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Mobile Situated Analytics of Ego-Centric Network Data

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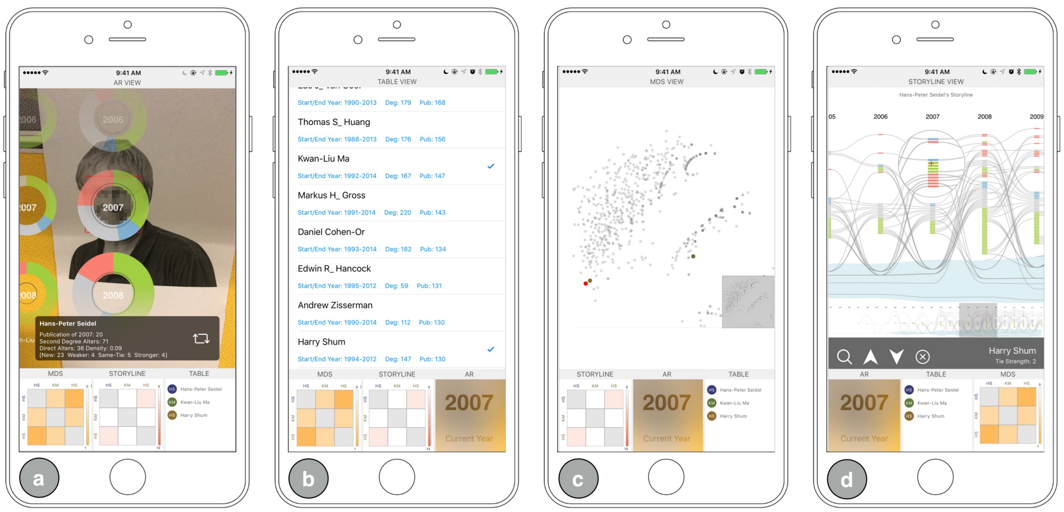

Figure 1: Four-view ego-centric network analysis on iPhone 7 Plus. The general layout is Main view+Thumbnails. a) AR view. Glyph-based timeline is embedded into the photo of Hans-Peter Seidel. b) Table view. Kwan-Liu MA and Harry Shum are selected. c) MDS view. The three egos in a) and b) are highlighted. d) Storyline view. Temporal tie strength between Hans-Peter Seidel and all his alters is shown.

ABSTRACT

Situated Analytics has become popular and important with the resurge of Augmented Reality techniques and the prevalence of mobile platforms. However, existing Situated Analytics could only assist in simple visual analytical tasks such as data retrieval, and most visualization systems capable of aiding complex Visual Analytics are only designed for desktops. Thus, there remain lots of open questions about how to adapt desktop visualization systems to mobile platforms. In this paper, we conduct a study to discuss challenges and trade-offs during the process of adapting an existing desktop system to a mobile platform. With a specific example of interest, egoSlider [Wu et al. 2016], a four-view dynamic ego-centric network visualization system is tailored to adapt the iPhone platform. We study how different view management techniques and interactions influence the effectiveness of presenting multi-scale visualizations including Scatterplot and Storyline visualizations. Simultaneously, a novel Main view+Thumbnails interface layout is devised to support smooth linking between multiple views on mobile platforms. We assess the effectiveness of our system through expert interviews with four experts in data visualization.

CCS CONCEPTS

•**Human-centered computing** →*Information visualization;*

KEYWORDS

Mobile and Ubiquitous Visualization

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1 INTRODUCTION

Situated Analytics, which supports visual analytical reasoning by aligning abstract data with real physical environment, has largely improved on-site visual analytics and decision-making [ElSayed et al. 2015]. Situated Analytics is demonstrated to be beneficial in diverse areas including environmental monitoring [Veas et al. 2013], navigation [Bell et al. 2002], construction [Zollmann et al. 2012] and agriculture [Engelke et al. 2016]. Low-cost mobile platforms including mobile phones and tablets are leveraged as the main platform in these works, considering their capability of serving as both the input sensor and output display to dynamically adapt to the real scene variation [Chandler et al. 2015; Kalkofen et al. 2011a]. With increasing attentions being paid to view data relevant to analytical tasks in its original context [Willett et al. 2017], we envision that people will adapt existing desktop visualization systems to these mobile platforms in the future for instant on-site decision-making.

However, current mobile situated analytical systems such as [ElSayed et al. 2016; Engelke et al. 2016; Grasset et al. 2012; Kalkofen et al. 2011b; Zollmann et al. 2012] could only support simple tasks such as data retrieval. Sophisticated visualization systems, which are capable of supporting complex visual analytical tasks such as clustering, evolution and comparison, are only designed for desktop and notebook users. These systems [Liu et al. 2015; Wu et al. 2016; Zhao et al. 2016] are usually equipped with multi-scale visualizations and Multiple Coordinated Views (MCVs) to support data analysis from different levels of details and perspectives (e.g., egoLines,egoNetCloud,egoSlider systems). There remains a considerable amount of open questions about how to tailor a desktop visualization system to mobile platforms which have comparatively limited screen real estate. For example, two main challenges for porting a desktop visualization to mobile platforms are: *(1) how to adapt multi-scale visual representations?* and *(2) how to adjust multiple views on mobile platforms?*

Of particular interest, desktop ego-centric network visualizations which involve both multi-scale visualizations and MCVs [Cao et al. 2016; Liu et al. 2015; Shi et al. 2015; Wu et al. 2016; Zhao et al. 2016] are chosen as the testbed in our study. We conduct a pilot study with a typical desktop ego-centric network system entitled *egoSlider* [Wu et al. 2016] to drill down on the two challenges mentioned above. Because of the higher popularity and portability mobile phones possess, we choose mobile phones other than tablets in this situated scenario. To the best of our knowledge, this is the first mobile phone-based Visual Analytics system supporting on-site situated ego-centric network analysis. The contributions of our work are summarized as follow:

- An iPhone-based ego-centric network visualization system supporting on-site analysis of temporal co-authoring patterns of researchers assisted by real time face recognition.
- A Main view+Thumbnails layout with novel thumbnail button designs to compensate the loss of visual linkings between Multiple Coordinated Views on a limited mobile phone screen.
- An initial evaluation with participants who specialize in data visualization to verify the usability and effectiveness of the system in completing complex ego-centric analytical tasks at three level of details.

2 RELATED WORK

2.1 On-Site Visual Analytics

Existing situated visual analytical systems mainly assist users in retrieving information from datasets [ElSayed et al. 2016; Grasset et al. 2012; Kalkofen et al. 2007, 2011b; Pick et al. 2010; Shibata et al. 2008]. These works focus on providing abstract information in terms of annotations [Grasset et al. 2012; Pick et al. 2010; Shibata et al. 2008], and X-ray or infrared ray rendering [ElSayed et al. 2016; Kalkofen et al. 2007, 2011b]. Some recent works incline to divide the visualization system into multiple views. For instance, Interactive 4D [Zollmann et al. 2012] helps end users retrieve as-planned and as-built data within the context of the real building from three different level-of-detail views. MelissAR [Engelke et al. 2016] includes several linked views to assist bee-keepers in understanding on-site bee behaviours with a tablet.

However, these works have neither systematically discussed the view management techniques, nor related to any complex analytical tasks such as clustering, comparison and evolution.

2.2 Multi-Scale Visual Representation

Generally, in a desktop system, there are four approaches in managing multi-scale views such as large graphs, namely Focus+Context, Overview+Detail, Zooming and Cue-based techniques [Cockburn et al. 2009]. With the last generation mobile platforms, e.g., PDAs, designers have highlighted the importance and proposed sizable solutions in data reduction when displaying multi-scale visualizations on mobile phone screens in order to reduce visual clutter and provide useful information. In [Ehret et al. 2004], an adaptive scalable visualization system for PDAs, tablets and desktops is implemented and [Hao and Zhang 2007] contributes in displaying hierarchical information through Radial Edgeless Tree. In [Chittaro 2006], World-in-a-Miniature and Cue-based view management methods are qualitatively compared when providing a large geographical map. ZuiScat [Büring and Reiterer 2005] provides a zoomable interface to reveal the relationships between the detailed part and the entire Scatterplot. Based on all these existing view management techniques, we address the issue of presenting multi-scale visualizations on iPhone platforms.

2.3 Multiple Coordinated Views

In traditional desktop-based visualization systems, Multiple Coordinated Views (MCVs) are widely adopted in order to depict data through diverse data representations [Andrienko et al. 2007; Roberts 2007; Sadana and Stasko 2016a]. According to [Javed and Elmqvist 2012], there are mainly four categories of MCV techniques for desktops, namely juxtaposition, superimposition, overloading, and nesting. A common way for coordination between MCVs is selection-based query interaction through brushing and linking [Andrienko et al. 2007; Roberts 2007; Sadana and Stasko 2016a]. When the meta-information is complex, it is difficult to understand which views are linked to the current views and thus in [Weaver 2004] arrows as are provided as cues. Other than brushing and linking, navigational slaving is another common interaction technique [Scherr 2008] between desktop MCVs.

However, MCV techniques on small screens have not been fully researched yet [Roberts 2007]. Our work is the first attempt to explore solutions for MCVs on mobile platforms.

3 VISUAL ANALYTICS OF EGO-CENTRIC NETWORKS

With the objective to drill down on how to adapt multi-scale visualization and MCVs to mobile platforms, we first analyze the existing ego-centric network visualization systems to extract the common analytical tasks, visual representations, and interactions and then in the next section we outline a list of challenges as well as design requirements of such mobile situated analytics systems.

Ego-centric network visualizations indicate how a specific person, i.e., an *ego* is tied to the outer social world, i.e., its *alters* [Wu et al. 2016]. A dynamic ego-centric network represents the temporal relationships between one specific ego and its alters.

3.1 Analytical Tasks

Key visual analytical tasks of ego-centric networks among previous works [Cao et al. 2016; Henry et al. 2007; Liu et al. 2015; Shi et al. 2015; Wu et al. 2016; Zhao et al. 2016] include:

- **T1: Information retrieval.** Basic information about egos, e.g., names, publication number.
- **T2: Local relationship between egos and alters.** Features of this level include but are not limited to: ego-network topology, new-comers, tie strength, number of alters, key collaborators, alters' clustering.
- **T3: Interpersonal comparisons and evolution pattern.** Tasks include: e.g., does *ego A* share similar collaboration pattern with *ego B* at *time*? Do they share similar evolution patterns along the timeline?
- **T4: Global pattern among all egos and variation over time.** Tasks includes: e.g., how many clusters and outliers could be observed? Whether *ego* belong to any main cluster in *year*?

3.2 Visual Representations

Typical representations in ego-centric network visualization systems include:

- **Timeline Visualization (T1, T2, T3, T4).** Both Glyph-based timeline [Cao et al. 2016; Farrugia et al. 2011; Liu et al. 2015; Shi et al. 2015; Wu et al. 2016; Zhao et al. 2016], storyline-based design [Wu et al. 2016; Zhao et al. 2016] and compressed ego-centric networks [Liu et al. 2015] have served as the main view in desktop systems.
- **Dynamic Graph (T1, T3, T4).** Scatterplots [Wu et al. 2016], large dynamic graphs [Shi et al. 2015; Zhao et al. 2016] are widely adopted for conveying clustering and outlier information among a large group of people.
- **Table View (T1, T3).** Aiming at facilitating uses' queries, specific information view [Liu et al. 2015] and ego name list tables [Cao et al. 2016; Liu et al. 2015; Wu et al. 2016; Zhao et al. 2016] are widely adopted.

3.3 Interactions

According to the basic interactions involved in the process of visual analytics [Yi et al. 2007], we also summarize interactions shared in desktop ego-centric systems.

- **Select and Filter.** Selection via clicking and filtering via brushing on range sliders are the most common approaches to mark several egos as the focus. Cursor-based zooming and panning are also commonly used to search for an extraordinary object that the user is interested in. Selecting and filtering results are then highlighted to guide further data analytics.
- **Connect.** We find most connect interactions occur between MCVs. General MCV techniques could be categorized into two groups, namely discrete selection through clicking and continuous filtering by 1D range slider dragging or 2D panning. The fundamental design objective in desktop MCVs is to maintain the synchronization among multi-form views through Snap-Together layouts.

4 DESIGN CONSIDERATIONS FOR MOBILE PLATFORMS

We choose a typical desktop ego-centric network visualization system *egoSlider* [Wu et al. 2016] as the testbed for adapting a desktop system to mobile platforms. EgoSlider consists of four coordinated views (i.e., Data overview, Summary timeline, Alter timeline and Data table) and three of them are multi-scale visualization representations. EgoSlider also involves visual analytical tasks (e.g., clustering, comparison and evolution) regarding MCV navigations.

Tailoring egoSlider system to a mobile setting could benefit users in analyzing academic collaboration information of researchers in public settings e.g., an academic conference, thus encouraging further social engagement among users. The niche in this mobile situated version of egoSlider is that even though the users do not know the ego's name, they may still be able to acquire public information of him/her, by leveraging the camera sensor on mobile platforms to achieve real time face recognition. To develop such system, we face the following challenges:

C1 How to align physical referents and spatial information, i.e., human faces for desktop egoSlider system, with abstract visualization presentations?

C2 How to tailor multi-scale visualization representations, i.e., Scatterplots (2D) and Storylines (1D) and interactions on limited mobile phone screens?

C3 What is the counterpart of a desktop Snap-Together layout for Multiple Coordinated Views on mobile platforms?

We follow Keim's [Keim et al. 2008] visualization mantra for Situated Analytics: analyze first, show the important, zoom, filter and analyze further, details on demand. After identifying proper physical referents, visualizations should be rendered via a see-through video on the screen of mobile platforms as a mix of situated and embedded information [Willett et al. 2017] with AR techniques. Design requirements considering the uniqueness and limitation of mobile platforms include:

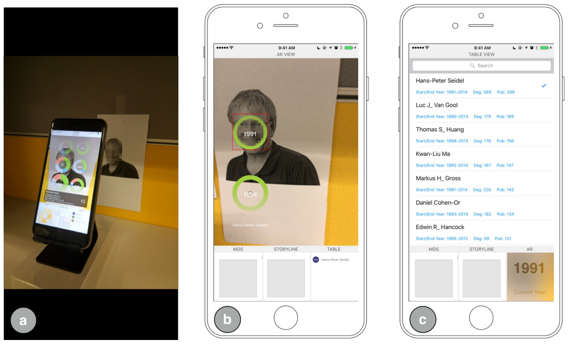

Figure 2: Face recognition simulation. a) Hans-Peter Seidel's image is printed and scanned. b) After identifying Hans-Peter Seidel, a donut chart tracks his face in real time. c) Tapping on the Table thumbnail to select Table view as the main view for further data analytics.

- **R1: Data reduction in each view.** With limited screen size, irrelevant information in each view should be eliminated to avoid potential distractions.
- **R2: Lower level of mental efforts.** Target audience in this work are general smartphone users. Thus, intuitive interfaces and commonly adopted interactions with which the users are familiar are needed.
- **R3: Temporal/spatial coherency with real scene.** Real-time updates of visualizations according to the environmental changes are required to maintain the integration of abstract information and physical referents.
- **R4: Consistency with the desktop system.** With the objective to adopt existing desktop visualization systems to mobile platforms, we want adaptions instead of designing from scratch.

5 SYSTEM OVERVIEW

In this paper, we use the scenario of exploring academic collaboration networks as an example, in which an ego could be a researcher and alters are co-authors of the ego. The whole system is encapsulated into a mobile app, which is implemented on an iPhone 7 Plus because it has powerful computational resources and a comparatively larger screen size. Face recognition in live streaming video data and visualization tailored for mobile platforms constitute the mobile situated analytics system in this work. After launching the mobile app, the user could first identify a specific ego after face recognition at a remote server. FaceNet [Schroff et al. 2015] with a pretrained Inception-Resnet model based on the LFW dataset [Huang et al. 2008] (Fig. 2-a) is utilized to achieve state-of-the-art performance on face recognition. As a prototyping system, we add web images of 10 researchers into the LFW dataset for demonstration and evaluation. Then the user enters the AR view (as the main view) with three other thumbnail views (Fig. 2-b) and the ego's basic information (T1) will appear in the main view (Fig. 1-a). The ego's face will be tracked in real time (R3) and tapping on either one of the thumbnails leads to a switching between the four views that are coordinated together (Fig. 2-c).

6 SYSTEM DESIGN

In this section, we first introduce how we adapt each view (i.e., Data overview, Summary timeline, Alter timeline and Data table) from desktop egoSlider and then discuss the process of designing mobile-oriented MCV layouts.

6.1 AR View

AR view corresponds to the Summary timeline view in egoSlider (R4). Each glyph consists of a donut chart and a black ring. The donut charts encode four kinds of 1-degree alters of an ego with categorical color scheme. The widths of donut charts encode the total number of 1-degree alters. Radii of the black rings encode the number of 2-degree alters.

Data registration. We directly overlay a donut chart glyph over human faces to create embedded visualizations while keeping the other three views in a situated manner instead of direct embedment [Willett et al. 2017]. This direct embedment largely improves the spatial and temporal consistency with the real scene via face tracking (R3) and reduces mental efforts in registering abstract information to its physical referents (R2). The radial glyph visual representations could not only save considerable amount of screen real estate but also serve as a summary at a mesoscropic level of detail, which also guides users' attention (R1).

Visual management. Considering limited screen size, we limit the glyph number to a maximum number of three (R1) and rotate the horizontal timeline to a vertical one. Annotation box with a brief summary of co-author patterns (Fig. 1-a) is provided at the bottom of AR view (C1). Detailed information about the ego is provided (T1). The button to the right is functioned as a switcher to change egos.

Interaction. In AR view, finger sliding along the timeline leads to the snapping of a neighbouring glyph to the real face. We set this Glyph-based timeline to be the only axis that could change the timestamp for the whole the system to reduce complexity (R1, R2).

6.2 MDS View

MDS View corresponds to the Data overview in egoSlider, revealing the similarity in collaboration patterns through Scatterplots (R4). Each dot represents one ego and the distances between two dots encode similarity.

Visual management. For a Scatterplot, it is hard to render the entire dataset while providing locally detailed information on mobile screens. The most adopted approaches for presenting this multi-scale visualization on desktops include Zooming+Panning, Overview+Detail, and Focus+Context [Cockburn et al. 2009]. From the study in [Pietriga et al. 2007], Zooming+Panning+WIM (World-in-a-Miniature), a hybrid of Zooming+Panning and Overview+Detail technique surpass both Focus+Context and Overview+Detail methods on desktops. As no work has ever shed light on which method works better for mobile platforms, we decide to implement both Zooming+Panning+WIM and Focus+Context at the pilot design stage. After implementation, we find that visual distortions and overlappings between enlarged dots in the Focus+Context approach (Fig. 5-a) makes the selection process arduous, which violates the

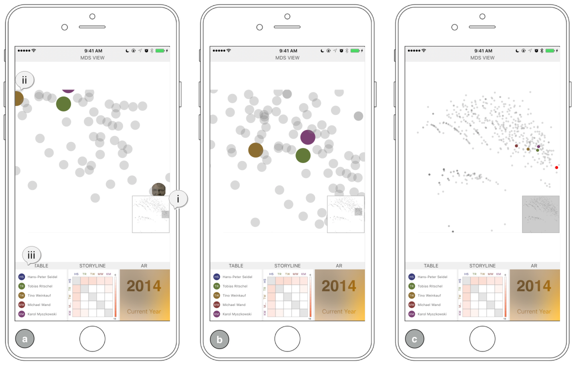

Figure 3: MDS view. a) Three selected egos are highlighted. b) MDS view after panning on a). c) MDS view after zooming out from b).

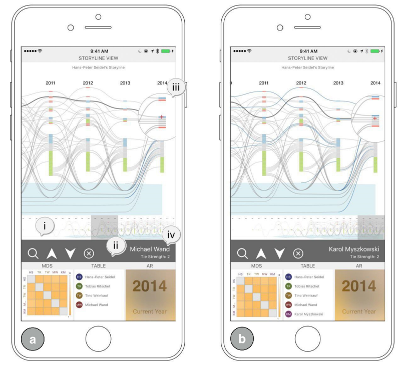

Figure 4: Storyline view. a) Storyline of Hans-Peter Seidel is shown. b) A fifth alter is added with the magnifier lens and the selection button.

initial design requirement of being easy to use (R2). However, in Zooming+Panning+WIM approach, with five different zooming levels introduced, each dot could be clearly rendered and easily selected at higher zooming levels with less visual clutter (Fig. 3-a(i)).

Interaction. Zooming with five levels of detail (Fig. 3-c) and panning (Fig. 3-b) is allowed in the MDS view. Selecting egos at a low level of magnification in a Scatterplot is difficult and inaccurate. Although previous works contributed in designing two-hand selection gestures with a quatrilateral polygon for tablets [Sadana and Stasko 2014, 2016b], we do not follow this method considering the even smaller screen size. To overcome this problem, we only allow selection at the highest level of magnification. The selected egos are highlighted with a categorical color encoding (Fig. 3-a(ii)). Double-tapping facilitates deselection.

6.3 Storyline View

Storyline view corresponds to the Alter timeline view in egoSlider (R4). This view is leveraged to show the detailed evolutional tie strengths between alters and the ego (Fig. 4). Small blocks presenting alters of a selected ego are ordered vertically. From top to bottom, the tie strength between an alter and the ego decreases. Lines linking alter blocks for the same alter at different timestamps show how the alter’s tie strength with the ego evolves over time.

Visual management. Storyline is viewed as a 1D multi-scale visualization in our work. Thus, we apply the Zooming+Panning+WIM approach similarly to the 2D multi-scale MDS view (Fig. 4-a(i)). We also add a functional control panel consisting of four buttons, i.e., a magnifier lens button, two arrow buttons, and a selection button for selecting different alters (Fig. 4-a(ii)).

Interaction. To replace the cursor-based hovering effect for acquiring additional information from small blocks on desktops, we adopt a magnifier lens in the Storyline view (Fig. 4-a(iii)). Users are allowed to freely drag the magnifier lens on the screen. The two arrow buttons in the control panel (up/down) help in snapping the magnifier lens to the neighbouring small block above/below the current one. Tie strength between the selected alter and the ego is then displayed to the right of the control panel (Fig. 4-a(iv)).

6.4 Table View

Table view corresponds to the Data table in desktop egoSlider system (R4). From top to bottom on the list, the accumulated publication number of an ego decreases. In the table view, we add cue-based “tick” hints to indicate the status of being selected (Fig. 1-b). Deselection of an ego is achieved by double-tapping.

6.5 Multi-View Coordination

Another challenge we encounter relates to the loss of linked view visual effects from desktops (C3). In the desktop egoSlider system, the four coordinated views are linked together, and are displayed in a Snap-Together layout. Changes in each of the linked views are noticeable to users due to less temporal separation introduced in this Snap-Together setting [Cockburn et al. 2009]. Rolling eyes between these views assists users in observing new patterns.

However, the screen sizes of iPhone platforms ranging from 4.0 inches to 5.5 inches severely hinder the direct transfer of Snap-Together solutions to mobile screens. Although it is possible to use the same layout from desktop (Fig. 5-c), little information is obtainable from the highly compressed visualizations. Thus, a special interface layout is demanded.

Main view+Thumbnails layout. Initially, we link all the views following the Model-View-Controller (MVC) data model. Data change in either view will cause synchronization and instant updates among other views (Fig. 4-b). As there is no straightforward focus and context relationship between the four views and also taking the limited screen size into account (R1), we design a Main view+Thumbnails layout similar to [Cockburn et al. 2006]. There is only one view shown in detail and thumbnails are rendered at the bottom. Although there is a subtle size shrink in the main view with less information presented, this layout is beneficial in navigation between various views with the thumbnails serving as both visual cues and entering buttons. The order of three thumbnails is carefully devised in case the users get lost in a long sequence of interactions (Fig. 1). The most recently appeared thumbnail is always rendered to the right.

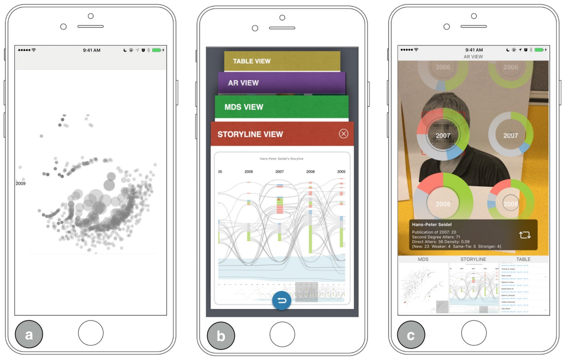

Figure 5: Alternative designs. a) Fish Eye distortion for visualizing multi-scale MDS view. b) 3D view switcher for Multiple Coordinated Views layout. c) Snap-Together interface for Multiple Coordinated Views layout.

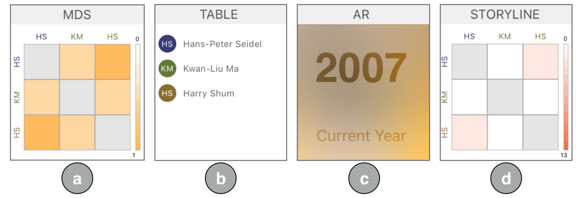

Figure 6: Thumbnail views. a) MDS thumbnail to encode collaboration pattern similarity between selected egos. b) Table thumbnail with the name list of selected egos. c) AR thumbnail with the blurred real scene and a ambient hint of the selected timestamp. d) Storyline thumbnail to encode tie strengths between selected egos.

Explicit encoding in thumbnails. The purpose of designing thumbnails is to facilitate comparison. We choose the explicit encoding method instead of the other two basic comparative visualization approaches i.e., side-by-side and superimposition from [Gleicher et al. 2011]. The reason is that side-by-side comparison consumes more screen real estate (R1) while superimposition lacks intuitiveness and results in more visual clutter (R1, R2). For the explicit encoding design, we prefer compact thumbnails which not only provide overview information of the corresponding views but also do not interfere with the analytical tasks conducted in the main view. We also design those thumbnails to be entering buttons responsive to finger tapping for view navigation.

MDS thumbnail. The tasks among MDS view relate to interpersonal comparisons between different egos (T3), i.e., *who shares a similar collaboration pattern with a specific ego in a certain year? Which year two egos share the most similar co-authoring pattern?* We adopt a matrix-based Heat map visualization as the MDS thumbnail to encode this similarity with a sequential color scheme (Fig. 6-a). We set an upper limit of five egos being compared at the same time (R1, R2). The similarity between egos who share the longest distance in all the MDS views is calibrated to 0, which results in a blank cell in the thumbnail matrix. The higher the similarity, the darker the color in the MDS thumbnail.

Storyline thumbnail. To encode detailed collaboration information such as whether several egos have ever collaborated before and what are the tie strengths (T4), we also choose matrix-based Heat map for Storyline thumbnail. Each cell in the matrix encodes tie strengths between chosen egos with a sequential color scheme. The darker the color, the more publications these two egos co-authored in that year (Fig. 6-d). If the alter did not co-author any paper with the ego, the matrix cell for the two of them will be completely blank. The upper limit of the ego number is also set to be five (R1, R2).

AR thumbnail. When serving as a thumbnail at the bottom, the original AR view with donut charts overlaid to the real human face is transformed into a blurred image of the real scene in order to both reduce potential distractions (R1) and function as a hint for easily switching back to the real physical world (R2). In the blurred image, the timestamp chosen through the Glyph-based timeline in the original AR view is shown as an ambient cue (Fig. 6-c).

Table thumbnail. The table view thumbnail displays the name of egos being chosen in the MVC model (Fig. 6-b). The same categorical color scheme to the MDS thumbnail view is applied in the table view thumbnails for users to link the same ego within different thumbnail views more easily (R2).

Design alternatives. An alternative design for the above Main view+Thumbnails layout is native 3D task switcher (Fig. 5-b). The switcher itself serves as the overview container for view navigation. Although there is no size shrink in the main view, this layout setting requires heavier mental efforts in remembering the previous views, interactions and data. As we do not want to overburden end users and trouble them in switching views in a situated analytical scenario (R2, R3), we discard this 3D view switcher design. For the thumbnail design, alternatively we could directly compress the original view for simplicity (Fig. 5-c). However, slight changes in these thumbnail visualizations become unnoticeable to the users due to the very limited screen real estate assigned.

7 INITIAL EVALUATION

To evaluate the effectiveness and usefulness of our system, we conducted a controlled user study in laboratory settings.

7.1 Methodology

We invited four participants who are experts in data visualization area from our university (referred as E1, E2, E3, and E4). All of them are daily users of mobile phones with iOS system. A within-subject study design was employed with the DBLP collaboration network datasets [DBLP 2014] to compare our mobile situated analytics system with the desktop egoSlider system. During the study, for each system, we first demonstrated its usage, and then participants were given five minutes to freely explore and ask questions about the system. Next, participants were asked to complete ten analytics tasks (Table 1). We slightly modified the tasks to ask different facts (e.g., different years and egos) in data for the two systems. The order of presenting the system to participants was also counter-balanced. In the end of the study, we conducted a semi-structured interview to collect feedbacks about user experience of using the systems.

Table 1: Visual Analytics Tasks in the Study

Question
How many clusters could be identified in *year*? (T2)
Does *ego* belong to *cluster* in *year*? (T2)
Any clustering evolution between two *years*? (T2)
Have *ego*, *ego*, and *ego* ever collaborated? (T3)
Do *ego* and *ego* have similar collaboration pattern? (T3)
How does two *egos*' collaboration similarity evolve? (T3)
Whose tie strength with *ego* is stronger in *year*? (T4)
How many 1-degree *alters ego* has in *year*? (T4)
Any relation between 1 and 2-degree alter numbers? (T4)
Any temporal evolution in tie strength between *egos*? (T4)

7.2 Results

Effectiveness in the prototyping system. It was mentioned by E1, E2, E3 that they preferred the current design of Main view+Thumbnails as the general layout in the mobile system. *"The Heat map thumbnail of MDS and Storyline with color encoding is informative for representing each of the detailed view (E1)."* Also all the four experts (E1, E2, E3 and E4) appreciated the magnifier design in Storyline view. *"The design of magnifier lens suits the mobile platform quite well in selecting a specific alter I am interested in (E2)." "I also find the two arrow-based buttons for snapping the magnifier lens very efficient when changing alters (E4)."* ER3 and ER4 used the word "flexible" to describe the mobile platform in on-site data analysis. *"It is natural to think about whether people I am familiar with, for example, my previous collaborators have ever co-authored with this ego before (E3)."*

Complexity of visual analytical tasks with mobile phone. According to E2, E3 and E4, the general complexity of tasks was fine with them. However, E1 voiced a different opinion. He regarded the system as a little bit complex and he thought it would better to drop the original Storyline view and only provide the Storyline thumbnail view instead.

Social implications. When we asked the question *"What is your preference among mobile and desktop platforms for on-site analysis?"*, E1, E2, E3, and E4 all agreed with the idea to leverage mobile phones. However, E2 and E3 also raised their concerns about privacy issues on scanning real human faces. The face tracking and recognition was done within a live video streaming and E3 pointed out that it would be better to scan some *"already existing files or photos instead of real human faces"*. And actually our system can be easily extended for ego-network evolution analysis based on the co-occurrence information between several egos within a series of group photos. Additionally, E3 commented that although there were privacy issues not fully addressed at this stage, this mobile-based system had already shown strong potentials in on-site data analytics for complex tasks.

8 DISCUSSION

In this section, we discuss several design implications obtained from our work and the limitations of the system and the study.

Design implications. It is possible to extend the system design and experimental results from our work to other desktop visualization systems. First, we systematically discuss the process of distilling the visual analytical tasks, visual representations, basic interactions from desktop ego-centric networks. Second, we discuss potential solutions to overcome the three challenges during the porting process. Also we achieve real time face recognition with deep learning models via remote servers.

Besides ego-centric network visualizations, other desktop visualization systems may also benefit from the lessons we learn in this work in presenting multi-scale visualizations and compensating MCVs on mobile phone. For instance, visualization representations such as Parallel Coordinates, Theme River and Stacked Graphs could be regarded as 1D multi-scale visualizations when rendered on mobile screens whereas Arc Diagram, Tree and Chord Diagram could be regarded as 2D multi-scale visualizations. When addressing the MCV issues on mobile phones, we generate compact thumbnail designs as both previews and buttons in a contextual form. These thumbnails not only provide advisable amount of overview information for completing visual analytical tasks but also assist in view switching and navigation.

Limitations. Currently, only one ego is tracked and overlaid with donut chart visualizations, and the alignment between abstract data and physical referents is not enough (i.e., only the AR view is linked to human faces). To some extent, this can be attributed to the limitation of ego-centric perspective of view in mobile AR [Tatzgern 2015] and the uniformity in the dataset. Moreover, our study lacks quantitative evaluation. Thus, we may need to invite more participants in a controlled experiment to further compare the desktop and mobile platforms, and collect deeper feedbacks for deciding a more suitable level of complexity in mobile visual analytical tasks.

9 CONCLUSION AND FUTURE WORK

In this work, we demonstrate how we adapt a complex desktop ego-centric network visualization system to mobile platforms. View management techniques and interaction adaptions are discussed during the porting process. We employ the Zooming+Panning+WIM technique to present multi-scale visualizations. For compensating the loss of MCV visual linkings, a Main view+Thumbnails layout with four novel thumbnail views are devised. Further, our initial user study demonstrates that the system is effective in completing different level-of-detail visual analytical tasks including clustering, comparison and evolution.

For future work, we will evaluate social acceptability and emotional comfort by conducting user studies with various settings. And also we will work on improving our system for joint analysis with diverse physical referents in the future.

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REFERENCES

Gennady Andrienko, Jonathan C Roberts, Chris Weaver, Ebad Banissi, Anita Dfipour, Tomi Heimonen, and Harri Siirtola. 2007. Coordinated & Multiple Views in Exploratory Visualization. (2007).

Blaine Bell, Tobias Höllerer, and Steven Feiner. 2002. An annotated situation-awareness aid for augmented reality. In *Proceedings of the 15th annual ACM symposium on User interface software and technology*. ACM, 213–216.

Thorsten Büring and Harald Reiterer. 2005. Zuiscat: querying and visualizing information spaces on personal digital assistants. In *Proceedings of the 7th international conference on Human computer interaction with mobile devices & services*. ACM, 129–136.

Nan Cao, Yu-Ru Lin, Fan Du, and Dashun Wang. 2016. Episogram: Visual summarization of egocentric social interactions. *IEEE computer graphics and applications* 36, 5 (2016), 72–81.

Tom Chandler, Maxime Cordeil, Tobias Czauderna, Tim Dwyer, Jaroslaw Glowacki, Cagatay Goncu, Matthias Klapperstueck, Karsten Klein, Kim Marriott, Falk Schreiber, et al. 2015. Immersive analytics. In *Big Data Visual Analytics (BDVA)*. IEEE, 1–8.

Luca Chittaro. 2006. Visualizing information on mobile devices. *Computer* 39, 3 (2006), 40–45.

Andy Cockburn, Carl Gutwin, and Jason Alexander. 2006. Faster document navigation with space-filling thumbnails. In *Proceedings of the SIGCHI conference on Human Factors in computing systems*. ACM, 1–10.

Andy Cockburn, Amy Karlson, and Benjamin B Bederson. 2009. A review of overview+ detail, zooming, and focus+ context interfaces. *ACM Computing Surveys (CSUR)* 41, 1 (2009), 2.

DBLP 2014. DBLP. (2014). http://dblp.dagstuhl.de/xml/.

Jochen Ehret, Achim Ebert, Lars Schuchardt, Heidrun Steinmetz, and Hans Hagen. 2004. Context-adaptive mobile visualization and information management. In *Visualization, 2004*. IEEE, 8p–8p.

Neven AM ElSayed, Ross T Smith, and Bruce H Thomas. 2016. HORUS EYE: See the Invisible Bird and Snake Vision for Augmented Reality Information Visualization. (2016).

Neven AM ElSayed, Bruce H Thomas, Ross T Smith, Kim Marriott, and Julia Piantadosi. 2015. Using augmented reality to support situated analytics. In *Virtual Reality (VR)*. IEEE, 175–176.

Ulrich Engelke, Peter Marendy, Ferry Susanto, Raymond Williams, Selim Mahbub, Huyen Nguyen, and Paulo de Souza. 2016. A Visual Analytics Framework to Study Honey Bee Behaviour. In *IEEE 2nd International Conference on Data Science and Systems*. IEEE.

Michael Farrugia, Neil Hurley, and Aaron Quigley. 2011. Exploring temporal ego networks using small multiples and tree-ring layouts. *Proc. ACHI* 2011 (2011), 23–28.

Michael Gleicher, Danielle Albers, Rick Walker, Ilir Jusufi, Charles D Hansen, and Jonathan C Roberts. 2011. Visual comparison for information visualization. *Information Visualization* 10, 4 (2011), 289–309.

Raphael Grasset, Tobias Langlotz, Denis Kalkofen, Markus Tatzgern, and Dieter Schmalstieg. 2012. Image-driven view management for augmented reality browsers. In *Mixed and Augmented Reality (ISMAR)*. IEEE, 177–186.

Jie Hao and Kang Zhang. 2007. A mobile interface for hierarchical information visualization and navigation. In *Consumer Electronics*. IEEE, 1–7.

Nathalie Henry, Jean-Daniel Fekete, and Michael J McGuffin. 2007. NodeTrix: a hybrid visualization of social networks. *IEEE transactions on visualization and computer graphics* 13, 6 (2007), 1302–1309.

Gary B Huang, Marwan Mattar, Tamara Berg, and Eric Learned-Miller. 2008. Labeled faces in the wild: A database forstudying face recognition in unconstrained environments. In *Workshop on faces in'Real-Life'Images: detection, alignment, and recognition*.

Waqas Javed and Niklas Elmqvist. 2012. Exploring the design space of composite visualization. In *Pacific Visualization Symposium (PacificVis)*. IEEE, 1–8.

Denis Kalkofen, Erick Mendez, and Dieter Schmalstieg. 2007. Interactive focus and context visualization for augmented reality. In *Proceedings of the 2007 6th IEEE and ACM International Symposium on Mixed and Augmented Reality*. IEEE Computer Society, 1–10.

Denis Kalkofen, Christian Sandor, Sean White, and Dieter Schmalstieg. 2011a. Visualization techniques for augmented reality. In *Handbook of Augmented Reality*. Springer, 65–98.

Denis Kalkofen, Christian Sandor, Sean White, and Dieter Schmalstieg. 2011b. Visualization techniques for augmented reality. In *Handbook of Augmented Reality*. Springer, 65–98.

Daniel A Keim, Florian Mansmann, Jörn Schneidewind, Jim Thomas, and Hartmut Ziegler. 2008. Visual analytics: Scope and challenges. In *Visual data mining*. Springer, 76–90.

Qingsong Liu, Yifan Hu, Lei Shi, Xinzhu Mu, Yutao Zhang, and Jie Tang. 2015. EgoNetCloud: Event-based egocentric dynamic network visualization. In *Visual Analytics Science and Technology (VAST)*. IEEE, 65–72.

Sebastian Pick, Bernd Hentschel, Irene Tedjo-Palczynski, Marc Wolter, and Torsten Kuhlen. 2010. Automated positioning of annotations in immersive virtual environments. In *Proceedings of the 16th Eurographics conference on Virtual Environments*. Eurographics Association, 1–8.

Emmanuel Pietriga, Caroline Appert, and Michel Beaudouin-Lafon. 2007. Pointing and beyond: an operationalization and preliminary evaluation of multi-scale searching. In *Proceedings of the SIGCHI conference on Human factors in computing systems*. ACM, 1215–1224.

Jonathan C Roberts. 2007. State of the art: Coordinated & multiple views in exploratory visualization. In *Coordinated and Multiple Views in Exploratory Visualization*. IEEE, 61–71.

Ramik Sadana and John Stasko. 2014. Designing and implementing an interactive scatterplot visualization for a tablet computer. In *Proceedings of the 2014 International Working Conference on Advanced Visual Interfaces*. ACM, 265–272.

R Sadana and J Stasko. 2016a. Designing Multiple Coordinated Visualizations for Tablets. In *Computer Graphics Forum*, Vol. 35. Wiley Online Library, 261–270.

Ramik Sadana and John Stasko. 2016b. Expanding selection for information visualization systems on tablet devices. In *Proceedings of the 2016 ACM on Interactive Surfaces and Spaces*. ACM, 149–158.

Maximilian Scherr. 2008. Multiple and coordinated views in information visualization. *Trends in Information Visualization* 38 (2008).

Florian Schroff, Dmitry Kalenichenko, and James Philbin. 2015. Facenet: A unified embedding for face recognition and clustering. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*. 815–823.

Lei Shi, Chen Wang, Zhen Wen, Huamin Qu, Chuang Lin, and Qi Liao. 2015. 1.5 d egocentric dynamic network visualization. *IEEE transactions on visualization and computer graphics* 21, 5 (2015), 624–637.

Fumihisa Shibata, Hiroyuki Nakamoto, Ryoichi Sasaki, Asako Kimura, and Hideyuki Tamura. 2008. A View Management Method for Mobile Mixed Reality Systems.. In *IPT/EGVE*. Citeseer, 17–24.

Markus Tatzgern. 2015. Situated Visualization in Augmented Reality. (2015).

Eduardo Veas, Raphaël Grasset, Ioan Ferencik, Thomas Grünewald, and Dieter Schmalstieg. 2013. Mobile augmented reality for environmental monitoring. *Personal and ubiquitous computing* 17, 7 (2013), 1515–1531.

Chris Weaver. 2004. Building highly-coordinated visualizations in improvise. In *Information Visualization,INFOVIS*. IEEE, 159–166.

Wesley Willett, Yvonne Jansen, and Pierre Dragicevic. 2017. Embedded data representations. *IEEE transactions on visualization and computer graphics* 23, 1 (2017), 461–470.

Yanhong Wu, Naveen Pitipornvivat, Jian Zhao, Sixiao Yang, Guowei Huang, and Huamin Qu. 2016. egoslider: Visual analysis of egocentric network evolution. *IEEE transactions on visualization and computer graphics* 22, 1 (2016), 260–269.

Ji Soo Yi, Youn ah Kang, and John Stasko. 2007. Toward a deeper understanding of the role of interaction in information visualization. *IEEE transactions on visualization and computer graphics* 13, 6 (2007), 1224–1231.

Jian Zhao, Michael Glueck, Fanny Chevalier, Yanhong Wu, and Azam Khan. 2016. Egocentric Analysis of Dynamic Networks with EgoLines. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems*. ACM, 5003–5014.

Stefanie Zollmann, Denis Kalkofen, Christof Hoppe, Stefan Kluckner, Horst Bischof, and Gerhard Reitmayr. 2012. Interactive 4D overview and detail visualization in augmented reality. In *Mixed and Augmented Reality (ISMAR)*. IEEE, 167–176.