Multi-Surface Interactions with Geospatial Data: A Systematic Review

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ABSTRACT
Even though Multi Surface Environments (MSE) and how to perform interactions in these environments have received much attention during recent years, interaction with geospatial data in these environments is still limited, and there are many design and interaction issues that need to be addressed. Alongside the rapid rise in the use of Geographic Information Systems (GIS) in group-based decision making, interaction with geospatial data has become highly important. In order to summarize the earlier research in this area, this paper presents a systematic review of MSE interactions with geospatial data. The review analyzes existing papers on MSE interaction techniques, discusses issues related to interaction with geospatial data in MSEs, and provides a comparison between common GIS tasks and existing interaction techniques in MSEs. Our results indicate that a substantial number of GIS tasks have not been investigated in MSEs.

Author Keywords
Geospatial data; Interaction techniques; Multi-surface environments; Systematic review

ACM Classification Keywords
H.5.2. Information Interfaces and Presentation (HCI): Miscellaneous

INTRODUCTION
Recently, there has been an increased research interest in designing and developing applications in Multi Surface Environments (MSE). By MSE we mean "*a system where interaction is divided over several displays, such as digital tabletops, wall displays and personal devices like tablets or mobile phones*" [19] (See Figure 1). The diversity of devices in these environments, ranging from smartphones to high-resolution wall displays, with different capabilities, provides a collaborative environment that enables multiple users to easily and seamlessly create, share, and manipulate data. While considerable studies into MSEs have looked at how users interact with MSEs and how different configurations affect collaborations and interactions, there is limited research on what interaction techniques with geospatial data are most effective in these environments. Interacting with geospatial data when group-based decision-making is required can be challenging. For example a number of domains including emergency operation centres, traffic control rooms, and military command and control centres utilize geospatial data. These domains are increasingly transitioning towards MSEs and require the design of appropriate gestures to interact with geospatial data across multiple devices.

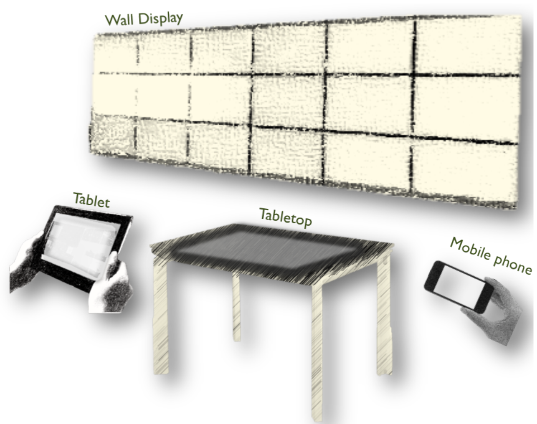


Figure 1: An example of a Multi Surface Environment consists of Wall display, Tablet, Tabletop and Mobile phone.

To summarize the research on multi-surface interactions with geospatial data we conducted a system literature review. This review seeks to analyze, classify, and present the common tasks and interaction techniques in MSEs. Moreover, it provides a comparison between these tasks and common geospatial tasks and activities that users can perform during their work with digital maps. We address the following questions:

RQ1: What interaction techniques can users perform in MSEs?
RQ2: What interaction techniques can users perform for geospatial tasks/activities in MSEs?

The paper is structured as follows: we review the existing literature discussing common geospatial tasks/activities and bring an overview of these tasks from system and cartography perspective. We then describe the review method that we used to select and analyze the papers for our review and describe the selected methodology for analyzing each of the included papers. We discuss the results and findings of the review based on our research questions. Finally, we conclude the review with some recommendations for future research.

ITS 2014, November 16–19, 2014, Dresden, Germany.

http://dx.doi.org/10.1145/2669485.2669505

COMMON TASKS TO WORK WITH DIGITAL MAPS

User interactions with geospatial data (i.e. digital maps) can be highly complex with lots of tasks and analysis that cannot be done easily with ordinary paper maps [7]. In this section, we present actual tasks that GIS analysts perform and classify these tasks into two categories, which are provided by Davies [6]:

- System perspective tasks (e.g. interactions with the commands and menus)
- Cartography perspective tasks (e.g. interaction with the data inside a map)

System Perspective Tasks

Davies [6, 7] has conducted two studies (survey and observation) to explore the common tasks from a system perspective that analysts perform during their interaction with digital maps. In the first study, respondents were asked to write free-text answers to a question ''What tasks do you currently do with your GIS?" In the second study, 21 GIS users were asked to determine how often they perform the tasks from a predefined checklist of 48 common GIS activities/tasks. The results of these two studies indicate that zooming, panning, map presenting/plotting, digitizing objects, and adding information to them, and searching for specific information are basic system tasks which the majority of GIS analysts perform during their interaction with digital maps.

Cartography Perspective Tasks

McCann [18], Calkins and Obermeyer [5], and Knapp [16] each have provided a category of tasks that users perform during their interaction with digital maps. These categories have been extracted from the information perspective rather than the system. Considering that the tasks provided by McCann [18] include tasks which have been presented by Obermeyer and Knapp [5, 16], in this section we only focus on McCann's tasks:

1. Symbol detection: determination of the presence/absence of a symbol at a certain point on a map.
2. Symbol interpretation: association of a detected symbol with a concept stored in the user's memory.
3. Pattern detection and interpretation: identifying patterns to code map information such as lakes and vegetation.
4. Determine the attributes of map features: interpretation of symbol characteristics, which code attributes of the map feature such as determining a town population.
5. Calculate, count, measure, estimate, interpolate: these tasks are often introduced by a question like; *'How many?'*, *'How far?'*, and *'How long?'*
6. Comparison of symbols/patterns: determining whether two symbols/patterns show the same/different map features.
7. Annotation, updating, highlighting: user interaction with the map display to change the data on it.
8. Communication: passing information among map users to discuss features of the environment, make plans or solve problems.
9. Map memorization: processing map information combined with other knowledge about the environment, which together provide a deeper understanding of the environment.
10. Determine absolute location of a map feature: searching for the nearest reference markers related to the feature.
11. Determine relative location of a map feature: this task usually is introduced by a question such as *'Where is town X relative to town Y?'* and requires that the user process information about both distance and direction.
12. Search for a map feature: selecting a set of map features from criteria that may include type, attributes and spatial locations. (e.g., find all Italian restaurants within 3 minutes drive to downtown).
13. Integrate discrete map information: this task is characterized by questions such as 'what is the extent of the flooding?' and user should characterize map features that satisfy the criteria.
14. Determine spatial and temporal changes: comparing the distributions of features which occur in different regions, or occur in the same region, but over a period of time.
15. Inferring unportrayed features: forming hypothesis about the unportrayed features on the map based on information available from the map or other non-map data.
16. Orientation: matching a map feature with a geographical location.
17. Visualization: a user imagines what features and their relationships will look like when viewed in the environment.
18. Where am I?: locating map users in the environment.

It is important to note that the main focus of these cartographic tasks is on users' goal, whereas the *system perspective* tasks focus on what users have to do with the system to achieve these goals [6, 7].

REVIEW METHOD

This study follows the systematic review methodology described by Biolchini et al., Gough et al., and Kitchenman et al. [4, 11, 15] and consists of the following distinct steps: inclusion and exclusion criteria, paper selection and search strategy, quality assessment, data extraction, results, and discussion.

Step1: Inclusion and Exclusion Criteria

Papers were considered for inclusion in this review if they presented interaction tasks and techniques in MSEs. Inclusion of papers was not limited to empirical studies. In this review we considered both application and experience papers. We excluded papers that were not related to MSEs tasks and techniques. As an example of exclusion, we found several papers that mentioned only "interaction in MSE" in their future work section and were outside the scope of this systematic review. We did not include papers that only focused on one device. Editorials, position papers and keynotes were excluded in this step.

Step2: Paper Selection

Identifying unbiased and comprehensive papers is the primary goal of a systematic review [11]. Comprehensiveness (recall) should be balanced with relevance (precision); high recall of a search reduces its precision and may return more irrelevant papers. For this reason, information retrieval plays a crucial role in the systematic review process and is a key

Iterations	# of Papers at each iteration	BWS	FWS	Expert Knowledge
1	36	6	3	0
2	45	5	1	0
3	51	0	12	1
4	64	1	0	0
5	65	0	0	0

Table 1: Iterations of information retrieval. BWS= Backward Snowballing, FWS= Forward Snowballing

Multi-Surface Keywords	Geospatial Keywords	HCI Keywords
Tabletop	Geospatial	Interaction
Big Display	Geographic	Gesture
Wall display	Map	Collaboration
Multi-Surface	GIS	Communication
Multi-Display	Location	CSCW
Digital Surface		Groupware

Table 2: Search Keywords

factor that distinguishes a systematic review from other forms of literature reviews [11].

Search Strategy

Development of appropriate search terms is an iterative process, and consists of modifying the search terms based on the papers that have already been retrieved [17]. At the first step, we started with 378 papers and used the following steps iteratively to retrieve the relevant papers. We continued modifying the search terms until we were unable to find any additional papers that we considered relevant. The result of each iteration is given in Table 1.

Google Scholar (GS): GS provides a simple and quick way to perform a search for scholarly literature across many disciplines and sources [1]. At the first stage of information retrieval, we queried GS using the search terms listed in Table 2 and found 378 papers at this step. Dean et al. [9] recently performed an experiment to evaluate if GS is sufficient to be used alone for systematic reviews and concluded that GS does not meet the required search standards for systematic reviews, and is not able to identify all known and relevant papers in a specific area. For this reason, at the next step we searched electronic databases to find more relevant papers.

Electronic Databases: At this step, we searched the following electronic databases by using search terms that are listed in Table 2:

- ACM Digital Library, ScienceDirect, Elsevier, SpringerLink, IEEE Xplore, Scopus, ISI Web of Science, Wiley InterScience Journal, and Kluwer Online.

Furthermore, we manually searched HCI and GIS journals and conference proceedings:

- HCI: *IJMMS, TOCHI, ACM sigchi Bulletin, ITS, CHI, CSCW, ECpapersSCW, DIS, GROUP, ICMI, IWAI (workshop)*
- GIS: *COSIT, ACM SIGSPATIAL, GIS, IGRSM, JOSIS, RSETE, IGARSS, Geoinformatica*

Snowballing: In some cases, it was not possible to find all of the relevant papers by searching databases. Snowballing, which is *"a powerful technique for identifying high quality sources in obscure locations"*, can be used as a supplement for the search process [13]. Before applying this technique, we reviewed all of the retrieved papers from the previous steps and judged their relevance based on title, keywords and abstract. In a few cases that *inclusion* decision was not possible based only on these criteria, we reviewed the outline, conclusion and references of the papers.

After creating a base list of 36 relevant papers, we then used snowballing by scanning the reference list (backward snowballing [13]) of identified papers in the previous step. Furthermore, there were papers that have been published after the selected papers, so we performed citation tracking (forward snowballing [13]) to identify relevant papers citing the papers in the previous step.

Expert Knowledge: Some relevant papers that have unrelated titles or use different wording in their text, might be ignored in searching databases or snowballing [11, 13]. In this step we found one more paper by asking academic colleagues.

Step3: Quality Assessment

Evaluating the quality and relevance of individual papers included in a review plays a key role in the review process and has a direct impact on the quality and reliability of the review [11]. By quality we mean the extent that each paper contributes to answering our review questions [10]. To this end, the quality assessment was performed for each of the 65 selected papers after the information retrieval step. Three main issues should be considered when evaluating the quality of research papers [2]:

- *Rigour*: Has a thorough and appropriate approach been applied to key research methods in the study?
- *Relevance*: How useful are the findings to the software industry and research community?
- *Credibility*: Are the findings well presented and meaningful?

Table 3 gives the summary of the quality assessment criteria related to each of these issues. These criteria are provided by the Critical Appraisal Skills Programme (CASP) [2]. In addition to these criteria, we added some more criteria based on existing issues in HCI research [12, 14].

While novelty is highly valued in HCI papers, evaluating the results and generality of previous papers, which can be achieved by replication, is a key challenge in HCI research [14]. As the majority of HCI research are conducted without an underlying theory, replication is not possible unless the exact experiment is performed. Greenberg and Thimbleby [12] presented the following factors that contribute to difficulties in replicating HCI experiments:

- Lack of enough information and data in HCI papers due to page limitations and difficulties to describe interactive systems in words.
- Using very specific and context-dependent platforms to perform the experiments. For example software packages

Screening Questions
1. Does the paper present information on *task based* interactions in MSE? 2. Is there a clear statement of the aim of the research? 3. Is there an adequate description of the context in which the research was carried out?
Rigorous
4. Have the researchers justified the research design? (e.g. have they decided which method to use?) 5. Have the researchers explained how the participants or cases were identified and selected? 6. Have the researchers justified the method that were chosen? 7. Has sufficient data been presented to support the findings and claims?
Relevance
8. Does the researcher discuss the contribution the paper makes to existing knowledge or understanding?
Credibility
9. Is there a clear statement of findings? - Have the researchers discussed the credibility of their findings? - Are the conclusions justified with the results? - Are the findings discussed in relation to the original research question?
Replicability
10. Was there enough information to allow replication? - Are experimental artifacts and circumstances accessible to community? - Are stable and widely used hardware and software platforms used to perform the study? - Are descriptions of interactive systems critical to the experiment available?

Table 3: Quality criteria [2, 12, 14]

with a very short life-span, using some unavailable prototype systems that were developed by the researcher, or running the experiment on a specific version of an operating system.

- Presenting a summary of the collected data, which makes it difficult to regenerate the data through replication.

Criteria related to *replicability* issues are listed in Table 3. Each of the 10 criteria was rated on a scale of 0-1 (0=No, 1= Yes) and we included or excluded papers based on the value of criterion 1. At this stage, after reading the full text, from 65 papers evaluated for quality, 37 papers were excluded from further analysis, for not providing information on task-based interactions in MSEs. Most of these papers, with a few exceptions, have focused on design and infrastructure of MSEs, especially spatial awareness and smooth transition between different devices (n=32). Five other papers only provided details about information sharing in MSEs. At the end of the *quality assessment* step, we selected 28 papers for data extraction and analysis (See Section Systematic Literature Review Papers for the papers in this review). A summary of the quality assessment results for these papers is presented in the results section.

Step4: Data Extraction

During this step, we applied a revised version of the grounded theory methodology to extract data from each of the 28 primary papers included in this review [23]. During the paper selection process, we categorized papers into two different groups: papers related to MSE interactions with geospatial data, and papers related to interaction techniques in MSEs.

In grounded theory we analyze all of the included papers line by line to extract concepts, which involves with high volumes of qualitative data. To help with this process, we used *Saturate* [21], which is a web-based open coding tool to enable traceability between codes and data. We started analyzing each set of papers as follows.

Of the 9 papers in the first group of papers, we selected a random paper and read and coded each data point of the text that was relevant to the scope of our review. With the same procedure, we highlighted all of the selected papers in this group. At the next step, we re-read all of the highlighted words, sentences and expressions and categorized them base on their common properties and similarities. This process of "generating higher-abstraction level type categories from a set of concepts/variables" [23] is called open coding. After building a clear structure of concepts during the open coding stage, we made an initial axial coding to find the relationship and links between categories and their subcategories (see Table 4).

We read the remaining papers (n=19) one by one and performed both of the analytical coding steps (open coding and axial coding) iteratively, moving between papers, concepts, categories and sub-categories until 'theoretical saturation' was achieved. Theoretical saturation occurs when no new information, concept or relationship emerges from the data and analytical coding process [22, 23]. Table 4, gives an overview of the results of applying grounded theory on all of the papers included in this review.

RESULTS

In this review, we analyzed 28 papers and categorized them into two main categories: (1) papers on MSE interactions with geospatial data [P1-P9], and (2) papers on MSE interaction tasks and techniques [P10-P28]. Before going into the main results of this review, first, we provide an overview of the primary papers included in this review according to the concepts they cover and briefly describe their methodological quality based on the quality criteria that has been addressed in the *Quality Assessment* section.

Overview of Papers

With regard to the concepts and open codes that have been extracted during the 'Data Extraction' step, we can see from Table 4 that the *Interaction Devices* code were addressed in all of the included papers in this review and more specifically combination of 'Tabletop+Wall Display' and 'Tablet+Tabletop+Wall Display' have been used more than other combinations of devices. The majority of papers focused on interaction techniques and relationships between different entities in MSEs. Papers that have addressed *Hand Gestures* to perform geospatial tasks, *Spatial Relationship* between devices, and *Orientation* issues in MSEs come next, with them being 14 (50%), 10 (35%), and 9 (32%) of papers respectively. *Scalability Issues* and *Privacy* in MSE, were addressed in 8 (29%) papers each. *Communication* between

Category	Open Code	Concepts
Relationships Between Entities (47)	**Spatial Relationship (11)** [P4, P7, P10, P12, P16, P20-22, P25-26] [# of papers: 10]	Spatial relationship between walls and table (1), Distance independent interaction (1), Different point of views for different displays (1), Spatial relationship between different devices (6), Slide-under as a spatial relationship (1), Seamless interaction (1)
	Orientation (19) [P1-2, P4, P7-8, P12, P16, P23, P26] [# of papers: 9]	Optical tracking technologies (1),Device orientation and location (3), Tracking objects with optical markers (3), Using markers to determine location and orientation (1), Synchronizing and coordinating different views (1), Measuring device to determine position and orientation (2), Tracking objects position (1), Flexible work division (1), Sensor-enabled phones (1), Perspective correction (2), Rotate wall's point-of view (POV) and tilt from tabletop (2)
	Communication (4) [P2, P4, P8, P9], [# of papers: 4]	Wireless communications (3), Interface components are visible on mobile device (1)
	Scaleability Issues (13) [P1-3, P6-7, P9, P20, S24] [# of papers: 8]	Maps with different scales (3), Quality of navigation (2), Increase resolution of map with tablet (3), Providing detail view (2), Overlay interface to improve resolution (1), Automatic image processing algorithm (1), Scalability of user interface (1)
Interaction Tasks and Techniques (45)	**Hand Gestures (36)** [P1, P4, P7-8, P10-11, P13, P17 ,P21-23, P25, P27-28] [# of papers: 14]	Flicking (3), Pinching (1), Zooming (5), Mouse Click (1), Pouring (1), Bi-manual operations (2), Sliding (2), Dragging (4), Panning (2), Throwing (3), Swiping (1), Five finger touch (1), Rotation (1), Pointing (4), Chucking (1), Bumping (1), Position up (2), Camera gesture (5)
	Add Annotations (7) [P4-5, P9], [# of papers: 3]	Drawing (3), Pre-defined graphics (2), Tagging (2)
	3D Interaction (2) [P8], [# of papers: 1]	3D interaction (2)
Workspace (58)	**Conflict Management (12)** [P4-5, P8, P27] [# of papers: 4]	First to touch technique (1), Same map on different surfaces (1), Same view with same latitude and longitude (1), Control changes of views from table (1), Shared view across distributed surfaces (2), Table as primary input device (2), Conflicting views on a shared device (1), Asynchronous collocated collaboration (1), Different roles (1), Separating action and reflection (1)
	Privacy (18) [P1-2, P4-7, P9, P28] [# of papers: 8]	Immediate visibility of content on shared wall display (1), Value of data differs among different members (1), Different views displayed on multiple machines (1), Working together and working separately (1), Access to details and annotation capabilities by smaller devices (2), Private domain data (iPad) (1), Visibility of objects on wall is locally (1), Tablet as private workspace (2), General views and local tasks (1), Open access vs dynamic interaction (1), Authorized reviewers (1), Shared and private working areas (1), Private working area (3), Large display as shared environment (1)
	Interaction Devices (28) [P1-28] [# of papers: 28]	Tabletop + Wall display (5) Tablet + Tabletop + Wall display (5) Table + Wall + PC/Laptop (3) Laptop + Wall display (2) Tablet + Tabletop (2) Mobile phones+ Tablet (2) Mobile phone + Wall display (2) Mobile phone + Tablet + Wall display (1) Tabletop + Three Wall Displays + Tablet (1) Tablet + Tabletop + Stereoscopic display (1) Tabletop + Large display + Fovea-Tabletts (1) Tabletop + Wall display + Mobile phone + Laptop (1) Tabletop + Wall display + Mobile phone + Motion tracking system (1)

Table 4: Overview of concepts extracted from the papers included in this review. Numbers in parentheses show the number of occurrences of each code in the included papers

different devices, *Conflict Management* approaches, *Add Annotation*, and *3D Interaction* as interaction techniques, were addressed in only 4, 4, 3, and 1 papers respectively.

Regarding the quality of publications, as mentioned in the *Quality Assessment* section, we evaluated each of the primary papers according to the 10 quality criteria on the CASP [2] and by principles of good HCI research [12] (see Table 3). After evaluating papers based on their quality, we found that: most of the papers did not have a clear and sound description of their methods and issues of replicability and validity were not addressed properly. The data collection and analysis methods were not explained clearly and not enough details were provided. The rest of this section is structured based on the research questions of this review.

RQ1- Interaction Tasks and Techniques in MSEs

In order to answer RQ1 of this review, we use the output of the grounded theory process that has been presented in Table 4. This table represents three levels of the grounded theory approach: concepts, open codes, and axial codes (categories of open codes). In this section we discuss each of these categories combined with their related codes and concepts in more detail.

(1) Relationship Between Entities

This category includes concepts related to the spatial relationship between different devices in MSEs, device orientation techniques, scalability issues as well as technologies, and different ways that devices in MSEs can communicate with each other.

- *Spatial relationship:* This code refers to the position of each device in MSE relative to other devices in the environment. Out of 23 papers in the *relationships between devices* category, 10 papers addressed spatial relationship. For example, Piazza et al. [P12] proposed the *side-under* technique using a magic lens and Toolglass [3] to control the relative position of devices during their interactions. In this technique, one device can be inserted underneath another device and their spatial relationship is controlled by using the distance between the centre-point of the devices. The other papers in this category only addressed concepts related to the spatial relationship between devices.

- *Orientation:* By orientation we mean the relative positions or directions between different devices and users in MSE. In the context of performing collaborative tasks in MSEs, different entities inside the environment need to determine their position and orientation with regard to other entities. Among included papers in this review, [P1, P2, P4, P7, P8, P12, P16, P23, P26] have addressed orientation technologies or techniques in MSEs. For example, Yao et al. [P8] presented a collaborative workspace which includes advanced display systems and optical tracking technologies and is used to track the orientation and position of entities inside a room.

-*Communication:* Four papers [P2, P4, P8, P9] addressed communication between devices in MSEs. All of them use wireless networks to connect each device with other devices in a room. Other included papers in this review did not address communication.

- *Scalability issues:* With respect to scalability issues in MSEs, Peinsip-Byma et al. [P6] uses an automatic image processing algorithm that offers users a detailed view of shared information on a tabletop or wall display on their personal device. Satyanarayan et al. [P24] provides an overlay technique which enables collaborative interaction on wall displays in different scales. [P1, P6, P9] use another device (i.e., Tablet, mobile phone) to provide a personalized view with high resolution. Other papers in this category only address scalability issues in MSEs.

(2) Interaction Tasks and Techniques

Hand gesture, Adding annotation, and 3D interaction are interaction techniques that have been discussed in several papers. In this section, we briefly describe each of these techniques.

- *Hand Gestures:* Flicking [P7, P11, P13], Pinching [P7], Zooming [P1, P7, P22, P25, P28], Mouse Click [P4], Pouring [P7], Bi-manual Operations [P4, P8], Sliding [P7, P11, P21], Dragging [P10, P17, (P27-28)], Panning [P22, P25], Throwing [P11, P13, P23], Swiping [P11], Five figure touch [P11], Rotation [P11], Pointing [P11, P16, P19, P22], Chucking [P11], Bumping [P11], Camera gesture [P2, P7, P11] and Position up [P11] are hand gestures used for interaction and collaboration among users in MSEs. Each of these gestures along with their description are presented in Figure 3.

- *Add Annotation:* This technique consists of Drawing [P5], Pre-defined graphics [P9] and Tagging [P5]. These interaction techniques enable users to highlight particular information and improve the attention of participants during their interactions.

- *3D Interaction:* 2D and 3D displays in this technique [P8] provide a seamless touch interaction with 3D objects in MSEs.

(3) Work Space

In this category, conflict management, privacy control, and interaction devices are the main concepts that have been addressed in the papers of this review.

- *Conflict Management:* In the last few decades, empirical studies have shown that in collaborative and interactive workspaces, conflict is inevitable [8]. Among four papers of this review that have addressed *conflict management*, study by Forlines et al [P4], used *first to touch technique* to manage the conflict between user interactions and [P27] manage this conflict by defining tabletop as the primary input device. Two other papers (P[5], P[8]), only mentioned this conflict as an issue in MSEs without providing any solution for it.

- *Privacy:* While smooth transfer of information among team members is a requirement in collaborative activities, users should be able to have control of their individual workspace. Of all the papers in this review, seven papers [P(1-2), P(4-7), P9, P28] highlighted concepts related to privacy in MSEs. Defining a large display as the shared environment and own devices as private environments is the main approach that have been used in these papers.

Bump: Make temporary physical contact between two devices for contact transfer [19]
Flick: Quickly brush surface with fingertip, [24]
Drag: Move fingertip over surface without losing contact [24]
Pinch: Touch surface with two fingers/hands and bring them closer together [24]
Zoom: Touch surface with two fingers/hands and move them apart without lifting them from the screen [24]
Rotate: Touch surface with two fingers and move them in a clockwise or counterclockwise direction [24]
Camera: Capture shared information on a personal devices (e.g., Tablet, Mobile phone) and view and manipulate the data with higher resolution
Swipe: Drag objects on the surface, but faster than dragging
Pour: Send objects from tablet to a tabletop, in close proximity [20]
Chuck (Throw): Throwing or passing objects to another device [19]

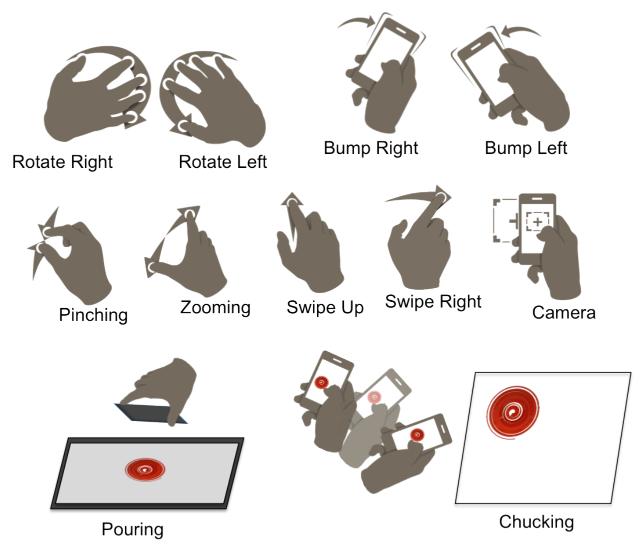


Figure 2: MSEs' hand gestures that have been addressed in the included papers

- *Interaction Devices:* Regarding the interaction devices, tablets, tabletops, wall displays, mobile phones and PC/laptops are the most frequently used devices in the included papers in this review. Stereoscopic display [P8], motion tracking system [P22] and Fovea-Tablett [P2] are other devices that were used in only one paper each. Stereoscopic display provides an accurate and detailed 3D presentation of data and allows users to interact in 3D mode. A motion tracking system enables tracking devices and people in MSE with high accuracy and minimal delay. Fovea-Tablett is a small portable display unit with high pixel density which enables users to have access to a small portion of shared information with high resolution.

GIS System Tasks	MSE Tasks and Techniques
Pointing	Mouse Click [P4], Pointing [P(13-14), P19, P22]
Search attributes	Mouse Click [P4], Pointing [P(13-14), P19, P22], Bi-manual operations [P4, P6]
Associate	Mouse Click [P4], Drawing annotation[P(4-5), P9]
Zooming	Zooming [P1, P7, P22, P25, P28]
Panning	Panning [P22, P25]
Printing report	Mouse Click [P6]
Digitizing features	Drawing annotation[P(4-5), P9], Pre-defined graphics[P9], Tagging[P6]
Map presenting	Mouse Click [P6]
Data Conversion	Mouse Click [P6], Dragging [P10, P17, P(27-28)]
Map creation from coordinates	Mouse Click [P6], Drawing annotation[P(4-5), P9]
Measurements	Mouse Click [P6], Pointing [P(13-14), P19, P22]
Editing features	Mouse Click [P6], Pointing [P(13-14), P19, P22]

Table 5: Mapping between GIS system tasks/activities and MSE tasks/techniques

RQ2- Interaction with Geospatial Data in MSEs
In order to answer RQ2, first we need to answer the following questions:

- RQ2-1: What interaction techniques are proposed in MSEs to perform geospatial tasks from a *system* perspective in MSEs?
- RQ2-2: What interaction techniques are proposed in MSEs to perform geospatial tasks from a *cartographic* perspective in MSEs?

GIS System Perspective Tasks in MSE (RQ2-1)
In order to answer RQ2-1, about the relation between common GIS tasks from a system perspective and existing MSE tasks and techniques, we draw a mapping between these two categories. In Table 5, for each of the GIS system, there is at least one corresponding task in MSEs. For example, in order to perform the *editing features* task from the left column, we can use *mouse click* or *pointing* tasks from the right column to select the feature on the map and then edit it.

GIS Cartographic Perspective Tasks in MSE (RQ2-2)
Earlier in the paper, we presented the common tasks that users can perform during interaction with digital maps from a cartography perspective. Aiming to answer the RQ2-2, we com-

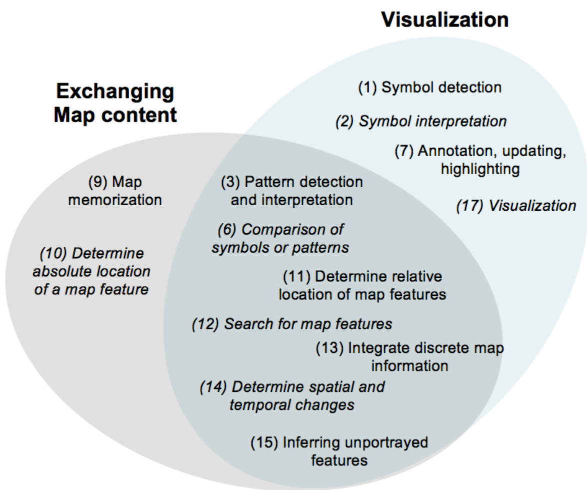
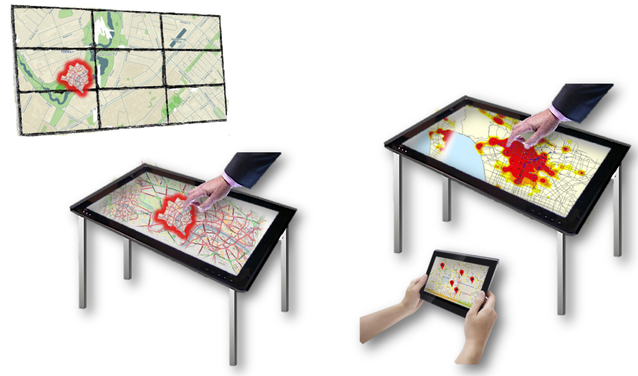


Figure 3: Classification of common cartographic GIS tasks



(a) Pattern detection and interpretation

(b) Symbol interpretation

Figure 4: Examples of cartographic GIS tasks in MSEs

pared these tasks with interaction techniques and tasks that are provided by papers included in this review (Table 4). In this case, we found that there is little discussion on cartographic GIS tasks in MSEs and most of these tasks are not discussed or supported by the MSE literature. While most of the prerequisites for performing cartographic GIS tasks in MSEs, such as *defining relationships* among different entities inside the environment, core *interaction tasks and techniques* and addressing issues related to *workspace* are addressed by papers in this review, there are still some specific issues related to visualization and exchanging geospatial data that need to be addressed. In the next section, we discuss these issues in more detail.

DISCUSSION

Our review is the first systematic review that provided a mapping between GIS tasks and existing tasks and techniques in MSEs. Related work and papers in this area, only addressed a limited number of papers related to their research goal. We found papers in this review by using an iterative search strategy and defining explicit inclusion and exclusion criteria.

Our systematic review has a number of implications for future research. The results of the review illustrate the need for more research on the useful interaction techniques to perform cartographic GIS tasks. As in recent years geospatial data has become a key component in group-based decision making and is widely accessible and used by users, we believe that interaction with geospatial data in collaborative environments needs more attention by researchers in industry and academia.

As the uniqueness and complexity of geospatial data [6, 7], exchanging map content is a major challenge during performing GIS tasks in collaborative environments. Moreover, "Using colour effectively can and will enhance the ability of users to identify features, objects, and patterns" on the map [6]. Considering these two issues, we classified cartographic GIS tasks into two categories; (1) Visualization and (2) Exchanging map content, (see Figure 3).

In order to make this classification more clear and understandable, Figure 4 gives an example of each of these two categories. In Figure 4(a), a tabletop user has detected a specific pattern in an area while performing a *pattern detection and interpretation* task, which might be of interest to some members of the team. This user should be able to share this pattern on a public device without interrupting other members if they are working with the shared device. In Figure 4(b), a tablet user is displaying some symbols to represent real world objects on the map. At the same time, a tabletop user has detected some patterns on the map which are highlighted with red colour. In this situation, as red symbols are not properly readable on a red background, sharing symbol between these two devices requires some visualization techniques. More research on *visualization* and *exchanging* geospatial content are the other research implications of this review.

CONCLUSION

This systematic review has addressed the following research questions: (1) What are the proposed tasks/techniques that users can perform during their interaction in MSEs? (2) What useful interaction techniques are proposed in MSE to perform geospatial tasks/activities? In order to answer these questions, we initially identified 378 papers by searching the literature. 28 papers were selected as primary papers of this review, while the others were not relevant to address the research questions. To answer the first research question, we analyzed all of the identified papers by using a revised version of grounded theory method and extracted concepts related to interactions in MSEs. For the second research question, we compared the results of the first question with common GIS tasks and techniques from the system and cartographic perspectives. Our main finding from conducting this systematic review is although MSEs have received much attention during recent years and several platforms and applications have been developed in these environments, but there is still a need for specific interaction techniques to perform GIS tasks in MSEs.

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