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Exploring Collaboration with Geospatial Information in Multi-Display Environments

by

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Abstract

Devices such as tablets and tabletops are now common and widespread, presenting opportunities to explore how these devices can be used in a variety of environments and application domains. Multi-display environments (MDE) incorporate several displays and allow tasks such as information sharing and collaboration amongst users. The geospatial domain affords opportunities to explore collaboration within MDEs, as information can be spread across different geographical layers, scales, and views (e.g. an overview map).

This thesis describes the results of a study that investigated how tablets can be used as collaborative tools for geospatial information exploration within MDEs. Participants were divided into pairs within an MDE, and given tasks with differing numbers of tablets and of visualizations per tablet. Results indicated that most users preferred two tablets with all visualizations as ideal for collaboration within the geospatial MDE, and the number of tablets did not significantly impact the completion time of tasks.

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Publications from this Thesis

Portions of the materials, ideas, and figures presented in this thesis have appeared previously in the following peer reviewed publications:

F. Marinho Rodrigues, T. Seyed, F. Maurer, and S. Carpendale, “Bancada: Using Mobile Zoomable Lenses for Geospatial Exploration,” In *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces – ITS ‘14*, 2014, pp. 409–414.

F. Marinho Rodrigues, T. Seyed, F. Maurer, S. Carpendale, "Bancada: Mobile Zoomable Lenses for Collaborative Geospatial Exploration," In *Proceedings of the 2nd Collaboration meets Interactive Surfaces Workshop (CmIS) in Ninth ACM Interactive Tabletops and Surfaces – ITS '14*, Dresden, Germany, 2014.

T. Seyed, C. Burns, P. King, **F. Marinho Rodrigues**, M. Costa Sousa, and F. Maurer, “MRI Table Kinect: A multi-surface application for exploring volumetric medical imagery,” in *Proceedings of the Workshop on Safer Interaction in Medical Devices (MediCHI’13)*, 2013.

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List of Abbreviations

1D	1-dimensional
2D	2-dimensional
3D	3-dimensional
CSCW	Computer-Supported Cooperative Work
EOC	Emergency Operations Centre
F+C	Focus + Context
HCI	Human-Computer Interaction
InfoVis	Information Visualization
MDE	Multi-Display Environment
MLMT	Multiple Lenses on Multiple Tablets
MLST	Multiple Lenses on Single Tablet
O+D	Overview+Detail
SL	Single Lenses
ZOIL	Zoomable Object-oriented Information Landscape
ZUI	Zoomable User Interface
ZUIO	Zoomable User Interface with Overview

The design of collaborative technology needs to be guided by an understanding of how collaborative work is accomplished. By understanding what resources the collaborators use and what hindrances they encounter in their work, tools can be designed to augment resources while removing obstacles in collaborative activity.

—J. C. Tang [1]

Chapter One

Introduction

> Instead of viewing and manipulating a computerized world through a large stationary computer and display, we want to shift to a new model in which we carry around a very small palmtop computer that acts as our personal display onto information spaces.
>
> —Fitzmaurice [2]

Fitzmaurice proposed the model described above in 1993. Since then, mobile personal devices, such as tablets and smartphones, became ubiquitous devices and much effort has been undertaken to investigate how to integrate them with devices situated within public environments, such as wall displays and tabletops. **Multi-display environments** (MDEs) are systems where the interaction is divided over several heterogeneous devices, such as digital tabletops, wall displays and personal mobile devices, *"to take advantage of different capabilities such as their size, position, resolution or mobility to support the task at hand"* [3, p. 41]. Within MDEs, the notion of situated information spaces [2], as described by Fitzmaurice, becomes feasible as they allow users to use their personal mobile devices in conjunction with situated devices to explore large information spaces, i.e. large bodies of information. In order to provide efficient access to large information spaces within MDEs, due the heterogeneity of devices, how the information is distributed, represented, displayed, and also manipulated, changes according to the capabilities of each device. For example, considering geospatial information, a non-interactive wall display can display an overview map of a region, while a tablet provides different detailed views from the same region and allows users to explore them through touch gestures on its screen.

Although it is common to see people using multiple mobile devices during collaborative activities, e.g. an office meeting, it is possible to notice that these high-tech tools still do not support natural collaboration as we see with low-tech tools, such as a sheet of paper, a traditional table, or a whiteboard [4], [5]. For example, when an office meeting is taking place, a low-tech medium, such as a whiteboard marker, can be seen as a "private" asset when a collaborator uses it to annotate a particular aspect of the problem being solved on a whiteboard; and then it becomes a shared asset when the "owner" passes it to others and they are then able to add their own contributions, in the form of new annotations or changes in the existing ones. In these situations, the sense of individual ownership of the marker is almost nonexistent. With personal mobile devices, especially smartphones, the opposite situation is observed. There is a resistance from people to share mobile phones, since *"it* [the phone] *contains our data and is thus tied to us"* [6, p. 949]. Tablets, also, are personal devices however, due their larger screen, there is a higher potential to support and enhance collaborative activities, as seen in [5], [6]. My interest to research such potential, especially when tablets are integrated with situated devices (devices situated within public environments), led to the study described in this thesis.

In this thesis, I explore how **different numbers of tablets**, providing **multiple detailed views**, **impact the collaboration** between pairs during geospatial information exploration activities within MDEs. Also, I explore how the **collaboration is affected** when tablets are **specialized tools**, i.e. each tablet provides a specific detailed view, *versus* when they are **"all-in-one" tools**, i.e. all detailed views are available on all tablets. I compare both approaches to a single-purpose tool (e.g. a screwdriver) and a Swiss Army knife, respectively. In the first case, collaborators have access to detailed views based on the tablet they are interacting, while in the second, they have access to all views independent of the tablet.

This Chapter provides an introduction to this thesis. Section 1.1 provides context and frames the scope of this thesis. Section 1.2 describes the research questions, followed by the contributions in Section 1.3. Finally, Section 1.4 describes the structure of the remainder of this thesis.

1.1 Setting the Scene

This thesis falls under the broad context of Human-Computer Interaction (HCI), where researchers investigate how people interact with computer systems. Within HCI, this work lies in the research area of Collaborative Visualization, which explores how computer systems can support groups of people performing information exploration activities. This area emerges from the intersection of the research fields of Information Visualization (InfoVis), which studies strategies and tools to visualize information; and of Computer-Supported Cooperative Work (CSCW), which explores the design and evaluation of tools to support activities performed by groups of people. My work investigates how multiple devices support groups of two people co-located in the same environment performing information exploration activities. In the following subsections I provide an overview of the research space related to this thesis, which details its context and frames its scope.

1.1.1 Information Visualization

More recently, portable devices such as tablets have experienced an explosion in pixel density, but the physical interaction limits of the screens have not kept pace. When large amounts of information are presented, the limiting factor is the size of the screen on which the information is being presented. A high number of pixels per inch allows the displaying of more information however, a user interacting with a small screen device may not be able to identify and extract useful information from two adjacent points. The discrepancy between information space and display size characterizes the **screen real estate problem** [7], also called the **presentation problem** [8] in Information Visualization.

Information Visualization (InfoVis) is *"the use of computer-supported, interactive, visual representations of abstract data to amplify cognition"* [9]. Interfaces providing visual access to information, to amplify the aforementioned cognition, have two components, as described by Carpendale and Montagnese [7]. The first, **the representation of the information**, is "the act of creating an image that corresponds to the information", while the second, **the presentation**, is the act of displaying the image from representation, emphasizing and organizing areas of interest. The presentation, when changed, impacts the way the information it represents can be explored. One approach demonstrating how the information can be explored differently by changing the presentation is called Magic Lens [10] (also referred to in this thesis as *lens*), presented in 1993, by Bier *et al.* With Magic Lenses, a user is able to *"modify the presentation of application objects to reveal hidden information, to enhance data of interest, or to suppress distracting information"* [10, p. 73] using widgets emulating see-through interfaces positioned over the information space. Figure 1.1, reproduced from [10], shows two lenses changing the presentation of a 3D model. While the circle lens magnifies the model, the square lens reveals its wireframe.

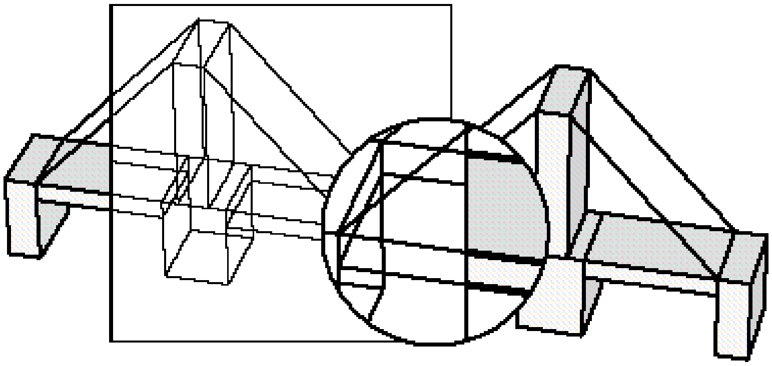

Figure 1.1 Magic Lenses[1]**.**

Besides lenses, other approaches aim to mitigate the presentation problem and provide means for users to explore information spaces. These approaches can present the information (i) without distortion, such as zooming, scrolling, and panning interfaces, or (ii) through distortion-based techniques, such as *fish-eyes* [11]. Approaches without distortion provide simple implementation solutions for the presentation problem; however, at the cost of user experience: users typically experience information discontinuity. This means that they are required to keep a mental overview model of the information while also interacting only with portions of the information [11]. One possible solution to address the information discontinuity problem is to provide multiple simultaneous views displaying different portions of the information at the cost of screen space [12], as seen in Figure 1.2. Distortion-based techniques present focus and overview simultaneously by magnifying, stretching or squishing portions of the information space [13], as seen in Figure 1.3. Besides having high complexity to implement, prior research has shown that distortion hinders users in tasks that require precise judgement about *"scale, distance, direction, or alignment"* [14, p. 260].

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[1] Source: Bier *et al.* [10]

Figure 1.2 Multiple views displaying different portions of an image. An overview is displayed on the top-right corner of the window containing the detailed view of the image.

Figure 1.3 Presentation of an image with distortion.

Considering the primary purpose of the study described in this thesis, i.e. to explore the use of tablets as collaborative tools for geospatial exploration within MDEs, the use of distortion-based approaches would not be adding significant value to the study. Therefore, I opted for focusing on approaches without distortion in this thesis.

1.1.2 Collaboration and Information Visualization

Sensemaking [15]–[17] is a process by which information is *"collected, organized, and analyzed to generate knowledge and inform action"* [18, p. 49]. During the past decades, sensemaking activities that were seen as solitary experiences, e.g. exploring company's financial data, became social processes involving *"parallelization of effort, discussion, and consensus building"* [18, p. 49]. However, groups of people wishing to collaboratively perform sensemaking activities with traditional systems experience frustrations, such as conflicts when sharing input mediums (e.g. keyboard and mouse) and crowding around a single display. Such frustrations result from the *"single-display, single-user assumptions"* that designers and developers make [19]. In order to mitigate such frustrations, researchers have been exploring how to design systems to support groups of people during collaborative activities since the 1970s [20].

Between the 1970s and the 1980s, the term **groupware** was coined as result from the fusion *group* + soft*ware* [20], [21]; and, in 1984, Greif and Cashman formalized the research field by introducing the phrase **computer-supported cooperative work** (hereinafter, CSCW) [22], which is defined as *"an identifiable research field focused on the role of the computer in group work"*. During the past decade, an increasing interest in collaborative analysis of information visualizations resulted in a new research area defined as part of InfoVis: **Collaborative Visualization** [18], [23]. Isenberg *et al.* defined Collaborative

Visualization as *"the shared use of computer-supported, (interactive,) visual representations of data by more than one person with the common goal of contribution to joint information processing activities"* [23, p. 3].

Palmer and Fields point out that the key factor for the success in CSCW activities is making users comfortable with system operations [24]. These operations must consider the context of the collaboration, since collaborative activities can happen according to two dimensions [25]: place and time – seen in Table 1.1. Both dimensions have two possible values: same or different. When collaborators perform an activity at the same time, it is considered **synchronous** collaboration, when they perform activities at different times, it is considered **asynchronous**; when collaborators are in the same place, the activity is **co-located**, and when in different places, it is **distributed**. An example of a synchronous co-located activity is an in-office meeting; an example of a synchronous distributed activity occurs when collaborators are in different geographic places and use a videoconferencing application (e.g. Skype) to meet. Considering different time (asynchronous collaboration), a co-located collaboration takes place when collaborators share the same environment, but are separated by time. For example, in a hospital, nurses from different shifts may manipulate the same patient record; and a distributed asynchronous collaboration can be seen when people in different places have discussions exchanging emails. This thesis focuses on the co-located synchronous collaboration quadrant.

		Time	
		Same	Different
Place	Same	Collocated synchronous (e.g. in-office meeting)	Collocated asynchronous (e.g. nurses from different shifts)
	Different	Distributed synchronous (e.g. meeting using Skype)	Distributed asynchronous (e.g. email discussion)

Table 1.1 Place x Time collaboration matrix

1.1.3 Multi-Display Environments and Collaborative Visualization

Nowadays, it is common to see people carrying multiple mobile devices, especially tablets, in their bags. Besides mobile devices, situated devices, such as wall displays and tabletops, also are becoming part of our daily lives – it is possible to interact with touch-enabled public displays situated in shopping centers, museums and restaurants, as seen in Figure 1.4. Dix and Sas [26] describe opportunities and synergies obtained from the integration between personal mobile devices and situated public displays. The authors highlight the complementary properties from personal and public devices, for instance, personal devices, due to their small screens, are poor for sharing the view of the information being displayed on its screen, while public displays, due to their larger screens, are *"not suitable for keeping things private"* [26, p. 4]. However, while public displays may not allow for input, personal devices provide direct input through a keyboard or touch screen, and can also include indirect inputs through sensors such as accelerometers, gyroscopes and GPS.

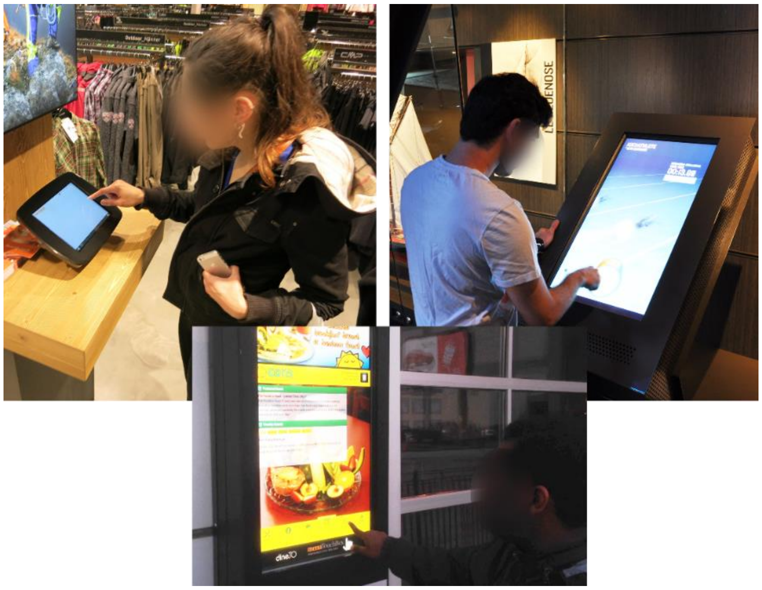

Figure 1.4 Users interacting with situated displays in a shopping center in Berlin, Germany (top-left); in a museum in Calgary, Canada (top-right); and in a restaurant in Toronto, Canada (bottom).

Seyed *et al.* define a multi-display environment as *"a system where interaction is divided over several displays, such as digital tabletops, wall displays and personal devices like tablets or mobile phones. MDEs often include heterogeneous displays to take advantage of different capabilities such as their size, position, resolution or mobility to support the task at hand"* [3, p. 41]. Figure 1.5 shows an example of MDE used to explore medical magnetic resonance imaging (MRI). Within this MDE, each device provides a different view from the information space based on their capabilities: the tablet displays a detailed MRI view and allows users to interact directly; the tabletop displays an overview body; and the wall display, due its larger screen, provides the same detailed view seen on the tablet plus information from the patient.

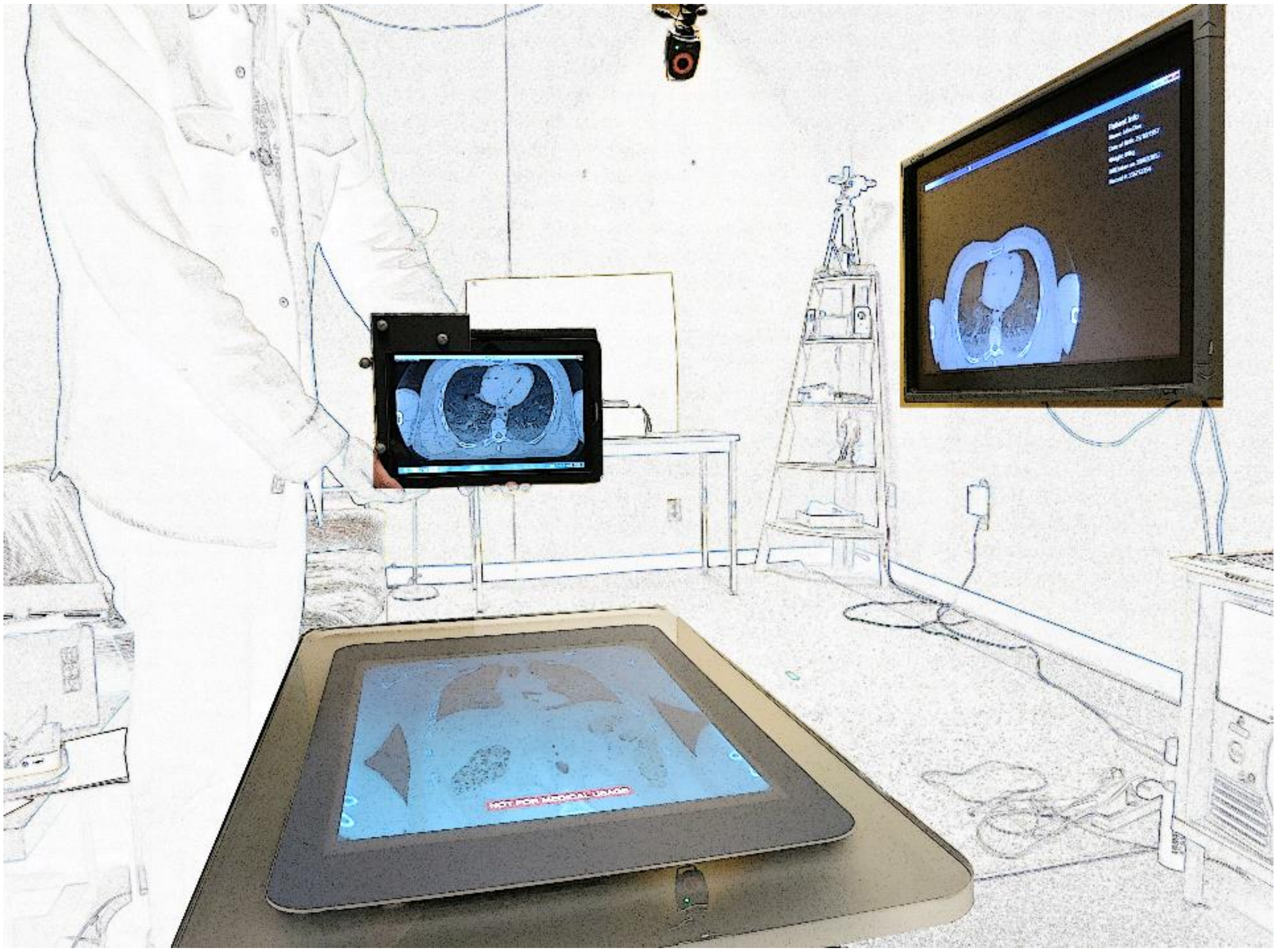

Figure 1.5 Example of MDE.

Aiming to take full advantage of the complimentary properties of personal devices and public displays to support user (and groups of users) activities, researchers have been exploring how to design multi-display environments since the 1980s. Colab [27] is attributed to be the first of such environments and it was designed to support meeting processes. Within Colab, users have access to individual terminals to interact with a large shared display, as seen in Figure 1.6, reproduced from [27]. Since then, research has shown that multiple-display environments can benefit collaborators from many different domains: users can explore geospatial information (e.g. [28]) and browse the web (e.g. [29]); during an emergency, professionals working at an Emergency Operation Center (EOC) can have an overview of the situation [30]; retail stores can provide personalized advertisement based on the customers present in a given moment [31]; and physicians can visualize MRI images [32].

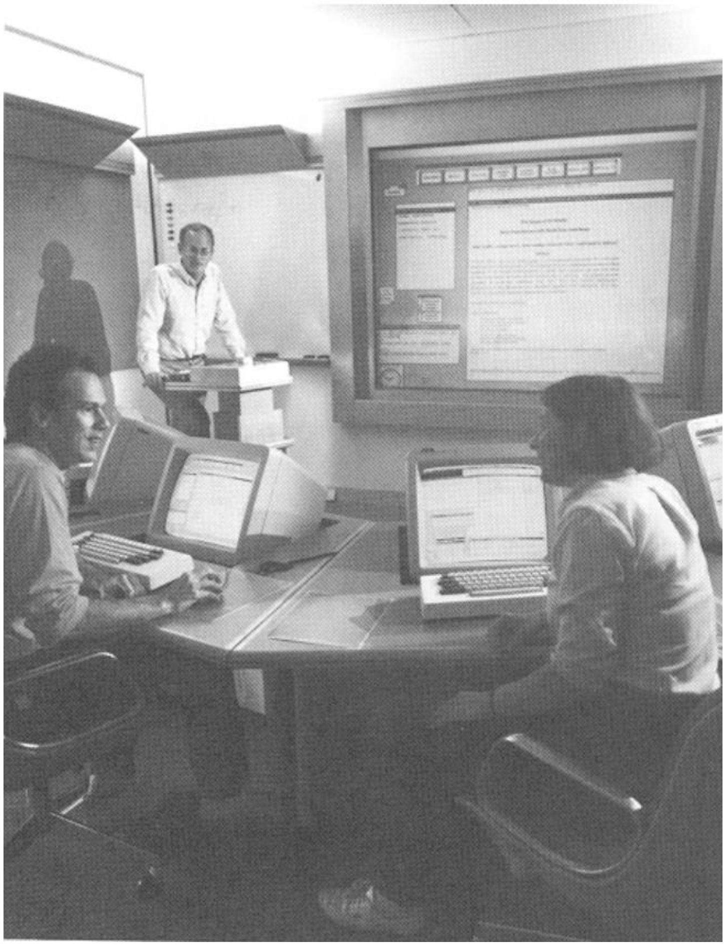

Figure 1.6 Colab[2].

In the Collaborative Visualization research space, much effort has been invested to explore co-located collaboration using single-display environments (e.g. [4],

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[2] Source: Stefik *et al.* [27]

[33]–[37]). However, the research space on Collaborative Visualization within MDEs is quite sparse and affords multiple research opportunities: there are examples of Collaborative Visualization systems integrating mobile personal devices and situated devices (e.g. [38]–[41]); however, few studies explore the impact of personal devices on co-located collaboration (e.g. [29], [42], [43]) during such activities. And, to the best of my knowledge, there are no studies exploring different numbers of tablets and different numbers of detailed views per tablet available for geospatial collaborative activities as described in this thesis.

1.1.4 Why Maps?

The geospatial domain was chosen for multiple reasons. Besides the aforementioned gap in the research space, maps are often used for sensemaking tasks on which individuals have to match the available information to the task aspects [15]. When performing geospatial tasks collaboratively, collaborators have to be able *"to convey information about the specifics of their location on the map and also infer their partner's location from the information their partner shares with them"* [44, p. 177]. As pointed out by Diamant *et al.* [44], when people have access to different data, e.g. different representations of the same geographical location, they are required to find ways to achieve mutual understanding, surpassing limitations such as the communication medium and the access to partial information from each collaborator. Misunderstandings negatively impact the sensemaking process, leading the collaborators to the wrong conclusions or to longer time needed for answering the question. Besides the fact that most people can readily read maps, two other characteristics of maps are described in [45]: since they contain elements seen in hierarchical and network information structures, *"results concerning maps may be generalized to other* *information structures*" [45, p. 369]; and the direct relation between representation and physical reality provides easier interpretation compared to abstract information spaces.

1.2 Research Questions

The main goal of this thesis is to investigate the impact on **collaboratio**n between **pairs** when **configurations with different numbers of tablets** providing **different detailed views** are available to explore **geospatial information** within **MDEs**. To achieve this goal, I look to answer the following research questions:

RQ1. What is the impact on the collaboration between pairs collaboratively exploring geospatial information within MDEs when the number of tablets providing detailed views changes?

By answering this question, a better understanding of the **role of personal devices** in collaborative visualization is expected. As mentioned in the introduction of this Chapter, when dealing with personal devices, people "own" the resource, e.g. the tablet or the smartphone, and it is unclear if they are willing to share it as easily as they would with low-tech tools. To answer this question, I look at how pairs collaborate when they interact with three different configurations: when only one tablet is available for the pair; when each person has access to a tablet; and when there is more than one tablet per person.

RQ2. What is the impact on collaboration of providing multiple detailed views within MDEs using tablets for geospatial information exploration?

The goal of this question is to explore how the aforementioned configurations of tablets can provide **multiple detailed views**, while a **digital tabletop provides context** (overview) to explore geospatial information spaces. In this thesis, a detailed view displayed on a tablet is also referred to as a *lens*. By answering this question, I expect to identify how the collaboration is affected when tablets are specialized tools, i.e. each tablet provides a specific detailed view, *versus* when they are "all-in-one" tools, i.e. all detailed views are available on all tablets.

RQ3. What are the preferred configurations to provide multiple detailed views within MDEs using tablets for collaborative geospatial information exploration?

The answer for this question is based on the **subjective preference** of the participants. Specifically, which mode they preferred considering the collaboration with their partners while performing geospatial information exploration within MDEs.

1.3 Thesis Contributions

The main contribution of this thesis is resultant from the study exploring how mobile personal devices impact collaboration between pairs during geospatial information exploration activities within MDEs. Besides filling a gap in the research space described in subsection 1.1.3, this study provides insights on how tablets integrated with situated displays can support collaborative visualization activities.

A secondary contribution from this thesis is Bancada, the multi-display environment developed to conduct this study and also as a means to research how geospatial information can be displayed and manipulated across multiple devices. Within this environment, users interact with detailed views from a map on one (or multiple) device(s), while an overview map is being displayed on a different device.

1.4 Thesis Structure

The remaining of this thesis is structured as following.

Chapter Two – An Overview of Interface Schemes for Information Presentation and Exploration

In this Chapter, I present the concepts regarding InfoVis and MDEs grounding this thesis. I also present the prior related work realized within the research space of InfoVis and InfoVis in MDEs.

Chapter Three – An Overview of Exploring Collaboration during Collaborative Visualization Activities

This Chapter provides the concepts regarding CSCW and Collaborative Visualization grounding this thesis. I present the different aspects from collaboration, seminal collaborative data visualization tools, and prior research exploring how groups of people collaborate when performing collaborative visualization activities.

Chapter Four – Using Tablets and Lenses as Collaborative Tools within MDEs: Study Design and Bancada

In this Chapter, I describe the design of the study conducted to evaluate the impact of using different configurations of devices on collaboration. I also present Bancada, the multiple display environment used to conduct the study.

Chapter Five – Study Results

In the first part of this Chapter, I describe how the study was conducted, the participants, and the techniques and methodologies used during the quantitative and qualitative analyses. Then, I present and discuss the results from both analyses.

Chapter Six – Conclusion

I conclude this thesis in Chapter Six by presenting a summary of the contributions from this work, and future work.

Chapter Two

An Overview of Interface Schemes for Information Presentation and Exploration

Providing efficient access to large information spaces is one goal of Information Visualization (hereinafter, InfoVis) [9]. With devices becoming smaller every generation, designers have to address the **presentation problem** [7], [46]. This problem shows up when the screen real estate available does not allow users to identify and extract useful information when large amounts of information are presented. Within multiple-display environments (MDEs), designers have to consider the heterogeneity of devices – tablets have displays only a few inches long while wall displays can be several meters wide. Also, another problem emerges when presenting the information space across multiple views and displays, the **visual separation of information** [47], defined as "*the division of information across space in MDEs*" [47, p. 451]. This visual separation, if not handled properly, reduces a user's efficiency when exploring information, as seen in [48] and [49].

In this Chapter, I present an overview of the InfoVis research space related to this thesis, specifically, how researchers have been addressing the aforementioned problems in single- and multi-display environments. In Section 2.1, I describe different approaches used to present and manipulate information. Then, I describe how researchers have been exploring these approaches in MDEs and how they assessed different approaches in Sections 2.2 and 2.3, respectively. Lastly, I conclude this Chapter in Section 2.4. For further insights about the concepts described in this Chapter, please refer to [7]–[9], [11], [12], [50]–[52].

2.1 Displaying and Manipulating Information

When designing systems to explore large amounts of information, designers are limited by the fixed size of screens on which the information will be presented [46]. Typically, they face a trade-off between presenting an overview of the information space without users being able to distinguish details, and presenting details, leaving to users to build a mental model of the information space. Much research effort (e.g. [11], [12], [50]) has been invested to reduce the effects of this trade-off, resulting in many **interface schemes, i.e. user interfaces,** to present and explore information, such as zoomable user interfaces (e.g. [46], [53]), when the interface allows the user to change the zoom scale; focus+context (e.g. [54]), when the interface provides focus within context in a single region of the screen; and overview+detail (e.g. [12]), when the interface provides focus and context in distinct regions of the screen. Surveying the literature and commercial systems, Cockburn *et al.* [11] classified such schemes according to the mechanisms used *"to separate and blend views"* [11, p. 1] from the information space. According to this classification, an interface can:

i. Provide **temporal separation**, as seen when a user scrolls, pans or zooms-in a document, the information displayed before the action may not be available after the action, as seen in Figure 2.1;
ii. Provide **spatial separation** when different portions of the information space are being displayed simultaneously on distinct portions of the screen, e.g. Figure 1.2;
iii. Provide **focus within the context** on a single display, typically, through distortion-based techniques, e.g. Figure 1.3;

iv. Use **cue-based techniques** to highlight or suppress items within the information space, as seen with the blue dot in Figure 2.1. This approach depends on information semantics and it is typically used to augment the previous three schemes, e.g. [55], [56].

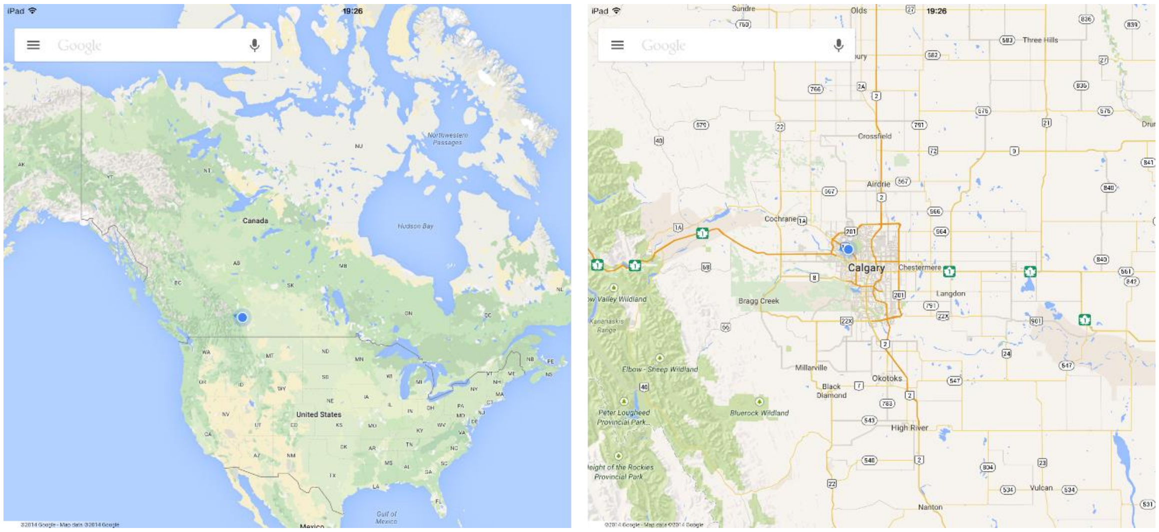


Figure 2.1 Google Maps running on an Apple iPad provides temporal separation: the overview map (left) and the zoomed detail (right) are displayed on a single display in different moments. The blue dot on both views indicates device's current location on the map.

Plaisant *et al.* [12], in 1995, surveyed systems used to browse information and classified them according to the number of views available on the screen to display information. They can be **single-view browsers**, when the whole screen real estate available is used to present only one view of the information space, e.g. Figure 2.1; or **multiple-view browsers**, when the screen is divided into multiple views, each view displaying different portions of the information space. In the following subsections I detail all aforementioned schemes and how the two classifications relate to each other. I am considering only these two classifications because they are broad enough to provide an overview of the different types of interfaces and are also vastly used in the literature.

2.1.1 Single-View Browsers

Single-view browsers display the information space in a single view using the whole screen real estate available, as seen in Figure 2.1. These browsers present information by temporally separating the information or providing focus within context. Providing temporal separation there are (i) **detail-only interfaces**, when the browser displays the information in a fixed scale, and (ii) **zoomable user interfaces**, when the browser allows the user to change the zoom scale. **Focus+context interfaces** present focus within context on a single view. These three categories of interfaces are generalizations from the variations presented in [11], and their characteristics, usage, benefits and drawbacks are as following.

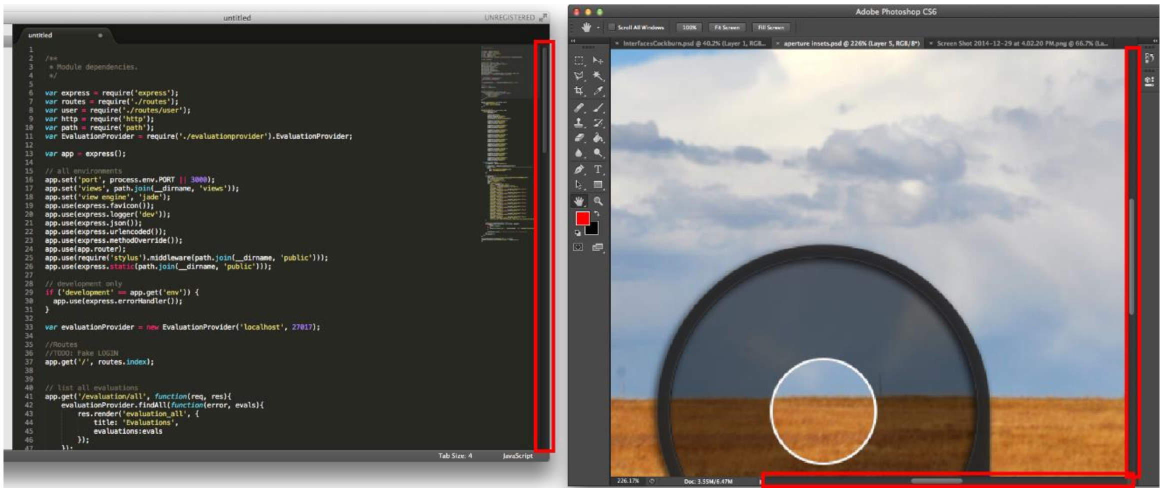
2.1.1.1 Interfaces with Temporal Separation

Interfaces with temporal separation display the information space in a single view on which users can interact through controllers such as buttons, scroll bars, or touch gestures on touch-enabled screens to perform panning, scrolling or zooming. Despite users' familiarity with such interfaces [12], prior research has shown that interaction with such interfaces can be cognitively complex, disorienting, and tedious [57], [58], due to the temporal separation of the information, e.g. when a user scrolls a document, the text displayed before the action may be partially or fully unavailable on the screen after scrolling.

2.1.1.1.1 Detail-Only Interfaces

Detail-only interfaces, also called linear [59], make full use of the screen real estate available to display the information space in a fixed scale. Using such interfaces, users are required to move (pan) the portion of information currently displayed to access a different portion of the information space.

The most basic approach to interact with the information in detail-only interfaces is through scroll bars [12]. As described by Plaisant *et al.*, *"scroll bars let users move through the document incrementally and by jumps and they indicate the current position of the screen"* [12, p. 21]. This approach is highly effective for one-dimensional (1D) spaces, for example, the text editor seen in Figure 2.2 (left). However, for spaces with more than one-dimension, such as images and maps, this approach starts to be ineffective. To browse a two-dimensional (2D) space, systems usually provide two independent one-dimension scroll bars, one vertical and one horizontal, as seen in Figure 2.2 (right). Although this approach provides freedom of interaction in each dimension, one of the drawbacks can be seen when a user wants to pan diagonally a map. In such cases, the user would need to interact with one dimension at a time. When users can pan large information spaces without decomposing the movement into two components (i.e. two dimensions), the navigation is less tedious and much faster than when using two scroll bars [58]. Nowadays, with the pervasiveness of touch-enabled screens, dragging the finger on a device screen allows the user to interact directly with the information space and pan it in any direction, as illustrated in Figure 2.3.



```
/**
 * Module dependencies.
 */

var express = require('express');
var routes = require('./routes');
var user = require('./routes/user');
var http = require('http');
var path = require('path');
var EvaluationProvider = require('./evaluationprovider').EvaluationProvider;

var app = express();

// all environments
app.set('port', process.env.PORT || 3000);
app.set('views', path.join(__dirname, 'views'));
app.set('view engine', 'jade');
app.use(express.favicon());
app.use(express.logger('dev'));
app.use(express.json());
app.use(express.urlencoded());
app.use(express.methodOverride());
app.use(app.router);
app.use(require('stylus').middleware(path.join(__dirname, 'public')));
app.use(express.static(path.join(__dirname, 'public')));

// development only
if ('development' == app.get('env')) {
  app.use(express.errorHandler());
}

var evaluationProvider = new EvaluationProvider('localhost', 27017);

//Routes
//TODO: Fake LOGIN
app.get('/', routes.index);


// list all evaluations
app.get('/evaluation/all', function(req, res){
    evaluationProvider.findAll(function(error, evals){
        res.render('evaluation_all', {
            title: 'Evaluations',
            evaluations:evals
        });
    });
```

Figure 2.2 Scroll bars (highlighted in red) are used to browse 1D (left) and 2D (right) information spaces.

Figure 2.3 2D browsers on touchscreens do not require scroll bars. Users are able to pan the image in any direction by dragging the finger on device's screen.

2.1.1.1.2 Zoomable User Interfaces (ZUI)

The Visual Information Seeking Mantra [60], presented by Schneiderman, summarized the most common guideline to design interfaces for information seeking: *Overview first, zoom and filter, then details-on-demand*. Following this principle, Zoomable User Interfaces (hereinafter, ZUI), also called zoom-and-replace [12], attempt to tap into *"our natural spatial and graphical ways of thinking"* [53, p. 57] to interact with data objects organized in space and scale [61], [62]. ZUIs typically combine panning and zooming interactions [63] to provide a valuable, intuitive and elegant solution for the presentation problem in small screens [62]. Successful commercial implementation of ZUIs can be seen in many different domains, such as maps (e.g. Google Maps[3]), image editors (e.g. Adobe Photoshop[4]) and presentations (e.g. Prezi[5]). Although being speculated that this interface scheme improves the understanding of large information spaces [61], research has shown that, due to the temporal separation, users tend to lose their overview of the information space when interacting with ZUIs [9], [63]. To mitigate this disorientation, ZUIs can be combined with Overviews, e.g. [45], [62], [63]. This hybrid approach is detailed in Section 2.3.

In the context of ZUIs, the scale determines the appearance of data objects. Two zooming techniques can be used to adapt information presentation: **geometric** and **semantic zooming** [45], [46], [53], [62]. The first provides a linear magnification of the information space, i.e. the scale and the apparent size of the object are linearly related. Semantic zooming adapts the information space according to the real estate available and the current scale, i.e. as the magnification changes, different types of information from the object are displayed or hidden. For example, while browsing a map, when a user performs a geometric zooming, the interaction will make features from the map appear bigger or smaller, as one would see when changing the distance of a magnifier over a paper map, as illustrated in Figure 2.4. With semantic zooming, variations in the scale will make features, such as labels, be present or absent from the same region on the map, as seen in Figure 2.5.

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[3] http://maps.google.com

[4] http://www.adobe.com/photoshop

[5] http://www.prezi.com

Figure 2.4 Map before (left) and after (right) performing geometric zoom.

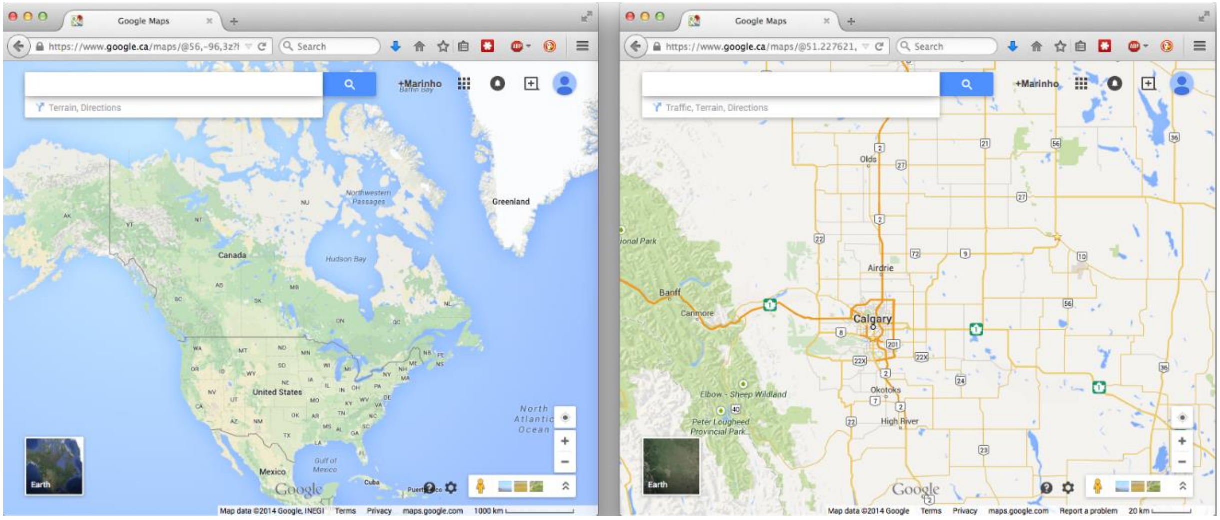

Figure 2.5 Semantic zoom: features such as cities labels and roads are available according to the scale. On the left map is not possible to see the cities or roads, while on the right map is not possible to see the province label.

Users typically change the scale on ZUIs through buttons (e.g. [63]), sliders (e.g. [64]) or stylus/touch gestures (e.g. [65]) on a device screen. Figure 2.6 shows an example of ZUI from a map application available on airplanes. The user interacts with the display by pressing the buttons to change the map scale (highlighted in red) and to pan the map (highlighted in blue).

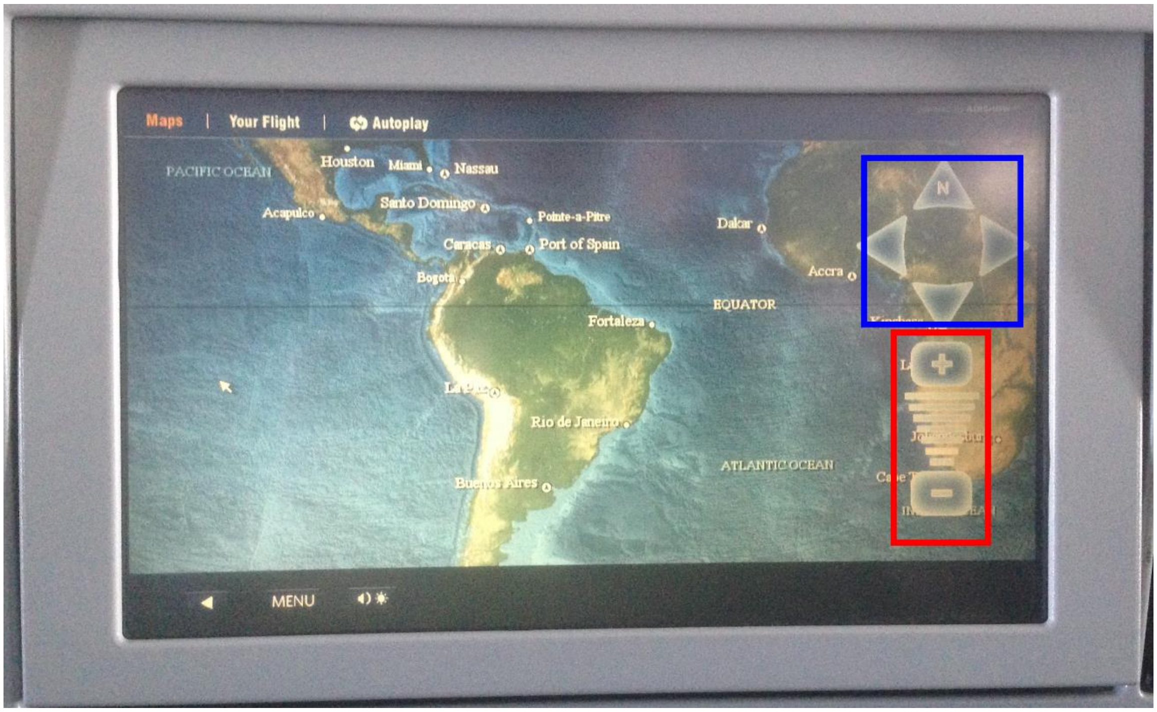

Figure 2.6 ZUI available on airplanes. It provides controls to pan (blue) and to change zoom scale (red) for map exploration.

As seen with the other interface schemes described in this thesis, how to implement zooming interactions is task dependent [12]. For example, research has shown the effectiveness of ZUIs for calendars [66], infinite canvas [46], [53], and also to explore scatterplots on small screens [65]. Nowadays, the modern touchscreens allow users to perform zooming operations through pinch gestures [67], [68].

2.1.1.2 Interfaces with Focus within Context

One way to provide context and detail to users in a single view is through Focus within Context interfaces, hereinafter F+C. The term F+C is typically associated to distortion-based interfaces, e.g. Rubber Sheet [69], Melange [70], and JellyLens [71]. Examples of these interfaces are seen to explore webpages [72], texts [73], tables [74], calendars [66], and maps [75]. Distortion improves user performance for large steering tasks [76] and to explore charts in small screens [77]; however, research has shown they hinder users for tasks that require precise judgement about *"scale, distance, direction, or alignment"* [14, p. 260]. As described in subsection 1.1.1, these approaches are out of scope of this thesis.

There are approaches that provide focus within context without distorting the presentation of the information space, though, at the cost of occlusion of local context. **Insets** are selected sub-regions of the information space magnified in place [7], [64]. Figure 2.7 shows an inset available on Apple Aperture[6]. On this image editor, a user places a loupe, i.e. the inset, over the context (left) where the magnification will be performed. It is possible to see two distinct regions inside the loupe (center). The shadowed area represents the occluded portion of the image once the magnification is performed over the area inside the white circle (right). As described, there is a visual separation between the focus presented on the inset and its context due the occlusion of adjacent context, represented by the shadowed region.

Figure 2.7 Example of inset providing focus within context without distortion.

An approach used to mitigate occlusion is allowing users to translate the inset without changing the portion of the information space presented on it, transforming them into **offsets** [7]. Offsets are insets spatially dislocated from their context, i.e. sub-regions of the information space that are displayed outside

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[6] https://www.apple.com/aperture/

their context. As consequence of providing the ability to translate insets on the screen, there is an increased visual separation between context and focus, which may lead to disorientations [63]. Providing visual cues is an effective way to minimize the consequences of this separation [7]. For instance, Ware and Lewis [64] proposed DragMag, an approach using lines connecting the focus with its respective region on the context. Figure 2.8 shows the elements from DragMag: the Mag Window shows where in the context the content displayed on the Zoom Window (i.e. the focus) is located – both windows connected by lines; and the Zoom Slider allows users to change the scale of the information presented on the Zoom Window.

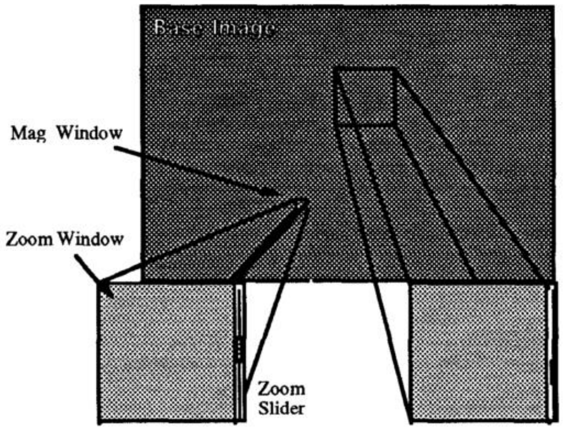

Figure 2.8 DragMag[7].

2.1.2 Multiple-View Browsers

Interfaces with temporal separation may provide an overview of the information space without sufficient details, or details without an overview with relevant content off-screen. F+C interfaces provide alternatives to such issues at the cost of distorting the information space, or occluding adjacent information. Multiple-view browsers provide a solution for the presentation problem without distorting the information space

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[7] Source: Ware and Lewis [64].

and providing users with information that allows them to locate relevant off-screen data [56]. This approach divides the screen real estate available into multiple windows on which different perspectives of the information space are simultaneously displayed. The most common implementation, described in the following sub-subsection, has two views and is called Overview+Detail [12], [50]. Its main characteristic is reducing user disorientation [63] by providing context and detail without distortion through two windows displayed in parallel.

Plaisant *et al.* [12] point out three major aspects for the design of multiple-view browsers. The first is related to **window management**, the system should automatically manage the position and size of the windows, since manual management might *"take considerably effort and time for the users"* [12, p. 28]; Second, the **synchronization of windows** (i.e. how interactions performed on one view affect the others) can be (a) nonexistent, i.e. the views are independent of each other, (b) unidirectional, i.e. interactions performed on one window won't affect a second window, but changes performed on the second will affect the first, or (c) bidirectional, i.e. interactions on any window will always affect the others; Lastly, the **information density** presented in each window is dependent on the target public. For example, for specialists, high-density global views might be more suitable than for the general public. The following sub-subsection relates these aspects and the design of overview+detail interfaces.

2.1.2.1 Overview + Detail Interfaces (O+D)

As mentioned previously, **Overview + Detail** interfaces (hereinafter, O+D) separate information according to space, displaying contextual and detailed information simultaneously [11]. Offsets (described in sub-subsection 2.1.1.2) are also considered O+D interfaces however, the difference between both schemes is the visual integration between the two windows [7]. For instance, O+D uses part of the screen to display the overview while the other portion of the screen displays the detailed information without explicit visual integration between the two views, for example the lines from the DragMag. The most common implementation of O+D presents the overview window as a small scale thumbnail of the information space with a viewfinder, i.e. a *"properly positioned graphical highlight of that portion of space which is currently displayed by the detail view"* [63, p. 147]. Figure 2.9 illustrates an O+D interface with viewfinder: the blue rectangle highlights the detail view, the yellow rectangle, the overview, and the red rectangle is the viewfinder.

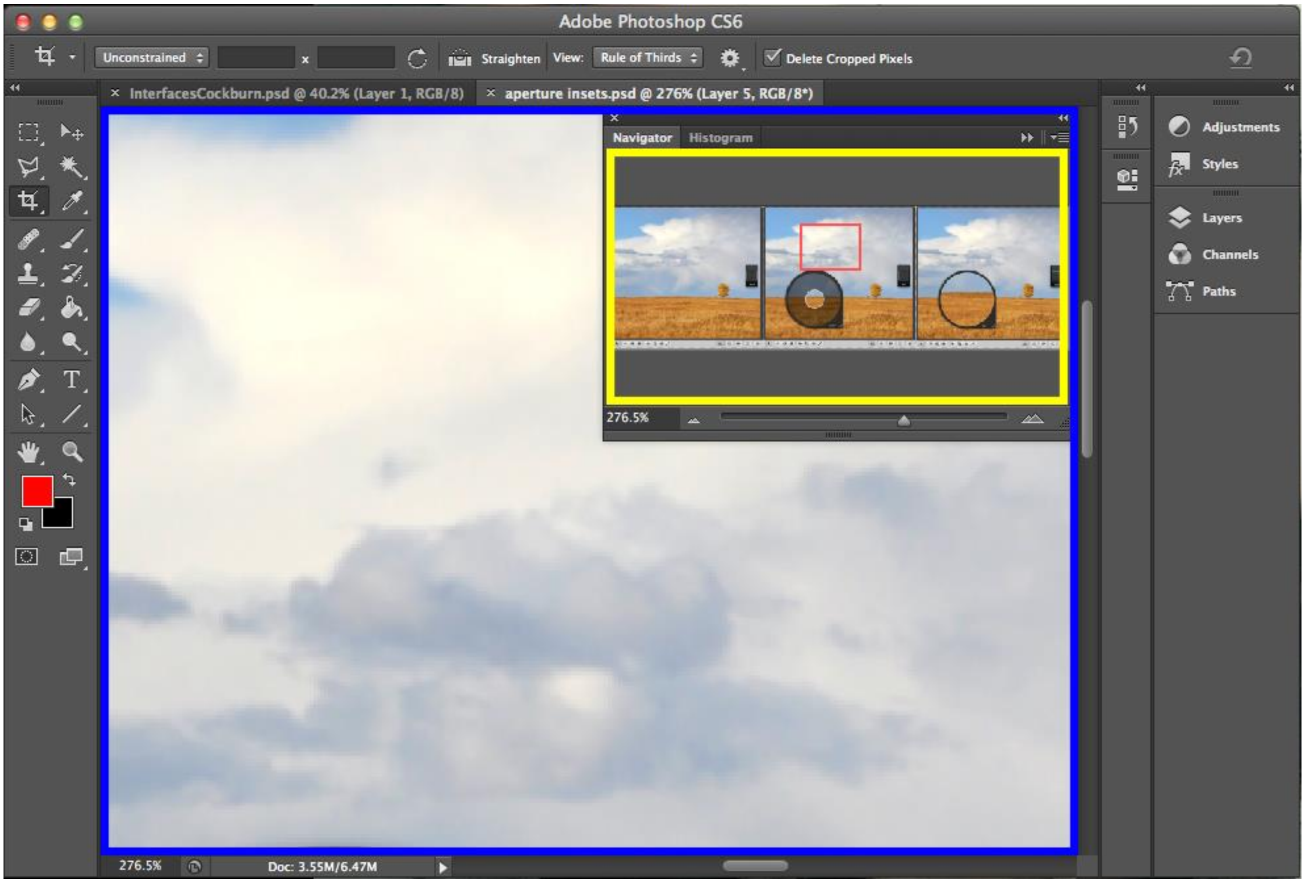

Figure 2.9 Overview+Detail interface.

Considering the information density and window management design recommendations presented in the previous subsection, the size of the overview window has direct influence on how much information can be seen at the overview scale [45]. Since the screen real estate is a constant, there is a trade-off relative to the size of the overview and detail windows [62]: large overview windows allow more information to be displayed at the cost of the area available to display the detail. Determining the size for each window is task dependent [12]. Inappropriate sizes can strain memory and increase the time used for visual search [9], [72]. The literature shows that monitoring tasks benefit from large overviews, while diagnostic tasks benefit most from large details [12], [45].

The main function of the overview is to help users to orientate themselves, specifically, through the viewfinder, which major benefit is to reduce the time required for re-orientation when users are switching focus from the detail to the overview [14]. Without an overview, users have to rely on their mental model of the information space or perform a series of zooming-out and zooming-in operations to reorient themselves. As mentioned before, viewfinders highlight the position of the detail view within the overview. They can also provide a means for user interaction; for example, users can pan the content from the detail view by interacting directly with the viewfinder. This interaction plus the interactions with the detail (e.g. panning or zooming), exemplifies the bidirectional synchronization, from the overview to the detail, and from the detail to the overview. Synchronization is highly recommended for O+D [78], [79], and commonly, it is unidirectional from the detail to the overview, or bidirectional [11].

The first known publication describing O+D [80], is from 1978 [53]. Since then, O+D interfaces have been applied to many domains, such as sports (e.g. [81]), documents (e.g. [59]), source code (e.g. Sublime Text[8]), and maps (e.g. [63]).

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[8] http://www.sublimetext.com/

2.1.2.2 Combining ZUI with O+D: Zoomable User Interfaces with Overview (ZUIO)

Interfaces combining multiple schemes provide more flexibility in navigating information spaces while mitigating the weaknesses of the interfaces being integrated [63]. Typically, designers provide different views and interactions through multiple windows (as seen in subsection 2.1.2). A common hybrid approach is the **Zoomable User Interface with Overview** (hereinafter, ZUIO) [45], [63], a variation of the ZUI with the Overview from O+D. With ZUIOs, users benefit from having an overview while also simultaneously exploring an information space through pan and zoom-based interactions. An example of ZUIO is Bing Maps[9], seen in Figure 2.10. The overview is presented on the top-right corner, highlighted in red, and buttons allow users to change the zoom scale of the detail, highlighted in green.

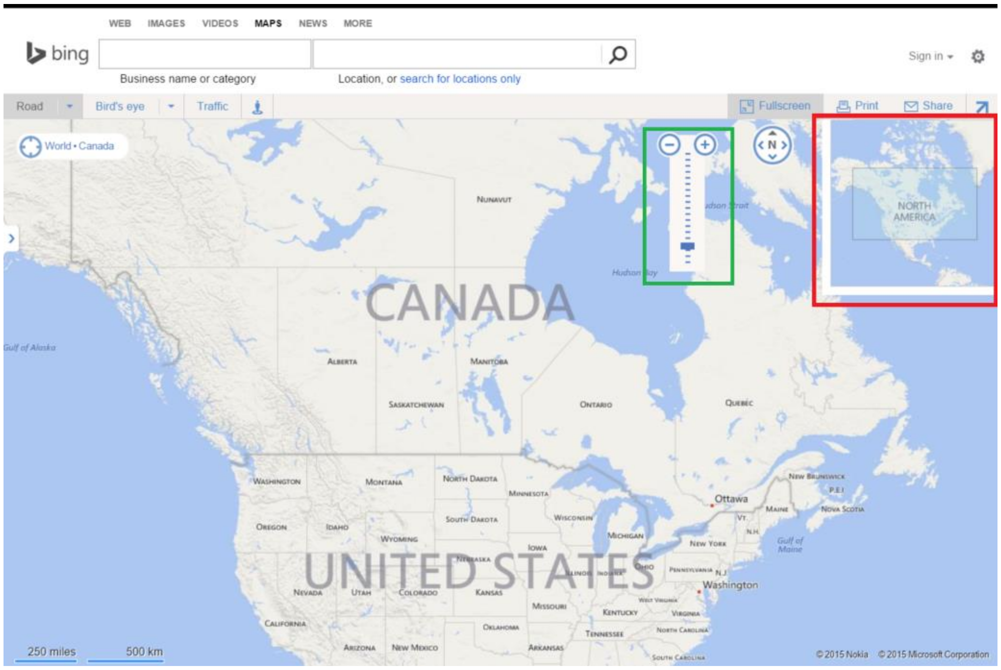

Figure 2.10 Bing Maps[9]: an example of ZUIO. Overview highlighted in red and buttons to change the zoom scale highlighted in green.

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[9] http://www.bing.com/maps/

2.1.3 Lenses

As mentioned in Chapter One, a user is able to *"modify the presentation of application objects to reveal hidden information, to enhance data of interest, or to suppress distracting information"* [10, p. 73] using **lenses**, i.e. widgets emulating see-through interfaces positioned over the information space [10]. There are different types of such widgets and they can provide temporal separation, e.g. by displaying an x-ray image from a 3D model; spatial separation, e.g. on an approach similar to insets and offsets; or both, temporal and spatial separation, simultaneously, e.g. when revealing hidden information magnified from the context.

Lenses allow users to modify the presentation of the information space considering only specific regions, i.e. lenses operate only over the portion of the information space within its boundaries. Each lens provides an operation on which the portion of the information space within the lens will be modified and displayed according to the result of that operation. For example, a magnifying lens acts as a magnifier for the correspondent region; an x-ray lens would display the correspondent x-ray image from that portion; and a population density lens over a map would display the population density of that corresponding region. Lenses can be placed on top of other lenses resulting on a stack of lenses – as Bier *et al.* describes, *"when several lenses are composed, the effect is as though the model were passed sequentially through the stack of lenses from bottom to top, with each lens operating on the model in turn"* [10, pp. 77–78]. Figure 2.11 revisits Figure 1.1 and highlights each lens and the result of stacking lenses. For instance, the wireframe lens is the square lens in blue and it shows the wireframe of the 3D model within its boundaries (also highlighted in blue); the magnifier lens is the circular lens, in green; and since the magnifier lens is placed on top of the wireframe lens and there is an intersection between them, i.e. they are overlapping each other, the result of such intersection can be seen in red – the wireframe from the 3D model on the intersection portion is being magnified by the magnifier lens.

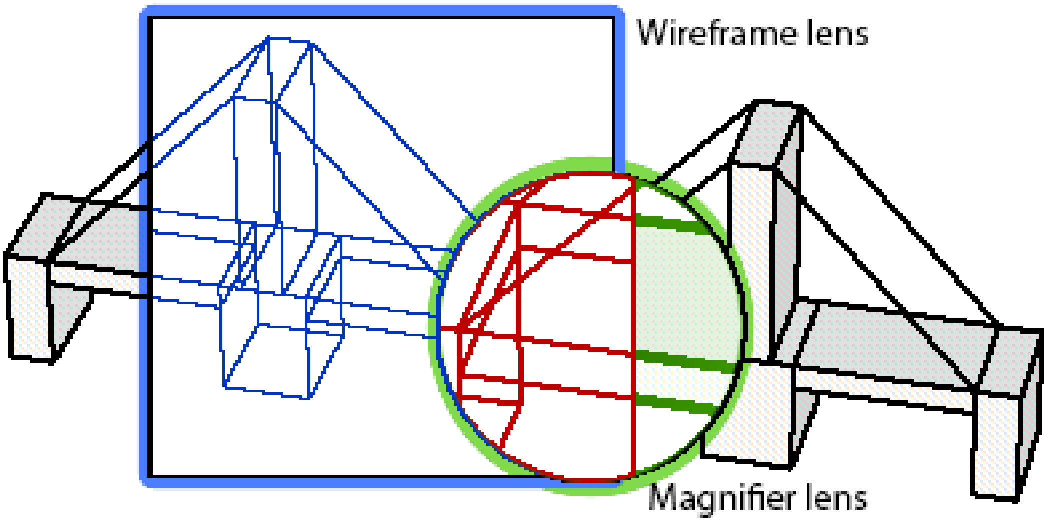

Figure 2.11 Revisiting Figure 1.1: wireframe lens highlighted in blue, magnifier lens highlighted in green, the result of the intersection (stack) of both lenses highlighted in red.

Since lenses may have different shapes and sizes, they are independent of each other and can be stacked, multiple users can interact, simultaneously, with different lenses to explore information spaces independent of each other (e.g. [36]).

2.2 Exploring Information within MDEs

In the previous Section, the main focus was to describe different approaches to present and interact with representations of information. This Section relates those approaches with MDEs, describing how information can be distributed and explored within multiple display environments.

A multi-display environment is *"a system where interaction is divided over several displays, such as digital tabletops, wall displays and personal devices like tablets or mobile phones. MDEs often include heterogeneous displays to take advantage of different capabilities such as their size, position, resolution or mobility* *to support the task at hand*" [3]. With the pervasiveness of touch-enabled screens on modern devices, displays in this context are not only output devices, but used as means for user interaction.

Using multiple screens can significantly improve user efficiency by increasing access to information as well as the peripheral awareness of information [82], [83]. One example showing how multiple displays can enhance user experience is from the gaming industry. The Nintendo Wii U[10] is a videogame console on which its controller provides a touchscreen display that can be used alone or can be connected to an external display, such as a TV, for an improved experience. When being used solo, the controller's display is the main output and the interactions are performed with the buttons. However, when connected to a TV, the main output becomes the TV while the controller displays a different portion of the information (e.g. detail displayed on the TV and overview on the controller) and augments user interaction by allowing players to perform touch gestures on its screen. Figure 2.12 illustrates how the controller from the Wii U can present different information during a race game. It is important to highlight that users have control of what mode is displayed on their controllers and they can change it at any time.

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[10] https://www.nintendo.com/wiiu

Figure 2.12 Wii U integrated with a TV. (A) TV displaying two players; (B) controller displaying the same information as TV; (C) menu to change the content displayed on controller; (D) controller showing only the player's view; (E) controller displaying an overview and additional information of the race.

The heterogeneity of devices within an MDE provides an opportunity to enhance user experience by spreading the information space across multiple devices and making effective use of each device's features, as seen with the Nintendo Wii U in Figure 2.12. Given the freedom of users bringing their own devices to interact with public displays, e.g. [26], [84]–[86], the presentation of information in such environments can be done in multiple ways. For example, wall displays can provide an overview of the information space; tablets can present detailed views or be lenses to adapt the information presented on a tabletop or a wall display; and tabletops can also present overview or middle scale views.

Besides information presentation, user interaction also changes within MDEs. For example, if the wall display has a touch-enabled screen, the user can interact directly using touch gestures – otherwise, the interaction can be performed indirectly using a tabletop instead of a mouse and keyboard; if the user has a mobile device, this device can be used as input, as seen in [41], [47], [87], [88]; sensors can be used so that the physical position of a person determines how and what portion of the information space is presented on a wall display and on a mobile device, e.g. [89]; and tangibles (e.g. [90], [91]) and gestures performed with or without devices (e.g. [3]) within the MDE also provide alternatives to keyboard + mouse.

PaperLens [91] demonstrates how tangible magic lenses can be used to explore multi-layered information spaces. Interaction is provided by positioning a cardboard above a tabletop and based on the distance to the tabletop, a user is able to see a corresponding layer projected. Also exploring the space above tabletops, MRI Table Kinect [32] demonstrates how the relative position of a tablet above a tabletop can be used to explore volumetric medical imagery – moving the tablet above the tabletop will change the image displayed on the tablet according to its physical position. While PaperLens illustrates a ZUI using physical space as a means for determining the scale, MRI Table Kinect presents the information space in an O+D fashion, with the overview on the tabletop and the detail on the tablet, as seen in Figure 2.13.

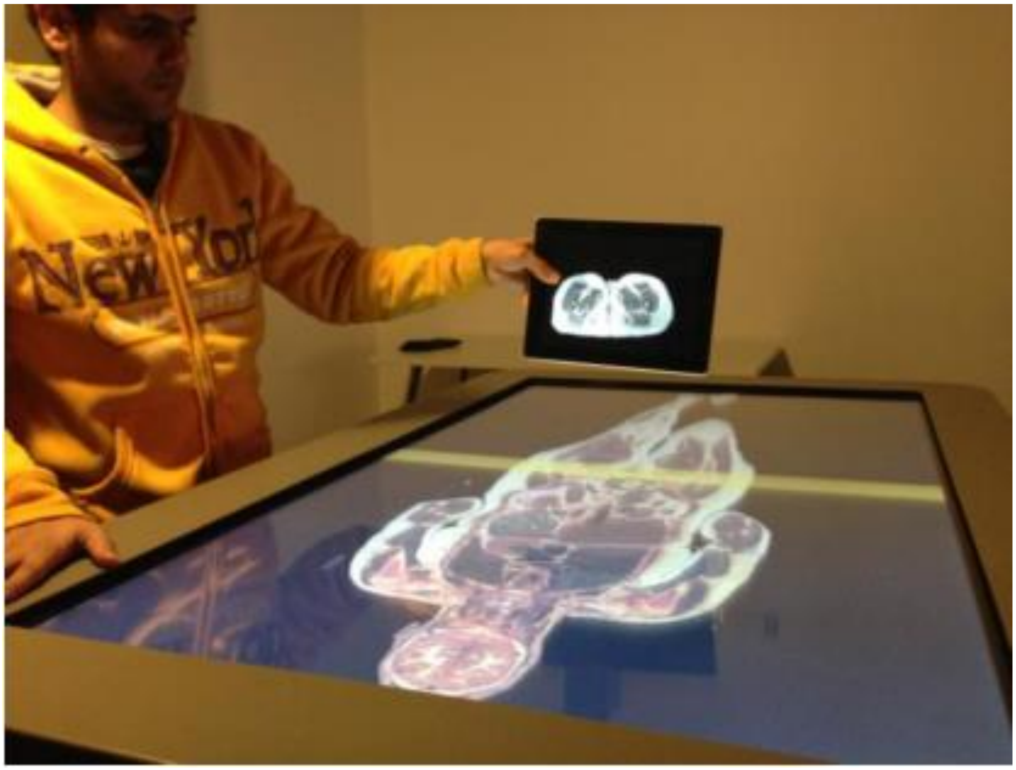

Figure 2.13 MRI Table Kinect[11].

iPodLoupe [68] is a lens-based interface for the Apple iPod Touch that provides a semantic ZUI for users to explore visualizations of dense data presented on a tabletop. Figure 2.14, reproduced from [68], shows the parts from iPodLoupe: (i) on the iPod, users interact with the focus, which is a portal affording detailed exploration of the information space presented on the tabletop; and (ii) on the tabletop, a base (the green iPod Touch outline) indicates which region of the visualization is being explored on the iPod, in the same fashion as a viewfinder. One of the main advantages of using such an approach is seen when a small region of interest from the tabletop is explored on the device. Due to its form factory, the iPod Touch allows users to visualize and manipulate the visualization at a much finer scale than when

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[11] Source: Seyed *et al.* [32].

interacting with the tabletop. Besides allowing such finer grained interaction, presenting the lens on the tablet also *"minimizes the degree of visual distraction on the tabletop display"* [68, p. 114].

Figure 2.14 iPodLoupe[12].

Also allowing users to explore information spaces using personal devices integrated to situated devices, Jetter *et al.* [92] present the zoomable object-oriented information landscape (ZOIL) design approach and framework. ZOIL is a multi-display interface framework where each display provides means for users to explore zoomable information spaces. Within ZOIL, ZUIs are available on all displays; tablets provide tangible lenses; and tangible objects can be used to control and synchronize views within the environment.

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[12] Source: Voida *et al.* [68]

The aforementioned research projects explore how information visualizations and interactions with information spaces can be distributed across the multiple displays available within MDEs, which does not imply they were designed considering aspects of collaboration. In subsection 3.2.2, I revisit MDEs focusing on systems that were designed to support collaborative activities.

2.3 Comparing Different Approaches for Information Exploration

Prior research has, in different domains and with different number of displays, investigated the effectiveness of each approach mentioned in previous sections. The purpose of this subsection is to present how researchers have explored the impact of different interface schemes to represent large information spaces, starting with single- and then multiple-display environments. It is also important to highlight that the studies described in this Section were conducted with single-users. Studies with multiple users are described in the next Chapter, Section 3.3.

2.3.1 Within Single-Display Environments

Nekrasovski *et al.* [69] evaluated the impact of the presence of overviews in a study comparing ZUI and F+C (specifically, Rubber-Sheet Navigation) to perform navigation tasks in the biology domain. Although the authors did not find the presence of an overview significant for performance, users preferred when it was available. The authors argue this preference is due to a *"cognitive cushion"* giving users *"a greater feeling of satisfaction and imposing less subjective load"* [69, pp. 18–19]. Subjects performed tasks significantly better using ZUI than with F+C. Findings suggest that F+C required more mental effort while completing the task. It is important to highlight one finding from this study regarding familiarity with techniques. The authors do not believe the familiarity with a technique will impact on performance. This was concluded after noticing there was no significant difference in performance after the participants became familiar with both approaches.

Büring *et al.* [77] describe the results of a study comparing ZUI and F+C (specifically, fisheye) for view decomposition and detail access of a scatterplot interface on PDAs. Although the task completion times were not significantly different, users preferred the fisheye approach. The qualitative analysis suggests this preference is due to the better orientation features and the more precise navigation offered by the interface. The authors argue that distortion-based techniques may integrate better with abstract information spaces, such as diagrams, while user satisfaction decreases with domains such as maps, in which a higher degree of fidelity to the standard layout is essential. Another finding is related to screen size, users place higher value on the ability to preserve navigational context when interacting with small screens.

Still in the space of small screen devices, Büring *et al.* [62] analyzed the usability of ZUIs and ZUIOs considering the spatial ability of the participants. Spatial ability is *"the ability to generate, retain, retrieve, and transform well-structured visual images"* [62, p. 234], and it is measured using psychometric tests. The experiment involved exploring a movie database on a PDA. Participants were significantly faster using ZUI compared to ZUIO. Results suggest in the context of small screens, a larger detail window can outweigh the benefits gained from having an overview displayed on screen. For high-spatial users, the authors argue the performance difference is also partly due to the rich navigation cues provided by scatterplot labels. For low-spatial participants, the completion times for detail-only and ZUIO interfaces were nearly equal – the authors point out that the overview *"may have actually supported the participants by preventing them from relying on their potentially incorrect mental model of the information space"* [62, p. 239].

Regarding subjective preference, users did not show preference between the two interfaces. The authors concluded, *"Interface efficiency does not necessarily correlate with user satisfaction or preference"* [62, p. 239].

The findings from this last study, [62], support the results from [63], which compared ZUI and ZUIO for map navigation tasks using PDAs. The researchers in this study concluded that overviews bring enough benefit to justify the used space if (i) they highlight relevant semantic information that users can exploit during search and (ii) the structure of the considered information space does not provide appropriate orientation cues. On another study comparing ZUI and ZUIO for map navigation tasks, [45], researchers found that users preferred when the overview was available, although they solved the tasks faster when the overview was absent. The authors argue the fact that participants had similar accuracy when using both interfaces and performed best when there was no overview are arguments against the belief that users get lost when interacting with ZUIs.

Investigating the effects of display size in geographical maps navigation tasks, Jakobsen and Hornbæk [83] compared F+C, O+D and ZUI. For medium and large size displays, users performed the tasks without significant difference. However, for small displays, F+C was found to be difficult to use, conflicting with [77] and supporting [69]. Generally, O+D was found to be the best approach for solving the proposed tasks and the preferred interface among users.

2.3.2 Within Multi-Display Environments

One problem emerges when distributing information over multiple displays: the **visual separation** of information [47], i.e. presenting the information space across multiple displays. This visual separation, if not handled properly, reduces a user's efficiency when exploring information, as seen in [48] and [49]. Factors such as size and depth of displays, angular separation between displays [48], field of view [93], and the presence of bezels [49] impact the severity of visual separation [47]. The mobility of devices within an environment can also influence user performance, as seen in the study described by Cauchard *et al.* [49]. In this study, the researchers found that the design of mobile multi-display environments, i.e. mobile devices with more than one display, is more flexible than for MDEs with fixed devices. Although displays in the same field of view reduce the mental load, the study could not find differences in performance or error rates when displays were at different angles, contrary to findings from [48], [93]. The authors attribute this to the difference in screen size of mobile devices and other displays.

Investigating the cost of focus change in mobile multi-display environments, Rashid *et al.* [93] describe a study comparing three configurations: (i) mobile-only, smartphone providing input and output; (ii) mobile-controlled large display, smartphone providing input for a connected large display; and (iii) hybrid, the smartphone was input and output, while the large display provided output as well. Contrary to the findings from [47], the hybrid configuration performed worst due to the number of gaze shifts, while the mobile-controlled large display was best. Users demonstrated a preference for the hybrid configuration – the authors speculate this is due to the freedom of choosing which screen to use. Regarding interactions with the information, the authors could not find any evidence *"suggesting that the loss of 'directness' between input and output is important"* [93, p. 105] in such a study. The researchers also confirm the positive impact from the mobility of the smartphone since users were allowed to place the device anywhere in their field of view while using both screens.

Aiming to investigate how performance is affected by visual separation of classic interfaces, Baudisch *et al.* [14] compared ZUI, O+D and F+C in two studies. The first involved tasks with static documents (e.g. exploring images), while the second was for dynamic tasks (e.g. playing games). For the static documents, three configurations were used: (i) ZUI on a single screen; (ii) overview and detail separated from each other, by displaying them in two different monitors; and (iii) F+C was adapted so the focus was presented using a high resolution screen while the context was projected by a low resolution projector. Configurations (ii) and (iii) were used for the realization of the dynamic tasks. Results from both studies showed that F+C, not only outperformed the other two, but also was the most preferred by the participants. One aspect from the results to highlight is the error rate when participants were interacting with O+D during the second study: it increased 254% from the F+C configuration. The authors argue that this is due to the nature of the tasks. Since users had to keep track of simultaneous changes in both perspectives, F+C allowed users to use their peripheral vision, while the O+D configuration required too many focus changes.

Exploring user interactions within MDEs, Boring *et al.* [94] compared three different techniques to control a pointer on a large public display using smartphone sensors (gyroscope and accelerometer) and keyboard. The three techniques used were scrolling using phone's keyboard, tilting the device, or moving the device in space. Results from this study suggest that, although moving and tilting outperformed scrolling, the latter was more accurate and preferred according to participants' subjective preference. Supporting these findings, Cheng *et al.* [41] compared four types of navigation using tablets as viewport for context displayed on large displays (as described in subsection 2.2). The results from this study suggested that touch interactions (e.g. touching the tablet's screen with the overview using two fingers to define the size and position of the viewport) are preferred over navigation based on the orientation of the tablet (e.g. tilting), and also have better performance. Based on the results, the authors recommend touch-based techniques for exploration of large visualizations using tablets integrated with big displays.

2.4 Summary

In this Chapter, I provided an overview of how the presentation problem is addressed in single- and multiple-display environments. Interfaces for information presentation can be classified based on the mechanisms used to separate and blend views as well as the number of views they provide. Single-view browsers provide temporal separation through detail-only and zoomable user interfaces, and provide focus within context visualizations by distorting the information presentation or occluding adjacent context. Single-view browsers can promote user disorientation, or distort or occlude portions of the information space. Multiple-view browsers mitigate such drawbacks by presenting overview and details in different portions of the screen. When exploring different interfaces within MDEs, the large displays can provide overview visualizations while mobile devices provide detailed views in the form of portals or lenses. These detailed views allow finer grained interactions not available on larger displays, such as tabletops and wall displays. Also, when tablets are tangible lenses, they afford means to explore different visualizations from portions of the information space displayed on larger displays.

How a system must present information, aiming at efficient user interaction, depends on the purpose and the tasks performed with the system. This dependency is supported by conflicting findings from the studies comparing different approaches. General subjective preference however, leans toward interfaces providing overviews, even if tasks are performed faster using different approaches. Although the studies described in this Chapter assessed performance and subjective preference of single users, they provide reference for the studies with multiple users described in the next Chapter, e.g. the impact of large displays providing overviews is enhanced when groups are performing collaborative activities.

Chapter Three

An Overview of Exploring Collaboration during Collaborative Visualization Activities

Sensemaking activities are often social processes involving *"parallelization of effort, discussion, and consensus building"* [18, p. 49]. Examples can be seen when family members are planning a vacation, students are working together to complete assignments, and colleagues are investigating solutions for a work problem. In such cases, social and collaborative activities are essential to advance the knowledge work process [95]. Exploring in the early 1990s how collaborative activities take place, Tang [1] analyzed how small groups of three or four people performed collaborative drawing activities using low-tech tools, such as paper and whiteboards. His study resulted in a set of design implications for collaborative technology based on collaboration aspects he observed, such as non-verbal communication, e.g. hand gestures; the importance of the shared space available for collaborators to mediate the activity; and the process of performing the activity, as he pointed out, *"the importance of experiencing the process of creating and using drawings, especially when expressing ideas, is indicated by the fact that the resulting drawings often do not make sense by themselves. They can only be interpreted in the context of the accompanying dialog or interaction of the participants"* [1, p. 152]. Since then, researchers from Computer-Supported Cooperative Work (CSCW) have been exploring the impact of modern technologies, such as smartphones, tablets, digital tabletops, and wall displays, on collaboration (e.g. [4], [36], [96], [97]), and how they can be used in different domains, such as meetings (e.g. [27], [98]), web-search (e.g. [34], [37], [99]), and photo organization (e.g. [100]).

More recently, researchers have been integrating design concepts from CSCW and Information Visualization (InfoVis) to support multiple users performing collaborative data analysis (e.g. [38], [101]–[103]). This integration resulted in a new research field called collaborative visualization [23], defined by Isenberg *et al.* as *"the shared use of computer-supported, (interactive,) visual representations of data by more than one person with the common goal of contribution to joint information processing activities"* [23, p. 3]. As described in this Chapter, although much effort has been spent to develop applications to support collaborative visualization, research on the impact on collaboration during information exploration activities within MDEs is still in its infancy.

In this Chapter, I will provide an overview of the research space of Collaborative Visualization related to this thesis. I start with focusing CSCW concepts extracted from the literature to ground how collaboration can be explored – specifically, the mechanics of collaboration are described in Section 3.1. I provide examples of Collaborative Visualization tools in Section 3.2. In Section 3.3, I describe studies exploring collaboration within single-display and multi-display environments. Lastly, I conclude this Chapter with Section 3.4. For deeper insights in CSCW and groupware, please refer to the seminal work in Greif [22] and Greenberg [104]. Isenberg *et al.* [23] and Heer *et al.* [18], provide surveys in Collaborative Visualization.

3.1 Mechanics of Collaboration

When a group is performing a collaborative task, it is possible to observe participants alternating between individual and shared work as the task and situation demands. For example, when a family is planning a trip using multiple travelling brochures placed on their living room table, family members alternate between reading the brochures and discussing about destinations with others. This **mixed-focus**

collaboration [105], i.e. with changes in focus between individual and group work and vice-versa, is supported by different aspects, such as collaborators' **awareness of the workspace** (e.g. the presence of brochures on the table) and **of each other's actions** (e.g. one is reading a brochure), and the **resources** available for the activity (e.g. brochures, table, chairs) [106], [6]. Low-tech tools, especially paper, are efficient mediums to support mixed-focus collaboration, as they can be easily viewed, transferred and manipulated by individuals and the group [6]. With traditional high-tech tools however, this efficient support is almost non-existent due to reasons such as designers focusing on the system instead of the task [107], and *"single-display, single-user assumptions"* that designers and developers make [19]. When designing collaborative technology, as Tang [1] observed, beyond focusing only on system functionalities, designers must consider collaboration aspects (e.g. communication and access to resources) to provide efficient support for the collaborative activity.

Providing a means to explore and assess collaboration aspects, and based on previous research on shared workspace collaboration and on their experience with groupware, Pinelle *et al.* [108] formed a framework describing the mechanics of collaboration. These mechanics represent the lowest level of representation for interactions, i.e. they are *"the small-scale actions and interactions that group members must carry out in order to get a task done in a collaborative fashion"* [108, p. 287]. According to the authors, they provide objective means for analysis of collaboration, since they can be broken down into specific actions that can be assessed one at a time. The framework defines two main categories of activity: (i) **communication** among collaborators and (ii) **coordination** of resources. These categories and the mechanics associated to them are represented in Table 3.1, from [108]. I briefly describe each category and mechanic in the following subsections.

Category		Mechanic
Communication	Explicit communication	Spoken messages
		Written messages
		Gestural messages
		Deictic references
		Manifesting actions
	Information gathering	Basic awareness
		Feedthrough
		Consequential communication
		Overhearing
		Visual Evidence
Coordination	Shared access (to tools, objects, space, and time)	Obtain resource
		Reserve resource
		Protect work
	Transfer	Handoff object
		Deposit

Table 3.1 Categories and mechanics of collaboration [108].

3.1.1 Communication

Communication can be seen as *"the most fundamental element of collaboration"* [108, p. 289]. It is used to send messages for others and also as a medium to gather information from others. There are different ways for collaborators to communicate. For instance, they explicitly send messages through **verbal** and **written** conversations, and also using **gestures**, e.g. pointing to an object. When in co-located situations, collaborators typically combine verbal and gestural communication, i.e. **deictic reference**, when referring to objects present in the environment. For example, during a meeting, when one says "that one" while pointing to a specific whiteboard marker, the message can only be fully understood by the other collaborators if they have *"knowledge about what objects are being discussed and what the sender is doing"* [108,

p. 290]. Lastly, collaborators can perform **actions** without the need for verbal communication to indicate what their intentions are. Manifesting actions differ from common gestural communication regarding the significance of the action, for example, the act of uncapping a marker in front of a whiteboard represents the message of "the collaborator is about to perform an annotation" without the need for verbal communication.

While the first category of communication deals with active communication, i.e. one collaborator sending messages to the others, the second category of communication deals with how collaborators gather information from the environment and from other collaborators' activities. The first mechanic relates the **basic awareness** every collaborator maintains about the environment and each other. For example, they identify *"who is in the workspace, where they are working, and what they are working on"* [108, p. 290]. Collaborators can also retrieve information from (i) the manipulation of objects in the workspace (**feedthrough**), e.g. by hearing the keys from a keyboard being pressed, one is aware that the person typing is busy; (ii) people's bodies (**consequential communication**), for example, the gesture of a person erasing a whiteboard can be understood even from a distance; (iii) **overhearing** others' explicit communication; and (iv) **visual evidence** in form of feedback that their communication was understood, e.g. when someone is giving instructions, the actions from the person being instructed are the feedback the instructor needs to verify if the instructions were understood or not.

3.1.2 Coordination of Resources

The second major category of collaboration activities deals with the coordination of shared resources (tools, objects, space, and time) in the workspace. This category is divided into the *management of shared access* and how resources are *transferred* among people, both categories are described as follows.

The management of shared access deals with how collaborator **obtain** resources, **reserve** them for future use, and **protect the work** performed with the resources. For example, consider an office meeting with one whiteboard and two markers. One collaborator, immediately after entering the room, may grab one of the markers, sit on the closest chair to the whiteboard, and place the marker on the table in front of him/her. By performing such actions, this collaborator is obtaining the resource marker by physically grabbing it; reserving the marker for future use by placing it on the table on his/her front; and, by sitting on the closest chair to the whiteboard, he/she is able to monitor others' actions on the whiteboard and protect his/her work.

The framework describes two approaches for resource transfer within the workspace. The first approach is through **handoff**, i.e. when a collaborator synchronously transfers a resource to another collaborator, in the form of physically giving an object, while the other takes it; or verbally offering the object, while the other accepts the object. For example, a person could give a hammer to another person so that he/she could hammer a nail into a bench. The second approach to transfer resources is through **deposit**. Through this asynchronous transfer, a collaborator leaves a resource in a particular place so another person can access it later. Considering the earlier example, a deposit is seen when a person places the hammer in a shared toolbox, making the hammer available for any other person to use it.

The authors define the mechanics of collaboration as primitives that can be evaluated independently. However, collaboration has many subtleties and a mechanic, like communication, has influence over others, as seen in [36], [37], [42], [106]. Therefore, researchers have been exploring collaboration considering themes, such as awareness (e.g. [106]), which relates to mechanics from information gathering, and territoriality, which relates to coordination of resources (e.g. [4], [35]). Section

3.3 details the research and the relationships between the systems used to support collaboration and the mechanics of collaboration.

3.2 Collaborative Visualization Environments

In this Section I provide an overview of the environments proposed for collaborative visualization. I consider the term *environment* as a system supporting collaborative visualization activities based on the characteristics of the devices used to perform such activities. I start with single-display environments, specifically tabletops, followed by multi-display environments for collaborative visualization activities.

3.2.1 Single-Display Environments for Collaborative Visualization

Traditional tabletop workplaces are considered ideal collaboration environments for small groups, since they provide a high degree of workspace awareness, allow people to orient and manipulate items in different ways, and collaborators can define distinct regions from the tabletop as their own space [4]. Based on these characteristics, researchers have been exploring the use of multi-touch tabletops to support co-located collaborative visualization activities: the tree comparison visualization system [109] is attributed to be the first effort to facilitate such activities on a tabletop. Through the tree comparison visualization, pairs can explore and modify independently and collaboratively representations of information; Cambiera [110] facilitates document exploration activities and analysis by allowing multiple users to explore documents individually and providing cues indicating each other's activities; Lark [111] allows multiple users to explore data through multiple coordinated views; DTLens [112] allows collaborators to interact with multiple simultaneous and independent zoom-in-context lenses to explore geospatial information; WebSurface [37] was developed to support collaborative web browsing on a tabletop; and PairedVis [113] is a recent effort to support experts from different domains while performing data analytic tasks. It is possible to observe that, the horizontal form factor of a digital multi-touch tabletop *"democratizes the interaction between multiple users"* [95, p. 623], providing enhanced support for awareness and communication [34], [37], [107], [114].

3.2.2 Multi-Display Environments for Collaborative Visualization

Parallel to the research with tabletops, researchers have been proposing and assessing MDEs for collaborative visualization activities. Forlines *et al.* [28], in 2006, described the experience of adapting a single-display, single-user application into a multi-display environment comprised by one tabletop, three wall displays and a tablet. The MDE provides synchronized coordinated views to support co-located collaboration of small groups exploring geospatial data. Forlines and Lilien [19] describe similar experience when adapting a molecular visualization system for use in a MDE. In 2009, Isenberg *et al.* [115] presented CoCoNutTrix, a low-cost collaborative environment comprised by multiple projectors and multiple input devices to explore information visualizations. In 2012, Jetter *et al.* [92] introduced the zoomable object-oriented information landscape (ZOIL) design approach and framework, described in Section 2.2. Cheng *et al.* [39] describe a MDE for data exploration based on the iPodLoupe (described in Section 2.2). In a similar fashion as seen in Figure 3.1, users are able to explore the information space using the ZUIs on their tablets while the wall display provides overview with viewfinders representing each tablet. In the web browsing domain, MobiSurf [29] integrates personal mobile devices with shared interactive surfaces to support co-located collaborative web-browsing activities. In 2014, Chung *et al.* [38] presented VisPorter, a collaborative text analytics MDE to support sensemaking activities. Within VisPorter, each display is a tool with specific purpose, as seen in Figure 3.2, and they allow users to distribute artefacts such as documents, images, and visualizations into any situated display or personal device. It is possible to observe in these projects the effort to make efficient use of the capabilities and characteristics of each device within the environment to support collaborative activities. While personal devices support individual work, the shared displays enhance communication and coordination of resources by providing overview visualizations and cues for collaborators while working with their personal devices.

Figure 3.1 Collaborators exploring information within MDE.

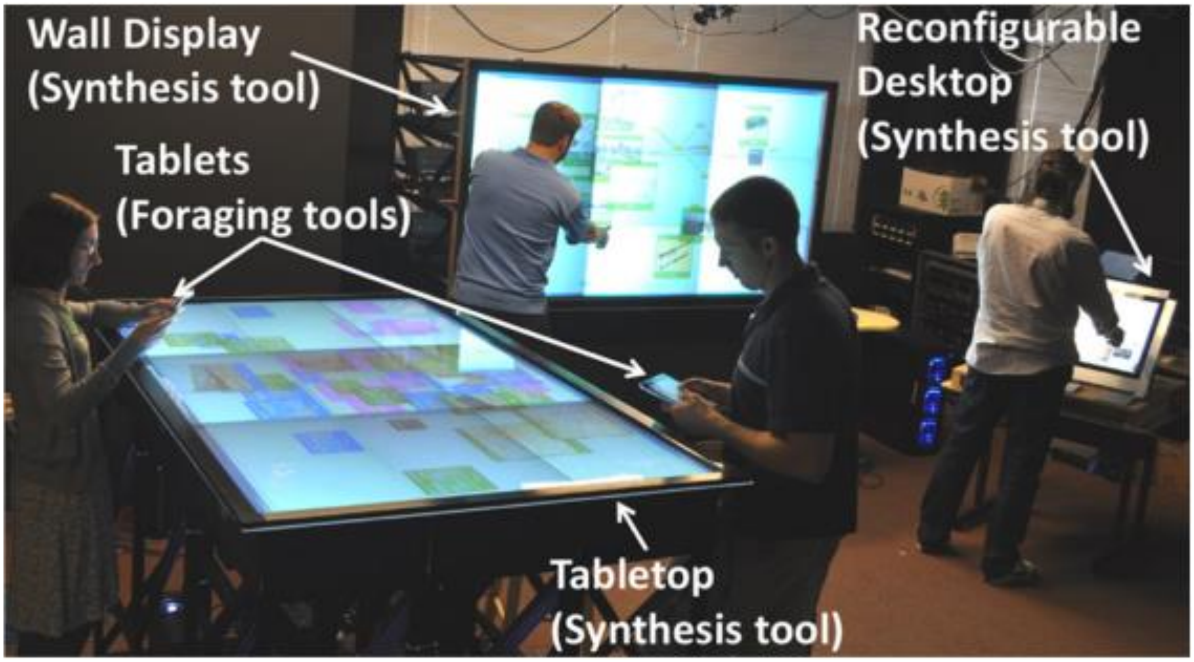

Figure 3.2 Devices (tools) have different purposes within VisPorter[13].

3.3 Exploring Collaboration within Collaborative Visualization Environments

In the previous Section, I presented some tools developed to support collaborative sensemaking activities. However, much effort has been done to assess collaboration based on available technologies. In this Section, I provide an overview of the research on how researchers have been exploring the impact on collaboration by using different collaborative technologies for sensemaking tasks. I start presenting relevant studies in single-display environments and then in MDEs, specifically, research comparing different configurations of devices.

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[13] Source: Chung *et al.* [38]

3.3.1 Territoriality and Collaboration Styles with Tabletops

Due their horizontal form factor, digital tabletops, analog to traditional tabletops, provide a high degree of awareness [34], [37], [107]. However, awareness is not the only mechanic of collaboration influenced by digital tabletops. The coordination of resources also has significant influence from such devices, as Scott *et al.* [4] describe in their work investigating the role of territoriality in digital and traditional tabletop collaboration. According to the authors, *"territories serve to help people mediate their social interaction through laying claim to a space or through association of a space to a person due to repeated use or the passage of time"* [4, p. 300] – which can be related to obtaining resources and reserving resources for the future. Results from the studies showed that, as with traditional tabletops, collaborators defined three types of territories on the digital tabletops: personal, group and storage territories. For instance, personal territories *"provide each person with dedicated space on the table for performing independent activities"* [4, p. 297]; group territories serve as *"place to share task resources"* [4, p. 299]; and storage territories are places to store task resources. The researchers observed that the location of a storage territory has influence over who utilizes the resources contained within it – if located between participants, the resources were fairly shared; however, if located near or in someone's personal territory, that person becomes responsible for the resources. These territories were naturally defined, with little to no verbal negotiation, to help collaborators *"coordinate their task and social interactions"* [4, p. 300] within the workspace. When coordinating such interactions, collaborators shift attention between individual and group work. Shifts of attention have direct relationships with the mechanics of collaboration, as detailed below.

Collaborators identify appropriate opportunities to transition between working independently and closely together by maintaining awareness of the workspace [36] and of each other's actions [106], as described in Section 3.1. Working closely together or independently are two examples of **collaboration styles** or **coupling styles** [105]. According to Tang *et al.* [36], coupling reflects *"collaborators' need or desire to work closely or independently of one another"* [36, p. 1182]. Aspects such as physical arrangement, tool use, and fluidity of work influence the coupling. When a pair is tightly coupled, i.e. working closely together, the actions appear *"coordinated and fluid"* [36, p. 1182], while a loosely coupled activity (each collaborator working independently) requires collaborators to rely on *"social or explicit protocols to negotiate conflicting needs"* [36, p. 1182].

Observing how pairs collaborate to realize independent and shared tasks on a digital tabletop, Tang *et al.* [36] identified six different collaboration styles, ranging between tightly coupled, i.e. fully engaged collaboration, to loosely or no coupling, i.e. completely independent entities. Isenberg *et al.* [114] extended Tang *et al.*'s set to eight styles after observing pairs performing complex collaborative data analytic tasks on a tabletop with Cambiera. In both studies, the researchers observed that communication was highly correlated with collaboration style and, in [114], with the success of the activity. For instance, tightly coupled pairs had higher success rates performing the tasks compared to pairs that worked more in parallel, and when communication happened while collaborators were working in a loosely coupled style, it was typically associated with a transition to a more coupled style. The researchers speculate that the lack of support for communication and resources sharing from the tool had major influence on the failure rate of loosely coupled pairs. They believe that it is possible to encourage closely coupled work by providing system features such as additional overview visualizations, stronger visual connections between common information, and low-cost means to share resources between collaborators, e.g. a shared notepad.

3.3.2 Collaboration with Different Configurations of Devices

Research exploring co-located collaboration with different configurations of devices and interfaces has shown that collaborators change the way they work based on the devices and interfaces available. When analyzing this research space, it is possible to notice the focus on tabletops, with just a few studies relating tablets and other devices. Below, I describe studies involving personal devices and shared displays. They are grouped based on the configurations the researchers assessed. For instance, the first group has studies in which the conditions involved low-tech versus high-tech tools; the second group has studies comparing conditions with independent displays versus a shared display (e.g. laptops *vs.* tabletop); and the third group has studies comparing conditions with independent plus shared displays (e.g. mobile devices + tabletop vs. tabletop only).

Low-Tech versus High-Tech Tools

Based on the fact that tablets have been replacing laptops in office meetings, Takano *et al.* [5] looked into how groups of two people discuss documents available on tablets, papers, and laptops. In this study, both collaborators had access to the documents in paper form, on their laptops, and on their tablets. The researchers observed that, due to their form factor, tablets better supported the collaborative process when compared to laptops. When interacting with tablets, collaborators demonstrated more explicit communication, specifically, conversation, use of demonstrative pronouns (deictic references), and eye contact. However, the collaboration using tablets was outperformed by collaborators using paper, i.e. when using paper, collaborators demonstrated a more tightly coupled style than with the electronic devices. The researchers attribute this result to the ease to manipulate (flip pages) and share paper sheets, and to the distraction-free medium provided by paper. Multiple times, collaborators became distracted when interacting with the electronic devices, resulting in loosely coupled work, with reduced communication, and situations where collaborators ignored their partners because their focus was on interacting with the system (e.g. enlarging or panning an image).

Yuill *et al.* [6] recently described a study where an iPad was used as a collaborative tool for co-located creative group work in families. The researchers designed and implemented a drawing application for iPad supporting co-located collaboration. Then, they performed a study comparing the results of using the iPad and using paper for drawing tasks involving shifts between collaborative and individual working. The results showed that when using the iPad, the resultant drawings were *"more original and cohesive"* [6, p. 941] than when using paper. The authors attribute these results to a *"more immersive experience"* [6, p. 948] while interacting with the iPad, and also to explicit indications about previous contributions to the drawing, unavailable on paper. The authors also identified that the form factor of the tablet can support rapid and smooth shifting of attention between individual and small group as seen with paper. Although these findings contradict the previous study [5], I attribute this contradiction to two factors: the activities (reading text documents and drawing) and to the tools used in both studies. In [5], a traditional document visualizer application displayed the documents used to perform the tasks, while for Yuill *et al.*'s study, the tool was designed to support co-located collaborative drawing activities – demonstrating the potential of effective use of tablets for co-located collaborative activities.

Individual Displays versus Shared Displays

Heilig *et al.* [95] describe an experimental user study on the impact of different interface types (one using tangibles and tabletops, *versus* three synchronized PCs with keyboard and mouse) for collaborative information seeking situations. Results suggested that, although verbal communication was not affected by the interface being used, the non-verbal communication was highly affected by the interface type, especially when physical objects were used for interaction. When interacting with tangibles, participants *"seamlessly perceived gestures of their group members and used the physical artefacts to communicate and produce meaning"* [95, p. 638]. Also, instead of classifying the group collaboration, they considered the role of each participant while performing the tasks. For instance, the researchers observed participants adopting five different styles depending on the interface being used. These styles range from *leading and active participants* to *cautious and passive participants.* The authors attribute this finding to the opportunities tangibles provide to physically express and communicate ideas.

WebSurface [37] was developed for collaborative web browsing on a tabletop. The researchers conducted a study with pairs interacting with three different configurations of devices: (i) tabletop running WebSurface, (ii) single laptop, and (iii) dual laptops. The results showed that the tabletop-only configuration allowed smooth transitions between independent and group work. Also, in this configuration, participants could work without disrupting their partners. When performing tasks in the dual laptop configuration, the participants worked independently and often browsed the same websites, without being aware of the actions of the partner. For the single laptop configuration, since independent work was not possible, the researchers observed one participant being in control of the computer while the partner would suggest actions. Regarding active participation, participants ranked the tabletop configuration as best. This preference was attributed to the freedom of users to choose to work independently or collaboratively at any given time.

When Individual Displays Meet a Shared Display

Wallace *et al.* [116] investigated the impact of two different display configurations during collaborative optimization tasks. The configurations of devices were: (i) a single shared display projected on a wall with multiple inputs; and (ii) a laptop for each participant providing personalized views and the shared display providing an overview. The study showed that while the single shared display condition promoted group awareness, providing a personal device for each participant promoted task accuracy. The researchers observed that participants rarely used the shared view in the second condition. And when used, the purpose was to gain awareness of task progress and groups' activities. In a follow-up study, [117], Wallace *et al.* explored the role of the large shared display when each participant had access to a laptop. The results showed, when the shared display replicated the interfaces from the three laptops, participants *"were better able to ground conversation"* [117, p. 531]; and when it provided task progress status, participants *"were better able to monitor one another's progress"* [117, p. 531].

The MobiSurf [29] concept integrates personal mobile devices with shared interactive surfaces to support co-located collaborative web-browsing activities. A study was conducted comparing when pairs had access to laptops, and when they had access to mobile devices (one collaborator with a tablet and the other with a smartphone) integrated with a tabletop. The results showed that the combination of mobile and tabletop resulted in improved communication and an exchange rate of resources three times higher than when the traditional computer was used. Although participants considered MobiSurf as a physically demanding approach, subjective preference rated it as the best approach for collaboration.

Observing pairs performing sorting tasks with text documents, Bachl *et al.* [42] explored the impact on performance, awareness and collaboration strategies of different content transfer techniques between personal and shared devices. In this study, there were four different configurations: one with a tabletop as the only device available for interaction, and during the other three, each participant had access to a tablet integrated with a tabletop. The results showed that there was no significant difference in completion times across the four conditions. As described previously, during the tabletop-only configuration, the researchers observed that all groups but one worked closely together. When tablets were available, collaborators performed tasks according to four styles: (i) *team-up*, when both collaborators are working close together; (ii) *split-up*, when they are working in parallel; (iii) *prepare-and-conquer*, characterized by an initial phase of parallel work followed by close collaboration towards the end; and (iv) *divide-and-combine*, characterized by recurrent switches between close together and parallel work. These collaboration strategies are also related to the awareness. When working close together, participants pointed to a higher awareness of each other's actions through the use of the tabletop – which was highlighted by the authors as an important medium for maintaining awareness of task progress and *"feedback about the activities taking place on the personal display"* [42, p. 388]. The findings from this study support the point of view of Isenberg *et al.* [114]: closely coupled work is encouraged when the system provides a means to support communication and coordination of resources.

Wallace *et al.* [43] observed groups of four people performing sensemaking activities with three different device configurations: tabletop only; tablets only; and tabletop and tablets. In the second and third configurations, each participant had access to a tablet. Results showed that the tabletop supported collaborative exploration of information, e.g. they were able to prioritize and compare the information together. Supporting findings from [114], they observed correlation of coupling style and task success based on configuration. For instance, during the tablets only condition, there was a higher frequency of loosely coupled work, not observed when the tabletop was available. This loosely coupled work resulted in groups performing tasks poorer during this condition compared to when they worked tightly coupled with the shared device.

3.4 Summary

In this Chapter, I presented the mechanics of collaboration, a set of primitives representing aspects of collaboration. Since one primitive may have influence over others, researchers typically assess collaboration based on major themes, such as awareness, explicit communication, and coordination of resources such as tools, objects, space, and time. Researchers noticed patterns of the behaviour of groups performing collaborative activities. These patterns, called collaboration styles, emerge from the recurrent focus switching between individual and group work that collaborators demonstrate while performing tasks. When working closely together, they are considered tightly coupled; when working independently, they are loosely coupled. Collaborators identify appropriate opportunities to transition between working independently and closely together by maintaining awareness of the workspace and of each other's actions. When the environment does not promote closely coupled styles, it is possible to observe a negative impact on collaboration. Collaborators communicate less and tend to have higher error rates when performing tasks, compared to when features to afford awareness, conversation, and low cost coordination of resources are available in the environment.

In the past ten years, much has been done to identify efficient means to support collaborative visualization activities. Many systems have been proposed for single- and multi-display environments within different domains. These systems enable users to explore information spaces through independent and shared views of the information space. Also, it is possible to visualize, modify, and share visualizations independently and collaboratively. Besides proposing applications, researchers have been exploring how collaboration is impacted by the use of different collaborative technologies. Studies have shown that large shared displays, such as tabletops, have major positive influence on awareness, communication and coordination of resources. When working only with individual devices, collaborators typically demonstrated a loosely coupled style. Regarding the configurations described in the studies, all studies but one involving individual devices considered equal number of collaborators and devices. When investigating the role of devices within MDEs for collaborative visualization activities, researchers focus on shared displays (wall displays and tabletops) or in techniques for content transfer between devices. This thesis extends the prior research work by exploring the collaboration between pairs when the number of tablets providing different detailed views within the MDE changes during geospatial information exploration.

Chapter Four

Using Tablets and Lenses as Collaborative Tools within MDEs: Study Design and Bancada[14, 15]

Multi-display environments (MDEs) provide means to explore information considering the capabilities of each device in the environment. For example, tablets can display detailed views, while stationary large displays, such as tabletops and wall displays can provide context (overview). As seen in Chapters 2 and 3, the literature provides examples of MDEs developed to support collaborative visualization activities (e.g. [19], [29], [38]). Researchers have also been exploring collaboration with large shared displays (e.g. [36], [117], [118]), and when personal devices are integrated to large displays (e.g. [29], [42], [43]). However, almost all studies involving personal devices considered an equal number of collaborators and personal devices. Only one study, [37], considered a configuration on which pairs had access to a single laptop (without multiple inputs) to perform web browsing tasks, and it only considered single-display

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Francisco Marinho Rodrigues, Teddy Seyed, Frank Maurer, Sheelagh Carpendale: Bancada: Mobile Zoomable Lenses for Collaborative Geospatial Exploration. In Proceedings of the 2nd Collaboration meets Interactive Surfaces Workshop (CmIS) in ACM Interactive Tabletops and Surfaces 2014 (ITS 2014), Dresden, Germany, 2014.

[15] In this chapter, the use of the plural "we" refers to Francisco Marinho M. Rodrigues and the co-authors Teddy Seyed, Dr. Frank Maurer and Dr. Sheelagh Carpendale, who provided guidance in the design of the study and for the implementation of Bancada.

environments. The results from this study demonstrated that, during this configuration, one collaborator controlled the computer while the other provided instructions.

Within MDEs, research investigating the role and impact on collaboration of personal mobile devices, specifically tablets, is still sparse. Researchers have shown that tablets support individual work [43] and, due to their form factor, they afford rapid and smooth shifting between individual and group work [5], [6]. However, when there are different numbers of tablets available providing different detailed views within a MDE, it is unclear if collaborators are willing to share their personal devices for the sake of the sensemaking process or if they prefer their tablet devices to remain personal. In exploring such opportunities, I conducted the study which design is described in this Chapter.

The design of the study is described in Section 4.1. Section 4.2 describes the system used to conduct the study, Bancada, a multi-display environment developed for geospatial information exploration. Then, I conclude this Chapter in Section 4.3.

4.1 Study Design

Through this study, I expect to answer the three research questions (described in Section 1.2) of this thesis and to achieve its main goal: to investigate the impact on **collaboratio**n between **groups of two people** (also referred as *groups* or *pairs*) when **configurations with different numbers of tablets** providing **different detailed views** (hereinafter, *lenses* or *views*) are available to explore **geospatial information** within **MDEs**. Considering the different configurations of devices and findings from related prior work (e.g. [29], [37], [43]), it is expected that collaborators will demonstrate distinct collaboration styles based on the number of personal devices available in each configuration.

To perform the geospatial tasks, a group has access to an overview map displayed on a tabletop and to different zoomable lenses provided by tablets, in a similar fashion seen in ZOIL [92] and iPodLoupe [68]. Each lens allows users to explore distinct geospatial visualizations, specifically: population density heat maps, referred to as Population Density lens; geographic labels from cities, provinces, and lakes, referred to as Cities lens; or transportation networks, such as streets and major roads, referred to as Streets lens. These three geospatial visualizations were chosen to limit the complexity of the tasks, given that we wanted to conduct several tasks during a short period of time. During the study, pairs had to use a set of lenses to solve geospatial problems. The study intentionally required pairs to collaborate in problem solving.

In the following subsections I describe the different configurations of devices and the geospatial tasks.

4.1.1 Configurations of Devices

A within-participants approach was chosen due to time available to conduct the study. Therefore, participants were required to interact with all the different configurations of devices to perform geospatial tasks in the MDE. A configuration consists of a certain number of tablets integrated with a tabletop. Characterizing the independent variable of this study, the number of tablets changes for each configuration. Based on the number of tablets on which I had access to conduct the study, i.e. three tablets, three configurations were defined, namely:

- **Multiple Lenses on Single Tablet (MLST)**: there is only one tablet available for both participants and this tablet provides all lenses.

- **Multiple Lenses on Multiple Tablets (MLMT):** each participant has access to a tablet providing all lenses.
- **Single Lens (SL):** participants have access to three tablets, each device containing a single distinct lens.
- A fourth configuration, Single Lens on a Single Tablet (SLST), was omitted from the study as it would not allow to solve the geospatial tasks.

These three configurations provide the means to observe how pairs perform tasks according to the number of tablets available, answering RQ1, and to observe the impact of tablets being specialized tools (SL) *versus* all-in-one tools (MLST and MLMT), answering RQ2. Table 4.1 and Figure 4.1 summarize the configurations and the number of tablets available. It is important to highlight that the tabletop provides an overview map in all configurations, as seen in Figure 4.1.

Configuration	# of Tablets	# of Lenses per Tablet
Single Lens (SL)	3	1
Multiple Lenses on Multiple Tablets (MLMT)	2	3
Multiple Lenses on Single Tablet (MLST)	1	3

Table 4.1 Description of the three configurations of devices.

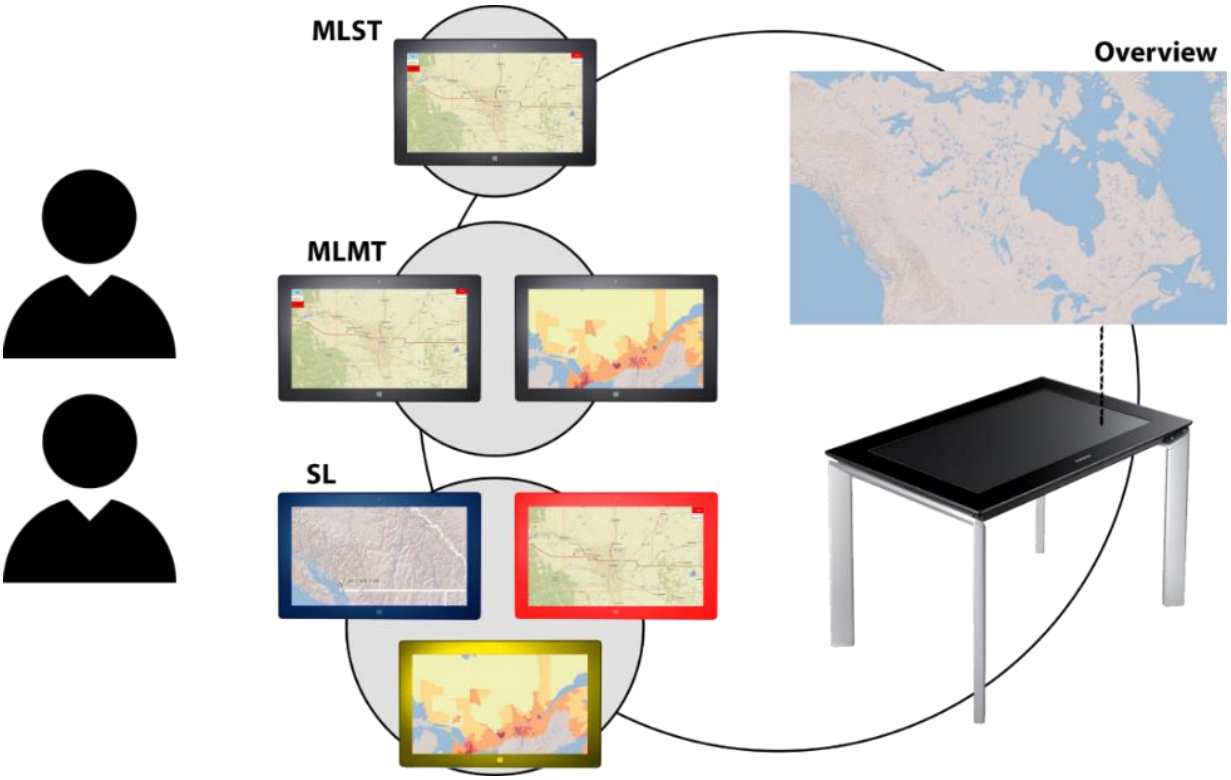

Figure 4.1 Configurations of devices.

Each configuration is associated to a set of tasks, referred in this thesis as a **round**, and the order in which participants are exposed to each configuration is defined according to a Latin square (n=3) distribution. The resultant three different combinations are classified into the study types described in Table 4.2. A group is associated to a type based on the order of participation. For instance, the first group is assigned type A, the second, is assigned type B, the third, type C, and then, the order repeats, i.e. the fourth pair is assigned type A, the fifth, to type B, and the sixth, to type C.

Study Type	Round 1	Round 2	Round 3
A	SL	MLMT	MLST
B	MLMT	MLST	SL
C	MLST	SL	MLMT

Table 4.2 Study types according to Latin square distribution.

4.1.2 Tasks

In this this study, the primary focus is examining collaboration between non geospatial information specialists. Consequently, the tasks chosen for the study avoid obstacles that could arise from domain-based tasks. For instance, a person not familiar with the geography of a certain region should still be able to perform the tasks. Based on such premises, twelve tasks related to the Canadian geography were defined. They were classified and grouped according to the minimum number of lenses required for solving them. Then, each task was allocated into one of the three rounds following two criteria: first, participants had to perform the same number of tasks in all rounds, i.e. four tasks per round; second, across rounds, the tasks should have similar level of difficulty according to the order they are presented, for example, the first task should be the easiest and it always requires the use of only a single view; the second and third tasks require two views; and the fourth, three views. Table 4.3 describes the set of twelve tasks: the round of each task, the order number they are presented (Task #) and the minimum number of lenses required (# Lenses).

Round	Task #	# Lenses	Description
1	1	1	Point to one street, any street, in Vancouver using the Streets lens.
	2	2	What is the population density of Edmonton, Alberta?
	3	2	What is the population density of Brandon, Manitoba?
	4	3	How would you go from Edmonton to the closest city west of Edmonton with population density greater than 400?
2	5	1	Point to cities really close to Ottawa using the Cities lens.
	6	2	What is the population density of Prince George, British Columbia?
	7	2	Which city is denser: Missisauga or Hamilton, Ontario?
	8	3	How would you go from Winnipeg to the closest city northwest of Winnipeg with population density greater than 400?
3	9	1	Which highway ends in Goose Bay in Newfoundland and Labrador?
	10	2	What is the population density of Whitehorse, Yukon?
	11	2	What is the population density of Lethbridge, Alberta?
	12	3	How would you go from Regina to the closest city to the US border, still in Saskatchewan, with population density greater than 400?

Table 4.3 Tasks set.

The tasks were designed so that to solve them collaborators would have to use multiple lenses at the same time and follow a similar process based on the order in which they were presented:

- The first task of each round involves finding a specific city using Streets or Cities lenses, and identifying some information from the lens, i.e. the name of a street, a highway or adjacent cities.

- During the second and third tasks, the participants have to find a specific city on the map and then use the Population Density lens to identify the population density of that city.
- The fourth task requires all three lenses. First, they are required to find a specific city then, to identify an unknown city in a certain direction from that city that has population density greater than 400. Finally, they have to identify the major roads from the first city to the second using the Streets lens.

It is important to remember that, to maintain the number of tablets available for interactions and the number of lenses per tablet as the two only independent variables, the tasks were presented in the order described in Table 4.3 for all groups.

4.2 Bancada

Bancada is the MDE developed to conduct the study described in this thesis. This system integrates concepts from ZUIO and lenses to explore geospatial information spaces. Figure 4.2 illustrates Bancada running on a setup with a tabletop and three tablets. Interactions can be performed with multiple tablets, where each tablet provides a specific lens (a specific geospatial layer), or by interacting with a single tablet containing all lenses. While a user interacts with the tablet, the tabletop provides an overview and displays lens-based viewfinders, i.e. viewfinders showing the content of all lenses that are being manipulated at a given moment, and insets with intermediate scale views. The overview is provided by a basemap, which is a map used for background reference *"onto which other thematic information is placed"* [119]. Figure 4.3 illustrates the different views a user has when the Streets lens is placed over Calgary. The overview (Figure 4.3A) displays a viewfinder (small rectangle) and an inset (large rectangle on top of the screen) relative to the lens from the tablet (Figure 4.3B). The user interface elements from Bancada are detailed in subsections 4.2.3 and 4.2.4.

Figure 4.2 Bancada running on a setup composed of one tabletop and three tablets.

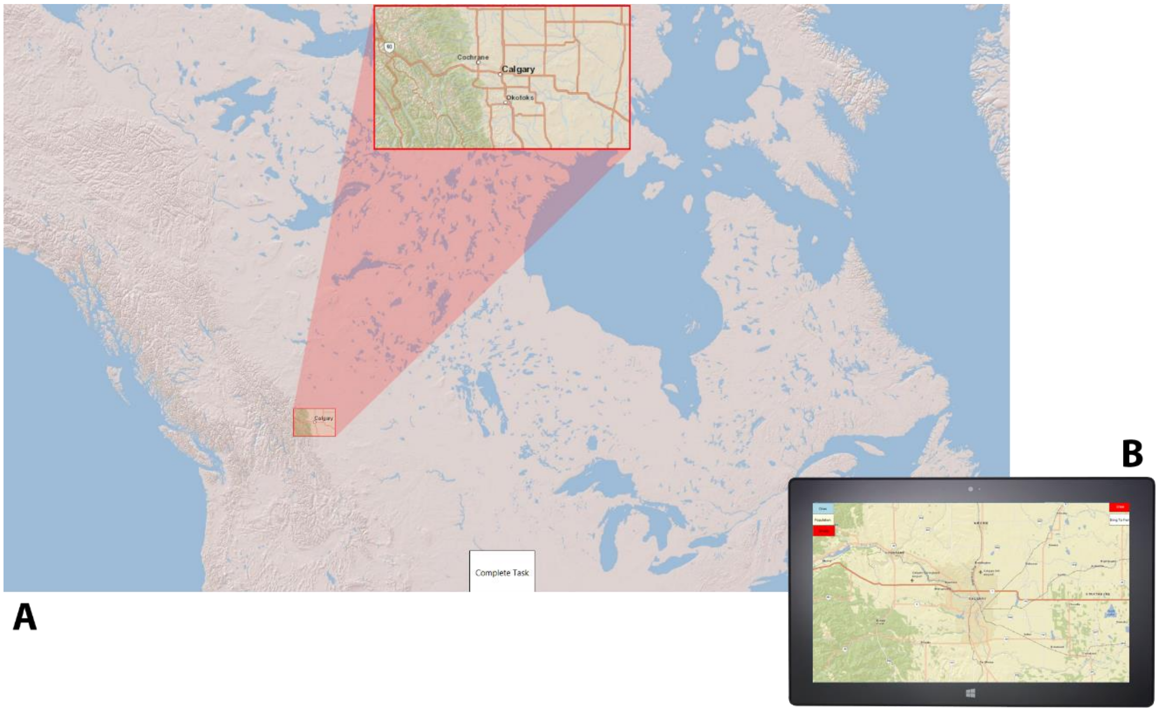

Figure 4.3 Overview map (A) shows a lens-based viewfinder and an inset (top-center) relative to the lens being manipulated on a tablet (B).

4.2.1 Technical Information

Bancada is a standalone application that can be deployed on any device running Microsoft Windows and it allows a researcher to define and change the purpose of any device, e.g. displaying the overview map or providing a specific (or all) view(s), at any time during its execution. These two characteristics allow researchers to explore different modes of information presentation without the need to modify the source code.

The MDE was developed using Microsoft C# with the Windows Presentation Foundation[16] (WPF) UI framework. The communication between devices is using the communication layer provided by the multi-surface environment toolkit Society of Devices[17] (SoD). Last, for geospatial information rendering, ESRI's ArcGIS SDK for C#[18] was used and the maps and layers were provided by the ESRI Canada Community Map Program[19].

The following subsections describe the lenses, modes, interactions and limitations of Bancada.

4.2.2 Lenses

As described in subsection 2.1.3, lenses are used to modify the presentation of a portion of the information space to reveal, supress or enhance information. In Bancada, lenses are geospatial layers revealing geographic visualizations on a basemap displayed on a different device. Each lens is identified by a particular color on the overview map. Considering the example when a user activates the Street lens, seen

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[16] http://msdn.microsoft.com/en-us/library/ms754130(v=vs.110).aspx

[17] http://sodtoolkit.com/

[18] https://developers.arcgis.com/net/

[19] http://maps.esri.ca/

in Figure 4.3. It is possible to interact with a map containing streets and highways on the tablet, while the overview map presents that specific area inside a red rectangle (viewfinder) and also through an inset on the upper part of the screen. To conduct the study, Bancada provided three lenses:

- Streets (Red), shows streets and highways and their corresponding labels.
- Population Density (Yellow), shows the population density heat map according to the Canadian 2006 census.
- Cities (Blue), shows labels for cities, lakes, rivers, provinces.

Regarding user interactions, there are seven possible interactions with lenses in Bancada. Users can turn on (activate) and off (deactivate), remove (erase), pan, and zoom in/out a lens. It is also possible to switch between different lenses and change the order on which they are displayed. The availability of interactions is dependent on the configuration and they are detailed in the following subsections.

4.2.3 Modes

Bancada is a standalone application that can be executed according to three modes: Overview, Single Lens, and Multiple Lenses. When Bancada is first executed, a menu is displayed prompting the user to choose which mode should be executed on that specific device, as seen in **Error! Reference source not found.**. This characteristic brings flexibility: a wall display can provide an overview, a tabletop can provide multiple lenses and a tablet can provide a single lens – all devices running copies of the same executable file. The following sub-subsections describe each mode.

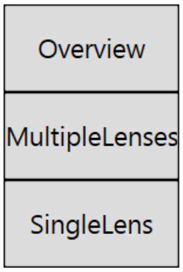

Figure 4.4 Mode selection menu.

4.2.3.1 Overview

The overview mode is a multi-view browser responsible for providing context and detail within the MDE. As seen in Figure 4.5, this mode shows a base map with fixed geographic scale and position (extent) and all active lenses. The active lenses are presented in two views: viewfinders and insets (on the upper part of the screen). While the viewfinders have dimension and position defined based on the portion of the information space a user is exploring on a tablet, insets have fixed dimensions. This feature was motivated by the following scenario: given the fixed scale and extent of the base map, if a person is exploring a city with the Streets lens, the zoom level might be so high that another person without access to the lens will only see a small rectangle on the overview indicating that lens position and no other information can be extracted. To mitigate this problem, the insets allow anyone to see through the lenses, independent of the zoom scale.

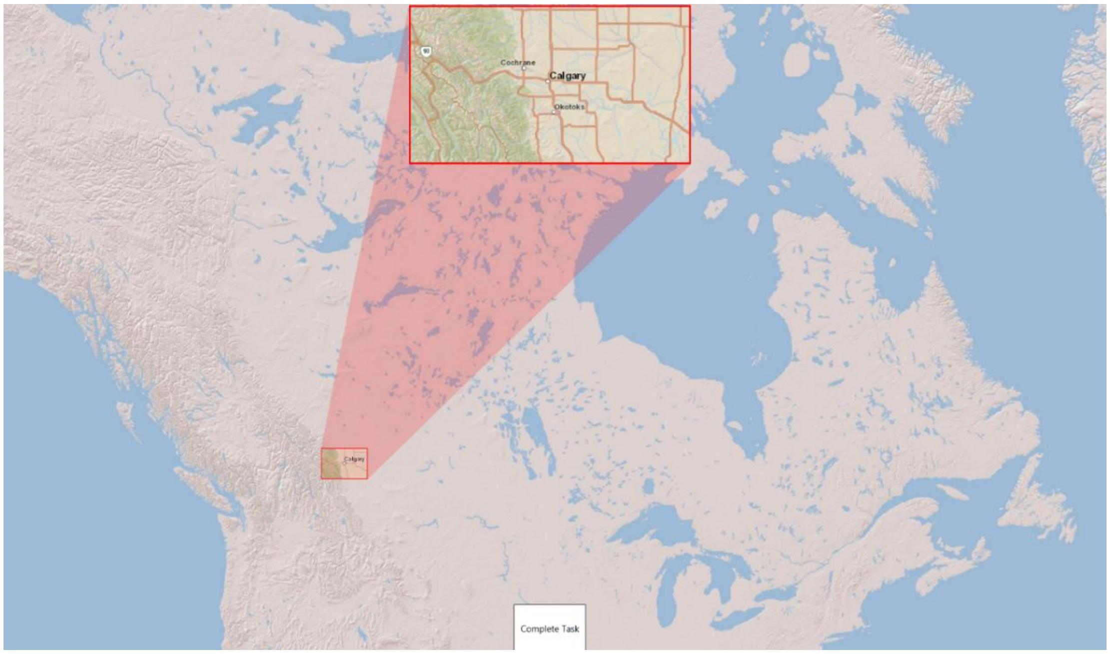

Figure 4.5 Overview displays lenses through viewfinders and insets on the superior part of the screen. Shadows are used to reduce the effects of separation between views.

The overview also allows users to create custom layered maps by overlapping lenses, in the same fashion as described in subsection 2.1.3. This overlapping results from placing lenses on top of each other and it is determined by the order lenses are activated. For example, if a user activates the Population Density lens, and then Cities, s/he can see the labels of the cities on top of the population density heat map. However, if one lens is panned, the overlapping area will be seen only where the lenses intersect, similar to the behaviour from [10] (seen in Figure 2.11), and illustrated in Figure 4.6.

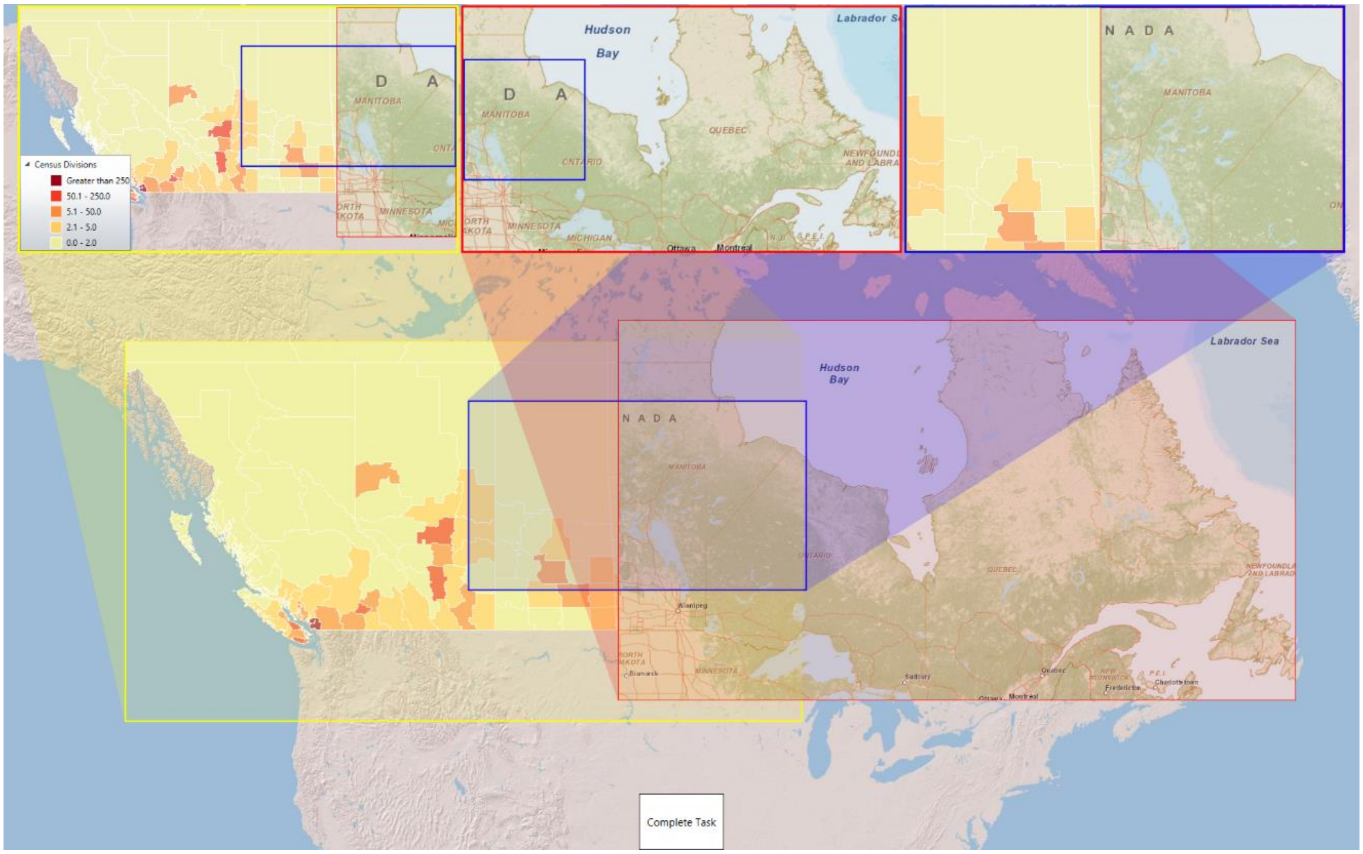

Figure 4.6 Overview showing three lenses overlapping each other.

Following the recommendations from [12], Bancada manages automatically the size and location of insets. The size of an inset is calculated based on the screen real estate available, the resolution of the device operating that lens and the number of lenses available for interaction. Regarding location, insets are centralized on the top portion of the overview and placed automatically based on the order of activation of the lenses. For instance, when a lens is activated, the inset will be placed on the top center of the screen. When users activate subsequent lenses, their corresponding insets are positioned at the right side of the last inset added and all insets are then centralized. When a lens is deactivated, its inset is removed from the screen and the remaining insets are re-aligned. When reactivated, instead of placing the inset on its previous position, the overview considers it a "new" inset. Aiming to aid users and mitigate the discontinuity problem from the separation of the focus and context, i.e. the viewfinder and the respective inset, there is a shadow with the same color as the lens connecting both views, as recommended by [64].

The overview mode provides means for users to orient themselves in case of disorientation when interacting with detailed views (through viewfinders and colors), as seen in [62]. Also, if this mode is running on a large shared display during collaborative activities, it promotes awareness of collaborators' activities, since their interactions with lenses are updated in real-time, as seen in [117].

4.2.3.2 Single Lens

Figure 4.7 shows an instance of Bancada running in Single Lens mode. A device executing Bancada in this mode allows users to interact directly with a predefined lens. It is also possible to activate, deactivate, erase (i.e. remove from all devices and restore to the initial state) and bring the lens to the front (i.e. put the lens on top of all others on the overview map). All mentioned interactions are described in subsection 4.2.4. This mode is used when there are multiple tablets and each tablet is used for only one specific lens.

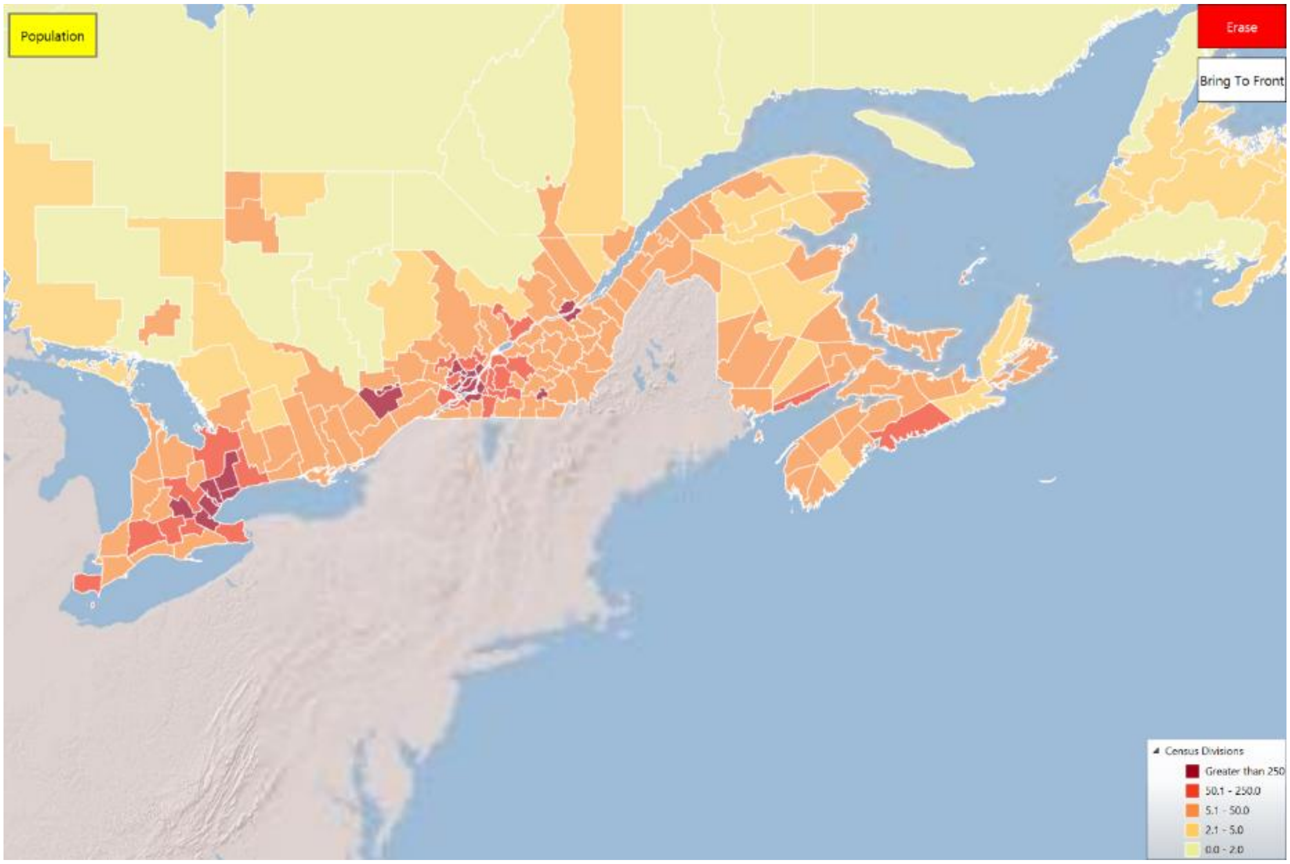

Figure 4.7 Population Density lens displayed on a device running Single Lens Mode.

4.2.3.3 Multiple Lenses

Besides all interactions available in Single Lens mode, when in Multiple Lens mode, the system allows the user to swap lenses at any moment through the lens selection menu, as seen in Figure 4.8. When changing lenses, for instance, from Cities to Streets, the system will save the state (geographic position and scale) of Cities and, if Streets has been activated before in any device, the system will restore the lens to its previous state, i.e. where the last user interacting with the lens left. If Streets is being used for the first time, the system will initialize the lens according to the overview extent, respecting the visual information-seeking mantra “overview first, zoom and filter, then details-on-demand”, as described in sub-subsection 2.1.1.1.

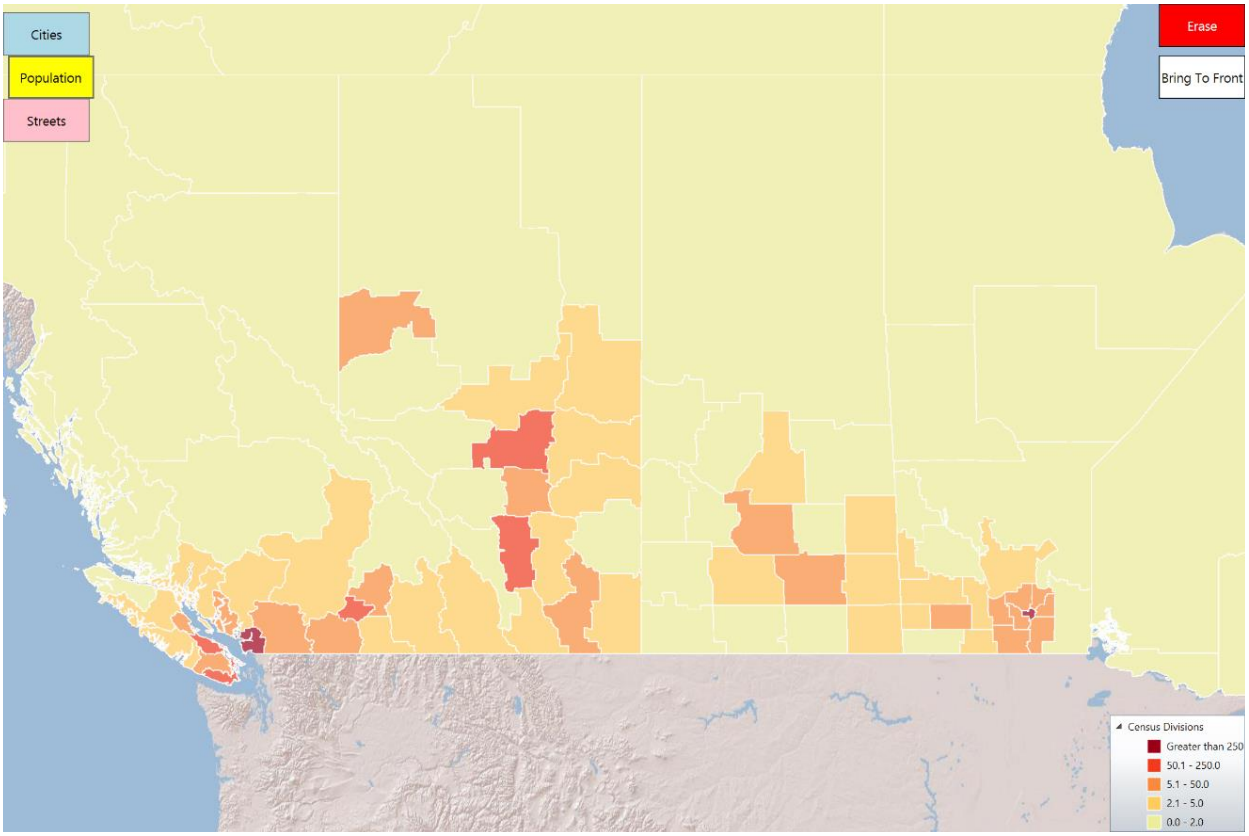

Figure 4.8 Population Density lens displayed on a device running Multiple Lenses Mode. This mode allows users to change lenses through the menu on the top-left corner.

4.2.4 Interactions

As seen in Chapter Three, to provide efficient support for collaborative activities, the interactions with the system have to be *"efficient, enjoyable and easy to learn"* [94] and users should focus on performing the task instead of the system [1], [114]. Therefore, they should not be concerned on learning multiple and difficult gestures to interact with information. All operations with lenses available in Bancada are restricted to five buttons, seen in Figure 4.9 (A and B), and two popular touch gestures, performed directly on the map, as seen in Figure 4.9C. The operations available when in Multiple or Single Lens modes are as following.

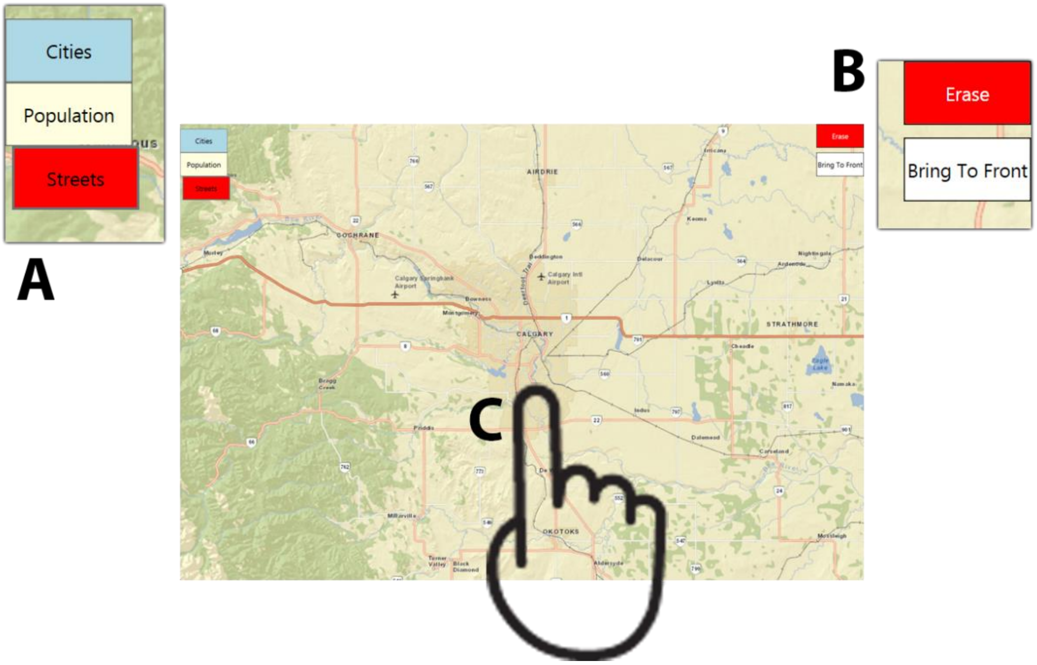

Figure 4.9 Users interact with lenses through (A) the lens selection menu, (B) the operations menu, and (C) touch gestures.

4.2.4.1 Activating and Deactivating Lenses

When in Multiple or Single Lens mode, activating and deactivating a specific lens is done through the lens selection menu seen in Figure 4.9A. The buttons on this menu are switch buttons that, besides activating and deactivating a specific lens, provide the status of that lens across the system. For instance, if a user is manipulating a lens, the corresponding button on all other devices, if running Multiple Lenses mode, will display "Unavailable". Once that user deactivates or erases the lens, it will become available for other users. Also, another cue is seen on the color-lens association, it helps the user to identify the position of each lens on the overview.

4.2.4.2 Erasing Lenses

The Erase button (red button from the lens operations menu, Figure 4.9B), allows users to remove the information associated with a lens from all devices, including the device being used. As consequence, when activating an erased lens, Bancada will consider that it was being activated for the first time. This feature differs from deactivating a lens regarding the persistence of information – the last position of an inactive lens is persistent across all devices, as described in sub-subsection 4.2.3.3.

4.2.4.3 Bring to Front

The Bring to Front button, seen below the Erase button (Figure 4.9B), is responsible to place the current lens on top of all other active lenses on the overview. This operation is useful for situations when two collaborators are exploring different lenses and they need the lens from the bottom to be on top without performing any change on their positions in space.

4.2.4.4 Touch Gestures

The gestures used to manipulate lenses in Bancada are well known by users of modern mobile devices: to zoom in/out, the user performs a pinch gesture, illustrated in Figure 4.10; and dragging the finger on the screen pans the lens, illustrated in Figure 4.11.

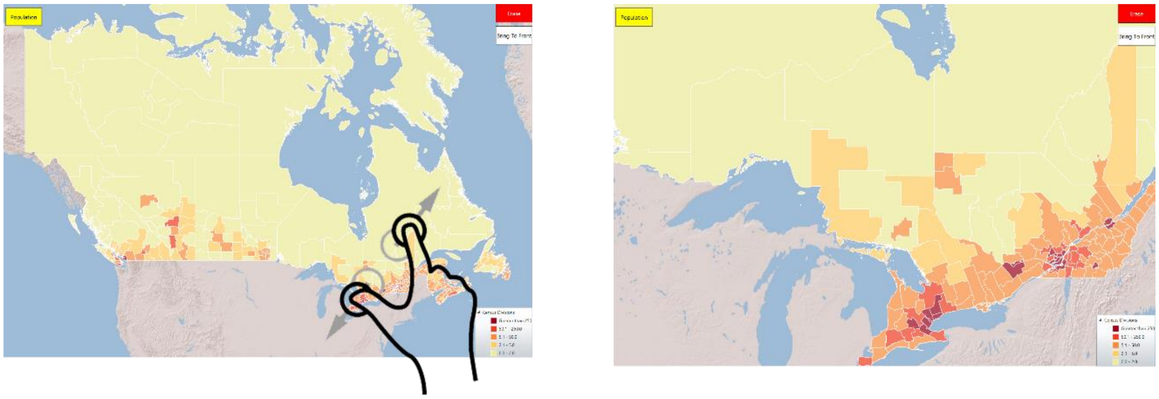

Figure 4.10 User performs a pinch gesture (left) to zoom in a lens. The resultant position of the lens is seen on the right frame.

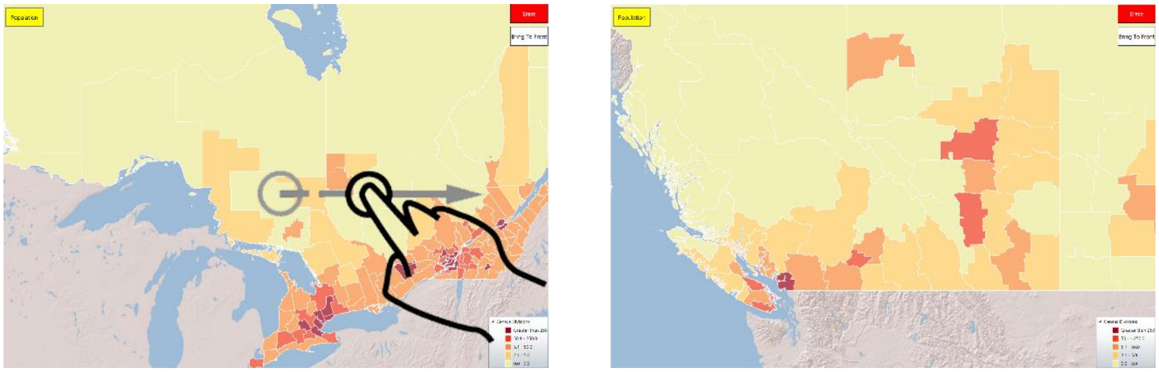

Figure 4.11 Dragging the finger on device's screen (left) pans the map. The resultant position of the lens is seen on the right frame.

4.2.5 Design Choices

Bancada was developed as means to conduct the study described in this Chapter, and although it goes against the recommendations from [11], the only interaction available with the overview is through the buttons on the bottom of the screen, which are the means by which participants explicitly indicate that a task has been started and concluded – explained in detail in the next Chapter. The decision to not allow direct interactions on the overview was made to restrict the interaction with lenses to the tablet, i.e. the tablet is the only medium to manipulate lenses, and the tabletop is an output-only display which main purpose is to afford orientation and awareness.

To encourage/enforce collaboration, lenses are unique and cannot be activated on two tablets at the same time. Also, each configuration has its own characteristics regarding availability of lenses (i.e. SL has one lens per tablet, MLMT has all lenses on all tablets, and MLST has all lenses on a single tablet). In the SL and MLST configurations, lenses are associated with tablets and there can only exist one "instance" of a specific lens at a time for example, there is only one Streets lens across the system. If the MLMT configuration allowed two users to activate the Streets lens at the same time, two situations emerge: (i) there are two Streets lenses in the system and they are independent of each other, resulting in up to six viewfinders and insets on the overview (all lenses doubled), a situation that is not possible with the other two configurations; or, (ii) there is only one lens and the system would be required to resolve conflicting interactions, such as both participants panning the same lens in opposite directions at the same time. We opted for keeping the lenses unique across the system, as seen with SL and MLST. This decision avoids the complexity of implementing conflict resolution techniques and maintains the availability of lenses consistent across all configurations, i.e. only one instance across the system.

4.3 Conclusion

In this Chapter, I described the design of the study conducted to investigate the impact on collaboration between pairs when configurations with different number of tablets providing different detailed views (lenses) are available to explore geospatial information within MDEs. In this study, participants are required to perform twelve tasks using three different configurations of devices. In all configurations, a tabletop displays an overview map. I also presented Bancada, the MDE developed as a mean to conduct the study. In Bancada, tablets are zoomable tangible lenses, which enable users to explore different geographic aspects while having access to an overview map displayed on a large display. This overview map displays the lenses through viewfinders and insets. The results from this study are presented in the next Chapter.

Chapter Five

Study Results

In this Chapter, I will present and discuss the results from the quantitative and qualitative analyses of the data collected while conducting the study. I start describing how the study was conducted in Section 5.1, followed by the methodologies used to perform a quantitative and a qualitative analyses (Section 5.2). Then, the results from the analyses are presented in Sections 5.3 and 5.4, respectively. I discuss the results in Section 5.5 and describe the limitations of the study in Section 5.6. Last, Section 5.7, provides a conclusion for this Chapter.

5.1 Conducting the Study

This Section describes the study participants, the apparatus used during the sessions, the procedure for each session and how the data was collected. For the study design, please refer to Section 4.1.

5.1.1 Participants and Descriptive Data

Using email lists and word of mouth as recruitment methods, a total of 20 unpaid participants were gathered for this study. They are described as follows:

- 11 were male and 9 female.
- 8 participants were between the ages of 20 and 25; 8 participants between 26 and 30; and 1 participant between 31 and 35; 3 did not answer.
- Backgrounds included veterinary medicine (1 participant), user experience design (1), industrial design (1), geomatics engineering (1), political science (1), economics and international relations

(1), computer science (13), and software engineering (1). By the time of the study, 3 participants were professionals from industry, while the others were students.

- When asked how well versed they considered themselves in Canadian geography, 1 participant considered himself advanced; 12 intermediate; and 7 novice.
- All participants indicated that they make use of map related software on a frequent basis. 7 participants consider themselves as having advanced knowledge in such systems; 11 consider themselves intermediate; and two are novice. The electronic map services used by the participants and the number of participants users of these services are seen in Table 5.1.
- Regarding the devices they use to explore electronic maps, 17 participants use desktops/laptops, 15 mobile devices (7 of which were tablets), two use GPS, and two participants did not provide answer.
- Ten participants had experience or interactions with MDEs before the study. This experience was due to working with research projects with MDEs.

System used to explore electronic maps	No. of participants
Google Maps	17
Google Earth	6
Bing Maps	4
ArcGIS	3
Dedicated GPS devices	2
Apple Maps	1
Domain specific GIS applications	2

Table 5.1 Electronic maps services and number of participants.

The twenty participants were divided into ten pairs according to their availability. An online schedule was provided so they could choose a time slot in which they would be available to participate. Figure 5.1 shows a breakdown with the groups (hereinafter, referred using the G# notation), the participants and their knowledge about Canadian geography and their experience with electronic maps.

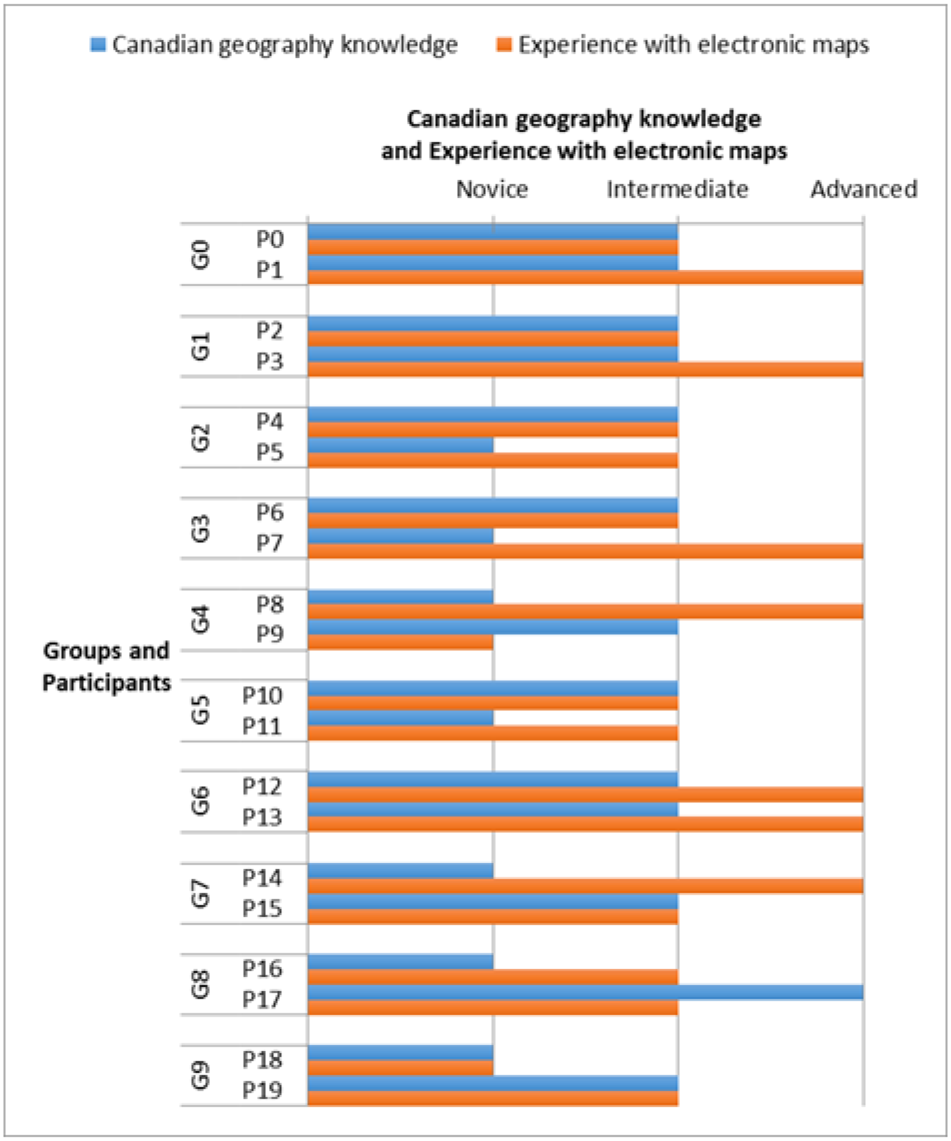

Figure 5.1 Canadian geography knowledge and experience with electronic maps for each participant and the group on which they belong.

Based on my knowledge about the participants, only the groups G2 and G4 were composed of members that did not know each other, i.e. all the other participants knew their partners.

5.1.2 Apparatus

The hardware used during the study is composed of: a Samsung SUR40 Digital Tabletop with PixelSense; three Microsoft Surface Pro tablets with color borders. The borders are used to identify the lens available on each tablet during the SL configuration (i.e. each tablet providing a unique lens). The Streets tablet has a red border, the Population Density is yellow, and Cities is blue. They were made from cardboard and attached to each tablet as seen in Figure 5.2; and a Microsoft LifeCam Studio video camera recorded the interactions performed by users.

Figure 5.2 Tablets used for the study. The color border indicates which lens they provide when running SL.

Regarding the software used during the study sessions, besides Bancada (described in Section 4.2), a specific application was built to automatically compute the total time spent on each task.

5.1.3 Procedure

For all participants, the session started with a brief introduction to describe the purpose of the study and to ask them to fill consent forms and a questionnaire about demographic information and their experience with Canadian geography and electronic maps. Then the participants were introduced to Bancada, the role of the tabletop and the tablet (or tablets, if starting with a multiple tablets configuration) and all interactions available, e.g. how to activate, pan, and zoom in a lens. After presenting the system, the process to perform a task was explained as follows.

First, they would receive a task, and once they felt ready to perform it, they would press the "Start Task" button available on the tabletop. Only after pressing this button, Bancada would allow them to interact with the tablets to perform the tasks. After performing the task, they would indicate their answer on the tabletop and then press the "Complete Task" button on the tabletop. At any point during a task, participants were able to ask questions to clarify what was being required from them.

The buttons on the tabletop were used to give participants the control to explicitly indicate when a task has started and finished. Also, when the buttons were pressed, Bancada would send messages to the logging application to create the files related to each task, and to automatically compute task completion time.

As mentioned in Section 4.1.2, the tasks from Table 4.3 were asked following the same order for all pairs, i.e. different pairs solved tasks with different conditions. After all twelve tasks were completed, they were asked to individually fill in a survey about the study. Then, to conclude the session, I performed a follow-up interview with both participants at the same time, in which they were asked about their general impressions of the study.

5.1.4 Data Collection

The study sessions were videotaped and audiotaped, and field notes were recorded, respecting the ethics approval obtained to conduct the study. The field notes had the purpose to inform initial impressions about how participants behaved during the experiment and they also contained elements of the initial coding used as a basis during further analysis. Besides the initial demographic and background questionnaire, a final questionnaire containing Likert scale, ranking and open questions, was distributed at the end of each session to collect individual subjective preference regarding configurations, opinions about the information separation within the MDE, and what their impressions were while interacting with each configuration. Last, as mentioned in the previous subsection, the logging system created files containing task time completions for all groups.

5.2 Analysis Techniques

This Section describes the methodologies and techniques used for both qualitative and quantitative analyses of the results from the study. Both analyses were performed with the data collected from nine groups (G0 to G8). During the last study session, with G9, multiple technical difficulties occurred, such as network instability (resulting in multiple failed attempts for the same task) and defects with the audio and video camera, resulting in a corrupted data collection. This session was then excluded from the analyses.

5.2.1 Quantitative Analysis

A quantitative analysis was performed to evaluate the influence of using different configurations of devices on performance and collaboration. This analysis was performed with the help of Dr. Tak Fung, a mathematical and statistical consultant from the University of Calgary. He indicated the appropriate statistical methods (described below) to use, considering the format of the study (within-participants), the collected data (questionnaire answers and task completion times), and the number of data points (N=9).

In this study, the performance of a task is defined as its task completion time; the configuration performance of a group is defined by calculating the mean task completion time from the round on which that configuration was used; and the overall performance of a configuration is defined by calculating the mean task completion time from all groups. The data used in this analysis encompass the configuration used to perform each task, task completion times, and the answers provided on the final questionnaire. The results of the quantitative analysis are described in Section 5.3, and they answer four questions, described below.

1. *How did the groups perform in general and using which configuration did the groups perform best, i.e. which configuration required less time to solve the tasks?*

This question aims to provide a summary of the performance for each configuration, and to identify which configuration allowed the participants to perform best. To answer this question, the task completion times were summed up for all configurations and the configuration with minimum value among the three configurations was considered as the best performance, i.e. less time performing tasks indicates a better performance.

2. *Is there any correlation between the configuration in which participants performed best and their subjective preference?*

As part of the final questionnaire, the participants answered which configuration they preferred. This question aims to verify if there is a correlation between configuration performance and their subjective preferences, i.e. if participants preferred the configuration on which they performed best.

This question was answered through the creation of a contingency table to verify the correlation between subjective preferences, extracted from the questionnaire, with the performance per round from the previous question. A Chi-square test with Fischer's Exact Test was then used to evaluate the significance of this relationship.

3. *Is there any correlation between performance and individual preference for collaboration?*

Besides individual preference, the participants also ranked the configurations according to how they perceived the collaboration during each round. They ranked first the configuration on which they perceived the collaboration was best, while the third place was for the worst configuration. As with the previous question, this question aims to verify if there is a correlation between the ranking of configurations and the performance.

To answer this question, the Pearson Correlation Coefficient was calculated using the performance per configuration per group and its respective position on the ranking provided by the participants.

4. *Are there significant differences in performance considering the tasks and the configuration used to solve them?*

Groups were exposed to the configurations according to a Latin-square distribution, as described in subsection 4.1.1. Since different groups performed the same tasks using different configurations, this question investigates if the configuration used during a task has influence on its performance.

This last question was answered by testing the Within-Subjects Effects using the sphericity assumed condition. This condition is used when there are more than two levels of the independent variable (in this thesis, configurations), and it assumes that the variance of the difference scores computed for each configuration are equal across all groups. To test the effects, a comparison was performed between the performance of each task from a round and the configuration used to perform the task.

5.2.2 Qualitative Analysis

Using an approach based on the literature [1], [4], [36], the qualitative analysis was performed according to an iterative process grounded by the field notes, the videos and the answers from the questionnaires. As Tang *et al.* affirms, *"this methodology facilitates an intimate familiarity with the intricate, subtle mechanics occurring in the sessions, providing a very rich understanding of the underlying collaborative processes"* [36, p. 1186].

The field notes provided means for an initial coding regarding collaboration styles observed during the sessions, especially, how collaborators interacted with their partners and with the system. Based on these initial codes, the videos recorded from each session were analyzed and partially (due to time constraints) transcribed, aiming at the identification of actions supporting or countering the codes described on the field notes. The transcriptions were based on the importance of the observations for the study.

Based on the field notes and the partial transcriptions, I noticed that different groups shared resources (i.e. lenses and tablets) in distinct ways and the way they shared resources influenced how they performed the tasks. Also, the communication between collaborators had different purposes when it was performed before performing the task and during the realization of the task. For example, when verbal communication happened before the task, I observed collaborators planning the steps necessary to perform the task and asking their partners about the location of the city from the task. When it happened while they were performing tasks, I observed collaborators giving verbal instructions to their partners followed by pointing gestures.

From these observations and using the field notes and the partial transcriptions, I performed a second coding and analysis iteration focusing on three aspects:

- The impact on **communication** according to the configuration, with the identification of the different purposes of communication, such as giving instructions, dividing a task into steps, and defining which collaborator is responsible for which step. Also, to verify the relationship among communication, configuration and the different stages of a task, e.g. before starting a task, interacting with a lens to find a city or to identify the population density of a city;
- The impact the **coordination of resources** had on the collaboration and its relationship with the number of tablets and lenses available. Using the terminology from Pinelle *et al.* [108], I was interested in identifying how collaborators obtained the resources and if they reserved or transferred the lenses (or tablets);

- The role the **overview** map has for the collaboration, identifying if collaborators used the overview and with what purposes.

Then, I analyzed the answers from the questionnaires and compared what I observed with the participants' answers and impressions. The results of this process are described in Section 5.4.

5.3 Quantitative Analysis: Results

The results of the quantitative analysis, through the answers of the four questions described in subsection 5.2.1, are described below.

1. *How did the groups perform in general and using which configuration did they perform best, i.e. which configuration required less time to solve the tasks?*

Table 5.2 summarizes the overall performance of each configuration. The performance of a group was determined by calculating the average duration (in minutes) of a task during a round. A breakdown of configuration performance per group is seen in Table 5.3. The green cells identify the best performance for a group (the minimum time spent); while the red ones represent the worst performance (the maximum time spent).

	Minimum	Maximum	Mean	Std. Deviation
SL	1.55	5.32	2.54	1.19
MLMT	1.36	2.53	2.01	0.47
MLST	1.31	3.30	2.01	0.62

Table 5.2 Overall performance per configuration in minutes (N=9).

Group	SL	MLMT	MLST	Best
G0	1.93	2.32	1.80	MLST
G1	1.80	2.43	2.03	SL
G2	3.03	2.28	3.30	MLMT
G3	1.96	2.53	1.63	MLST
G4	1.55	2.25	2.43	SL
G5	1.93	1.36	1.33	MLST
G6	2.08	1.41	1.31	MLST
G7	5.32	1.49	1.93	MLMT
G8	3.33	2.06	2.38	MLMT

Table 5.3 Performance (in minutes) per configuration per group. Best and worst performance are highlighted in green and red, respectively.

Considering the overall mean values for each configuration (Table 5.2), there is no difference between MLMT and MLST. However, when observing the performance per group (Table 5.3), it is possible to see that four groups performed best when there was only one tablet available (MLST); three groups, when using two tablets (MLMT); and two groups, when using three tablets (SL).

2. *Is there any correlation between the configuration in which participants performed best and their subjective preference?*

The answer for this question is divided into two parts. First, a contingency table, seen in Table 5.4, was created to compare the individual preference of the 18 participants (extracted from the final questionnaire) with the configurations in which they performed best, identified in the previous question. It is possible to see that 10 (sum of the highlighted cells on the table) out of the 18 participants preferred the configurations in which their group performed best and 8 preferred other modes. Specifically, 2 preferred SL when they performed best with MLMT; 4 preferred MLMT, when they performed best with MLST; and 2 preferred MLST, when they performed best using SL.

		Individual preference			Total
		SL	MLMT	MLST	
Best performance	SL	2	0	2	4
	MLMT	2	4	0	6
	MLST	0	4	4	8
Total		4	8	6	18

Table 5.4. Contingency table: best performance configuration x individual preference.

Based on the contingency table, the correlation between individual preference and best performance configuration was evaluated and the value from the Fischer's Exact Test from the Chi-square test (N=18) was 9.312 with exact significance (2-sided) equals to 0.023. This result shows that there is no significant correlation between individual preference and performance.

3. *Is there any correlation between performance and individual preference for collaboration?*

The Pearson correlation coefficient (N=18) was calculated for each configuration to answer this question. This coefficient tested the correlation between the performance of the configuration and the respective position of that configuration on the ranking provided by the participants. The results can be seen on Table 5.5.

	Pearson Correlation	Sig. (2-tailed)
SL	-0.085	0.737
MLMT	0.327	0.185
MLST	-0.047	0.854

Table 5.5 Pearson correlation coefficients per configuration (N=18)

As with individual preference, there is no statistically significant correlation between the preferred configuration for collaboration and performance.

4. *Are there significant differences in performance considering the tasks and the configuration used to solve them?*

To answer this question, it was necessary to calculate the overall performance per task considering each task from a round and the corresponding configuration, as seen in Table 5.6. Then, the within-subjects effects, considering the sphericity assumed condition, from the three configurations were calculated and the results can be seen in Table 5.7.

Round	SL (N=9)		MLMT (N=9)		MLST (N=9)	
Task #	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1	3.39	5.73	1.66	1.04	1.36	1.08
2	2.82	2.36	1.64	0.72	1.26	0.71
3	1.50	0.57	1.73	0.99	1.44	0.49
4	2.45	1.10	3.01	1.34	4.00	2.40

Table 5.6 Overall performance per task (in minutes)

Task #	df	F	P (Sig.)
1	2, 16	0.813	0.461
2	2, 16	2.710	0.097
3	2, 16	0.428	0.659
4	2, 16	2.591	0.106

Table 5.7 Tests of within-subjects effects (condition: sphericity assumed)

As seen with the previous two answers, the tests of within-subjects effects show no significant statistical difference between the modes. These results are discussed in Section 5.5.

5.4 Qualitative Analysis: Results

This Section presents the results from the qualitative analysis performed through the analysis of the field notes, videos, and questionnaires. The results are described as following: first, I describe the multiple behaviour approaches I observed according to the categories of the mechanics of collaboration, specifically, explicit communication (subsection 5.4.1) and coordination of shared resources (5.4.2). Then, I provide my observations and a summary of the answers from the questionnaire about how participants used the overview map (5.4.3). Last, I describe their impressions and subjective preferences relative to the configurations used for collaboration (5.4.4).

Since I observed participants switching collaboration approaches multiple times during each task, the approaches described in this Section are generalizations from the multiple behaviours I observed.

5.4.1 Explicit Communication

When analyzing the data, I noticed that the explicit communication between collaborators varied according to the moment in which it was happening, the task, and the configuration used to perform the task. For example, during the round with MLST, the members of G6 switched control over the tablet alternately before each task without verbal communication. However, when multiple tablets were available, P12 verbally communicated which lens he wanted to use before he started performing the task.

I describe next the different approaches for explicit communication the participants demonstrated when they were starting and performing tasks.

5.4.1.1 Starting a Task

Before starting to work on a task, participants planned how they would solve the task, negotiated roles and resources, and asked geographic orientations to their partners. Also, they started to perform the tasks narrating their actions (in a think aloud fashion) or without any verbal communication. Each of these actions, with references to the groups and the configurations, is described below.

Planning

I observed different groups during different rounds planning how they would solve the task by describing steps and their sequence. For example, P16 asks P17 *"Do you know how to start?"* then P17 replies, *"Well, first thing I'm going to do is go to Manitoba* [using Cities], *find where Brandon is, I don't know where Brandon is but…* [inaudible]. *And then with Population Density, I'll just zoom in"*. The most common variation, would be to communicate just the initial steps, as seen when P12 suggests *"Let's look at Population Density then we just move west from Edmonton"*, and when P0 suggests *"I would put the first layer as the city, do you agree?"*, P1 confirms, *"Yeah, sure"* and P0 continues *"And then we can find British Columbia"*.

Negotiation

Collaborators verbally negotiated who would be responsible for starting the task or, for simple tasks, for performing it as a whole. For example, P8 asks P9 *"do you start first?"* and P9 replies *"sure"*, then, P9 performed the whole task. P16 offers the tablet to P17 asking, *"Do you 'wanna' do it?"*, P17 receives the tablet saying, *"Ok"*. This type of negotiation was observed with three groups (G4, G7 and G8) and only during the first three tasks of the first round, when they were interacting with MLMT or MLST.

When multiple tablets were available, especially during rounds with MLMT, I observed multiple times collaborators coordinating the resources needed for the task by:

- Informing their partner about the lens they will use, as seen when P15 says, *"Ok. So I'll pick Streets so we can find [Brandon]"* and when P4 says *"I'll take the streets because it has the names on it"*;
- Indicating which lens they would be responsible for, as seen when P13 said *"you go ahead, sir,* [with Cities] *I'll go with Streets"*;
- Indicating the required lenses for the task and letting the partner choose one, as seen with G3, *"one of us needs Cities and one of us needs Streets"* (P4);
- Negotiating the resources based on the roles they would perform, for example, P0 asks P1 *"Do you 'wanna' find the city and I find the population density?"*, and with G4, P8 suggests *"you find the city first and then I look for the population density"*.

Geography

Geography also had a place in the communication. Collaborators asked their partners about locations needed to perform the task. Examples are seen when P11 asks P10 *"where is it* [Newfoundland and Labrador]*?"*, and when P4 asks P5 *"do you know where Winnipeg is?"*. The answers were generic as when P10 answered P11 saying *"it's in the east"* or specific as when P5 pointed to the location on the overview map saying *"it's there"*.

Think aloud

Last, a behaviour not observed during rounds with the SL configuration occurred when collaborators started tasks describing what they were doing in a think aloud fashion. Examples of this behaviour are seen when P10 starts interacting with the tablet while saying *"Ok, so, first, Streets…"*, P11 starts saying *"This is easy. I know where it is. So, Streets."*, and P0 says, *"Ok. So, let's start with [Cities]"*.

No verbal communication

When there was no verbal communication before starting the task, one of the collaborators would take the lead by pressing the "Start Task" button and start performing the task. The partner then would only observe, or interact with his own tablet, following the first collaborator. The verbal communication would start when they were performing the task, described in the following sub-subsection. This lack of verbal communication was mostly seen during the second and the third rounds, independent of the configuration the groups were using.

5.4.1.2 Performing Tasks

While performing tasks, collaborators alternated between multiple collaboration approaches, varying according to the discussions from before starting to perform the task, the task itself and the configuration used. As described in sub-subsection 4.2.3.3, lenses are unique and the same lens cannot be activated on two tablets at the same time, and each configuration has its own characteristics regarding availability of lenses (i.e. SL has one lens per tablet, MLMT has all lenses on all tablets, and MLST has all lenses on a single tablet). These constraints required the collaborators to coordinate the access of resources, i.e. lenses and tablets, in order to perform the tasks.

After starting to perform the tasks, the explicit communication had two main purposes: to provided verbal instructions while pointing to regions on the overview map, and to discuss the answer using the detailed views provided by the tablets in conjunction with the overview map displayed on the tabletop.

Providing and Following Instructions: Driver-Navigator

I observed all groups working in a similar fashion as seen with the pair programming [120] concept of collaboration from agile software development methodologies. When providing instructions, a collaborator assumes the role of **navigator** (responsible for reviewing and helping the partner), while the partner becomes the **driver** of the lens (or tablet), responsible for all interactions with the resource. Navigators assumed the role mostly due to a lack of access to the lens their partners were interacting with in a given moment. Their instructions are usually followed by gestures referring to regions of the overview map, and they guide the driver to place the lens in a way that the solution can be discussed or identified. After receiving instructions, I noticed drivers manipulating their lenses staring at the overview map, instead of their tablets, to confirm that their interactions are following the instructions and the lens is being placed on the location pointed to by the navigator. Figure 5.3**Error! Reference source not ound.** illustrates the driver-navigator approach with the driver interacting with his tablet but staring at the location the navigator is pointing on the tabletop.

Figure 5.3 Driver (left) following instructions from the navigator (right).

The driver-navigator approach was observed with all configurations and all groups. Typically, the driver and navigator roles were implicitly defined and switched between collaborators as the situation required, as seen in the following dialogue from G6.

> *P12 "Ok there's a city right here *pointing a region on the overview map*. We have to figure out what it is* [the name]*."*
>
> *P13 "Ok. Zoom out a little bit." *looking at the overview**
>
> *P13 "Ok, so, that's Winnipeg." *pointing a region on the overview**
>
> *P12 "Northwest. So, it's that." *pointing another region on the overview**
>
> *P13 "Yeah. That should be* [the answer]*."*
>
> *P12 and P13 switch focus from table to P13's tablet with Streets**
>
> *P12 starts switching focus multiple times between P13's tablet and the overview*
>
> *P12 "Zoom in."*
>
> *P13 switches focus multiple times between his tablet and the overview*
>
> *P13 "Can you bring yours to front?" *staring at the overview**
>
> *P12 "It's right here." *points a region on the overview**
>
> *P13 "I think it's <inaudible>, but..." *staring at his tablet* "Let me just...* [activate] *Cities" *starts navigating with Cities**
>
> *P13 "Where's Winnipeg?" *staring at his tablet**
>
> *P12 "Just follow this" *points the position of his lens on the overview**

In the above example, P12 and P13 fluidly switch roles multiple times during the same task while interacting with MLMT. However, during rounds with MLST, I observed counter-examples: P1 was the driver during the whole round without explicit negotiation; and the members from G8 negotiated the roles before the third task of the first round – P16, after driving during the first two tasks, offered the tablet to P17 saying *"Do you wanna do it?"* then P17 received the tablet saying *"Ok. Yeah. Switching roles"*.

Overall, collaborators used the driver-navigator approach while performing the tasks. However, with some groups I observed this approach being alternated with, or replaced by, other approaches based on resources sharing, described in subsection 5.4.2.

Discussing the answer

The second purpose of the communication while performing tasks is to discuss the answer using the detailed views provided by the tablets in conjunction with the overview map displayed on the tabletop. As seen with the above transcription from G6, both participants switched focus multiple times between their tablets and the tabletop. They were performing the fourth task from the second round and it has three parts. The first is to find Winnipeg, the second, to find the closest city on the northwest of Winnipeg with population density greater than 400. Last, they have to identify the major roads connecting both cities. To illustrate the discussions about the answer and the role of the tabletop while performing the task, I highlight the following snippet, from when P12 and P13 are looking for the city with population density greater than 400:

> *P12 "Ok there's a city right here *pointing a region on the overview map*. We have to figure out what it is [the name]."*
>
> *P13 "Ok. Zoom out a little bit." *looking at the overview**
>
> *P13 "Ok, so, that's Winnipeg." *pointing a region on the overview**
>
> *P12 "Northwest. So, it's that." *pointing another region on the overview**
>
> *P13 "Yeah. That should be [the answer]."*
>
> *P12 and P13 switch focus from table to P13's tablet with Streets**

From this transcription it is possible to observe that when P12 finds a potential city on the overview, he informs P13 saying "*there's a city right here*" while pointing to the region on the overview map. P13 then asks P12 to change the zoom on his lens to identify where Winnipeg is. The location of Winnipeg is identified by P13 verbally, *"that's Winnipeg"*, and gesturally, with P13 pointing to the location on which the *"that"* makes reference. P12 then confirms that the city he pointed to previously is located northwest from Winnipeg by pointing to its location and saying *"Northwest. So, it's that"*. After analyzing the content on the overview map of the location where P12 is pointing, P13 agrees with P12 saying *"Yeah. That should be [the answer]"*. After this agreement, they change the focus from the table to the tablet to solve the third part of the task.

As illustrated above, the tabletop was the device which all collaborators used to discuss or identify the answer. When a tablet was not shared between collaborators, one participant would lean towards the table to have a better view of the inset while the other used the detailed view on the tablet. When leaning over the tabletop was not enough to analyze the map, the participants stood up, sometimes seeing the map from the side, or the opposite side of the table, with the map upside down, as seen in Figure 5.4.

Figure 5.4 Collaborators analyzing the map from the regular position (left), besides the table (center), and from the opposite side (right).

The availability of multiple tablets influenced the use of the overview map and also the verbal communication, especially, when both collaborators were looking for a city whose location both people did not know. In such situations, each collaborator would activate a lens with labels, i.e. Streets and Cities, and independently search for the city – using the overview only as awareness medium to know which area the partner is exploring. During these activities, the verbal communication would stop completely, until one of them found the city or suggested different search areas.

5.4.2 Controlling and Sharing Resources

Across the nine study sessions, I could observe distinct ways in which collaborators coordinated the access to lenses and tablets. Since the first session I had the impression that the tablets were "owned" by fixed collaborators, for example, P1 assumed the role of driver without verbal negotiation and maintained control of the tablet during the four tasks with MLST. Therefore, he owned all lenses during this round. And only during brief times, when P0 was switching attention from the overview to the tablet, P1 would tilt the tablet towards P0, without handling it, so she could see the detailed view or perform minor interactions. Based on this impression, I observed how participants obtained and maintained control over lenses/tablets, whether they shared resources with the partner and how they shared. Also, I looked into relationships between these factors such as the way participants collaborated and the configurations used.

5.4.2.1 Controlling and Sharing a Single Tablet

When the participants were performing tasks with the MLST configuration, the most common approach observed was driver-navigator – with one participant with full control over the tablet and the other providing instructions, as described in the previous sub-subsection. The definition of who was controlling the tablet was done:

- **Without verbal negotiation**, with collaborators assuming fixed roles at the beginning of the round and maintaining them during the four tasks, e.g. G0; or with both participants switching roles before each task, e.g. G6: P12 drove during the first task, P13 assumed the role of driver during the following task, then P12 returned to drive during the third. During the fourth task, they changed their approach and shared the tablet as described below;
- **With verbal negotiation** before the third task of the round, e.g. G8, described previously.

Another collaboration approach with this configuration is characterised by both collaborators fully sharing the tablet, observed with G4 and G6. The participants placed the tablet on the table between them, or they held the tablet together, shown in Figure 5.5. Then, they performed tasks by alternating interactions with the tablet. I observed minimum verbal communication while the participants were sharing the tablet, and when it happened it focused on the answer.

Figure 5.5 Participants shared tablets by placing it on a shared space (left) or holding the tablet together (right)

Besides the two aforementioned collaboration approaches, I observed two participants (P4 and P10) taking full control of the tablet without explicit negotiation, and allowing minimum participation of their partners. This behaviour was characterised by dominance from one participant over resources and the process of performing the tasks. However, these "dominant" participants changed the way they performed the tasks when multiple tablets were available.

The first case was seen with G2: during the first round, P4 was in control of the tablet, holding it on his side. He would press the Start Task button as soon as the task was described and start performing the task, giving P5 minimum opportunities to participate. P5 tried between tasks to move the tablet towards the center; however, she left the device where it was before. P5 could only follow P4's actions observing the overview, or entering into his personal space to interact or see the detailed view on the tablet, as seen in Figure 5.6. Then, during the following rounds (with multiple tablets), P5 was seen participating actively on the process, usually as driver, following P4's instructions.

Figure 5.6 P15 observing the detailed view displayed on the tablet.

In the previous example (G2), during MLST, P4 kept the tablet by his side. With G5 the body language was different, it was possible to observe P10 and P11 holding the tablet together, as seen in Figure 5.7. However, P10 had control over the task resolution process and performed most of the interactions with the tablet. P11 could only interact with the lenses during the brief moments when P10 was looking at the overview map.

Figure 5.7 Participants from G5 sharing a tablet

5.4.2.2 Controlling and Sharing Multiple Tablets

When multiple tablets were available, participation from both participants in the collaboration improved. To exemplify this improvement, while P4 dominated the tasks during MLST, when multiple tablets were available, he depended on P5 to perform parts of the task, since she was in control of at least one lens.

Instead of immediately starting the task, they coordinated resources and actions, as seen during the beginning of the second task of the round with MLMT:

> *P4 "We need one of us with Population Density and one of us with Cities."*
>
> *P5 "I'll go with population."*

And also when P5 held Cities during the last task with SL:

> *P4 "Ok. So, now we need all of these tablets. Do you know where Winnipeg is?"*
>
> *P5 "No."*
>
> *P4 "It's that one" *pointing to a region on the overview* "So go close to that point."*

With multiple tablets, P11 was able to take the lead and participate actively, as seen during the second task with MLMT:

> *P11 "This is easy. I know where it is. So, Streets." *starts interacting with his tablet**

Also, during the last task with SL, P10 found Winnipeg using Streets and then said *"now we need to find the closest [city] with population greater than 400"*, P11 immediately started interacting with the Population Density tablet looking for the city that satisfied the conditions.

These results were observed in both configurations with multiple tablets. The specific findings of each configuration are described below.

SL Configuration

When performing tasks with three tablets, a common organization emerged: each collaborator holds a tablet, and the third tablet is left on the table between them, as seen in Figure 5.8. With this organization, I could observe participants maintaining ownership of a lens during all four tasks, e.g. P12 and P15 owned the Cities lens, while P13 and P14 owned Streets. Regarding the third tablet, due to its location, it was considered a shared asset on which both collaborators had equal opportunity to interact.

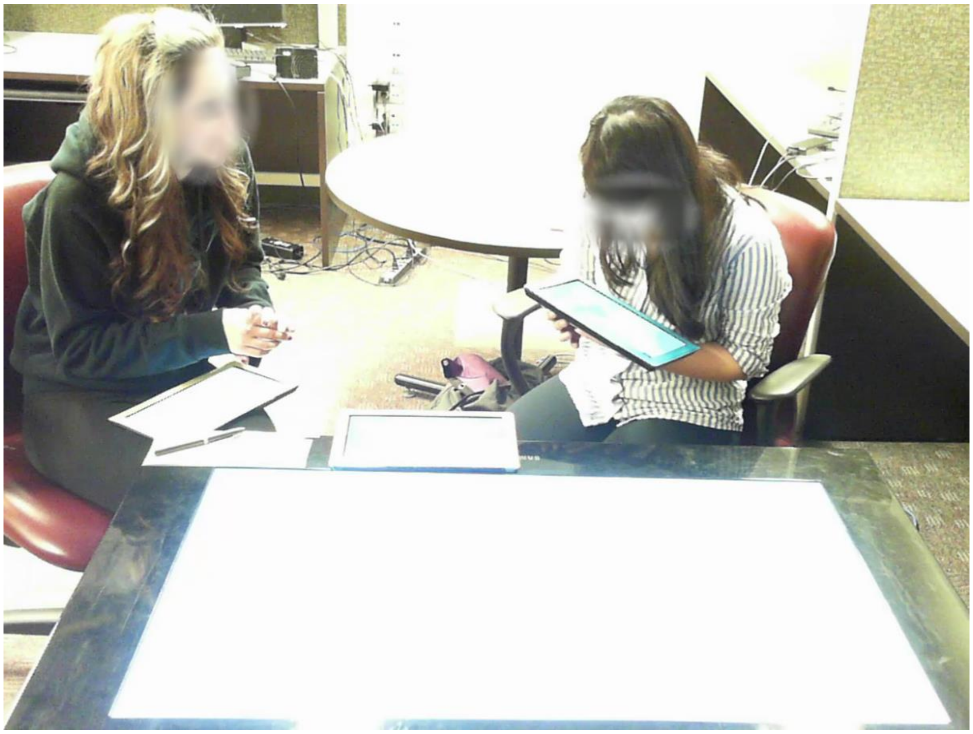

Figure 5.8 Common organization for SL

I observed alternatives to the common organization. For instance, the collaborators from G5 left all three tablets on the table and they would move with their chairs to interact with a specific tablet, as seen in Figure 5.9. In the case of G6, P13 was holding Population Density and Streets before the first task. When the task was described, he placed Population Density on his lap so he could interact with Streets. After concluding the first task, he placed Streets on his lap and kept possession of both tablets until the realization of the third task. During this task, since P13 was interacting with Population Density, P12 grabbed the Streets tablet from P13's lap and placed it on the table, between them. After this action, when P12 wanted to use the third tablet, he would switch tablets, leaving the one he was interacting before on the table.

Figure 5.9 Collaborators from G5 moving their chairs to interact with the tablets placed on the table.

The ownership of each lens was defined the moment after the configuration was explained and the tablets were placed on the table in front of the participants. Each collaborator would then grab one tablet and maintain ownership for all tasks. Without considering the shared tablet, it was possible to observe tablets changing ownership between tasks, but not during a task. Due to this ownership, multiple times I observed owners driving the lenses they owned while their partners were giving instructions. As a counter-example, during the second task of the round, P8 was holding Cities, P9, Population Density, and Streets was on the table. Instead of asking for an indication of the location of Whitehorse, P8 tilted her tablet towards P9, so P9 could move the lens to the respective position. When Streets was required, they kept their collaboration approach from the previous round (MLST), alternating interactions with the tablet while observing the overview, as described in the previous sub-subsection.

MLMT Configuration

Typically, when groups did not plan or negotiate resources or roles before performing the task, one collaborator would take the lead and start performing the task. If the task required more than one lens, and if the partner did not know where the city or region needed for the task is, he/she waited for the first collaborator to indicate the city's position with his/her lens. Then, he/she would start to interact with the second lens (Population Density) following the lens position on the overview map. However, some partners started following the leader with the other lens containing the labels, as soon as the task was started, independent of knowing the location of the city. Only after both found the city, one of the collaborators would activate the third lens and place it on the respective location.

When one collaborator had control over a specific lens, I again observed the driver-navigator approach. However, lens ownership was less predominant than with SL. Collaborators would switch lenses between tasks, as well as during the same tasks. They activated and deactivated lenses multiple times regardless of whether or not their partner was using that lens a moment before. They obtained the lens without informing their partner by pressing the corresponding button after verifying the desired lens was available; informing the partner, as seen when P13 says *"You go ahead, sir,* [with cities]. *I'll go with Streets"*. They also explicitly transferred lenses, as seen when P11 looks for confirmation of the answer for the first task, he says to P10 *"you can check my lens"* while deactivating the lens on his tablet. P10 then activates on her tablet and confirms *"Oh, good! Cool."*

5.4.3 Use of the Overview

As part of the investigation of how information can be displayed within multi-display environments, I looked into how participants used the overview map, and its role for the collaboration and for the tasks. I observed collaborators using the overview map displayed on the tabletop for different purposes:

- For reorientation: when a collaborator was focused on the tablet, eventually he/she would lose reference regarding the location of lenses, to reorient, he/she would glance at the overview map and return the focus to the tablet;

- To guide partners: as described in sub-subsection 5.4.1.2, navigators would observe the overview and provide instructions with pointing gestures, indicating regions of the overview map, or as a guidance, e.g. P4 said *"Follow me"*, referring to his lens on the overview, so that P5 could place her lens in the same position.

- For lens matching: since the lenses were independent of each other, when one collaborator wanted to place a lens based on the location of a pre-existing lens (e.g. place Population Density in the same position as Cities), he/she used the overview map as a guide. Across all groups, I observed participants staring at the table while interacting with the tablet.

- Monitoring a partner's activity: while providing instructions, navigators would typically focus their attention on the tabletop, observing whether their instructions were being followed correctly or they were required to provide new instructions. In situations in which one collaborator was waiting for the other to complete a step (e.g. finding a city) without navigating, the overview was used to identify if the step was completed or not. Lastly, when both collaborators were searching for a city of which they did not know its location and they had access to multiple tablets, they would use the position of the lenses on the overview to know which areas their partners were exploring.

- To discuss the answer: since all the tasks but the first from each round, required multiple overlapping lenses and the only device showing overlapping of lenses is the tabletop, the collaborators would discuss the answer while observing, pointing and comparing regions on the overview. Also, for the majority of the tasks, they would provide the answer based on the information displayed on the overview map, specifically, on the insets.

Ignoring the Overview

In the case of the last tasks of each round, I observed four groups where collaborators ignored the overview to provide the answers. The answer was provided based on the Streets lens displayed on the tablet. In such cases, the partner accepted what the driver was saying without visual confirmation; or confirmed the answer by following what was being displayed on the overview or observing the interactions from the driver on the tablet.

5.4.3.1 Answers from the Questionnaires

During the final portion of the session, a survey was handled asking questions related to subjective preference of the participants. The five first questions asked about subjective aspects from the system through a Likert scale with 5 options, ranging from Disagree (1) to Agree (5). Table 5.8 provides the mode (value with higher frequency) and the frequency of answers for each question.

Question	Mode	Answer	Frequency
Having an overview map helps to accomplish the tasks.	4	1	0
		2	2
		3	1
		4	8
		5	7
I can easily complete all the tasks without an overview map.	2	1	5
		2	6
		3	5
		4	1
		5	1
Having color borders is useful to identify the lenses in the overview map.	5	1	0
		2	1
		3	2
		4	3
		5	12
Adding, removing or moving a lens is easy.	5	1	0
		2	2
		3	2
		4	2
		5	12
It's easy to know the position of a lens from the overview map (e.g. A is on top of B).	4	1	0
		2	2
		3	5
		4	6
		5	5

Table 5.8 Mode and frequency of the answers from the Likert scale questions

5.4.4 Participants' Preferences and Impressions about Collaboration

When asked about which configuration they preferred, 8 participants answered MLMT, 6 preferred MLST and 4 preferred SL. When ranking the configurations according to the collaboration, 12 selected MLMT as the best configuration, followed by SL, selected by 11, and 10 selected MLST as the worst configuration for the collaboration. The breakdown of these preferences is seen in Table 5.9.

Participant	Preference	Collaboration ranking		
		#1	#2	#3
P0	MLST	MLST	SL	MLMT
P1	MLMT	MLMT	MLST	SL
P2	SL	MLST	MLMT	SL
P3	MLST	MLMT	SL	MLST
P4	MLMT	MLMT	MLST	SL
P5	SL	MLMT	SL	MLST
P6	MLMT	MLMT	SL	MLST
P7	MLST	MLST	SL	MLMT
P8	MLST	MLST	SL	MLMT
P9	SL	MLMT	SL	MLST
P10	MLST	MLMT	SL	MLST
P11	MLMT	MLMT	MLST	SL
P12	MLMT	MLMT	SL	MLST
P13	MLST	SL	MLMT	MLST
P14	MLMT	MLMT	SL	MLST
P15	MLMT	MLMT	SL	MLST
P16	SL	SL	MLMT	MLST
P17	MLMT	MLMT	MLST	SL

Table 5.9 Subjective preference and configuration ranking based on collaboration

Figure 5.10 summarizes the number of participants that indicated each configuration on each ranking place.

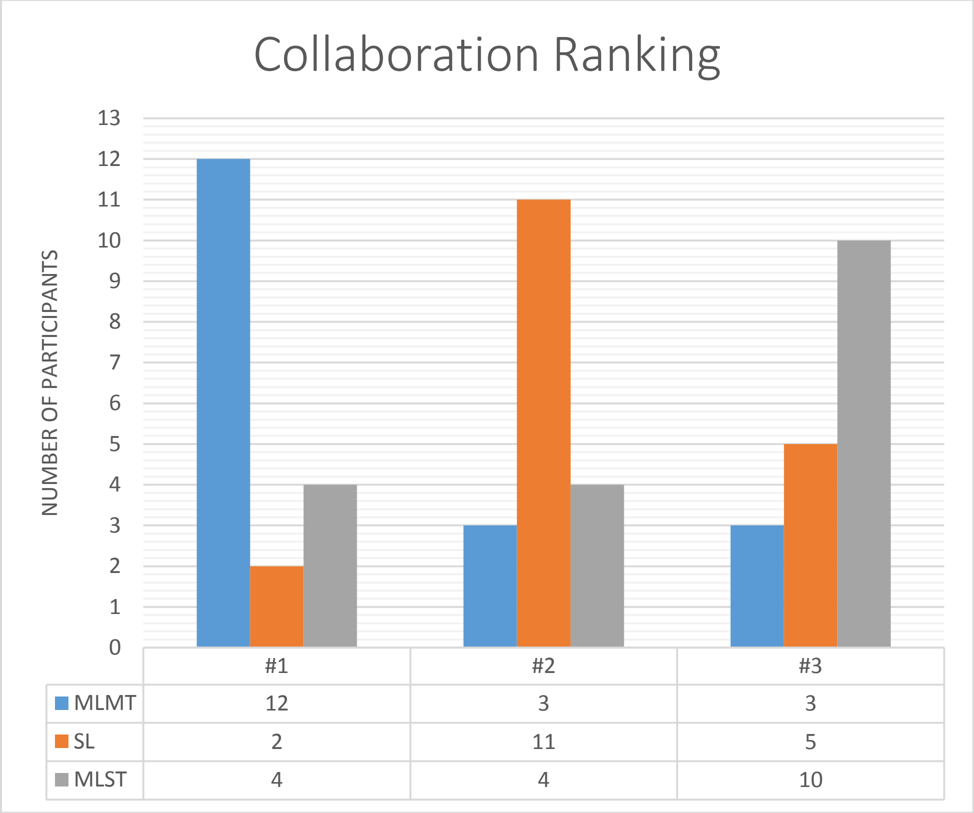

Figure 5.10 Number of participants per ranking per configuration.

Two open questions were asked of the participants to describe their impressions regarding their overall collaboration to perform the tasks, and their collaboration while there was only one tablet available for the group. The first asked, "What are your thoughts on the collaboration to solve the tasks?", and the second, "One of the modes only allowed interaction with one tablet. What is you impression and how does it relate with other modes?"

The answers for the first question demonstrated a preference for configurations with multiple tablets, consistent with the values observed in their ranking, and they highlighted positive impacts from the collaboration. P17 answered that the collaboration *"helped a lot for dividing parallel tasks like finding* *cities. I did not know where the places were and it also helped that my partner could focus on the other task while I would find a place"*. Similar opinions were provided by P0, *"it is helpful especially when somebody knows better geography than the other or is more familiar with computers/tabletops than the other"*, and by P8, *"it is good to combine people's knowledge to explore unknown locations or unfamiliar locations"*. Providing an opposite opinion, P4 affirmed that the collaboration was *"mostly unnecessary"*. P3 and P15 speculated that the study setup forced the collaboration, and it was *"necessary"* due the *"artificial setting"* (P15).

Comparing configurations, P10 affirmed, *"Collaboration was essential for configuration 2* [SL] *and 3* [MLMT]*, but not necessary for configuration 1* [MLST]". And relating the elements from the system with the collaboration, P1 pointed out that *"having the overview helps a lot to this* [the collaboration]. *However, having three layers on the overview can get a bit confusing"*; P2 described that the collaboration made the tasks being solved faster compared if she was alone but, *"it took time to match the view of my tablet to the view of my partner's"*. This aspect was also pointed out by P14, *"I would've liked it more if I could also be in the same lens as my collaborator, this way I could also help in finding stuff"*.

When asked about the collaboration when only one tablet was available, the majority of the answers expressed opinions against this configuration. P1 described the experience *"it could get quite frustrating to keep changing lenses. Also the collaborative aspect of the task was drastically reduced"*; P9 confirmed, *"It wasn't as easy to use as the multiple lenses* [tablets] *modes, because you constantly had to keep switching* [lenses]"; P12 described the configuration as *"the most cumbersome one. I think one tablet for each person is ideal, as we can work on different layers at the same time"*. P16 also pointed out the same limitation, *"we couldn't break tasks and do it simultaneously. Which decreased our speed. Also, if there were any conflict in opinions it was harder to address"*, P17 shared the same point of view, *"it was not as useful because one user would have all the control* *and the other would only be able to guide with the overview, but this takes more work and coordination to work. Multiple tablets with multiple lenses would let us both equally share tasks"*. P3 argued the size of the tablet as major problem of this mode, *"I think this mode was the least efficient because two (or more) people are trying to share one small display"*.

In the opposite direction, P0 had an opinion in favour of this configuration, *"I think it basically sums the other modes into a simpler* [mode] *and allow one of the people to collaborate more interacting with the overview map. It is also less complicated"*. This "less complicated" point of view was also shared by P13 when he described this mode as *"more user friendly"*. P4, P10 and P14 shared the same point of view by affirming that this configuration *"works great if there is only one user"* (P4) since this user can *"take over the task"* (P10), for more than one user, one *"would had to take the lead"* (P14) and perform the task, while the others *"analyze the overview map"* (P4).

Lastly, during the follow up interview, participants mentioned two frustrations they experienced when interacting with multiple tablets:

1. The first is related to manually matching the position of two lenses, i.e. placing two lenses on the same position. For example, when the task asked to identify the population density of a specific city, one collaborator was responsible to localize the city using Cities, and the partner was responsible to place Population Density on the same position the collaborator had left Cities. Since they had to manually match lenses at least three times per round (during the tasks that required a minimum of two lenses), they suggested a button that would *"match with my partner's lens"* automatically.

2. About the uniqueness of a lens, two participants were frustrated that they could not interact on their tablets with the lenses that their partners were using.

5.5 Discussion

Despite the quantitative analysis not identifying significant correlations among performance, configuration and subjective preference, the results from the qualitative analysis fulfilled the goals of this study. It was possible to observe the impact that configurations have on the collaboration between pairs while performing geospatial tasks within MDEs. The number of tablets available and the lenses they provided during each round, played important roles in how collaborators communicated, shared resources, and used the overview map.

As described in the introduction of Section 5.4, the approaches described in this thesis are generalizations from the multiple behaviours I observed. These generalizations represent the lower level of abstraction I could categorize the behaviour of the collaborators while performing the tasks. Although it is still a coarse grained categorization, it is important to highlight that it was not possible to reach saturation with the nine groups observed, i.e. considering a finer grained analysis, every group demonstrated different ("new") behaviour while performing the tasks.

5.5.1 Driver-Navigator Approach

To the best of my knowledge, five participants (specifically, the participants from domains not related to computer science) did not have knowledge about the driver-navigator approach from agile methodologies. The other participants were exposed to the concept during software engineering courses or while working as research assistants. The fact that all groups demonstrated this approach shows that, although the terms *driver* and *navigator* were borrowed from the agile methodologies from software engineering, the separation of the work and roles can be seen as aspects common to collaborative activities independent of domain of the collaborators.

5.5.2 Multiple Lenses on a Single Tablet

Analyzing from the perspective of the coordination of resources, when a single tablet is available for the group, one has to physically obtain control of the tablet to obtain a specific lens and reserve it for the future; to protect the work (e.g. to maintain the position of a lens), it is necessary to maintain control over the tablet; and to transfer a lens, the tablet has to be handled to the other or left on the table. If the participants are not willing to share the control over it, then only one collaborator is actively interacting with the tablet, and the partner provides instructions while observing the overview map – few exceptions were observed, as described earlier in sub-subsection 5.4.1.2. I did not observe one situation in which this coordination was performed during a task, i.e. the participants always negotiated roles before performing the task. I perceived an increase in the frequency of verbal communication due to more instructions being shared, besides the discussions about the answer; as well as an increase of the gestural communication, with participants pointing locations on the overview map while sharing instructions.

As seen in subsection 5.4.4, only four participants ranked having a single tablet as the best configuration for collaboration: P0, P2, P7 and P8. From the qualitative behaviour, I speculate different reasons for this preference. For instance, P0 was the navigator during the whole round and she pointed out that this mode *"sums the other modes into a simpler* [mode] *and allow one of the people to collaborate more interacting with the overview map"*. She also highlighted that the collaboration *"is helpful especially when somebody knows better geography than the other or is more familiar with computers/tabletops than the other"*; P8 despite not having a defined role, shared the same point of view of P0 describing the advantages of the collaboration during the study, *"it is good to combine people's knowledge to explore unknown locations or unfamiliar locations"*; and P2 and P7 were drivers. P7, specifically, highlighted that interacting with this mode *"was easier than two tablets* [MLMT] *and more collaborative than one tablet each* [SL]" and relating the collaboration, she affirmed, *"one person ends up deciding for the other"*. However, their partners did not share these opinions. For example, while P0 had the impression it was a *"simpler"* mode, P1 and P9 experienced frustration in changing lenses multiple times while driving, and P3 pointed to an inefficiency to interact with the tablet due its screen size.

Three participants indicated MLST as their preferred configuration but they said that a configuration with multiple tablets is best for collaboration: P3, P10, and P13. As described in sub-subsection 5.4.2.1, P10 had the control of the tablet and she confirmed the observations on her answers, "[this configuration] *required the least amount of collaboration because one could take over the task*". P13 attributed his preference to a better user experience, contradicting the opinions from P1 and P9. And P3 overcame the inefficiency of this configuration by *"having a person annotating on the tablet and another directing by watching the tabletop"*.

Based on the results from the qualitative analysis and the feedback provided by the participants, I concluded that a configuration with one tablet can be appropriate when there is a gap between collaborators regarding the geographic knowledge or technological experience. The collaborator that knows more can take over control of the interactions while the other uses the overview map to help the one in control. However, there is a chance of the one controlling the tablet to experience frustration while interacting with all lenses or to ignore the partner.

5.5.3 Configurations with Multiple Tablets

The configurations with multiple tablets allow collaborators to share responsibilities and give them equal opportunities to actively participate on the realization of tasks. Due to the distribution of lenses over multiple tablets, roles are defined based on tasks instead of resources. For instance, instead of negotiating who would be in control of the tablet, participants were able to break the task into steps and then negotiate who would be responsible for each step, e.g. while one finds the city, the other identifies its population density. As a consequence of this distributed control, I observed improvements on the collaboration: both collaborators participated actively controlling different lenses during the rounds and also during tasks, they switched between driver and navigator multiple times during a task, and discussed the answer more. However, it is important to highlight that some participants considered the collaboration forced, and as P15 speculated, this might be due to an artificial setting resulting from the study design.

Analyzing the ranking of configurations for collaboration, 12 participants designated as the best configuration for collaboration when each collaborator has access to one tablet containing all lenses (MLMT), and 11 participants indicated the second best was when there are three tablets containing one lens each (SL). Based on the results from the qualitative analysis, it is possible to speculate about reasons for this preference.

When interacting with MLMT, participants shared lenses more – compared to a stronger sense of lens ownership they demonstrated during SL and MLST, as detailed in sub-subsection 5.4.2.2. I speculate this is due to the distinct characteristics MLMT has regarding the coordination of resources. While for SL and MLST, having access to the physical device guarantees access to a lens, when participants have access to their own tablet containing all lenses, the participants have access to all lenses on the same device. For instance, to obtain a lens and protect the work, one has to activate it on his/her own tablet and keep it active. However, by doing this, it is not possible to interact with a different lens without releasing the current lens and making it available for the partner. Also, to reserve a lens for future tasks is impossible since Bancada returns to its initial state when a task is completed, i.e. the system erases all information from the previous task.

To conclude, when collaborators have their own tablets with access to all lenses, they are able to share responsibilities and actively participate in the process of exploring geospatial information within MDEs. Besides preventing a person from taking full control over resources, with this configuration, I could observe collaborators sharing lenses more than with the other two configurations. However, since the system did not support automation for common operations, such as matching two lenses, they experienced frustration in manually performing the same operation multiple times.

5.6 Study Limitations

The limitations from this study are as following.

Sampling

This study was analyzed based on the participation of eighteen participants (14 from technology-related areas) split into nine groups. Quantitative analysis did not produce significant results. Also, group formation was based on the availability of the participants, which resulted in only two groups in which the participants did not know each other prior to the study.

Tasks Definition

To conduct the study, I had access to only three tablets, which limited the maximum number of lenses to perform the tasks.

Qualitative Analysis

First, I was the only researcher to perform the qualitative analysis. The lack of crosschecking of the results may have added bias to the analysis. To reduce the effects from such bias, I specifically looked for counter examples and counter arguments during the video analyses.

The videos were not fully transcribed, therefore, the results I describe in this thesis are in part from general observations and might miss subtleties from the collaboration between the participants.

Tool

As discussed in subsection 4.2.5, design decisions while developing Bancada, may have influenced the results of this study. For instance, some frustrations experienced by some participants, described in 5.4.4, came from limitations of Bancada. I consider such frustrations as valuable findings, indicating what should be avoided when designing systems to support co-located collaborative activities.

5.7 Summary

The study presented in this Chapter aimed to identify the impact on collaboration between pairs of providing multiple detailed views within MDEs using configurations with different numbers of tablets for geospatial information exploration. I presented the results from the quantitative and qualitative analysis performed with the collected data from the study. Although it was not possible to identify statistically significant correlations between task completion time and configurations, the results from the qualitative analysis showed that the number of tablets available and the lenses they provide play important roles in how groups perform collaborative activities within MDEs. The majority of collaborators demonstrated a preference for when they have access to their own tablet providing all lenses, a configuration that was seen promoting tightly coupled collaboration.

Chapter Six

Conclusion

The main goal of this thesis was to investigate the impact on **collaboratio**n between **pairs** when **configurations with different numbers of tablets** providing **different detailed views** are available to explore **geospatial information** within **MDEs**. This investigation was divided into four parts. First, I researched how information is explored using multiple devices in MDEs, described in Chapter Two. Then, I looked into the different aspects of collaboration, and how previous related research assessed collaboration, presented in Chapter Three. These two Chapters provide the required background for the two remaining parts: the design and analyses of the results from the study conducted to answer the three research questions presented in Section 1.2. The design of the study was described in Chapter Four, and its results were discussed in Chapter Five. In this Chapter, I summarize the contributions of this thesis (Section 6.1), provide directions for further research (Section 6.2), and a conclusion (Section 6.3).

6.1 Contributions

The main contribution of this thesis are the insights provided by a study investigating the impact of different configurations of devices on the collaboration between pairs during geospatial information exploration activities within MDEs. The results from this study (presented in Sections 5.3 and 5.4, and discussed in detail in Section 5.5) highlight the role of tablets during collaborative visualization activities in MDEs, and also answered the three research questions, which are revisited in the following subsection.

A secondary contribution from this thesis is Bancada, is the multi-display environment that was developed to conduct this study, as it provides a means to research how geospatial information can be displayed and manipulated across multiple devices. Within this environment, presented in Section 4.2, users interact with detailed views from a map on one (or multiple) device(s), while an overview map is being displayed on a different device.

6.1.1 Revisiting the Research Questions

RQ1. What is the impact on the collaboration between pairs collaboratively exploring geospatial information within MDEs when the number of tablets, providing detailed views changes?

In single tablet scenarios, collaborators assume roles based on which collaborator is in possession of the tablet. For example, the collaborator holding the tablet is responsible for all device-based interactions (driver) while the partner monitors the task progress through an overview map and also provides instructions and clarification (navigator). In contrast, in multi-tablet scenarios, due to the distribution of lenses over multiple tablets, roles are defined based on tasks instead of resources, (e.g. one collaborator finds a city, while the other identifies its population density). As a result, collaborators are able to share responsibilities and have more equal opportunities to actively participate on the realization of tasks.

RQ2. What is the impact on collaboration of providing multiple detailed views within MDEs using tablets for geospatial information exploration?

When comparing tablets as all-in-one tools *versus* single purpose tools, the study results showed that the coordination of resources is the most impacted aspect of collaboration. Collaborators demonstrated a stronger sense of ownership when lenses were associated to specific tablets (SL configuration) compared to when tablets provided all lenses. This ownership was frequently characterized by collaborators maintaining possession of tablets (consequently, of the lens associated to them) while performing tasks. Comparatively, when tablets were all-in-one tools, the study showed that no association between lenses-tablets existed and there was an increased promotion of characteristics attributed to fairness (with respect to access of the lenses) and less costly access to resources.

RQ3. What are the preferred configurations to provide multiple detailed views within MDEs using tablets for collaborative geospatial information exploration?

As presented in subsection 5.4.4, study participants indicated configurations with multiple tablets as best for collaboration, specifically, when having access to their own tablets and with access to all available lenses.

6.2 Future Work

As described in 1.1.3, the research space on Collaborative Visualization within MDEs is quite sparse and provides multiple research opportunities. The study described in this thesis also provides multiple directions for further work.

Based on limitations presented in Section 5.6, the immediate future research steps are: to expand the transcriptions to a complete state; to analyze the data through a systematic methodology from the social sciences, (e.g. Grounded Theory [121]); and to have the results validated by other researchers. From this data set, further analyses of different aspects could provide valuable contributions to the research fields related to this thesis. For instance, an objective analysis of the impact on collaboration of each configuration is proposed by quantifying the mechanics (e.g. duration of conversation about answers, number of pointing gestures per person, and number of times collaborators switched roles) and correlating such values with the different configurations.

The feedback provided by the participants also pointed out at different directions to expand the research presented in this thesis. One specific direction is to explore approaches to mitigate frustrations they experienced with the different configurations, such as how to provide concurrent access to a lens, and how to reduce disorientation when switching lenses on the same tablet. This could then be followed up with conducting further studies with a larger and more diverse population to obtain more general results than the ones presented in this thesis.

6.3 Conclusion

In the introduction of this thesis, I presented Fitzmaurice's vision about situated information spaces. In such spaces, we explore information using our personal mobile devices integrated with devices situated in the environment. In this thesis, I described a study investigating the role of tablets for collaboration between pairs exploring geospatial information in multi-display environments. Specifically, I looked into how collaboration between pairs is impacted when the number of tablets and visualizations they provide can change. The results showed that both the number of tablets and the visualizations per tablet, play important roles in how collaborators communicate, share resources, and use shared visualizations (overview). Also, the majority of collaborators demonstrated a preference for having access to their own tablet providing all visualizations. These results provide insights and contribute towards making the vision from Fitzmaurice more feasible and accessible, as well as provide future research directions for a growing body of multi-display research.

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Appendix A

Study Materials

Pre-study questionnaire

Background

Profession (Major) ______________________________________

Age (18-20) (20-25) (26-30) (31-35) (36-40) (40+)

How well versed do you consider yourself in Canadian geography? (Novice, Intermediate, Advanced)

How would you define your experience using maps on computers? (Novice, Intermediate, Advanced)

What map-related systems have you used before? In what frequency do you use them? What devices do you use to access them?

Do you have any experience using multiple displays systems? If yes, what was the purpose?

Post-study questionnaire

About the study...

1. Having an overview map helps to accomplish the tasks.
   (Disagree 1 2 3 4 5 Agree)

2. I can easily complete all the tasks without an overview map.
   (Disagree 1 2 3 4 5 Agree)

3. Having colored borders is useful to identify the lenses in the overview map.
   (Disagree 1 2 3 4 5 Agree)

4. Adding, removing or moving a lens is easy.
   (Disagree 1 2 3 4 5 Agree)

5. It's easy to know the position of a lens from the overview map (e.g. A is on top of B).
   (Disagree 1 2 3 4 5 Agree)

6. Which configuration do you prefer? Why?

7. What are your thoughts on the collaboration to solve the tasks?

8. How would you rank the configurations according to collaboration?
   Multiple Tablets with Multiple Lenses ___
   Multiple Tablets with Single Lens ___
   Single Tablet with Multiple Lenses ___
9. One of the modes only allowed interaction with one tablet. What is you impression and how does it relate with other modes?

10. Additional comments?

Appendix B

Ethics

This appendix contains the consent form used for the study presented in this thesis. Its information is the following:

"Usability evaluations of data visualization and interaction tools" – Ethics ID: REB14-0387_MOD1.

Name of Researcher, Faculty, Department, Telephone & Email:

Francisco Rodrigues – Grad. Student Department of Computer Science E-mail: [redacted] Phone:	Apoorve Chokshi – Graduate Student Department of Computer Science E-mail: [redacted] Phone:	Teddy Seyed – Graduate Student Department of Computer Science E-mail: [redacted] Phone:

Supervisors:

Frank Maurer – Professor Department of Computer Science E-mail: [redacted] Phone:	Sheelagh Carpendale – Professor Department of Computer Science E-mail: [redacted] Phone:

Title of Project:

Usability evaluations of data visualization and interaction tools

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This consent form, a copy of which has been given to you, is only part of the process of informed consent. If you want more details about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

The University of Calgary Conjoint Faculties Research Ethics Board has approved this research study.

Purpose of the Study:

The purpose of this study is to help researchers evaluate how tools used for geospatial exploration can improve the collaboration between pairs. We are interested in evaluating the performance of our tools, as well as receiving user feedback in ways the tools can be improved.

What Will I Be Asked To Do?

You will be asked to perform several operations on a multi-surface environment or on a paper prototype of the tool. The gestures performed by you will be recorded by software on the device when a multi-touch device is used and when gestures are detected by the cameras in the environment. Also, a camera will be recording your interaction with devices or prototypes and also the collaboration with your study partner. During the whole process you will be encouraged to comment and give feedback about your impressions.

After the experiment, you will be asked to answer a survey about the experiment.

This whole process was designed to last approximately ninety minutes, although if you feel that you can discuss longer about a certain topic, or may have other insights to share, feel free to talk about it.

Participation is absolutely voluntary and you may withdraw at any time.

What Type of Personal Information Will Be Collected?

Should you agree to participate, you will be asked to provide your current occupation and contact information (should you agree to participate in follow-up questions).

There are several options for you to consider if you decide to take part in this research. You can choose all, some or none of them. Please put a check mark on the corresponding line(s) that grants us your permission to:

I grant permission to be audio taped: Yes: ___ No: ___

I grant permission to be video taped: Yes: ___ No: ___

I grant permission to save gesture data: Yes: ___ No: ___

I grant permission to save survey data: Yes: ___ No: ___

I grant permission to save interview data: Yes: ___ No: ___

I wish to remain anonymous: Yes: ___ No: ___

Are there Risks or Benefits if I Participate?

There are no known harms or risks associated to the participation in this study.

What Happens to the Information I Provide?

Participation is completely voluntary, anonymous and confidential. You are free to discontinue participation at any time during the study. No one except the researchers and their supervisors will be allowed to see or hear any of the answers to the questionnaires, interactions with the tools or the interview tape. There are no names on the questionnaires. The questionnaires are kept in a locked cabinet only accessible by the researchers and their supervisor. All the collected data will be kept by the investigators indefinitely and it might be used, in anonymized form, with publications and thesis purposes.

Signatures (written consent)

Your signature on this form indicates that you 1) understand to your satisfaction the information provided to you about your participation in this research project, and 2) agree to participate as a research subject.

In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from this research project at any time. You should feel free to ask for clarification or new information throughout your participation.

Participant's Name: (please print) ____

Participant's Signature ____Date: _______________

Researcher's Name: (please print) ____

Researcher's Signature: ______________________________________Date: _______________

Questions/Concerns

If you have any further questions or want clarification regarding this research and/or your participation, please contact:

Francisco Marinho Rodrigues
Department of Computer Science
[redacted]
Or
Apoorve Chokshi
Department of Computer Science
[redacted]
Or
Teddy Seyed
[redacted]
Or
Sheelagh Carpendale
Department of Computer Science
[redacted]
Or
Frank Maurer
Department of Computer Science
[redacted]

If you have any concerns about the way you've been treated as a participant, please contact the Senior Ethics Resource Officer, Research Services Office, University of Calgary at [redacted] email [redacted]

A copy of this consent form has been given to you to keep for your records and reference. The investigator has kept a copy of the consent form.

Appendix C
Co-Author Permission

This appendix contains the scanned copies or photos of the co-authors written permission to use the content of the following publications in this thesis and to have this work microfilmed:

F. Marinho Rodrigues, T. Seyed, F. Maurer, and S. Carpendale, "Bancada: Using Mobile Zoomable Lenses for Geospatial Exploration," In *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces – ITS '14*, 2014, pp. 409–414.

F. Marinho Rodrigues, T. Seyed, F. Maurer, S. Carpendale, "Bancada: Mobile Zoomable Lenses for Collaborative Geospatial Exploration," In *Proceedings of the 2nd Collaboration meets Interactive Surfaces Workshop (CmIS) in Ninth ACM Interactive Tabletops and Surfaces – ITS '14*, Dresden, Germany, 2014.

T. Seyed, C. Burns, P. King, F. Marinho Rodrigues, M. Costa Sousa, and F. Maurer, "MRI Table Kinect: A multi-surface application for exploring volumetric medical imagery," in *Proceedings of the Workshop on Safer Interaction in Medical Devices (MediCHI'13)*, 2013.

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February 25, 2015

I, Dr. Frank Maurer, give Francisco Marinho Moreira Rodrigues full permission to use the content of the following co-authored publications in his MSc thesis and to have this work microfilmed.

F. Marinho Rodrigues, T. Seyed, F. Maurer, and S. Carpendale, "Bancada: Using Mobile Zoomable Lenses for Geospatial Exploration," In *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces – ITS '14*, 2014, pp. 409–414.

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Sincerely,

[redacted]

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February 25, 2015

I, Dr. Sheelagh Carpendale, give Francisco Marinho Moreira Rodrigues full permission to use the content of the following co-authored publications in his MSc thesis and to have this work microfilmed.

F. Marinho Rodrigues, T. Seyed, F. Maurer, and S. Carpendale, "Bancada: Using Mobile Zoomable Lenses for Geospatial Exploration," In *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces – ITS '14*, 2014, pp. 409–414.

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Sincerely,

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Dr. Sheelagh Carpendale

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February 25, 2015

I, Teddy Seyed, give Francisco Marinho Moreira Rodrigues full permission to use the content of the following co-authored publications in his MSc thesis and to have this work microfilmed.

F. Marinho Rodrigues, T. Seyed, F. Maurer, and S. Carpendale, “Bancada: Using Mobile Zoomable Lenses for Geospatial Exploration,” In *Proceedings of the Ninth ACM International Conference on Interactive Tabletops and Surfaces – ITS ‘14*, 2014, pp. 409–414.

F. Marinho Rodrigues, T. Seyed, F. Maurer, S. Carpendale, "Bancada: Mobile Zoomable Lenses for Collaborative Geospatial Exploration," In *Proceedings of the 2nd Collaboration meets Interactive Surfaces Workshop (CmIS) in Ninth ACM Interactive Tabletops and Surfaces – ITS '14*, Dresden, Germany, 2014.

T. Seyed, C. Burns, P. King, F. Marinho Rodrigues, M. Costa Sousa, and F. Maurer, “MRI Table Kinect: A multi-surface application for exploring volumetric medical imagery,” in *Proceedings of the Workshop on Safer Interaction in Medical Devices (MediCHI’13)*, 2013.

Sincerely,

[redacted]

Teddy Seyed

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March 03, 2015

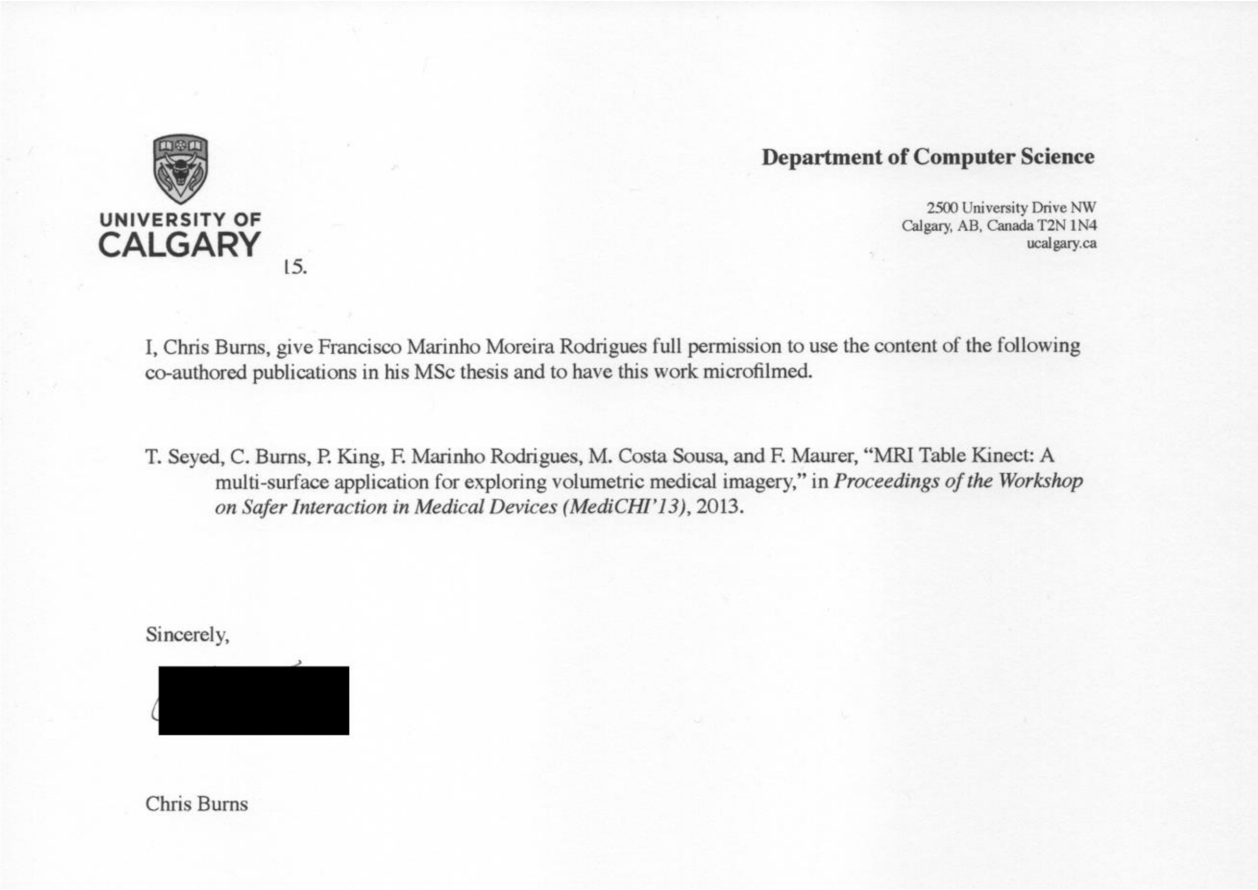
I, Dr. Mario Costa Sousa, give Francisco Marinho Moreira Rodrigues full permission to use the content of the following co-authored publications in his MSc thesis and to have this work microfilmed.

T. Seyed, C. Burns, P. King, F. Marinho Rodrigues, M. Costa Sousa, and F. Maurer, "MRI Table Kinect: A multi-surface application for exploring volumetric medical imagery," in *Proceedings of the Workshop on Safer Interaction in Medical Devices (MediCHI'13)*, 2013.

Sincerely,

[redacted]

Dr. Mario Costa Sousa



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15.

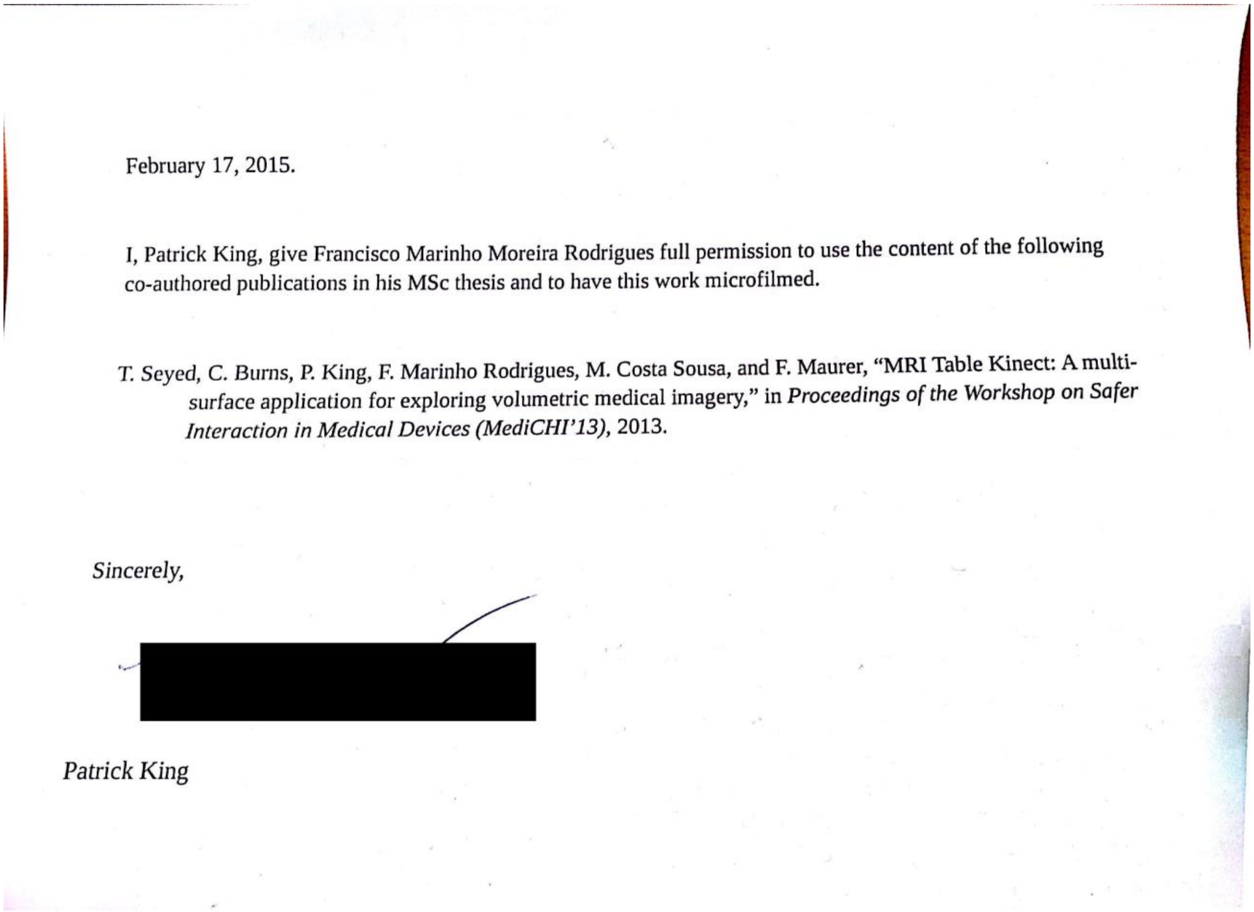
I, Chris Burns, give Francisco Marinho Moreira Rodrigues full permission to use the content of the following co-authored publications in his MSc thesis and to have this work microfilmed.

T. Seyed, C. Burns, P. King, F. Marinho Rodrigues, M. Costa Sousa, and F. Maurer, "MRI Table Kinect: A multi-surface application for exploring volumetric medical imagery," in *Proceedings of the Workshop on Safer Interaction in Medical Devices (MediCHI'13)*, 2013.

Sincerely,

[redacted]

Chris Burns



February 17, 2015.

I, Patrick King, give Francisco Marinho Moreira Rodrigues full permission to use the content of the following co-authored publications in his MSc thesis and to have this work microfilmed.

T. Seyed, C. Burns, P. King, F. Marinho Rodrigues, M. Costa Sousa, and F. Maurer, "MRI Table Kinect: A multi-surface application for exploring volumetric medical imagery," in *Proceedings of the Workshop on Safer Interaction in Medical Devices (MediCHI'13)*, 2013.

Sincerely,

[redacted]

Patrick King