nu-view: A Visualization System for Collaborative Co-located Analysis of Geospatial Disease Data

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ABSTRACT

In general, many factors contribute to the spread of diseases among populations over large geographical areas. In practice, analysis of these factors typically requires expertise of multidisciplinary teams. In this paper, we present a visualization system which aims to support the visual analytics process involving multidisciplinary teams of analysts in co-located collaborative settings. The current prototype system allows coupled and decoupled modes of interaction, using a combination of personal visualizations on private small displays and group visualizations on a shared large display. We have conducted preliminary fieldwork and a review study of this prototype with a group of medical experts who have provided feedback on the current system and suggestions for other usage scenarios, as well as further improvements. We found that our target user group have a generally positive attitude towards the use of a shared display with support for the suggested interaction modes, even though these modes are substantially different from the way their groups currently conduct synchronous collaboration, and that additional support for sharing image and textual data over the geospatial data layer may be required.

CCS Concepts

•Human-centered computing → Visual analytics; *Collaborative and social computing systems and tools;* **•Applied computing → Health informatics;**

Keywords

Visual analytics, collaborative visualizations, co-located visualization, geospatial visualizations, multi-surface displays, epidemiology, neglected tropical diseases.

1. INTRODUCTION

Collaboration has been identified as one of the grand challenges for visualization [28]. This is largely due to the fact that it is becoming increasingly difficult for individual analysts to deal with large data sets in very complex, broadly-scoped, and ill-defined problem settings [12]. Collaborative visualizations allow groups of people, with potentially different expertise, to combine their individual analytic skills and knowlege to tackle complex problems from different angles, in concert or independently [29].

A typical example of such a complex collaborative visualisation task is the analysis of how diseases spread geographically over time across large heterogeneous geographical regions. Our collaboration with researchers working on disease surveillance and analysis of the spread of neglected tropical diseases in Amazonia [4] has shown that analysis of this type of complex problem requires the combined expertise of multidisciplinary teams, encompassing medical doctors, epidemiological surveillance professionals, entomologists, veterinarians, public health managers, social scientists, and other specialists. Their work is based on data encompassing several factors relevant to epidemiological surveillance, including geographical distribution of human populations, as well as insect vectors and reservoirs, demographics, patterns of land use, location of forests, bodies of water (which might foster increases in the population of disease vectors), temperature and rainfall, and disease case reports. These experts meet to discuss and present these data from their own perspective with a view to establishing common ground, devising interventions, guiding health services policy and strategy development, and presenting research findings.

Motivated by this complex setting and by our collaboration with these researchers, we have embarked on a project to develop visualization systems to better support the visual analytic processes in collaborative co-located meetings involving such multidisciplinary teams of analysts, as part of their activities to better understand the spread of diseases.

In this paper, we introduce a prototype system, called *nu-view*, which provides a combination of personal visualizations on private small displays and group visualizations on a shared large display, to support such co-located collaborative analytics meetings. We also present results of preliminary fieldwork and a review study of *nu-view* which we have conducted with several experts to provide us with a critique of the current prototype, as well as suggestions for further development.

The main contributions of this paper are: a) the presentation of a functioning high-fidelity prototype, specifically focused on an area of collaborative visualizations for multi-surface environments, where research has been lacking, par-

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ticularly in supporting geospatial visual analytics; and b) the study conducted in a real work environment involving a group of medical specialists who require this type of support in complex analytical and presentation tasks.

2. COLLABORATIVE CO-LOCATED VISUALIZATIONS

In recent years, various visualization systems have been proposed to support synchronous co-located collaboration [12], with some empirical evidence that confirms their effectiveness in visual analytics [13]. These systems either rely on the use of a single large display (e.g. horizontal or vertical) around which group interactions take place [30, 9, 11, 29, 21, 19, 1], or use multiple displays where a large shared display is used in combination with a number of smaller private displays (e.g. mobile devices or laptops), each belonging to one of the group members [31, 6, 20, 25]. Settings in which interactions are divided across a number of displays are generally referred to as multi-surface or multi-display environments [24].

Regardless of the types or combination of displays used, collaborative visualizations need to support two different, but seamlessly interconnected, types of activities: a) *coupled*, group members working together, and b) *decoupled*, group members working alone [23, 27]. McGrath et al. [20] identify three problems with the use of a single display in these types of co-located collaborative visualization settings:

- adding private views to the shared display uses valuable screen real-estate,
- these views have to be managed as group members move around the display, and
- such private views are always visible to others, reducing the degree of decoupling that can be achieved.

McGrath et al. [20] then propose a different approach, which they call *Branch-Explore-Merge*, for supporting these coupled and decoupled modes of interaction that arise in co-located collaborations within a multi-surface environment (MSE). In this *Branch-Explore-Merge* approach, group members can view and interact with visualizations together on a shared display or branch and explore visualizations independently on their own mobile devices, which they can then merge and show on the shared display if needed. A qualitative evaluation of this approach for a task involving collaborative search [20] showed users spending between 40% to 80% of the total task time on private views, and using the public view mainly for consultations with others. In this paper, we also investigate this type of *Branch-Explore-Merge* approach to support coupled and decoupled group interactions in co-located collaborative meetings within a MSE, but with a focus on multivariate geospatial data.

As Abad et al. [26] point out, based on their systematic review of multi-surface interactions with geospatial data, although MSEs have received a lot of attention over the past few years, with many applications and platforms being developed, there is still a need to develop MSEs that specifically focus on geospatial tasks. Our research, therefore, contributes to addressing this need by studying an inherently multidisciplinary sub-domain of geospatial visualization. The diverse composition of the user group we have studied, and the heterogeneous nature of the data this group analyses and shares, requires support for coupled and decoupled viewing of epidemiological data as part of a collaborative visual analytics process directed towards understanding the spread of diseases.

3. ANALYSIS OF DISEASE SPREAD

Epidemiological work, specially in the area of emerging and neglected tropical diseases involves intense teamwork, relying on cooperation within multidisciplinary teams which comprise medical doctors and researchers, epidemiologists, local healthcare providers, nurses, and healthcare managers [17, 18]. Visual communication at meetings through sharing of data on large displays is a marked characteristic of multidisciplinary medical teamwork [16]. In such settings, where different experts present and discuss evidence from a variety of sources, a shared display acts as focus for discussion, and as a means for establishing and recording the team's common ground.

For multidisciplinary tasks related to the spread of diseases, maps typically form the background against which information sharing and decision making unfold. In epidemiology settings, such tasks include surveillance, risk assessment, early warning of outbreaks, planning of preventive interventions, countermeasures, medical examinations and others [10]. The use of maps to explain and predict patterns of disease spread and to support epidemiological reasoning is well-established in medical research [14]. With the widespread adoption of information and communication systems, the need for support in combining public health data with geographical and environmental data has also been acknowledged in the area of health services management [15].

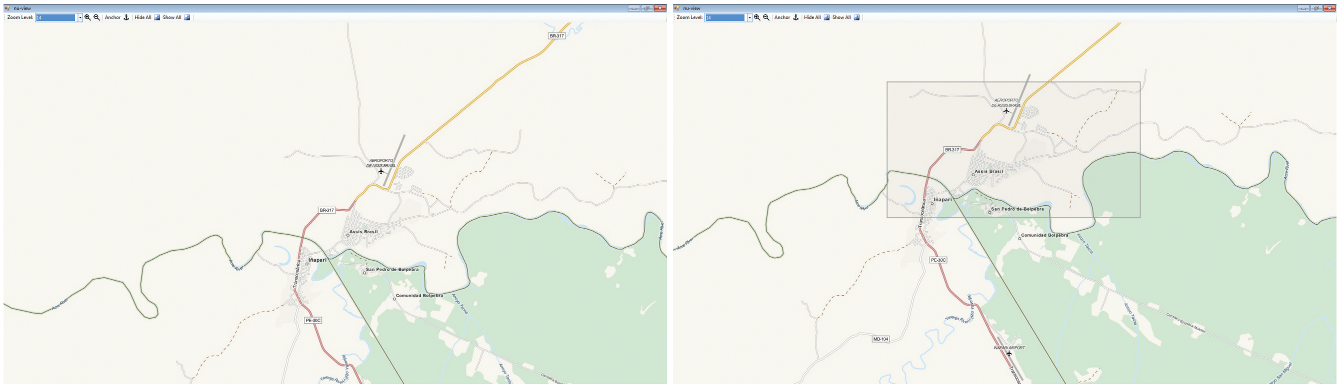
While support for map-based interaction exists, and is often integrated with data collection and epidemiological modelling [22, 17], collaboration support in these systems is mostly restricted to asynchronous interaction or individual data presentation. The *nu-case* system [17], for instance, introduced a unified platform to support data collection by epidemiologists and local fieldworkers working in remote regions. It included data aggregation functionality, and a visualization interface for mobile devices, through which users can view and analyse the compiled information on their individual mobile (e.g. tablet) displays [5].

However, observational studies have found that synchronous communication accounts for the vast majority of human-human interactions in epidemiology work, with co-located communication taking up to 42% of the time spent on the task [10]. In order to address this issue, the work described here builds on the *nu-case* system, and extends its visualization tools [5] by allowing information to be shared on large displays at meetings, while preserving its key features for supporting the tasks performed by individual analysts using their small displays.

It should also be noted that Davies [8] categorizes tasks performed using Geographic Information Systems (GISs) into two groups:

1. system perspective tasks (e.g. interactions with the system), and
2. cartography perspective tasks (e.g. interactions with the geospatial data).

Our prototype focuses mainly on system perspective tasks performed by multidisciplinary teams (e.g. zooming, panning, searching, viewing, etc.). Our future work, on the



a) b)

Figure 1: The group visualization without any personal visualizations (a), with one user sharing their area of viewing (b).

other hand, will focus more on the cartography perspective type tasks specific to our areas of interest (e.g. epidemiology work), which we will identify through empirical studies (see Section 6).

4. THE NU-VIEW SYSTEM

We have developed a prototype system, called *nu-view*, which supports coupled and decoupled modes of interaction in a MSE. Coupled interactions take place around group visualizations on a shared large display (vertical or horizontal), while decoupled interactions centre around personal visualizations on private small displays (e.g. using mobile devices such as tablets and smartphones). *nu-view* also facilitates sharing of personal visualizations in the context of the group visualization. Using these combinations, *nu-view* allows seamless transitions between visual analytics processes carried out individually on personal visualizations and collectively on group visualizations, which can include visualizations resulting from individual analyses on private displays.

Figure 1a shows the group visualization of *nu-view*, displaying a map of the tri-national region of South-western Amazonia where a number of neglected tropical diseases are being monitored by our research team [18, 17]. Although figures shown here display cartographic maps, *nu-view* also allows the use of satellite maps, as well as the display of external map overlays. The minimal level of information individual analysts may wish to share with others, is the area of the shared visualization they are viewing on their personal visualization, as shown in Figure 1b. This view is dynamically updated as personal visualization areas are moved (i.e. panned) and changed in size (i.e. zoomed in/out).

Individual analysts may also wish to share more detailed views of their personal visualizations, such as those resulting from their process of visual analytics in decoupled interaction mode. Figure 2 provides examples of this, where the images on the left-hand side show a selected set of patient cases with minimal case details (using black squares), while on the right-hand side more specific details of cases are shared in another part of the shared visualization (using various icons created based on individual case attributes). Cases that are not in areas being viewed by individual analysts, or selected by them to be shared, remain invisible on the group visualization.

As more analysts share their personal visualizations, these are overlaid on the group visualization as separate overlays, displaying their individual areas of view, selected cases, level of details, and other individual configuration parameters that specify the individual displays (see Figure 3). Note that the area of personal visualizations, shown as semi-transparent colour rectangles on the group visualization (Figure 3, top) are dependant on the actual size, screen resolution, and zoom level of individual devices. In our examples here, the tablet device with the gray area (Figure 2, bottom) is physically larger than the tablet device with the red area (Figure 3, bottom).

It should also be noted that when areas of different personal visualizations overlap (Figure 3, top), each visualization preserves its own level of details as well as the selected cases it is allowed to share on the large display. Using this functionality, individual analysts may choose to focus on the same area, but analyse and share data that are relevant to their own expertise. This would allow group visual analytics taking into account different factors or disease case attributes.

This process may also require more details of specific cases to be shown. This can be done by analysts tapping on the individual case icons on their personal visualizations, and revealing further case information, as shown in Figure 4.

Although we envisage that most of the interactions with *nu-view* will be carried out using individual devices used by the analysts, our prototype system provides some interactions with the group visualization on the large display. For instance, the group visualization can be focused on the area being viewed and shared by an individual analysts, as demonstrated in Figure 5. Similarly, it is possible to hide or show an individual, or all, shared visualizations, as well as zooming in/out using pre-specified levels on the group visualization.

5. IMPLEMENTATION

Figure 6 provides a schematic overview of the architecture of the *nu-view* prototype application. As can be seen, *nu-view* consists of a *host application*, providing the group visualization, and a series of *mobile applications*, each providing one of the personal visualizations. The communica-

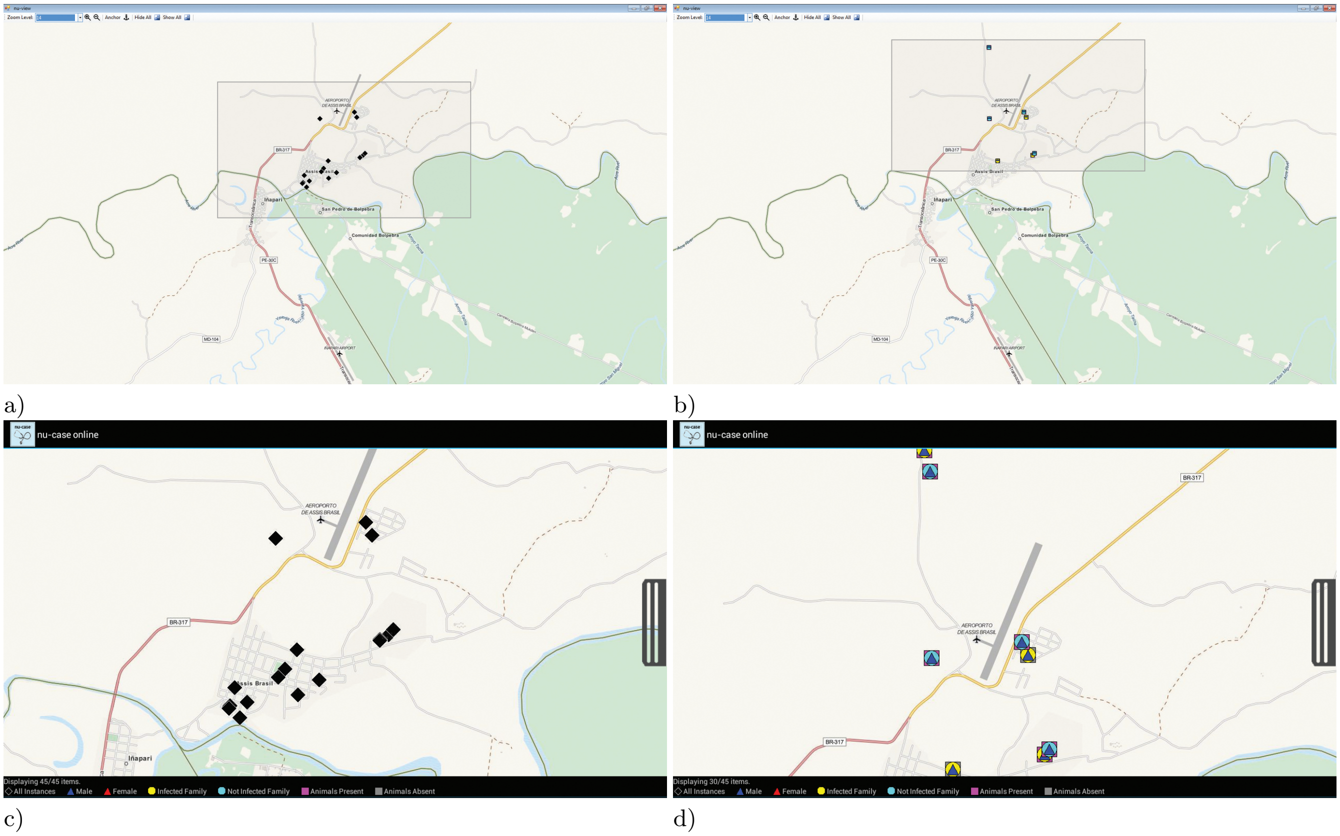


Figure 2: The group visualization changes when individual users share more details (a), or move their view (b), and the corresponding personal visualizations shown on their tablet display (c, d).

tion between the host and mobile applications is supported using the *Environs Framework*[1] [7].

While the *nu-view* mobile application uses *OsmDroid*[2] to request and display *OpenStreetMap*[3] tiles as a map, the *nu-view* host application uses the *BruTile*[4] C# library to perform almost identical tile requests to that of OsmDroid on the Android-based mobile application. These tiles are then displayed in a map viewing window within *nu-view* host application using the *SharpMap*[5] mapping library.

For the *nu-view* host application to track the activities of all the devices using the *nu-view* mobile application, both the host and mobile applications must be connected to the Environs Framework through their specific layers. The Environs layer in each application searches for devices on the same local network and prepares them for connection to one another. In this case, the *nu-view* host application is treated as an Environs hub. Multiple Android-based devices can be connected to the *nu-view* host application through Environs. Once a mobile device and the host are connected, a series of messages over the Environs link establish a record of the device's current view location, parameter settings, etc. using the *[Device display] and [Update _]* sequences.

The *nu-view* host application uses this information to display a rectangle showing the view of each mobile device on the map view provided by SharpMap. Each rectangle is centred on the mobile device's view coordinates with the corners placed at the coordinates for the four corners visible on the device's map view. Specifically, a polygon is created on an overlay layer within SharpMap with vertices as a Google Mercator projection of the coordinates provided. Whenever a view is panned/zoomed on a *nu-view* mobile application, an update message is sent from its Android Environs Layer to the Host Environs Layer containing the five coordinates needed for the rectangle. The Host Environs Layer listens for various messages from all the connected devices and updates the appropriate record. The *nu-view* host application then redraws the rectangle overlay for the updated device's view.

In a similar fashion to drawing views of each *nu-view* mobile application, the *nu-view* host application allows the display of individual disease case icons visible in each of the *nu-view* mobile applications. The data from each case is sent to *nu-view* host application via an Environs Layer, and an overlay is constructed on the host application from a series of point-symbols on a new SharpMap layer. The same shapes and colours are used to represent individual case attributes on both the host and mobile applications.

As mentioned in the previous section, it is also possible to set the views of all the personal visualizations to that of the group visualization. When this option is selected, a message with the current centre coordinate and zoom level of the *nu-view* host application map is sent to all the connected

[1]http://hcm-lab.de/environs
[2]http://wiki.openstreetmap.org/wiki/Osmdroid
[3]http://wiki.osmfoundation.org/wiki
[4]http://wiki.openstreetmap.org/wiki/BruTile
[5]http://sharpmap.codeplex.com

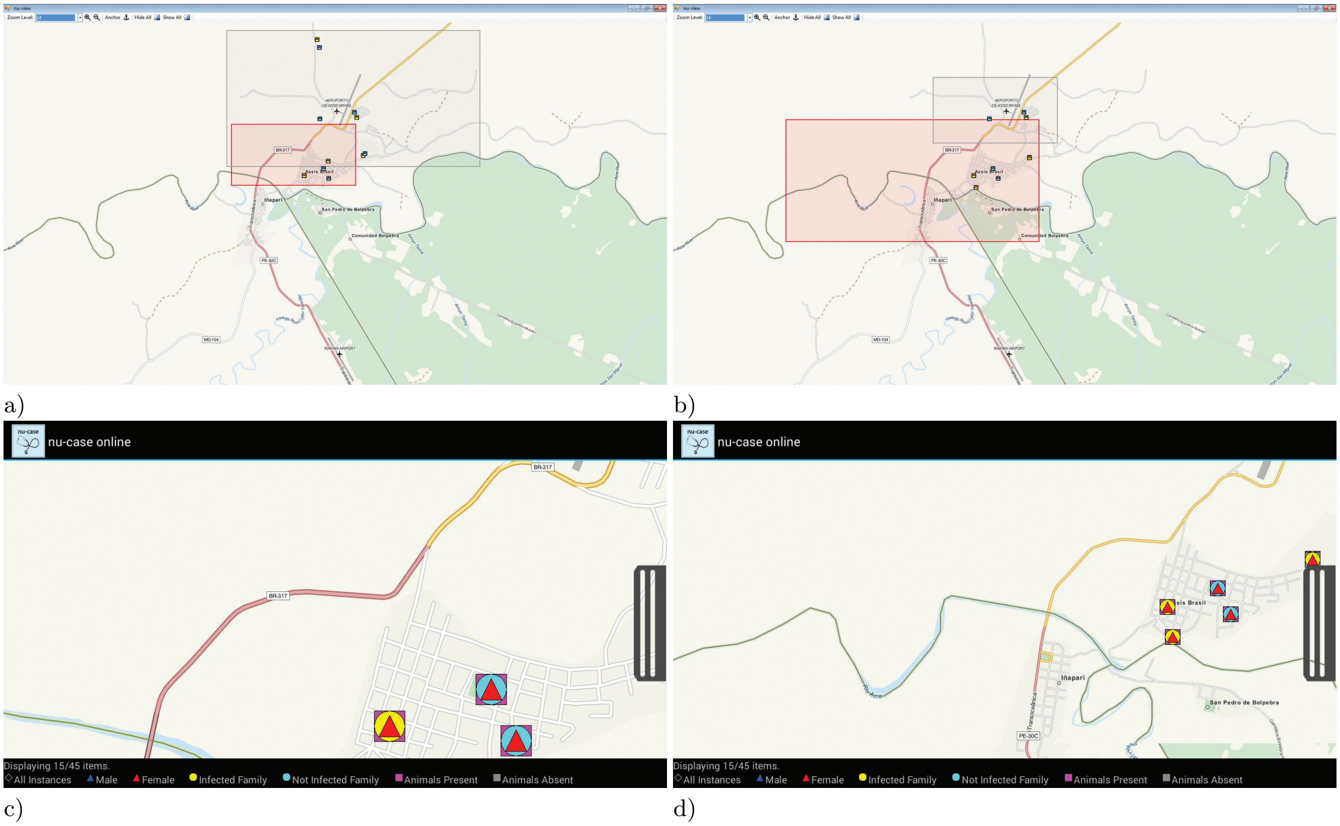


Figure 3: The group visualization with more than one personal visualization being shared (a), with their area of viewing and level of shared details changing (b), and the corresponding personal visualizations shown on one of the displays (c, d).

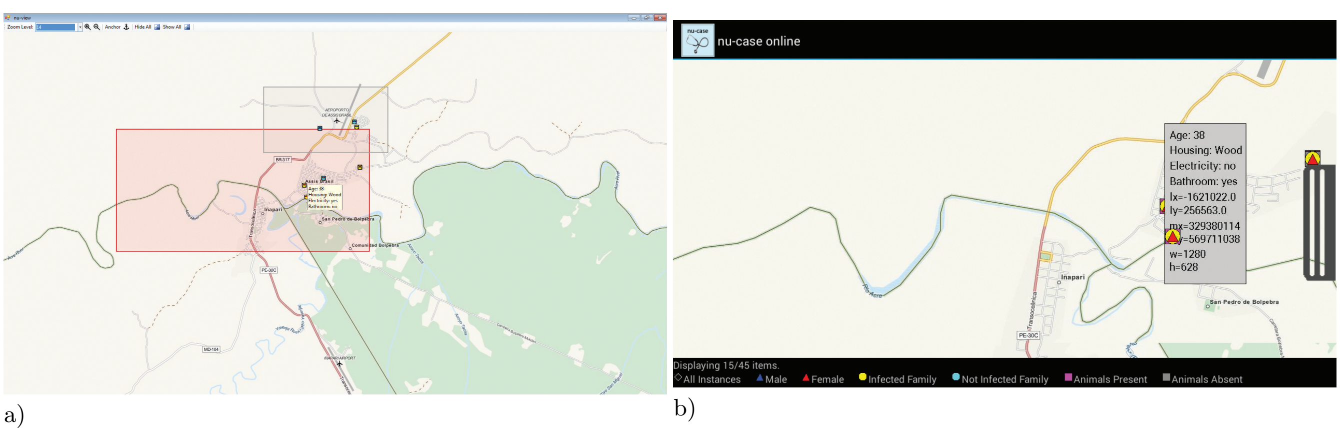
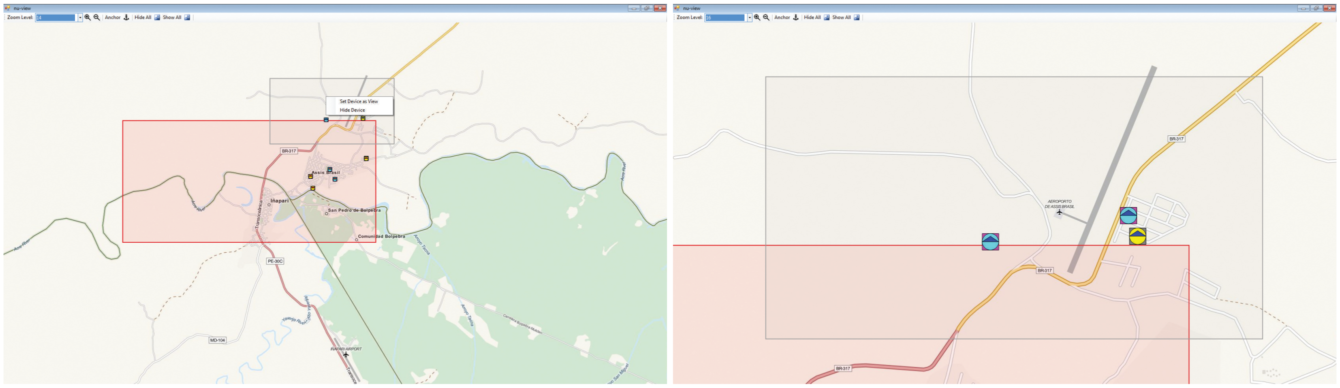


Figure 4: Details of an individual case shown on the group visualization (a) when it is selected on a personal visualization (b).



a) b)

Figure 5: Focus of the group visualization can be changed (a) to that of a particular personal visualization (b) by selecting it from a context-sensitive menu.

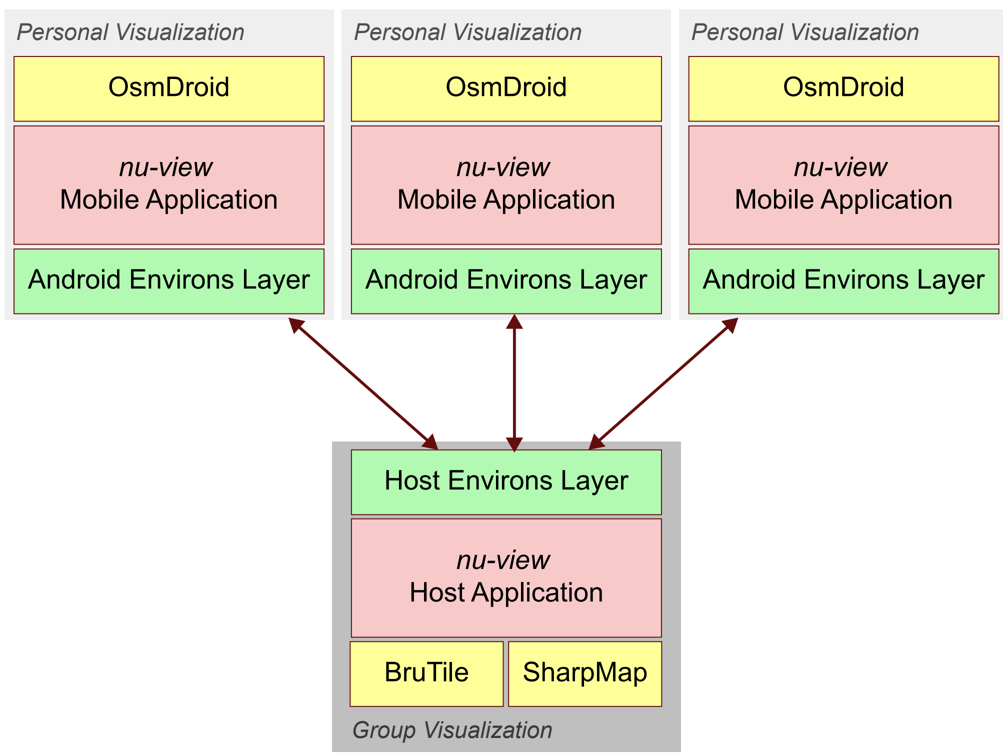


Figure 6: Architecture of the *nu-view* application.

devices via the Environs Framework. Each *nu-view* mobile application then sets its view to the same location as the host application, and new tiles are fetched and displayed by OsmDroid. This works seamlessly, because the zoom levels and map tiles used by OsmDroid and BruTile are both from OpenStreetMap and are almost identical. However, it is also possible to set the map tiles provider to another server to be used by OsmDroid and BruTile.

Other interactions provided by *nu-view*, such as hiding or showing views of each or all personal visualizations on the group visualization, etc. are supported in a similar manner using overlays and and sharing coordinate locations and zoom levels.

6. FIELDWORK AND EXPERT REVIEW

The development of the *nu-view* system has had strong user participation in that it has been based on our experience of working with researchers involved in monitoring the spread of neglected tropical diseases in Amazonia, as well as our consulting with them during the process of designing the prototype system.

Despite this level of involvement, and as pointed out earlier, we still need to better understand the types of cartography perspective tasks carried out by multidisciplinary teams of experts dealing with the spread of diseases, and specifically, how these tasks can be executed in a MSE. As a first preliminary step towards this goal, we have carried out observational fieldwork of the interaction of a multidisciplinary group working on epidemiological research, followed by a a review of our current *nu-view* prototype with a group of medical researchers. In this section we describe this study and present its early findings.

6.1 Method

Initially, one of the authors carried out a fieldwork by attending several meetings of a group comprising medical doctors, epidemiologists, biologists, social scientists and statisticians who met to present and analyse epidemiological data.

The second phase of the study took the form of an expert review, during which the *nu-view* prototype was presented to the participants, and their opinions were sought regarding its current and future potentials.

For the purpose of presenting the prototype to the participants we created an envisionment video [2], which was shown to the participants prior to the administration of a short questionnaire, followed by an open-ended interview. Figure 7 shows two scenes from this video, which was 3 minutes in length and had voiceover in Portuguese for our study participants in Brazil[6]

6.2 Questionnaire and interviews

The questionnaire served to elicit the participant's background and prior experience in medical team meetings in which different kinds of data are shared. We also enquired about the nature of the data normally shared in such meetings, about the use of mobile devices such as tablet computers in the meetings, and about the possibilities for use of a system like *nu-view* in the context of their work. The interviews served to further clarify the participants' opinions and to allow them to expand upon their suggestions.

Four healthcare professionals, all actively involved in disease surveillance, took part in the study: two were medics, and two were epidemiology researchers. Three participants were female and one male, and their age ranges were 30-40 (1) 40-50 (2) and 50-60 (1).

6.3 Findings

The observation of group meetings revealed that most disciplines relied on maps to contextualise the data presented at the meetings. This was clearer in the work of epidemiologists, who presented statistical data on a large display, using a slides presentation software), but made frequent references to a map of the region of interest (the tri-national region of South-western Amazonia) by switching back and forth between slides. Although analyses of patient case datasets were often presented, the presentation of these cases was not well supported by maps (which would have required preparation of individual maps well in advance of the meeting). In the absence of such maps, presenters had to rely on textual tables and verbal references to regions of interest, and information had to be essentially exchanged through talk. These preliminary findings were followed by the design and introduction of the *nu-view* prototype and the expert review phase of the study.

The review demonstrated that all participants regarded *nu-view* as a potentially useful tool in multidisciplinary meetings involving presentation of epidemiological data. Their comments in this regard focused on potential improvements on the analysis of *"the global picture"* (P1) by all participants, *"better integration of all experts into the meetings"* (P1), and as a general *"aid to the discussion process"* (P3). When asked to describe a potential scenario of utilization of *nu-view* in epidemiological surveillance, two participants described monitoring and control of dengue fever infection, outlining a process of cartographic mapping of disease cases, households and other areas of interest in public health, such as parks, schools, churches etc. Another interesting suggestion, was for the potential use of *nu-view* as a tool for Team Based Learning (a technique commonly employed in medical education), where the shared screen could be used to display student answers in a disease mapping context. This is similar to the use of our *nu-case* system (see Section 3), with which *nu-view* is integrated, for educational purposes [3].

Two of the participants (a medic and an epidemiology researcher) stated that they participate in multidisciplinary meetings where healthcare information is presented and shared in a collaborative setting. Professionals of other disciplines represented in such meetings, according to these participants, are: psychologists, medical doctors, healthcare services managers, other healthcare professionals, and in some cases students. The kinds of data presented during these meetings are rather varied, and include disease occurrence statistics and their geographical distribution, data on the utilization of public healthcare services, and public policy documents. The goals of sharing such data include strategic planning, assessment of interventions and identification of areas for future actions. Both participants stated that their teams employ large displays in their meetings, and one of them stated that they often employ tablet devices during the meetings (though not in combination with the large display). One of the participants stated that they use geographical maps, both in physical and digital forms

[6]A version of this video can be watched at https://youtu.be/C23ZWSq-ius

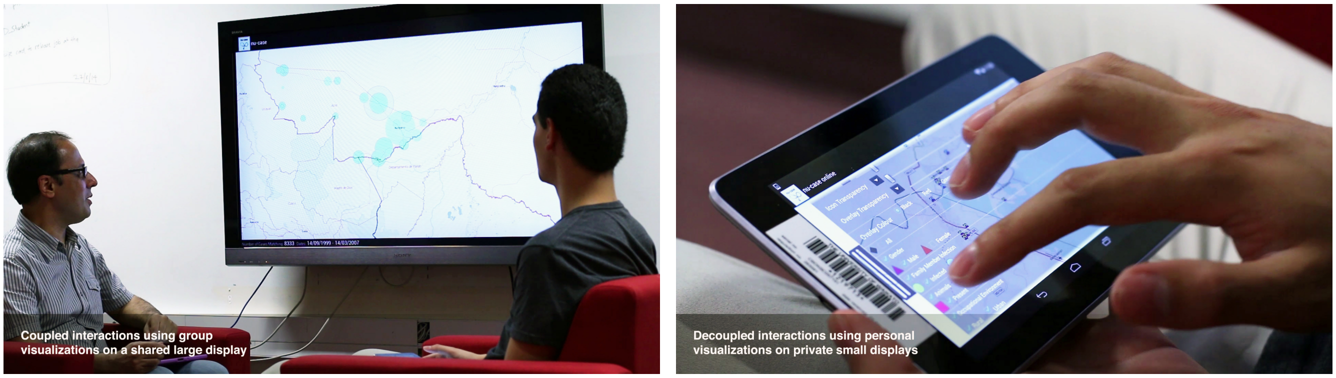


Figure 7: Two scenes from the envisionment video which was presented to the study participants.

during meetings, while the other stated that their meetings occur mainly in the context of administrative tasks at a higher education institution. However, they stated that even in these educational settings where maps are currently not used (except occasionally, and embedded in slide presentations), there is potential for the use of maps shared on a large display when discussing student work, disease mapping data, and similar items.

The participants suggested many possible additions to the functionality of *nu-view* in order to make it more useful in multidisciplinary meetings. One of the participants suggested that the screen could support the collaborative creation of tables and the sharing of (geo-tagged) photographs. Another suggestion (by two participants) was adding support for integration of externally linked data and overlays (e.g. an overlay layer showing the ethnic composition of the population in a given area of interest). Three of the participants also mentioned that being able to annotate the shared area by using the mobile devices would be useful to the group, while also serving as a means of documentation at an individual level.

7. CONCLUSIONS

In this paper, we have discussed the multidisciplinary nature of the complex task of analysing patient case data to better understand how diseases spread geographically over time. We have also identified the potential benefits of providing geospatial visualizations to better support visual analytics processes in collaborative co-located settings involving multidisciplinary team of analysts.

Our *nu-view* prototype system aims to facilitate these types of visual analytic processes by providing a seamless integration of personal and group visualizations that allow coupled and decoupled modes of interaction in a MSE using a number of individual and shared displays.

The review study of our prototype, which we have conducted with a group of medical experts, has revealed a positive attitude on the part of healthcare professionals towards *nu-view* and provided us with a number suggestions for further developments of the system. Once we have undertaken these improvements, we aim to carry out more comprehensive evaluations of our prototype, including its use in real-world co-located collaborative visual analytic meetings.

8. ACKNOWLEDGEMENTS

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