual-display.

In this perspective, it would be interesting to explore how devices could complement each other. For instance, how one could explore datasets using both a tablet and a large screen. Each device supporting interaction that is most suited, e.g., focused exploration on a tablet and context on a large screen, and how adaptive methods could be used to split relevant visualization elements to the right devices.

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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

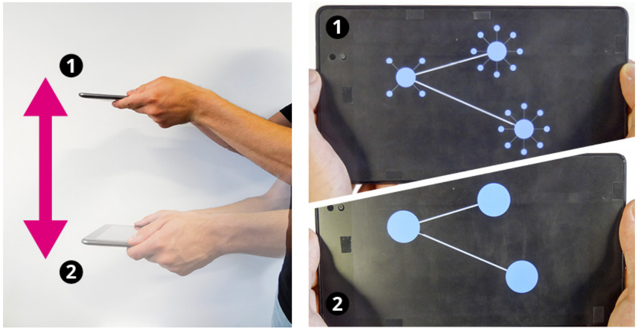

Figure 1. Mock-up of spatial input: semantic zoom based on vertical translation.

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

limitations. We assume that spatial input can only assist certain tasks, thus making a combination with multi-touch input a promising option.

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

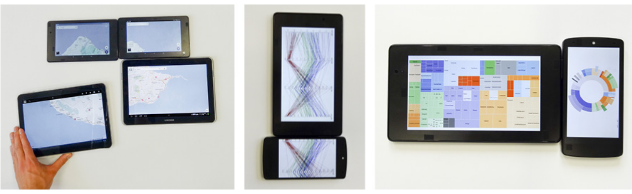

Figure 3. Mock-up of device combinations: simple extension of the graphical context (left, cf. [14]), aligned and extended parallel coordinate plot (center), two different linked visualizations (right).

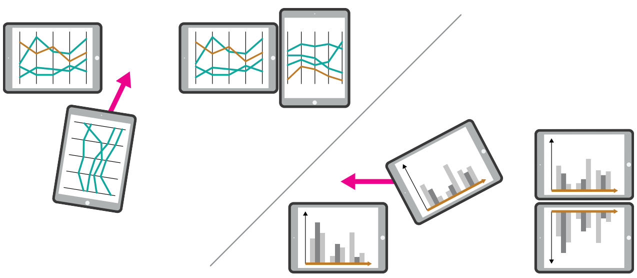

Figure 4. Adapting visualizations: automatic alignment of plot and object highlight (top left), inversion of scatterplot axes (bottom right).

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).

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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Making three Cases for Casual Geovisualizations on Interactive Surfaces

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ABSTRACT

In this paper, we present three case studies on visualizing spatiotemporal data on interactive tabletops and surfaces for casual use. While there is a growing interest among citizens to make sense of their social community and urban environment, most existing geovisualization tools have been designed for experts such as planners and analysts. We introduce situation-specific visualization systems that were particularly designed for public exhibitions to balance powerful data exploration methods with inviting accessibility for laypeople. Finally, we discuss some of the lessons learned regarding people's interest, interaction conventions, and information aesthetics.

ACM Classification Keywords

H.5.2. Information Interfaces and Presentation (e.g. HCI): User Interfaces

Author Keywords

Geovisualization; casual visualization; interactive tabletops.

INTRODUCTION

While geovisualization is an established area of research and practice concerned with the interactive exploration of geo-referenced data [11], visualizations are often aimed only at experts analyzing the data, and therefore tend to be sophisticated and challenging for laypeople to grasp [1]. As data related to people's surrounding increasingly become interwoven into people's life, visualizing such data for casual exploration is vital. We investigate how to best facilitate exploring and understanding such data sets for wider audience with varying visualization and data literacy. This question entails to explore effective ways of visualizing spatio-temporal data in interactive ways to reveal patterns, relationships, and trends, and to support different stakeholders gaining insights while engaging and attracting casual users in semi-public settings.

RELATED WORK

Information Visualization can benefit from interactive tabletops and surfaces, both by leveraging the dimension of large displays, as well as the usability of natural interaction mechanisms [3]. This can lead to more effective and engaging ways to employ visualizations [8]. Geovisualizations and interactive maps are common applications on large scale interactive displays. Since decades, large, high-resolution displays have been used for geographic information systems [4], or urban planning [9]. In a recent survey on visualization on ITS, maps were frequently used to represent information as they work especially well on large displays [7]. Traditional information visualization targets an audience of experts with extensive knowledge and skills in a domain, and supports them analyzing specific problems. In contrast, casual information visualization targets different audiences, and entails the use of "computer mediated tools to depict personally meaningful information in visual ways" [16]. While the purpose of visualization generally are insights, casual visualization also has additional purposes: to raise awareness, to fuel discussions, or to create a pleasant user experience [17]. Over the years, casual information visualization systems on interactive tabletops and surfaces have been designed, and put to use in museums (e.g. [6, 15]), libraries (e.g. [18]), and urban public spaces (e.g. [19]). By placing novel visualization systems on interactive surfaces in public settings may open up the use of visualizations to a broader audience beyond the traditional user group of data analysis experts [8].

In our work, we investigate the use of geovisualizations on interactive tabletops for casual use with multiple case studies tailored for specific scenarios.

APPROACH / METHODOLOGY

Our research approach was guided by an explorative methodology. Within this work, we designed and evaluated three case studies from different domains. For each, we followed principles from a human-centered design [5]. With every case study we investigated its domain while following the shared main goal of enabling a casual exploration of geo-referenced data on a large interactive screen displayed in semi-public spaces. We traversed the full design process of domain analysis, design requirements, prototype development, and evaluation in order to approach the research field in a holistic approach essential for real world use. We publicly exhibited visualization systems to large audiences in order to observe how people would interact with them in real world settings. We complemented these demonstrations with other established evaluation methods when necessary.

All case studies had in common that the knowledge inherent in the data was relevant to non-experts for their everyday life. However, each data set was different in its specifics, and exemplified different aspects of tempo-spatial data. These ranged from classic geo-spatial data such as information on buildings and places, to geo-referenced social network data, to mobility data based both on authoritative data sources (timetables), as well as sensors and smart phones (passenger data).

THREE CASE STUDIES

In the case studies, we explored how to visualize a) faceted data of urban redevelopment for casual exploration of citizens and urban planners, b) collaboration between research institutions for casual exploration of scientists in a conference setting, and c) public transit data for casual exploration of public transit experts and citizens. Besides these domain-specific design goals, with each case study we had a specific question we addressed in the visualization, yet are applicable for casual geovisualizations in general:

- How to facilitate interactive exploration of faceted data for casual users without providing complex user interfaces?
- How to support exploring personal relevant data in such ways to facilitate a social space to discuss insights with others?
- How to provide access to multiple perspectives into complex tempospatial data for casual users?

To illustrate how we addressed these questions, we briefly summarize the case studies along their domains, methods, and findings.

Case Study 1: Venice Unfolding

Figure 1. Tangible object to explore faceted architectural data.

What: Venice Unfolding [13] is a visualization of urban redevelopment projects, with tangible interactions to support faceted browsing of architectural metadata. It aims to invite citizens and urban planners to explore multi-variate data (e.g. construction year, material, function) within the Venetian redevelopment process.

How: On a large interactive tabletop, projects and their relations are shown on a map. A polyhedron acts as physical artifact allowing users to interact with the visualization in tangible way (Fig. 1).

Main Contribution: Design and evaluation of a novel interaction method consisting of a polyhedron people can tilt to filter and search through the taxonomy, place to select specific projects, and rotate to browse through a project's background information.

Case Study 2: Muse

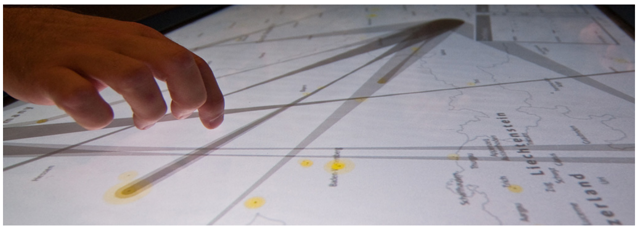

Figure 2. Map showing relations between scientific institutions.

What: Muse [12] is a tabletop visualization of collaborations between research institutions. It is intended to be used at scientific conferences and aims to engage audiences to explore their professional network, as well as to act as casual background to initiate discussions on future collaboration.

How: It visualizes scientific connections between institutions based on co-authorship, and shows the places and their relations on an interactive map (Fig. 2). Multiple in-situ demonstrations and in-the-wild studies with conference attendees.

Main Contribution: How to harvest and enrich metadata from data repositories in ways to show spatial relationships. A couple of best-practices and guidelines extracted from a multi-prototype iterative design process.

Case Study 3: Touching Transport

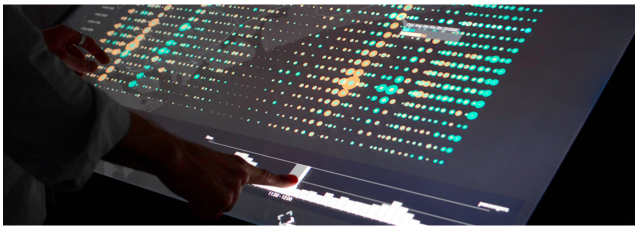

Figure 3. Time-series showing bus passengers for a day.

What: Touching Transport [14] is a multitouch visualization of public transit network. It supports the exploration and understanding of complex tempo-spatial data for experts and non-experts.

How: The system provides multiple perspectives of the data and consists of three interactive visualization modes conveying tempo-spatial patterns as map, arc view, and time-series (Fig. 3).

Main Contribution: Design and in-situ demonstration of tabletop visualization system. Lab study informed by in-situ observations, investigating how our system supports gathering insights for three different user groups (experts, citizens, and non as control).

DISCUSSION

Based on the design and the contributions of the case studies we identify and discuss some general lessons learned when constructing geovisualization for casual use on interactive tabletops.

Interest: Attract users in semi-public settings
In our publications [13, 12, 14], we have described how we designed our systems in ways casual users found it fun to use, and interacted with the information visualizations on large tabletops installed in semi-public spaces. In Venice Unfolding, we provided novel interactivity with a compelling looking tangible object. This polyhedron enables playful exploration of multi-faceted data. In Muse, we managed to attract conference attendees to explore the data by providing personal relevant data in established visualizations. In Touching Transport, a highly polished visualization style as well as an animation cycling through the day when no one was interacting with the table for a while drew in visitors in an exhibition.

In casual settings, users first have to be attracted to the system in order for them to start exploring the geospatial data. Each prototype provided at least one large map visualization, which most people were likely to be already accustomed to, both in terms of understanding the data (e.g. their city's transit network) as well as the interaction possibilities (e.g. pinch and zoom). In the map views, we reduced visual complexity by balancing level of details in the base maps between a simple visual style (to not overwhelm users with complexity, and to not interfere with visualized data atop), and sufficient geographical features (to allow viewers to understand geo context and to orient themselves).

Visualization systems in semi-public spaces should invite users through curiosity and aesthetics so they will be attracted to the system, start playing with it, and finally explore the visualized data. The systems should be designed in ways to engage such audiences to keep exploring the system, and to facilitate serendipitous discovery.

Conventions: Intuitive multitouch interactions
While demonstrating our case studies in-situ, we observed people struggling with a variety of interactions. Users tried to tap the menu element in Venice Unfolding, while our prototype only offered moving the polyhedron towards the element for selecting it. In the first Muse prototype, people tried to tap an item from the Exploding Menu, while one had to tap, slide, and release to select an item. In Touching Transport, users tapped on a row in the time series view, directly, instead of using the time range slider to select that specific time range. While each implemented interaction pattern had deliberate reasons, we learned that basic tapping interactions works best for an audience of casual users. We suggest to provide multiple ways of achieving the same task, and offer simple interaction methods while also including more advanced interaction techniques to be discovered.

Overall, we learned that casual visualizations on tabletops should provide simple multitouch interactions. Our design decision to focus on self-explanatory interaction patterns and avoid complex gestures helped users to explore the data set. People encountered few problems with the touch interactions and were able to pan the map and tap to select stops. We are confident that – due to the wide-spread dissemination of smartphones and tablet computers – basic touch gestures are well-known nowadays, and can be deployed for audiences in semi-public spaces.

Aesthetics: Minimalism and Fluidity
Chen included aesthetics as one of the top ten unsolved problems in information visualization, and stated that it is important to investigate how aesthetics affects insights, and how these two goals "could sustain insightful and visually appealing information visualization" [2].

In our case studies, visual and interface design were guided by principles of information aesthetics [10], aiming to combine accurate data representation with easy-to-use interactivity. Besides the visual form, aesthetics concern aspects such as originality, innovation, and further subjective factors comprising the user experience [20]. In order to design visualization systems easily understood and enjoyed by the users, we strove for an attractive and minimalistic visual style. Especially concerning the interaction aspect of visualization the notion of fluidity proved vary valuable, including the use of animated transitions, the immediate response of the system, the use of direct interactions, and continuous exploration possibilities [3].

In our case studies we explicitly designed towards minimalistic aesthetics and fluid interactivity. In Venice Unfolding we integrated faceted browsing with a map display in a single unified view. In the iterative process of designing Muse, we went from coordinated multiple views to single views due to user's feedback. Touching Transport has three distinct views, but shows one visualization at a time, rather than all three simultaneously, in order to lower visual complexity for casual users.

It is important to value user's satisfaction in visualizations for casual use. Participants in our Venice Unfolding study found the visualization system appealing, conference users in our demonstrations of Muse liked the system and found it aesthetically pleasing. With Muse and Touching Transport, we have demonstrated that visitors in semi-public spaces were attracted to the visualizations, and shown with Touching Transport that this enables lay people as well as experts to explore the data.

CONCLUSION

Through our case studies, we have learned that geovisualizations for tabletops can attract interest of passers-by and enable them exploring the data sets by showing visually pleasing und inviting visualizations, while also providing access to more complex data aspects. We have demonstrated that aesthetics and functionality work together, and support casual users to both enjoy and utilize the systems.

The design and description of our case studies, the explanation of our methodologies, and the discussion of our findings are important parts of our contribution. Moreover, the developed prototypes themselves also act as artifacts which encapsulate our design decisions, and thus embody parts of our research results.

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