Personalized Views for Immersive Analytics

Santiago Bonada
University of Ontario
Institute of Technology
Oshawa, ON, Canada
santiago.bonada@uoit.net

Rafael Veras
University of Ontario
Institute of Technology
Oshawa, ON, Canada
rafael.verasguimaraes@uoit.ca

Christopher Collins
University of Ontario
Institute of Technology
Oshawa, ON, Canada
christopher.collins@uoit.ca

ISS '16 Companion, November 06-09, 2016, Niagara Falls, ON, Canada
ACM 978-1-4503-4530-9/16/11.
http://dx.doi.org/10.1145/3009939.3009953

Abstract
In this paper we present work-in-progress toward a vision of personalized views of visual analytics interfaces in the context of collaborative analytics in immersive spaces. In particular, we are interested in the sense of immersion, responsiveness, and personalization afforded by gaze-based input. Through combining large screen visual analytics tools with eye-tracking, a collaborative visual analytics system can become egocentric while not disrupting the collaborative nature of the experience. We present a prototype system and several ideas for real-time personalization of views in visual analytics.

Author Keywords
visual analytics; immersive analytics; eye tracking; proxemics; gaze

ACM Classification Keywords
H.5.2 [Information interfaces and presentation]: User Interfaces; H.5.3 [Group and Organization Interfaces]: CSCW

Introduction
Retail-grade eye trackers are slowly becoming accurate to the extent we can begin to expect fine granularity in detecting users' focus of attention. In HCI and visualization, researchers investigating proxemic interaction have traditionally relied on motion capture systems to detect people's

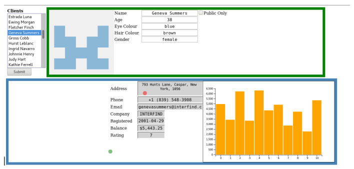

Figure 1: The full screen of our prototype visualization dashboard.

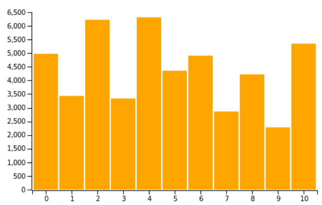

Figure 2: The average user sees a bar chart presenting such information as average bank balance of clients with a certain account rating.

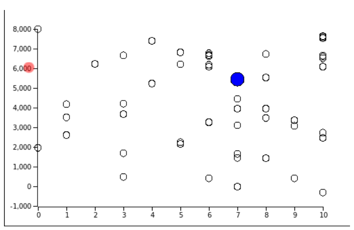

Figure 3: A user interested in more detailed information sees a scatter plot showing each client by bank balance and account rating. Their gaze point is represented by the red circle, the blue circle is the currently selected client they are querying information about.

position and orientation in front of wall displays, which, in turn, have been used to implement coarse-grained dynamic behaviour, such as dividing the screen into individual regions, adjusting the overall level of detail, zooming, filtering passers-by and pausing/resuming action [1, 4].

An eye tracker's ability to more precisely detect focus of attention offers an exciting new array of opportunities for collaborative visual analytics. In particular, UI elements as small as labels could be seamlessly customized according to individual preferences, skills, interests, and privacy needs with the goal of enabling a rich egocentric context within the broader collaborative setting. Eye tracking's promise of implicit input can potentially facilitate highly fluid transitions between public and personal.

In this paper, we lay out the conceptual basis for a gaze-aware collaborative visual analytics system (see Figure 1) as well as discuss potential analytical scenarios that could benefit the most from its capabilities.

Motivation

Collaboration

Isenberg et al. [8] reported on the strategies used by fifteen teams solving the VAST 2006 challenge on a tabletop environment. Four out of eight observed strategies involved the use of individual (as opposed to shared) views of the data, and the teams spent on average 40% of the time working in a loosely coupled manner. Even when working closely coupled, as characterized by the authors, teams had designated individual spaces and views. Based on these findings, it is evident that, despite immersion in a collaborative environment, groups often employ strategies that require division of labour to solve complex problems. Hence, we believe that gaze-aware adaptive visualization can be an important feature in co-located collaborative visual analytics, by means of enabling an egocentric context that leverages users preferences and skills.

Visualization Literacy

As Cox [3] points out, while some visualizations are ubiquitous, others have semantics that must be learned; hence, literacy is critical in determining how effectively an individual is able to use them [5]. Fortunately, the importance of visualization literacy has been recognized recently, with the first visualization literacy assessment method [2], and studies on how novices construct and make sense of information visualizations [6, 10]. At the same time, we see advances in user-adaptive information visualization, which studies personalized interventions to improve performance [16]. In the upcoming sections, we demonstrate through scenarios how interfaces that dynamically adapt to users' literacy and preferences may improve experiences in immersive collaborative environments.

Privacy

When discussing the privacy concerns of personal information in public displays, Vogel and Balakrishnan [18] recommend that "techniques should be provided that discourage other users from eavesdropping". The prospect of seamlessly delivering personal content enhances drastically the usefulness of public displays, provided that privacy is not at risk. With eye-tracking support, we believe that affordances and safeguards can be designed so that intrusion is minimized when featuring *harmless personal information* [18] in a public display.

Related Work

Visual Scoping

Hagen et al. [7] explore the problem space of a collaborative setting with a tabletop display wherein different collaborators either have different authorization to information on such a display or individuals have their own private work area with the display. The authors use the term 'visual scoping' to describe their concept of selectively giving access to information to different people based on any arbitrary metric. The most notable method discussed as to achieving visual scoping was having each participant using a personal display (e.g. a smartphone) that clones the public view while providing a private work area where participants can reveal or hide their work at their own discretion.

Poker Surface is a similar attempt at dividing visual scopes amongst devices, but also includes interactive gestures which players can use [15].

Computer Supported Collaborative Work
A significant domain in the research of immersive technologies is in realizing the potential for collaboration between individuals using those technologies. As has been discussed with visual scoping, there are many approaches to supporting multiple users working together on the same display. Scoping the information and delegating external devices for use as private work areas is one such approach, leaving the public display strictly as a space for sharing information [7, 14]. Another approach is in employing a large high-resolution display for use by multiple people each with their own set of input devices (e.g. mouse and keyboard) [19].

Tuddenham describes a system that, in contrast to *co-located* collaborative work, has the collaborators working away from each other on tabletop displays connected by internet [17]. There is even an avenue for behavioural studies researching collaboration and joint-gaze where two individuals working together are separated physically and can only communicate by microphone, augmented with displaying their gaze location to their partner[12].

Territoriality
Territoriality is very important when considering any display which will be used simultaneously by multiple people. While there have been works which seek to segregate the shared view from personal work areas [7, 14, 15], there have been studies on the interactions of people who all access one shared display. Isenberg et al. [8] identified eight different modes of collaboration a pair of individuals can be in ranging from deeply discussing a problem face to face to either one or the other being completely disengaged in the activity. Scott and Carpendale [13] conclude that the interfaces of multi-user displays support partitioning of work areas. Co-locality is not the bare minimum for the necessity of territoriality; Tuddenham implemented a system where territoriality was preserved even when collaborators were not physically in contact [17]. Though much of the theory for territoriality concerns tabletop displays, the principles can be extended to any situation where there is a shared display.

Public Displays
There has been a large amount of work on public displays; relative to the other immersive technologies, large public displays enjoy widespread use in mainstream society [20, 18]. From kiosk in malls and airports to interactive wall sized displays in city streets, researchers have been investigating different modes of interaction and methods of gauging interest or attention that fall out of the realm of physical contact.

GazeHorizon [20] is a system for public displays which are gaze-aware. The system instructs users where to stand and how to interact with the display, all of the interactions performed purely with gaze.

The work of Vogel and Balakrishnan [18], describes a system for adapting a visualization and facilitating interaction

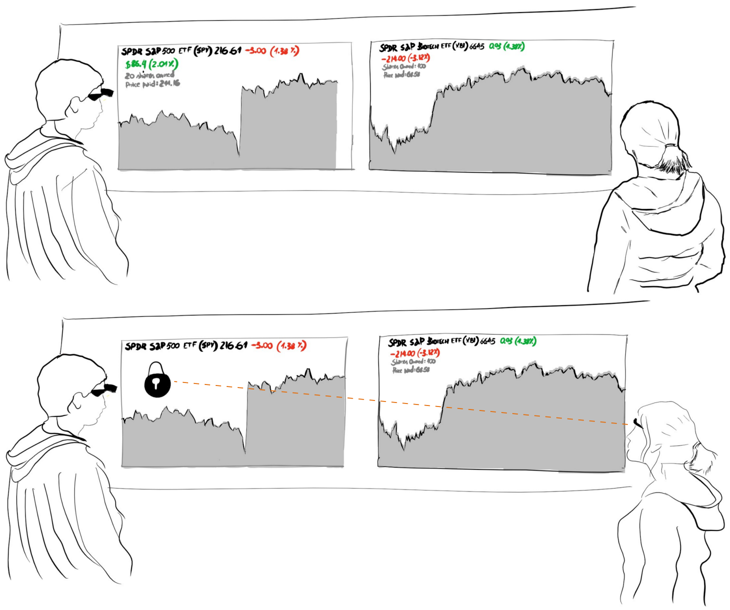

Figure 4: Top: Each user has a personal view of the information. Bottom: Private information is hidden when an unauthorized user views it.

based on the attention of its users. Users close to the display view and interact with information in different detail than those standing farther away, and random passers-by with no interest in the display do not affect it. The display is shareable in that each user gets their own section of the screen.

Similarly there is *SpiderEyes* [4] which follows the work of Vogel and Balakrishnan — a notable improvement is that collaborators in *SpiderEyes* can form groups to 'combine' their views of the visualization so that they can simultaneously work together with a larger screen space. Pfeuffer et al. demonstrate that an information display can support gaze based interaction from multiple users [11]. Gaze and proxemics for interacting with public displays are significant when investigating alternatives to touch-based interactions.

Concept

User Profiles

We assume that user profiles containing all information needed for user-adaptation are kept by the system. User profiles can include chart and overlay preferences, visualization literacy scores [2], domain-specific information (e.g., investments, health records) and data access permissions. However, the design of interfaces to elicit user profile information is out of the scope of our research.

User-Adaptive UI

We describe below the potential elements of a gaze-aware visualization interface.

Dynamic charts. The type of chart or layout should be adjusted depending on the user's visualization literacy and preferences (as shown in Figures 2 and 3). For instance, density chart could be a less complicated alternative to a box plot, or a pie chart could be chosen over a bar chart for purely aesthetic reasons. In visualizations of stock price movement, long term investors might be satisfied with a line chart, while day-traders might require a candlestick chart, which depicts intraday price variations more accurately.

Overlays. Additional markers and labels encoding personal data can be overlaid onto visualizations. For instance, in the aforementioned display of stock performance, the interface could react to a user's focus on an owned stock by overlaying portfolio-specific information, such as gain, number of shares owned and price paid (Figure 4). In a different scenario, users in

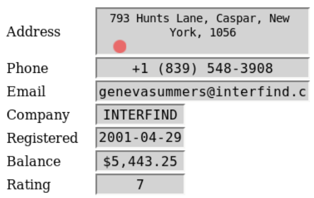

Figure 5: The authorized user (red marker) is viewing private information for a client of the bank.

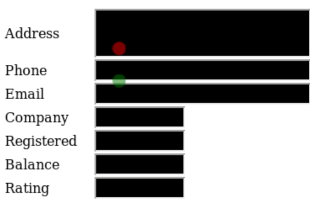

Figure 6: An unauthorized user (green marker) attempts to view the same information. The system locks them out.

a fast-food restaurant could see additional information of their interest on top of menu choices in a public display, such as allergy warnings, calorie count and origin.

Visual locks. Rendering personal information invisible or inaccessible when users other than its owner direct their gaze to it (Figures 5 and 6). Subtle or disruptive encodings may be used to make one or all parties involved aware of intrusions. For instance, in a scenario where the owners of sensitive data meet engineers to discuss the development progress of a custom data analysis tool, a gaze-aware layer could ensure only owners can see sensitive information.

Intrusion cues. Subtle visual indications in the boundaries of regions where personal information is being viewed, with the goal of preventing disruption caused by inadvertently invading one's visual space.

Conflict resolution

In user-adaptive gaze-aware interfaces, conflicts arise when users, intentionally or not, direct their gaze to UI elements displaying someone else's personal information. Managing such conflicts gracefully is a core challenge. Due to gaze signal being noisy, designers should minimize the effect of false positives and use with caution any binary show/hide strategy. Nonetheless, depending on the nature of the personal information, disruptive visual cues that provide awareness may be necessary. Following, we enumerate potential strategies for conflict resolution in gaze-aware systems. These strategies can employ different kinds of *visual locks* and/or *intrusion cues*.

Neighborhood Watch. Monitor the surroundings of personal information and progressively apply a visual lock, such as blurring or opacity reduction, as a function of distance. Also, trigger intrusion cues as intruder approaches foreign personal information.

Focus Prevention. Trigger visual locks only when intruder begins to focus on foreign personal information.

Intrusion Alert. Do not trigger visual locks, but display a visual cue to information owner upon intrusion indicating someone is watching. This strategy relies on users mediating the conflict.

Implementation

We based our implementation of mobile gaze tracking with no external markers on the system described by Lander et al.[9]. The hardware includes a head-mounted eye tracker by Pupil Labs[1] connected via USB to a desktop computer which was running the gaze-aware visualization.

The software component of the system was divided amongst three processes within a pipeline that passed gaze information from the eye tracker to the visualization. Firstly, there was Pupil Capture — open source software by Pupil Labs for use with their eye trackers — which was used to perform calibration of the eye tracker and to map the gaze location of the eye to the world space of the front facing camera on the tracker (the world camera). Pupil Capture publishes the gaze data and the video stream to the next process.

The second process is a Python program which performs feature matching between screenshots of the display and the streaming video from Pupil Capture using the OpenCV library. Similar to *GazeProjector* [9], the program obtains the transformation matrix of the world camera to the screenshot, therefore allowing us to project the gaze point which is

[1] www.pupil-labs.com

in the world camera's coordinate system to the display's coordinate system. The resulting system frees users to stand and walk around, to view part of a screen, or even switch between multiple screens.

Finally, the projected gaze point, along with the identity of the eye tracker, is sent to a web-server hosting a visualization written in D3.js. A script takes the projected gaze point and the tracker identity, checks to see if the position of the gaze point and the identity qualify to change the view of the visualization, and adapts the visualization accordingly.

Future Work

We have considered various strategies for resolving conflicts between users whenever the gaze of one user intrudes into the personal space of another. The next step would be to study the effectiveness of these strategies when they are employed in a gaze-aware application.

There is also the need for a system which, if one were to implement this concept in the wild, can query the identity of a user without needing to use any form of authentication that is not gaze based. To add to that, user profiles need not be static but subject to changing over time by analyzing the interest of the users based on gaze patterns.

Another challenge is the ergonomics of the hardware for the system. Our implementation utilizes head mounted eye trackers connected by cables to a computer. An improved system would be one where tracking gaze can be performed with a much decreased physical overhead.

Final Remarks

The improvements in eye tracking technology, both in fidelity and affordability, leads us to consider the possibility of multi-user gaze-aware displays becoming commonplace in mainstream society. In this work we have discussed not just the potential but also the principles a designer of such applications would have to consider when creating them. Through the system we implemented we discover that such concepts are feasible with our current level of technology.

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