Investigating Paradigms of Group Territory in Multiple Display Environments

SHUO NIU, Clark University, Virginia Tech, USA
D. SCOTT MCCRICKARD, JULIA NGUYEN, DEREK HAQQ, LINDAH KOTUT, TIMOTHY L. STELTER, and EDWARD A. FOX, Virginia Tech

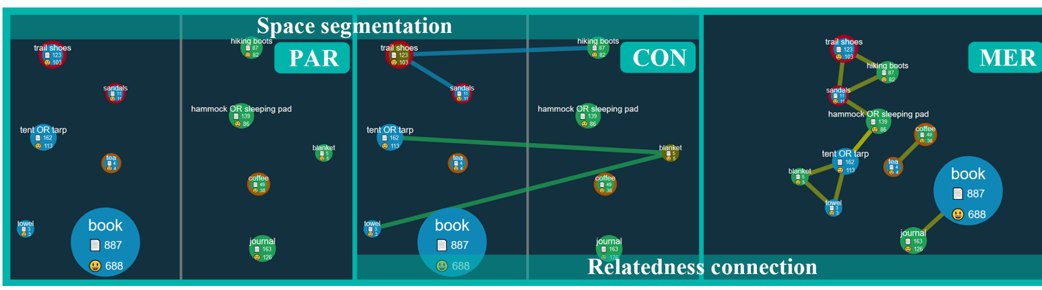

Fig. 1. This study examines three paradigms for separating or connecting individual work in a group territory: PAR - Separated individual sections; CON - Connected similar items from the separated individual sections; MER - Merged individual items in one integrated group territory.

Multiple-display environments (MDEs) have promise in helping co-located sensemaking tasks by supporting searching, organizing, and discussion tasks. Co-located sensemaking occurs when two or more sensemakers forage for useful information within a dataset, creating and leveraging knowledge structures individually and together. Group territories in MDEs support communicating and assembling findings, but questions remain regarding how to best represent individual sensemaking efforts in the group territory to support the sensemaking collaboration. This paper empirically examines exploration of a large Twitter dataset using three group territory paradigms: parallel, connected, and merged. Results reveal that merging group work increases task complexity while separating individuals' sections in the group territory supports monitoring, and more interactions are performed when individual work is not connected in the group territory.

CCS Concepts: • **Human-centered computing** → **Computer supported cooperative work**.

Additional Key Words and Phrases: multi-display environment, tabletop, co-located collaboration, group territory, sensemaking, control, awareness, communication

Authors' addresses: Shuo Niu, shniu@clarku.edu,shuoniu@vt.edu, Clark University, 950 Main St. Worcester, MA, 01610, Virginia Tech, 2202 Kraft Drive, Blacksburg, VA, 24060, USA; D. Scott McCrickard, mccricks@cs.vt.edu; Julia Nguyen, njulia2@vt.edu; Derek Haqq, dhaqq@vt.edu; Lindah Kotut, lkotut@vt.edu; Timothy L. Stelter, tstelter@vt.edu; Edward A. Fox, fox@vt.edu, Virginia Tech, 2202 Kraft Drive, Blacksburg, VA, 24060.

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1 INTRODUCTION

Collaborative sensemaking tasks involving large amounts of data require sensemakers to divide-and-conquer the understanding of the data, then eventually assemble findings. Sensemakers search for initial useful subsets individually, try out different ways of connecting information, and then work together to organize the findings to derive hypotheses [41]. Multiple-display environments (MDEs) are promising and increasingly-common platforms for supporting co-located collaboration on data-intensive sensemaking tasks [27]. To deal with the work division and knowledge integration in a sensemaking process, MDE workspaces are usually partitioned into *personal territories* and *group territories* to accommodate different individual and group activities [47]. Personal territories are dominated by one individual and avoided by others. Group territories are shared spaces where sensemakers assemble individual work, exchange information, integrate findings, and discuss outcomes. Our research examines how sensemakers perform individual searching and organization of the data while establishing group understanding and consensus using these territories.

To address the challenge of supporting collaborative sensemaking [25], more attention has been focused on the design of group territories. Earlier studies on shared workspaces with individual computers explored paradigms of strict view sharing and relaxed-WYSIWIS (What-You-See-Is-What-I-See) [50] for supporting workspace awareness [20]. Side windows that show group work are incorporated into individual monitors to offer peripheral awareness of others' activities and avoid interfering individual work [15, 18, 21]. More recently, the design of group views has focused on supporting more complex sensemaking processes [32, 43] with novel devices such as large tabletops [25, 26, 33], wall displays [37, 52], and handheld devices [5, 55]. The designs of group views seek to balance the individual control and collaborative activities. Views or displays presenting the group territories seek to associate and indicate actions performed in personal territories, display awareness information, and provide attentional foci for discussion, without restricting sensemakers' ability to divide the task and work at the same time.

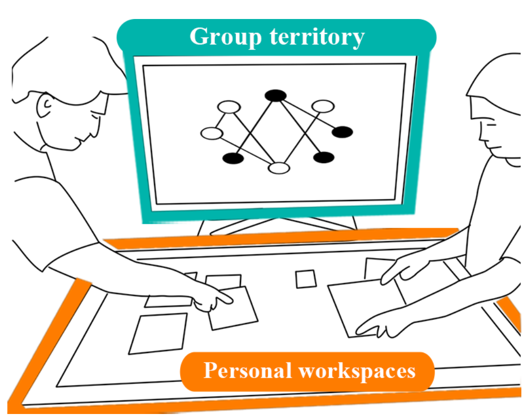

Fig. 2. The MDE setting explored in this study. A tabletop provides a space to establish personal territories and perform individual sensemaking. A vertical display assembles work from personal territories and serves as a group territory. The vertical display present one of the three group territory paradigms.

Although prior work on group territories explored different ways to connect individual work when people need to work at the same time (e.g., [5, 16, 43, 45, 53]), a critical but under-explored question remains – should individual work be connected or separated in group territories of MDEs, and how does this affect collaborative sensemaking? On one hand, separating the data representations from different sensemakers ensures simultaneous and independent work with the massive data, but the lack of linked common work could discourage externalization and communication [32]. On the other hand, connecting related data items using algorithms that dynamically integrate group work and constantly update related information could raise awareness of common activities and provide foci for discussion, but monitoring and coordinating group activities may reduce individual activities and degrade task distribution. This design question is investigated by exploring the design tradeoffs between *separation* and *connection* of group territories in MDEs. This work seeks to understand how different group territory designs facilitate individuals' control over their personal workspaces, support awareness of each other's work, and promote communication on sensemaking activities. Grounded in prior research on co-located sensemaking systems, *group territories* are defined as shared spaces in a multiple-display environment that associate work from the co-located sensemakers. In this work, group territories are presented in spaces between users in a position that is peripheral to personal territories. They are controlled or partially controlled by each sensemaker to support awareness, work integration, and communication.

To gain a deeper understanding of separation and connection of individual work in the group territory, three paradigms for presenting the data are identified. These paradigms separate or connect individual items differently in two factors–*space segmentation* and *relatedness connection*– as identified in review of prior work. Figure 1 shows three paradigms in a visualization, which are generated by the same card placement on a tabletop interface (Figure 6). The *parallel paradigm (PAR)* separates individual work into group territories without showing connections between related items from different people. The *connected paradigm (CON)* separates individual sections as in the PAR condition but uses cross-section links to highlight connections between related items. The *merged paradigm (MER)* shows all individual work in a single force-directed layout, constantly updating related items when changes are made. It uses the same representation for items as PAR and CON, but it uses a merged visual display instead of two separate ones. The differences between these displays, rooted in the parallel, connected, and merged paradigms though also including differences in layout and interaction, are hypothesized to affect the ways in which groups will interact with them.

The three paradigms of group territories are instantiated by an MDE system known as VISGRAINS (VISualizing GRoup Activities IN Sensemaking). VISGRAINS supports co-located sensemaking using a tabletop interface that allows sensemakers to establish personal territories and supports individuals in searching, creating, and organizing data representations. The system incorporates another vertical display between sensemakers to present a collaborative visualization as a group territory (Figure 2). To compare the three paradigms instantiated in VISGRAINS, we conducted a lab-based study of a Twitter analysis task completed by 27 sensemaker pairs. We analyzed the impact of the three paradigms on the effectiveness of sensemaking and collaboration styles. The paradigms are compared using three key collaboration components: control, awareness, and communication, derived from [48]. The findings contribute a comparative understanding of the options for separating and connecting individual work in shared views, visualizations, and display devices. The implications for group territory designs are discussed to advance the understanding of how different types of group territories are used to assemble group work in MDEs and how each type affects sensemaking activities and collaboration. The key findings of the study are:

- Non-connected individual work (PAR) in a group territory ensures control over the workspace and leads to more interaction with the data representations.
- Splitting the visual sections of the group territory to present individual work (PAR and CON) better facilitates monitoring of one's partner's work.
- Automatically integrating an amount of individual information in a constantly updated layout makes the group territory overwhelming and less effective due to the added complexity.
- Separated views without connection (PAR) encourage the establishment of sensemaking roles; links connecting individual sections in a group territory (CON) encourage joint discussion.

2 RELATED WORK

Although many tools are designed for solo information-seeking and sensemaking, it is increasingly common and important to support collaboration in tasks that involve massive amounts of data and information [27, 48]. Not only do increasingly large and complex datasets make such problems infeasible for a single sensemaker, successful collaboration can also help distribute workload, broaden expertise, and foster common understanding [27]. Real-life sensemaking tasks involving large datasets require stakeholders to explore relevant topics among the data individually and later meaningfully assemble findings [41]. This exploratory process benefits from groupware that support sensemakers in searching the data, exchanging findings, and assembling data sub-collections to answer sensemaking questions [26, 33]. This section reviews prior research on shared views for collaborative sensemaking, co-located groupware, and the designs of group territories.

2.1 Shared Views in Collaborative Workspaces

Sensemaking is a process of searching for information, solving ill-structured problems, and participating in social exchanges of knowledge to gain situation awareness from the data [42]. This process consists of multiple loops of searching for information conducted by individuals and making sense of the information through communication [41]. Collaborating on a sensemaking task is not a simple summation of individual thoughts. Gutwin and Greenberg argued that in the co-located workspace, *"individuals demand powerful and flexible means for interacting with the workspace, while groups require information about each other"* [22]. Sensemakers need to delve into individual tasks while also spending time staying aware of and communicating with each other. Chirag Shah has identified *control*, *communication*, and *awareness* as three key collaborative components that affect information-seeking behaviors and sensemaking outcomes [48]. Control over the workspace determines individual power and sensemakers' ability to participate [34, 35, 56]. Awareness is the understanding of others' activities in one's own work context [7, 11, 19, 36]. Communication is the most fundamental channel for exchanging findings and knowledge [14, 32, 48].

Supporting awareness and communication in the design of collaborative sensemaking systems is essential but challenging. When workers are using distributed devices or co-located devices that are not directly accessible to each other to work at the same time, a common solution to promote collaboration is to incorporate shared views. Strict view sharing (WYSIWIS) replicates the information in individual workspaces to support awareness [50]. WYSIWIS design limits individual control when users have different or competing needs. Relaxed-WYSIWIS allows individuals to control their personal workspaces by using side views to deliver awareness information (e.g., fisheye [18] and radar views [21]). Incorporating a shared view peripheral to personal territories helps sensemakers to monitor others' actions while being able to work at the same time [15]. Different forms of shared views (e.g., timeline [39], maps [5, 9], spreadsheet [40], and document graph [32]) are designed to support different tasks. With the advancement of data-processing techniques, automation and visualization techniques have been incorporated into shared views to facilitate sensemaking of more complex data [17, 23, 32].

2.2 Co-located Sensemaking with Tabletop-based MDE

Co-located sensemaking – when multiple sensemakers are present in the same place and working toward a common goal – allows stakeholders to divide the labor, contribute individual insights, and generate shared understandings [25, 48]. Multiple-display environments (MDEs) incorporating multiple computers [3], projectors [12, 43], tabletops [12, 26, 30, 33], wall displays [52], and tablets [5, 54] support co-located sensemaking by enabling simultaneous work, information sharing, and face-to-face communication. MDEs with individual computers have mostly divided personal workspaces. These systems feature displays shared between sensemakers [3, 53] or a group view on individual computers [31, 32] to serve as a territory to present group work. MDEs with touch-enabled devices such as tabletops or tablets allow open observation of other's work and face-to-face communication [4, 28, 33, 54].

Groupware on large interactive displays provide a face-to-face communication channel for exchanging findings. However, most studies on interaction with surface devices focus on interaction techniques, leaving social aspects of collaboration under-explored [27]. When a single tabletop or a large vertical display is used, sensemakers need to preserve personal spaces and work in parallel [26, 47, 52]. It has been widely noticed that people are not willing to give up control of personal workspaces and tend to avoid interfering with others' work [10, 19, 34]. Prior studies explored the use of external shared displays or views between sensemakers to facilitate awareness and communication [5, 8, 16, 53]. Presenting group activities on a secondary display offers peripheral awareness and serves as an attentional focus for communication [5, 46]. However, a recent study shows that interacting with more focused views reduces the actions performed by individuals [57]. Considering that individuals demand control over the workspace and individual exploration helps cover more information [49], it is essential to understand how the group view should be designed to balance collaborative activities in the group territory and individual activities in personal territories.

2.3 Group Territories in Multiple-display Collaboration

Prior research revealed that when people collaborate via multi-user devices, they establish *territoriality* [47] to accommodate different styles of collaboration. Personal workspaces allow for individual searching and information organization. Sensemakers prefer to have their personal territories always-open and uninterpreted by others [10, 29, 35]. Group territories are spaces open to the team and are used for monitoring other's work and assembling the findings. Interfaces of group territories designed to support different sensemaking tasks have been explored (e.g., [5, 32, 43, 45, 53]). Different opinions can be found in the literature as to whether the group territory or shared group views should provide separated individual sections or a merged view with related items connected. Both benefits and costs have been demonstrated for the design choices of separation and connection within the group territory.

Some designs provide space-segmented group territories where individual work is more separated. To support collaboration with individual computers, shared views of relaxed-WYSIWIS such as fisheye and radar view are based on the idea that individuals need flexibility, therefore relaxed-WYSIWIS present individual's view-ports in separated sections in an overall workspace picture [18, 21]. CoSense presents word clouds created by individuals in parallel [39]. Plaue et al. explored side-by-side shared displays and found they helped make like insights [43]. Wallace et al. compared the shared view with separated sections and the one with a status chart of the collaborative work, and noticed that the former was used to discuss common ground and the latter to monitor group activities [53]. When sensemaking roles are established, separated spaces in a group territory enable distributing tasks to allow people to work simultaneously [52]. In tabletop-based meetings, displaying conversation status in sections promoted communication [45].

Many other group territory designs seek to merge related work from personal workspaces. Brudy et al. examined use of an extra tablet in Voyageur which integrated individual work in a shared map and found that the group tablet helps sensemakers to initiate a discussion [5]. Many MDE systems merge geo-tagged information from personal workspaces into a shared map view [4, 6]. Goyal et al. explored implicit sharing by connecting related documents from different sensemakers in one space, which benefits collaboration but not the identification of key information [17]. Andolina et al. designed Querytogether which merges individual findings into different entity categories and found that the shared display does not effectively support common ground [1]. Miniature views in tabletop-based workspaces have been explored in WeSearch, which merges individual work and offer additional awareness, though the author noted that they presented over-cluttered information [33]. Niu et al. found that when findings are merged in the group territory, sensemakers take turns to make changes to the connected digital objects even though the digital workspace is simultaneously accessible to everyone [35]. Morris et al. found that a centralized space in tabletop groupware did not lead to better collaboration than replicated controls, and users actually preferred to have controls distributed in personal territories [34].

In addition to the group territories which segment individual sections or merge individual work, some other designs present individual work separately but connect related parts. Isenberg et al. augmented the WeSearch miniature windows idea and designed new widgets in Cambiera, which align search words from the same sensemaker and indicate the common search words of different sensemakers [26]. Chung et al. implemented VizCept, which groups and color-encodes documents from the same sensemaker and connects related documents from different sensemakers; they found the connections helped to generate sensemaking concepts [8]. Narges et al. investigated CLIP and found that connecting common work from the individuals' workspaces helped sensemakers to externalize the thoughts and communicate and coordinate more effectively [32].

Prior research implied that group territory settings affect sensemakers' individual control, awareness, and communication. The conflicting messages about separating or connecting individual work in a group space make it necessary to examine how each choice affects sensemaking activities and outcomes. This paper seeks to provide a deeper understanding of how three collaborative visualizations, representing three group territory paradigms, affect co-located sensemaking. Through observing sensemakers collaborating using different group territory paradigms, we examine how separation and connection of individual work in group space affects key collaboration components.

3 THREE GROUP TERRITORY PARADIGMS

Team members use the group territory to remain aware of the collective findings and communicate about how individuals' work is related. To investigate different group territories, we consider an MDE with a large multi-touch tabletop to offer personal territories and a peripheral display to serve as the group territory. To facilitate observation, we examine a simplified scenario in which two co-located sensemakers work at two sides of the tabletop and use the shared vertical display as a group territory to assemble findings (Figure 2). The tabletop allows people to establish personal territories and organize the data [47]. Its open face-to-face space helps avoid the degradation of communication caused by eyesight blocking when individual computers are used. The touch interface facilitates exchanging data representations. The group views on a large vertical display are widely used in MDEs [1, 8, 40, 43, 53] to provide better visibility and support joint attention, and are beneficial to present amount of data and their connections. In contrast to group territories of other forms, e.g., shared views at the tabletop center [47] or miniature views in personal workspaces[21, 26, 33], a side vertical display allows sensemakers to view the group territory from the same view angle and directly point to the items in a unified territory.

Based on prior work on shared views or collaborative visualization [5, 21, 43, 53], we identified two factors in group territory design that express the separation and connection of individual work: *space segmentation* and *relatedness connection*. *Space segmentation* refers to whether items from individual workspaces are visually separated. Providing individual sections for each sensemaker's work in a group territory enhances the sense of separation and ownership. *Relatedness connection* is the degree to which similar or relevant items from individual workspaces are connected. Machine learning techniques and data visualization offer technological approaches to automatically identify similar items and visualize related items in the group territory. These techniques can either connect items from individual sections in the group territory or completely merge individual items into one view. Based on the two design factors, this study identifies three paradigms of group territory: the *parallel paradigm (PAR)*, *connected paradigm (CON)*, and *merged paradigm (MER)* (see Table 1).

3.1 Parallel Paradigm (PAR)

The parallel paradigm (PAR) presents individual work in separated sections within the group territory without connecting it (e.g., fisheye [18], radar view [21], replicated view in JSS interface [54], wordcloud in CoSense [39], Figure 3). In co-located collaboration, collaborators establish personal territories near their physical positions to manage individual work [47]. People have a sense of protecting individual work [5, 19] and avoid intruding on others' personal territories [10]. PAR emphasizes preservation of individual sections in the group territory by separating them in the group territory [43, 52]. Changes in one's personal workspace are directly mapped to a section in the group territory, and the different sections collectively present the work of different collaborators. Mapping personal territories to different group territory sections reduces workers' interference with other's control. When two sensemakers work at different table sides, the group territory display also eliminates the need to read each other's work upside-down [29].

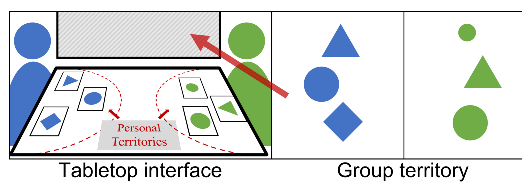

Fig. 3. The concept of the parallel paradigm (PAR) of the group territory

3.2 Connected Paradigm (CON)

The connected paradigm (CON) incorporates separated individual sections in the group territory but highlights related items between them (e.g., CLIP [32], VizCept [8], awareness widgets in Cambiera [26], Figure 4). Similar to PAR, CON maps the personal workspace into the group territory, but it recognizes related item pairs from personal territories and uses cross-section links to connect each pair in the shared view. Prior studies have suggested that connecting common work encourages sensemakers to express personal thoughts and supports coordination and maintaining awareness [32]. CON links similar parts and indicates common items in the group territory [13, 26, 33]. Since CON, like PAR, consists of separated sections, sensemakers preserve their individual work and can also monitor their partners' personal territory via the group territory. Recognizing related data and associating

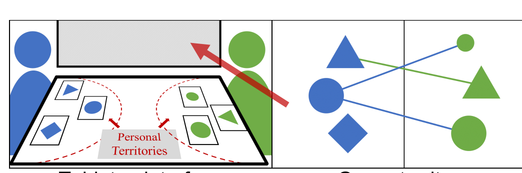

Fig. 4. The concept of the connected paradigm (CON) of the group territory

it into useful subsets centers sensemaking activities [41]. The links in the group territory draw attention to the common work and could trigger discussion about synthesizing individual findings.

3.3 Merged Paradigm (MER)

The merged paradigm (MER) merges all group work together into one integrated visualization (e.g., Analysis Space [17], status visualization in [53], Querytogether [1], overview tablet of Voyageur [5], Figure 5). Like CON, MER also connects related individual items, but it places similar ones closer together in the group territory. It reflects the design of shared views used in prior studies: associating individual contributions with each other, reorganizing collective information by the computer, and presenting group work in one view [1, 5]. MER aims to merge group work to depict the overall work status and knowledge structure [5, 32, 53]. It does not maintain separated sections in the group territory, and thus provides less support for awareness of others' individual work. Merging group work using data processing techniques and dynamically updated visualizations makes the group territory distinct compared to the personal territories. As individual actions result in changes in the group territory, sensemakers need to coordinate actions and interpret the group territory content. MER reorganizes connections between individual items and continuously re-layout to present all links at once, which could potentially support communication of the overall task.

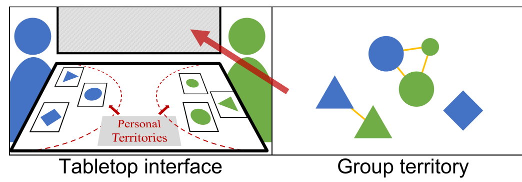

Fig. 5. The concept of the merged paradigm (MER) of the group territory

Table 1. The comparison of three group territory paradigms. PAR separates individual sections and does not connect related work. CON has individual sections but connects related items between different sensemakers. MER does not separate individual sections and constantly updating the force-directed layout.

	Space segmentation	Relatedness connection
PAR	Yes	No
CON	Yes	Yes
MER	No	Yes

4 SYSTEM DESIGN AND IMPLEMENTATION

There has been considerable research into the use of large interactive tabletops and wall displays to support co-located people in searching and making sense of large textual data such as social media data [6, 37], intelligence reports [26, 52], web searches [33], and documents [1]. Prior research has demonstrated ways that searching for words in a large dataset and making sense of the search results are common information-seeking and sensemaking activities that can benefit from large displays [2, 26, 33]. Our system design and implementation captures three common paradigms for showing group information on large displays, as described in this and the next sections. Then, we describe our accompanying study that explores the relative benefits of the paradigms.

This implementation focuses on supporting a basic sensemaking scenario in which two sensemakers collaborate using a tabletop interface to retrieve, organize, and make sense of a large Twitter dataset, while using a vertical display as the group territory to maintain awareness and communicate findings. This scenario represents real-life tasks in which stakeholders gain situation awareness from searching and analyzing large social media datasets [6, 37, 42]. To explore the options for space-segmentation and relatedness-connection in the design of group territories, an MDE-based sensemaking system called *VISGRAINS* is implemented that instantiates the separation and connection of individually retrieved data using three paradigms of group territories.

VISGRAINS allows two sensemakers to search through a Twitter dataset and organize data representations. VISGRAINS incorporates a large tabletop interface for establishing individual work territories, and another peripheral vertical display to show a visualization of group work. Tabletop displays feature a large interactive space and allow multiple users to establish personal workspaces and work at the same time [44, 46]. The VISGRAINS tabletop is a multi-touch interface for viewing, manipulating, and exchanging Twitter data representations. The visualization presents a group territory that assembles the data items created by the sensemakers. The collaborative visualization is implemented on a peripheral display to ensure that the sensemakers have enough space for managing the massive data representations created during sensemaking. The side view also seeks to ensure that the two sensemakers can view it from the same angle and that the connections in the group territory do not directly interfere with personal territories. This setting also facilitates the observation by researchers of users' interactions with the group territory. This study considers sensemaking of data from Twitter due to its popularity as a social media platform and importance in many data analysis tasks [38]. VISGRAINS is tailored to present Twitter data for this study, but it can be configured to support other document types as well. VISGRAINS enables simultaneous searching and organization of search results using the metaphor of digital cards. Sensemakers can visit the retrieved results represented by the cards to obtain an initial understanding of how Twitter users mention the term. Retrieving the data helps sensemakers learn about the dataset. Organizing and categorizing the search results facilitates generation of knowledge structures and acquisition of situation awareness [42].

4.1 VISGRAINS Tabletop Interface

VISGRAINS supports fundamental information-seeking and sensemaking activities: (1) searching keywords among the large dataset, (2) creating interactive data representations of retrieved results, and (3) organizing the search results for sensemaking. The VISGRAINS tabletop interface runs on a 55' Microsoft multi-touch display. The tabletop consists of duplicated controls on each table side to allow simultaneous searching and organization [35]. The design borrows the settings from prior similar systems [26, 33, 57]: two collaborators work at different table sides and interact with touch-enabled cards (Figure 6). Digital cards are an interactive metaphor that has been widely used by prior tabletop systems (e.g., [16, 36, 57]). The individual controls are placed on two opposite table sides to maximize personal territories on the tabletop and to help reduce the conflicts caused by overlapped personal spaces and potential physical contact. Texts on the cards created by one sensemaker will be opposite to the other, which could encourage sensemakers to use the vertical display to read partner's cards. The tabletop interface consists of three parts: two menu bars on two sides to search and create search cards, an open interactive space to organize the cards, and virtual boxes in the middle to categorize the cards. Sensemakers can search for keywords or keyphrases with a pop-up virtual keyboard (②, opened by tapping ① in Figure 6) and retrieve Twitter data from the database. After searching for a word or phrase, a search tab is added (③) and displays the matched tweets in a scroll-able list (④). Double-tapping a tweet opens it on the Twitter website. Clicking the add-card button on a search tab adds a card of the corresponding search onto the table (Figure 6 bottom center). Each search card shows the keyword and number of associated tweets and users (⑦), and can be dragged, rotated, and zoomed in on with touch interaction. Two or more overlapping cards form a *card group* (⑧). Three sort boxes in the middle of the table represent three categories for card organization (⑤). Dragging-and-dropping a card onto a box can sort it to that box, and the card border changes to the box color (⑨). Dragging-and-dropping a card to the recycling bin removes the card from the table (⑥).

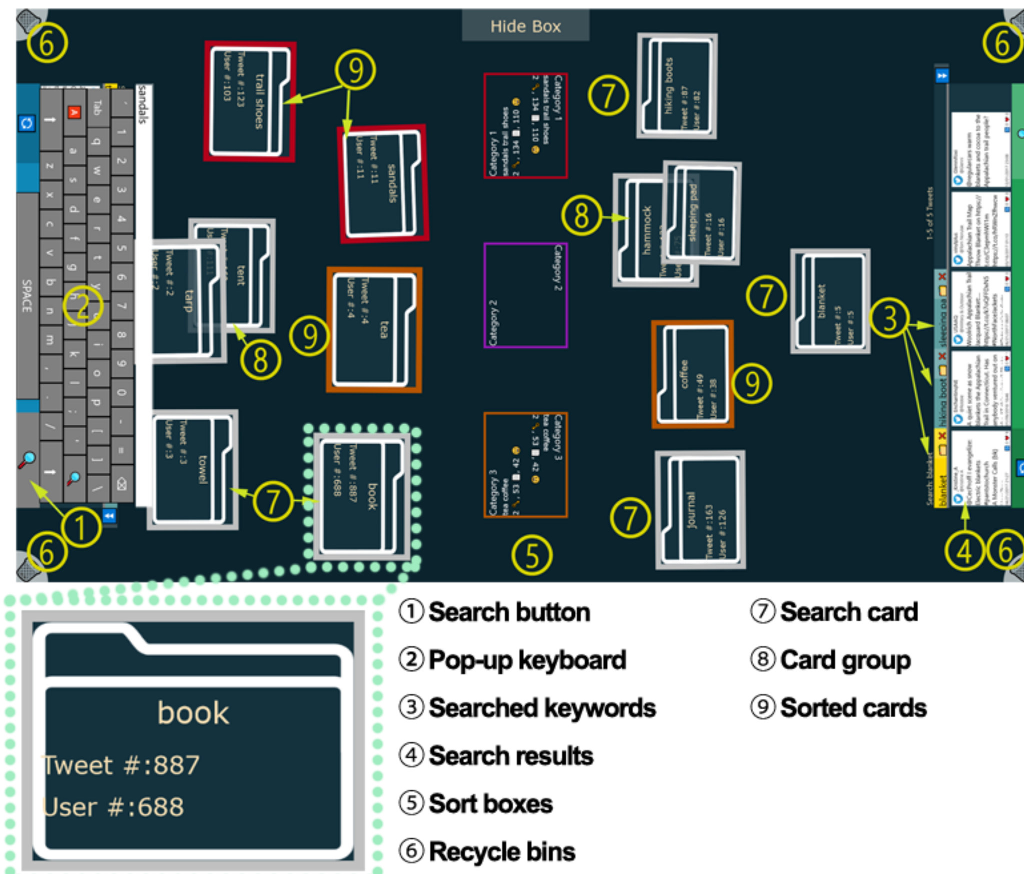

Fig. 6. The tabletop interface of VISGRAINS. Each digital card shows the number of tweets and users mentioning the keyword. Cards can be moved and zoomed in on with touch interaction.

4.2 Implementation of Three Visualization Paradigms

The vertical display has a visualization that presents an overview of card status in the personal territories (Figure 1 left). The visualization uses circle glyphs to represent each search result. The circles on the vertical display can be configured and arranged by interacting with the cards on the tabletop in a real time manner. Each card generates a circle with the keyword, the tweet number, and the user number (Figure 7 left). The circle size is proportional to the number of tweets in the search result. Cards created by the user on the left generate blue circle glyphs, while those by the user on the right generate green circle glyphs. The circle outline changes to the box color after its card has been sorted (Figure 7 middle). For a card group, the circle glyphs are merged into one circle, with tweet number and user number updated to the total number of mentions of at least one of the keywords (Figure 7 right). To compare different ways to present group work, VISGRAINS displays circle glyphs in three different paradigms.

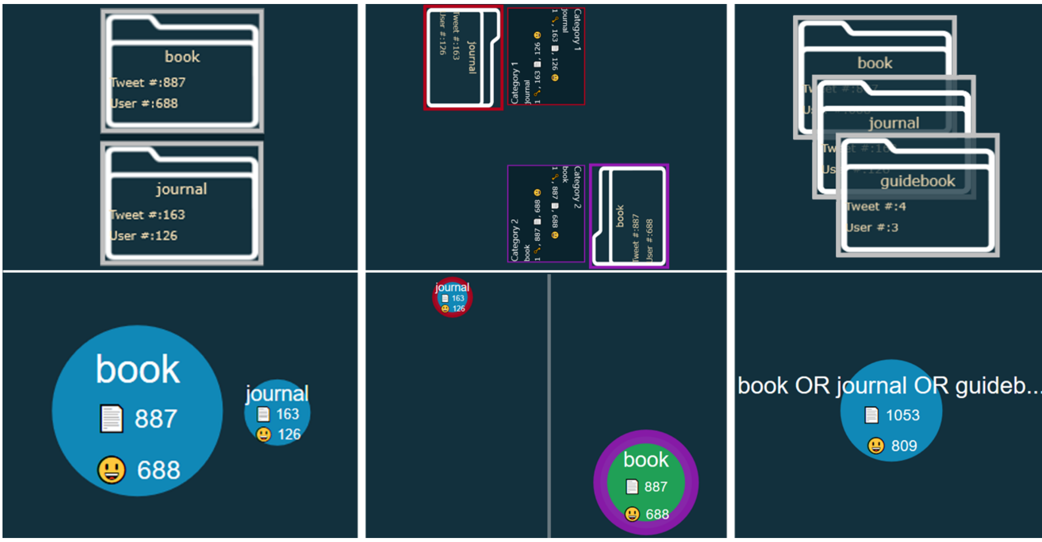

Fig. 7. The top row shows different card placement, while the bottom row depicts the corresponding circle glyphs in the visualization in PAR paradigm. Left: two search cards. Middle: two sorted cards created by different sensemakers in PAR paradigm. Right: a card group created by overlapping the cards.

PAR directly maps the positions of cards or card groups on the tabletop to the positions of the circle glyphs in the visualization (Figure 1 left). Moving the cards will move the corresponding circles in real time. A center line splits the group territory into two sections. The space segmentation of the group territory and the color encoding of glyphs reflect the sense of ownership of individual work and items. Like PAR, CON also directly maps the card positions to the glyph positions, but it uses lines to connect circle glyphs with the same or similar keywords (Figure 1 left). The similar keywords are determined by the Google word2vec machine learning model [1], which builds on the data corpus and can give a similarity score (0-1) to a pair of words or phrases. VISGRAINS determines that two circles/words are similar if the score is above 0.33 (threshold determined by empirical testing). When a card is moved or tapped, the system identifies similar keywords from the workspace and connects their glyphs to the circle of the last interacted card. The last interacted circles turn yellow. One circle from the left space and another circle from the right generate links one at a time. Links from the circle on the left are blue and those from the right are green. Finally, MER does not maintain separated spaces in the visualization. MER directly and dynamically merges all the circle glyphs into a self-layout, node-link graph generated using the force-directed technique [24] (Figure 1 left). The layout of circles in MER is re-generated whenever a change in personal workspace is made. The links are also identified by the Google word2vec method, but all similar keywords in the glyphs are connected at the same time. Adding, moving, or deleting any card from the table will automatically re-position all circles in the visualization to reconfigure the force-directed layout. The regeneration of the layout takes one second.

5 COLLABORATION COMPONENTS

To visualize individual work in the group territory, VISGRAINS uses a node-link graph to represent information and knowledge structures. The three group territory paradigms implemented on

[1] https://code.google.com/archive/p/word2vec/

VISGRAINS are distinguished by space segmentation and relatedness connection (Table 1). Previous studies have found that a group territory can be used to support activity awareness [7], provide materials for discussion [5], and that multi-displays allow individual control over the shared view [43]. To understand the group territories, this study compares the three paradigms with the three key collaboration components identified in [48]: *control*, *awareness*, and *communication*.

5.1 Control

Control over the workspace determines individuals' power to interact with the information and affect the collaboration [19, 32, 49]. When collaborating with a tabletop interface, sensemakers can divide the task and labor and work in parallel [35, 57], or collaborate in a closely coupled way to focus on the same problem at the same time [26, 51]. When interacting with digital cards on VISGRAINS, different visualization paradigms separate or link individual searches in the group territory. The dependency between the different users' work shown by the connections may introduce interference in individual work and reduce the control over the personal territories. Differences in control lead to different utilities of the data artifacts and abilities to contribute to the sensemaking task.

5.2 Awareness

Awareness in the context of collaborative activities refers to users' understanding of each other's activities performed in the work environment [7, 19]. Higher levels of awareness reflect an increase in a sensemaker's ability to consider and use others' findings in the context of his or her own activities [11]. Group territories affect the awareness of others' work and the smoothness of the collaboration [5, 32, 53]. Mapping cards from personal territories in the group territory offers a peripheral space to track others' searches from the other side of the table. Connecting similar searches by machine learning technique indicates common work to facilitate the grouping of related subsets. However, the awareness and understanding of individual and group work also depend on the way similar items are associated, presented, and interpreted.

5.3 Communication

Communication centers the social coordination and knowledge exchange in face-to-face sensemaking [32, 48]. Working separately and independently helps finish personal tasks, but lack of communication may result in duplicated work [36] and less effective teamwork [54]. Authors are increasingly in agreement that close collaboration through discussion and information exchange improves the quality of sensemaking outcomes [26, 52, 54]. The digital cards and the shared visualization in VISGRAINS offer references and materials to support the communication of the search results. Different ways to present group work in a group territory offer different information to discuss. Non-connected individual work depends on interpretation and discussion to synthesize group work. Automatically related items can be associated to form conceptual groups. Different paradigms of separating or connecting individual work could affect the approaches sensemakers take to reach a common ground and agreements.

6 USER STUDY

To investigate the effectiveness and effect of different paradigms for utilizing the group territory, a three-way comparative study is conducted with the PAR, CON, and MER implementations in VISGRAINS. The user study examines a collaborative Twitter analysis scenario in which sensemakers divide the searching and organization labor, and discuss with the group territory in VISGRAINS to associate findings. Study data is collected on the effectiveness of sensemaking, styles of collaboration, and the collaboration components of control, awareness, and communication.

6.1 Task Design

This study explores a scenario in which two collaborators divide a list of relevant topics to explore and use large interactive displays to make sense of a Twitter collection. Twitter data is chosen because it is increasingly used to forage for and make sense of public information to support decisions. The user study examines the sensemaking tasks that require searching for different keywords, organizing the information, and making sense of the facts. Specifically, pairs of sensemakers address a list of questions by exploring different items, organizing the information, and exchanging knowledge about findings. Searching for different concerns individually and interpreting search results together is a common practice to make sense of large textual data. Such collaborative information-seeking activities have been seen in analysis of crisis social media [6], intelligence reports [26], and other large documents [25, 48] The participants are asked to collaborate with their partner and use VISGRAINS to search for 50 hiking items among a hiking tweet dataset, and to answer a list of questions about the dataset. The Twitter data used in the study is a collection of 65,617 tweets crawled from Social Feed Manager [2] with the seed "Appalachian Trail" between Jan. 11, 2017 and Jan. 10, 2018.

6.1.1 Sensemaking Tasks. One participant is given a list of 25 items and the other the remaining 25 items, for 50 total. All items were identified, categorized, and assigned by the research investigators to one of the two lists in preparation for the study. On the worksheet, each hiking item contains a name, a picture, and a short description. Before beginning the tasks, a researcher introduces the VISGRAINS system to the participants, demoing functions including keyword searching, tweet viewing, creating and manipulating search cards, and sorting the cards. The visualization is introduced and its mapping to the card is explained. Each team has a 5-minute trial task to search for and sort eight words (lake, mountain, hill, valley, etc.) and answer three questions similar to the actual task questions. The participants are instructed to search for their own 25 items, work on their own side of the table, and complete the task together in 45 minutes. A researcher stays in the corner of the experiment room during the task to provide step-in help with the system, but does not intervene in the sensemaking process.

The experiment task consists of 11 questions provided on sheets of paper (see Table 2 for the questions). The two participants have identical question sheets and are informed that all questions are based on all 50 hiking items. The questions simulate a foraging process, in which the participants must sort the cards into general categories, and a sensemaking process, in which they must determine key facts about the data [41]. To ensure an optimal set of search terms to answer these questions, participants need to exchange information and pass the cards to form card groups. During the task, the participants are encouraged to use the shared visualization to identify related items. To calculate the number of tweets mentioning a group of items, participants are instructed to form card groups by overlapping multiple cards and to read the number from the combined circle glyph in the visualization. For the groups with CON and MER paradigms, participants are informed that related items are connected by the lines.

6.2 Measurements and Data Collection

Data is collected on three aspects: sensemaking effectiveness, collaboration styles, and the three key collaboration components. Overall effectiveness reflects the general usefulness of different group territories. Collaboration styles refer to the ways in which the system is used. The analysis of collaboration components helps to understand the advantages and disadvantages of each paradigm. The data is collected from system logs, video recordings, a post-study questionnaire, and answers on

[2]https://gwu-libraries.github.io/sfm-ui/

Table 2. Questions to be answered by the participants

Q1	Identify the top three items that have the largest number of tweets
Q2	Categorize 50 items into three categories, with each category containing 5-15 items. Write a short description about each category.
Q3-Q8	Identify four items that are related to a specific item (six different items for six questions). How many tweets mention these items?
Q9-Q10	Identify the top five electronic devices/overnight items. How many tweets mention these items?
Q11	Are there more tweets about cold or hot weather hiking?

the worksheet. VISGRAINS records every card movement with a time-stamp and screen coordinates on the tabletop. A camera records the participants' actions, the focus of attention, and conversation during the task. A post-study questionnaire is taken by every participant separately; it includes Likert-style questions and open-ended comments about the tabletop, the visualization, and the collaboration with the partner.

6.2.1 Effectiveness of sensemaking. Effectiveness of sensemaking is explored through the answer quality, task time, and subjective difficulty. The answer quality is measured using the missed items from the majority answer. Q3 to Q10 ask the participants to find multiple hiking items to form card groups and determine the tweet number (Table 2). The "golden answer" to Q3-Q10, respectively, is defined as the most common items identified by all the participants to answer that question. Then, for each participant group, the researchers count how many items in total are missed from the golden answers of Q3 to Q10. Making sense of a large dataset asks sensemakers to acquire situation awareness from the data. Recognizing common conclusions indicates that sensemakers obtained the commonly identified knowledge through collaboration [42]. Failure to identify common items in the answers indicates that the sensemaking missed information that could make more sense. The task time is tracked by VISGRAINS, from the launching to the closing of the system. Task difficulty is rated on a 7-point Likert-style scale in the post-study questionnaire.

6.2.2 Styles of Collaboration. Identifying and analyzing styles of interaction with MDEs centers the study of co-located collaboration. In this study, styles of collaboration are developed based on prior work and re-configured for this study's specific setting [5, 26]. The collaboration styles in which sensemakers use the visualization and tabletop interface to answer the questions are observed and identified to describe how attention is focused [5, 26]. Four researchers (who also encode the videos) watch four videos independently and make notes. The style categories are generated through affinity diagramming of the notes. Three hundred screenshots from six other videos (two from each condition) are sorted to validate the categories.

A total of 11 collaboration styles with six different styles of attention focus are identified (Figure 8). The styles are grouped by whether the participants communicate, interact with the cards, or maintain awareness of the collaborative work. Face-to-face communication (FTF) is when participants talk face-to-face. In joint focus on tabletop (FT) and joint focus on visualization (FV), the participants use cards on the table or the shared visualization to discuss or think about answers. Joint focus on different displays (FDD) and joint focus on one's workspace (FOW) reflect the time when the task is led by one participant and the other participant looks at his or her partner's cards or visualization, respectively, to give comments or just to observe his or her partner's work. Focus on individual workspaces (FIW) is a style in which the two participants interact with cards at the same time, with or without occasionally exchanging information. To distinguish communication versus no communication, sub-styles use trim -C (communication) and -N (no communication) to annotate conversation status for FT, FV, FDD, FOW, and FIW (e.g., FV-C is a sub-style when participants look at the visualization and talk; FV-N is a sub-style when participants look at the visualization but do not talk). To encode the video, each recording is segmented based on speech sessions (conversations about the same topic marked by the researchers) and interaction sessions (periods of time when two consecutive interactions are less than five seconds apart, as identified from the system record). Videos are separated by the beginning and end of speech and interaction sessions. One segment is tagged as one of the collaboration styles. Each video is tagged by two coders, and the third coder tags sections on which there is disagreement. The majority tag is used as the final style of each video segment. The video encoding is analyzed with ANVIL software[3]. The normalized time proportions are used to compare different paradigms with each of the collaboration styles. The initial agreement rate of tagging was 52%. The disagreed tags were solved by assigning 27 movies to the 4 coders (three coders solved 7 videos each and one coder worked on the remaining 6 videos).

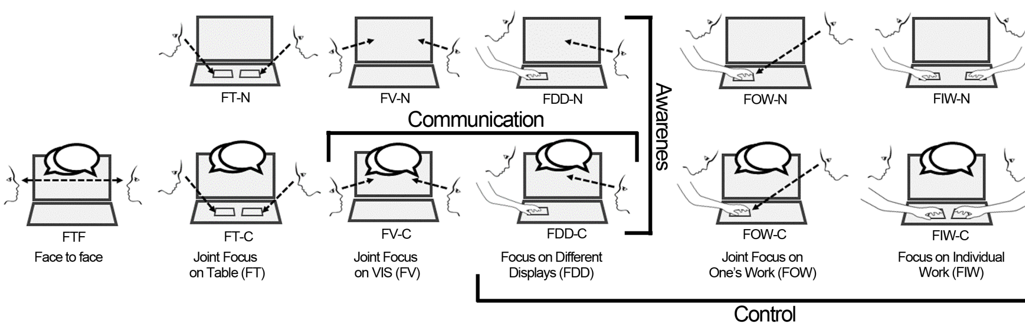

Fig. 8. Collaboration styles when interacting with VISGRAINS

6.2.3 *Collaboration Components.* Collaboration components are measured using a questionnaire, system logs, and video data. Different collaboration styles reflect different collaboration components affected by different group territories. In FDD, FOW, and FIW, participants interact with personal territories, indicating a higher level of control (Figure 8). Control is also measured by the amount and frequency of card movements, as well as by two questions about work altered by the partner and whether it is easy to concentrate on the individual task. FDD is when one participant works on the individual task and the partner obtains awareness of the changes from the group territory. Awareness is also compared by asking participants whether they use the tabletop or the visualization to track their partner's work, and another three questions about the effectiveness of the group territory in finding items. FV and FDD describe participants discussing the integrated work from the group territory. In addition to the video encoding, communication is also measured using a question about whether the participants refer to the visualization or the tabletop when discussing answers to the questions. To analyze the three collaboration components, we use the proportion of the time spent on the styles related to control, awareness, and communication as component scores. Scores on the three collaboration components are calculated based on the following formula (t is the normalized time spent on each style of collaboration, ranging 0%-100%):

[3]http://www.anvil-software.org

$$S_{CONTROL} = t_{FDD-N} + t_{FDD-C} + t_{FOW-N} + t_{FOW-C} + t_{FIW-N} + t_{FIW-C}$$
$$S_{AWARENESS} = t_{FDD-N} + t_{FDD-C}$$
$$S_{COMMUNICATION} = t_{FV-C} + t_{FDD-C}$$

7 RESULTS

A total of 54 college students (age 18-23, with 30 females) participated in the study. They were recruited from an email list and a pool of student volunteers. The participants' majors included computer science (19), psychology (10), neuroscience (5), human nutrition, foods, and exercise (5), and biology (3), among others. They were randomly assigned to one of the three conditions, with nine pairs using each of the group territory paradigms. The average task time was 37.52 minutes ($SD = 7.09$). The significance analysis for collaboration styles and system logs was performed with a one-way MANOVA, with the follow-up tests using the univariate ANOVAs and the Tukey-Kramer HSD. The missed common answer was analyzed using the one-way ANOVA test. The questionnaire results were analyzed with the Kruskal-Wallis test with the post-hoc analysis using the Mann-Whitney test. The significance level was set to 0.05. The normality was verified with the Shapiro-Wilk W test. The data from system logs and collaboration style encoding was all normally distributed. The video analysis revealed a statistically significant difference in scores on the collaboration components ($S_{CONTROL}$, $S_{AWARENESS}$, and $S_{COMMUNICATION}$) based on the group territory paradigm used ($F_{(3,22)} = 88.11$, $p = 0.016$, $Pillai'sTrace = 0.56$, Figure 11). In measurements of the system logs, including task time, card movement count, move frequency, card exchange count, and move other's cards count, there also existed significant difference ($F_{(5,20)} = 1019.98$, $p = 0.044$, $Pillai'sTrace = 0.67$). The following sections explain the results and refer to participant groups working with the group territory paradigm of parallel, connected, and merged as PAR groups, CON groups, and MER groups.

7.1 Sensemaking Effectiveness

The overall sensemaking effectiveness of the three paradigms was analyzed by comparing missed common answers, total task time, and subjective rating of the task difficulty. The quality of sensemaking outcomes was measured by how many common items for Q3-Q10 were not included in the corresponding answers. According to the results, PAR, CON, and MER groups missed 4.78, 4.33, and 6.67 common items respectively ($SD = 1.30$, 1.73, and 6.67, $F_{(2,24)} = 5.22$, $p = 0.013$, Figure

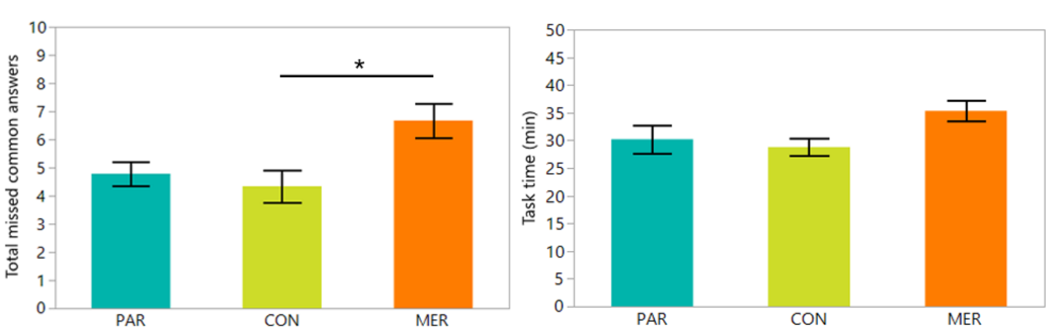

Fig. 9. Left: the number of missed common items for Q3-Q10. Right: the task time. Horizontal lines indicate statistical significance. Asterisks indicate p values from the Tukey-Kramer HSD test (p*<0.05, p**<0.01, p***<0.001).

9). The pairwise analysis further revealed that MER groups missed significantly more answers than CON groups ($p_{(CON,MER)} = 0.015$). MER groups took 41.52 minutes to complete the task ($SD = 6.24$), which was more than the PAR and CON groups (no sig, $mean_{PAR} = 36.16$, $SD = 8.15$, $mean_{CON} = 34.87$, $SD = 5.49$). When asked *"how difficult was it to complete this task (1-very easy and 7-very hard)?"*, the MER groups gave an average rating of 4.00 ($SD = 1.58$), which was lower than the ratings for PAR and CON groups ($mean_{PAR} = 5.28$, $SD = 1.13$, $mean_{CON} = 4.27$, $SD = 1.18$, $\chi^2 = 7.90$, $p = 0.019$, Figure 12 (1)). Pairwise comparison shows that MER groups rated the task significantly harder than PAR groups ($p_{(PAR,MER)} = 0.008$). The results regarding sensemaking effectiveness show that the MER groups were the least effective, while the performance of the PAR and CON groups was similar.

7.2 Collaboration Styles

During the task, participants began by searching all hiking-related items and creating cards, then organized the cards to answer the task questions. Since searching for the words was mostly conducted individually without referring to the group territory, the collaboration style analysis only includes the phase after all hiking-related items are searched and began to answer the questions with the cards. The analysis of collaboration styles revealed similar collaboration patterns as in previous studies [5, 26, 35]: working in the personal territories took the majority of the task time (Figure 10). In the video encoding results of the 11 collaboration styles with VISGRAINS (Figure 8), focusing on individual workspaces (FIW), a loosely coupled style, entails two sensemakers working individually on their own side [51]. It was noticed that PAR groups spent more time on FIW than CON and MER groups (no sig). One-way MANOVA revealed that significant differences exist among FV-C (focusing on the visualization and communicating), FV-N (focusing on visualization and no communication), and FOW-C (focusing on one's workspace and communicating, $F_{(3,22)} = 18.05$,

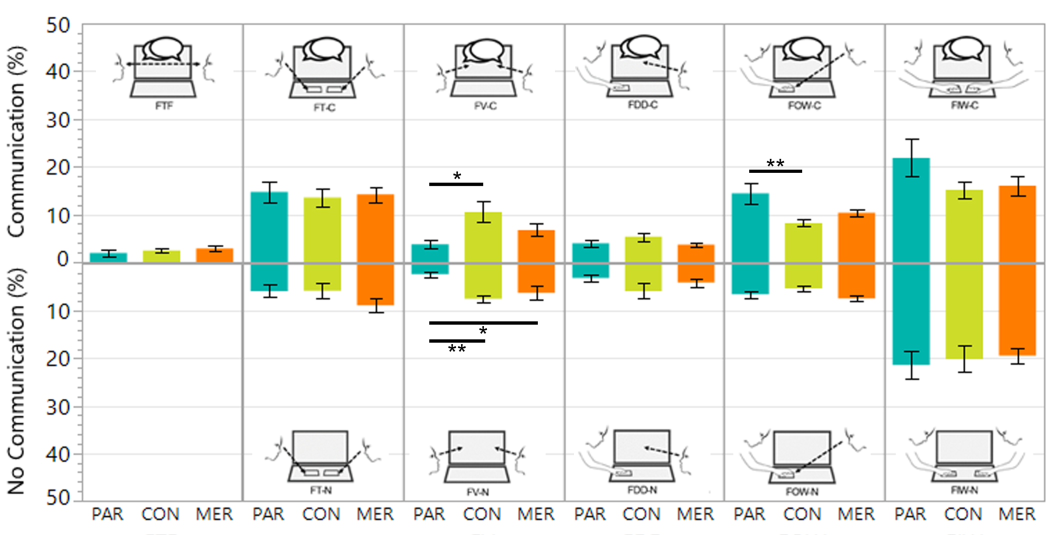

Fig. 10. Time distribution among six styles of collaboration. Top bars are time with communication. Bottom bars are time without communication. Red horizontal bars indicate statistical differences between different collaboration styles. Black Horizontal bars indicate statistical differences between communication sub-styles. Statistical differences are identified using the Tukey-Kramer HSD test (p*<0.05, p**<0.01, p***<0.001).

$p = 0.009$, $Pillai'sTrace = 0.60$). CON and MER groups spent more time looking at the group territory together in the FV-C and FV-N styles, and in both cases, this result was greater than that of PAR groups (see Figure 10 for significance levels). In addition to working separately in the personal territories, PAR groups also spent the most time on FOW-C, with PAR groups spending more time than CON groups. From these results, it can be observed that those in PAR groups tended to spend more time working in their personal territories, or with one participant helping the other. CON participants spent more time looking at the visualization and seeking the answers together. When collaborating with their partners, MER participants tended to look at the cards on the table rather than the visualization, indicating that their use of the latter was limited. CON and MER groups spent less time (this difference was not significant) working individually (FIW), suggesting the need to further investigate how to coordinate actions between the partners.

7.3 Control, Awareness, and Communication

Control, awareness, and communication are three key collaboration components in co-located sensemaking. This study seeks to understand whether and how different paradigms for segmenting individual sections and connecting related items in the group territory affect the three collaboration components. Our analysis of the three paradigms depends on associating the video encoding of collaboration styles (Figure 10), system logs, and post-study question (Figure 12).

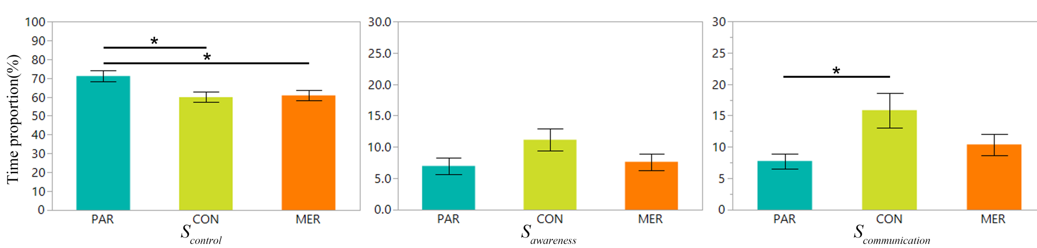

Fig. 11. The score of control, awareness, and communication from style analysis. Horizontal lines indicate statistical significance. Asterisks indicate p values from the Tukey-Kramer HSD test (p*<0.05, p**<0.01, p***<0.001).

7.3.1 *Control.*
In the styles of FOW, FDD, and FIW, sensemakers interact with the digital cards and control the workspaces. When comparing $S_{CONTROL}$ ($F_{(2,24)} = 0.014$, $p = 0.014$), PAR groups

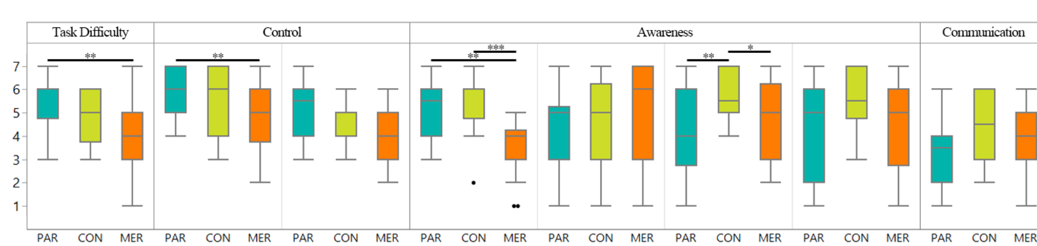

Fig. 12. Questionnaire results from the three conditions. All questions are Likert-style with a scale of seven. The box plots show the 25%, 50%, and 75% quartiles. Horizontal lines indicate statistical significance. Horizontal lines indicate statistical significance. Asterisks indicate p values from the Tukey-Kramer HSD test (p*<0.05, p**<0.01, p***<0.001).

were found to spend more time controlling the personal territories than CON and MER groups (Figure 11 left). PAR groups' $S_{CONTROL}$ was 71.12% (SD = 8.29), significantly higher than CON's 59.90% (SD = 8.28, $p_{(PAR,CON)}$ = 0.022) and MER's 60.78% (SD = 8.28, $p_{(PAR,MER)}$ = 0.036). Groups with the PAR paradigm also had the highest touch frequency and gave the lowest rating of the level of interference. PAR groups moved the cards more frequently ($mean_{PAR}$ = 43.48ct/min, SD = 13.12, $F_{(2,24)}$ = 4.77, p = 0.018, Figure 13 right) – significantly more frequently than CON groups ($mean_{CON}$ = 32.27ct/min, SD = 5.38, $p_{(PAR,CON)}$ = 0.042) and MER groups ($mean_{MER}$ = 31.48ct/min, SD = 7.34, $p_{(PAR,MER)}$ = 0.028). PAR groups moved the cards 1572.67 times on average (SD = 615.92), while CON and MER groups did so 1111.56 times and 1296.67 times (no sig, SD = 178.42 and 295.42, Figure 13 left) respectively. These results reflect that the groups with the PAR paradigm moved their cards more freely than those in the other two conditions, which indicates higher control over the workspace and shared artifacts.

Based on the questionnaire results, PAR participants also felt that their work was less altered by their partner and that it was easier to concentrate on individual work. When asked *"how often did the partner alter the cards you were using (1-always, 4-neutral and 7-never)?"*, the PAR respondents gave an average rating of 6.00 (SD = 1.08), which was significantly higher than the MER groups' rating ($mean$ = 4.72, SD = 1.49, χ^2 = 7.06, p = 0.03, $p_{(PAR,MER)}$ = 0.009, Figure 12 (2)). PAR participants also found it the easiest to concentrate on their individual work ($mean_{PAR}$ = 5.05, SD = 1.21); they rated this higher than the CON and MER groups (no sig, $mean_{CON}$ = 4.72, SD = 0.83, $mean_{MER}$ = 4.28, SD = 1.18, Figure 12 (3)). The results of the two questions suggest that the non-connected paradigm reduced the interference with each other's work.

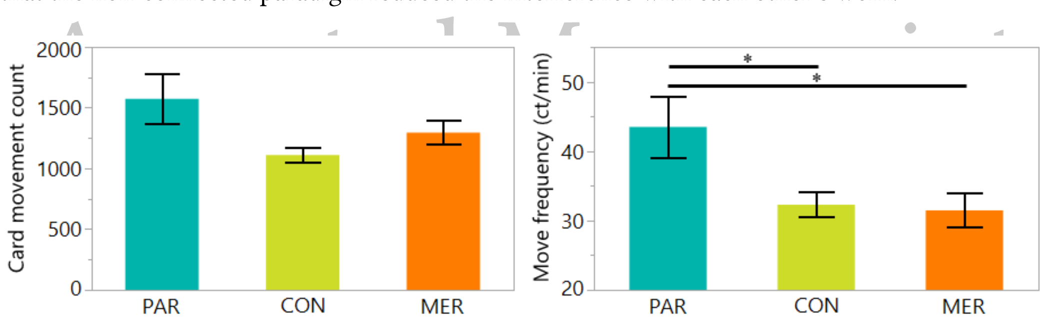

Fig. 13. Left: card movement count. Right: card movement frequency. Error bars show standard errors. Horizontal lines indicate statistical significance. Asterisks indicate p values from the Tukey-Kramer HSD test (p*<0.05, p**<0.01, p***<0.001).

7.3.2 Awareness. In the style of FDD, sensemakers consider group activities from the group territory. When comparing FDD, PAR groups were found to spend less time monitoring others' work and had lower $S_{AWARENESS}$ (no sig, Figure 11 middle). However, from participants' comments, the shorter time spent monitoring others' work did not mean that PAR groups did not use the group territory to maintain awareness. In fact, PAR and CON groups found the visualization more helpful than the tabletop to monitor others' work. When asked whether they found partners' items in the visualization or on the tabletop (1-tabletop only, 4-half/half, 7-visualization only), groups with PAR and CON gave an average rating of 5.17 (SD = 1.29) and 5.39 (SD = 1.29), significantly higher than MER groups ($mean_{MER}$ = 3.61, SD = 1.24, χ^2 = 16.13, p < 0.001, $p_{(CON,MER)}$ < 0.001, $p_{(PAR,MER)}$ = 0.002, Figure 12 (4)). The reason PAR groups spent less time looking at the group territory when the partner was working could be that the parallel paradigm made it easier to capture others' work, so that it required less time reading the group territory. For example, one PAR participant commented in the open-ended questions of the questionnaire about the visualization: *"the visualization on the vertical display helped me see what my partner was doing with her cards and help us figure out how to categorize my cards. I also found it useful in searching for a particular card."* Another participant from a different PAR group noted *"the vertical display was useful in collaborating with my partner, except for the fact that it was delayed in updating. However, it was particularly useful in determining what cards my partner had and was the quickest way to see how many tweets were counted in each card pile."* Similar comments were given regarding the CON paradigm. For example, one participant with the CON group territory stated, *"the visualization is where most of the collaboration comes in. It helped tremendously to see what the other person was doing"*. However, the links in the group territory caused confusion when several terms were related: *"(the visualization) allows you to see the related items very easily, but if there are a lot of items on the board then it's sometimes very difficult to see related ones because the lines overlap."* In contrast to PAR and CON, MER group found the connected group items in the group territory overwhelming and could hinder awareness: *"with large amounts of data, the connecting lines were more distracting than helpful ... (though) it was helpful to be able to see what my partner had."* and *"I think the visualization helped very much with tweet counting and finding the largest/most tweeted terms ... however, the relations indicated by the yellow lines were almost useless as they seemed to overlap too much for a user to interpret."* From these results, it was found that participants with the PAR and CON group territories used the vertical display to track their partners' work, suggesting that the separation of individual sections in the group territories helped maintain awareness. On the other hand, due to the additional information from interpreting lines in CON, using this paradigm to track others' work costed more effort and led to more time spent on looking at different displays (FDD).

In the question sheet, Q2 asked participants to identify categories; Q3-8 instructed them to identify items related to a specific item; and Q9-11 required them to find items with common features. The post-study questionnaire asked them how useful the collaborative visualization was in answering each type of question. The CON paradigm seemed to better support Q3-8 and Q9-11, but did not show a compelling advantage in identifying overall categories (Q2, Figure 12 (5)). The CON groups rated the helpfulness of the visualization in finding items related to a specific item as 5.89 (SD = 1.08), which is significantly higher than the ratings of the PAR groups ($mean_{PAR}$ = 4.17, SD = 1.89, $p_{(PAR,CON)}$ = 0.006) and MER groups ($mean_{PAR}$ = 4.72, SD = 1.71, $p_{(CON,MER)}$ = 0.042, χ^2 = 8.36, p = 0.015, Figure 12 (6)). Based on the post-hoc analysis, CON also appeared to be superior to PAR in supporting the search for items that shared some common features (no sig, Figure 12 (7)). The results indicated that in addition to supporting the monitoring of partners' work, the CON paradigm also helped participants to be aware of related items from the group territory.

7.3.3 Communication. Communication and information exchange are forms of close collaboration and center collaborative sensemaking activities [27, 32]. It was noticed that participants in the CON paradigm condition tended to communicate by looking at the group territory and discussing answers together, while PAR groups exchanged cards on the tabletop and determined the answer by following one participant's lead. Though there was no difference in total time of communication, the video analysis revealed that CON groups had higher $S_{COMMUNICATION}$ score ($mean_{PAR}$ = 7.76%, SD = 3.63, $mean_{CON}$ = 15.85%, SD = 8.25, $mean_{MER}$ = 10.34%, SD = 5.09, $F_{(2,24)}$ = 4.30, p = 0.025 $p_{(PAR,CON)}$ = 0.022, Figure 11 right). CON groups spent significantly more time looking at the group territory and discussing, indicating that they used the vertical display as a focus for discussion. However, PAR groups spent more time on FOW-C, with one participant interacting with the cards and the other participant communicating with her or him. The FOW-C for PAR, CON, and MER was 14.43%, 8.21%, and 10.35% respectively (SD = 6.32, 2.30, and 2.10), with PAR groups significantly higher than CON groups ($F_{(2,24)}$ = 5.43, p = 0.011, $p_{(PAR,CON)}$ = 0.009, Figure 10). This result indicates groups with PAR had more time with one participant leading the collaboration (Figure 14 left). When asked whether they looked at the visualization or the tabletop when discussing (1-tabletop only, 4-half/half, 7-visualization only), groups with CON group territory indicated looking at the visualization more than the PAR groups did. Groups with CON gave an average rating of 4.5 (SD=1.50), while the groups with PAR and MER rated this 3.44 (SD=1.38) and 3.83 (SD=1.38) respectively (no sig, Figure 12 (8)). The results suggested that CON encouraged participants to look at the group territories and discuss answers together (Figure 14 right).

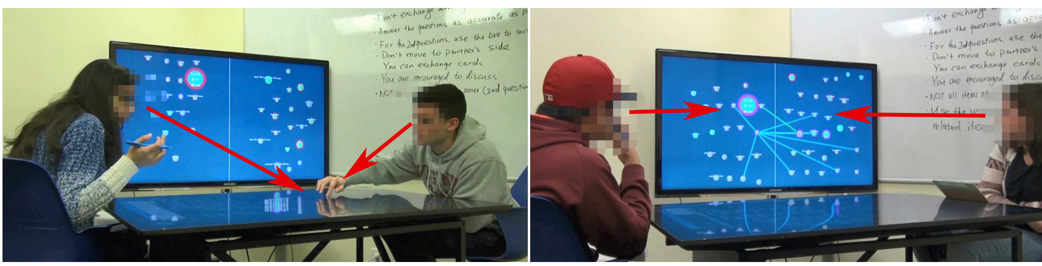

Fig. 14. Group PAR and CON used different styles of collaboration when answering questions. PAR groups (left) tend to gather useful cards to one's workspace and figure out the number from the visualization. CON groups (right) look at the visualization together and discuss.

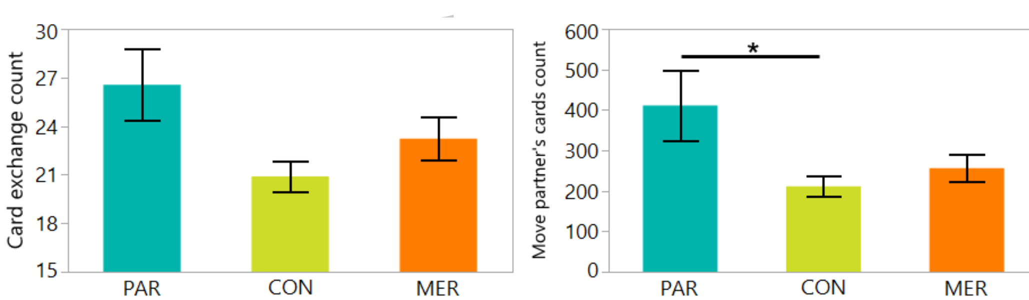

Fig. 15. Left: number of cards exchanged during the task. Right: card movements performed on the cards created by one participant and passed to the partner. Horizontal lines indicate statistical significance. Asterisks indicate p values from the Tukey-Kramer HSD test (p*<0.05, p**<0.01, p***<0.001).

The card exchange analysis also showed that PAR groups had one participant dominate the sensemaking while the partner foraged for useful information. PAR groups had more cards passed to the partner's space than the CON groups (no sig, Figure 15 left), and PAR participants performed more movements on the cards created by their partner (Figure 15 right). CON groups passed 20.89 cards on average ($SD = 2.76$) while the PAR groups passed 26.56 cards ($SD = 6.64$). PAR participants performed more actions on cards created by their partner ($mean_{PAR} = 410.89$, $SD = 263.02$, $mean_{CON} = 211.67$, $SD = 79.00$, $mean_{MER} = 256.22$, $SD = 98.73$, $F_{(2,24)} = 3.47$, $p = 0.048$ Figure 15 right) – significantly more than that of the CON groups ($p_{(PAR,CON)} = 0.049$). Figure 16 shows the accumulated move traces of the cards created by one participant but moved to the other participant's territories. PAR groups moved cards created by the partner more than CON and MER groups. Instead of discussing the answer with the group territory, the PAR groups preferred to pass potentially useful cards to each other and then made the decision (Figure 14 left). Summarizing these results, it was noticed that PAR groups had one participant act as the *forager* while the other led the decision as the lead *sensemaker*, which suggested that group territories with space segmentation may encourage the assignment of sensemaking roles [52].

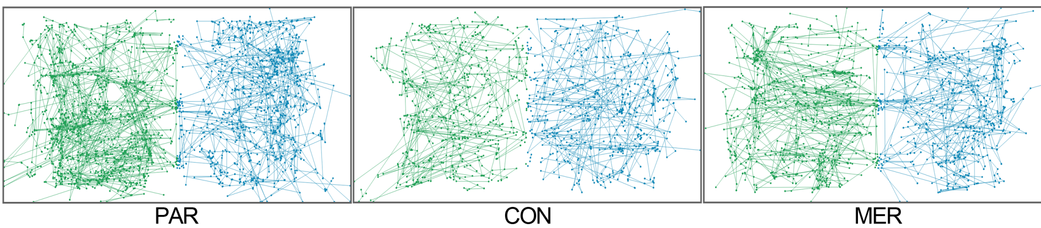

Fig. 16. Accumulated traces of cards created by the partner. Green lines are traces of cards created by the participant on the right but moved to the left side of the table. Blue lines are traces of cards created by the participant on the left but moved to the right side of the table. PAR groups performed highest movements on cards created by the partner. PAR's movement count is significantly higher than CON's.

8 DISCUSSION

Group territories in multi-display environments (MDEs) are key collaborative spaces in the process to obtain awareness [26, 33] and serve as channels for communication [5, 53]. Prior studies examining shared views have identified benefits of both separated and connected individual work. This study further investigates the space segmentation and relatedness connection by comparing three paradigms of group territories.

Finding 1: In co-located sensemaking, non-connected individual work (PAR) presented in a group territory ensures control over the personal territories and leads to more interaction with the data representations than having individual work connected (CON and MER).

The PAR paradigm uses separated views without connecting individual work in the group territory, which leads to higher interaction frequency and movement count with digital cards. Prior research found that sensemakers who collaborate with separated computers visit more information than those who use one shared computer [49]. An extra shared screen allows sensemakers to display personal content to the team without interfering with others' work in the group territory [43]. Relaxation of group views allows sensemakers to have more flexibility in individual work [21, 50]. This study's results show that more individual interaction with the cards is ensured by the less inter-dependent presentation of group activities. Displaying group work without relating the items of different sensemakers retains the individual control over the personal territories, which reduces interference and leads to more interaction with the digital cards. The higher card movement count and frequency with the PAR paradigm suggest that reducing connections between sensemakers in a group territory could avoid mutual influence and protect engagement in the personal territories. When designing group territory functionalities in co-located MDEs, designers could consider displaying individual work in parallel to ensure free interaction with personal territories.

Finding 2: In a group territory, segmenting the visual sections on the display to present individual work (PAR and CON) helps monitor partners' work better than merging items from different sensemakers into one integrated view (MER).

Prior studies on co-located collaboration have suggested that groupware needs to support workspace and activity awareness [7, 20]. The relaxation of view sharing should support awareness of each other's activities [7, 18, 21]. On-screen widgets [26, 33] and separated overview displays [5, 53] have been introduced in prior work to enhance sensemakers' awareness of others' actions and activities. This study's results indicate that distinguishing others' work from one's own by splitting view spaces in the group territory makes a shared overview more beneficial in tracking others' work. In this study, the PAR and CON paradigms of VISGRAINS projected the cards on the tabletop to the group territory and displayed individual glyphs separately. The layout of visual representations was not automatically adjusted to integrate group work. Participants with PAR and CON considered the visualization more helpful in finding items from their partner's side. CON also helped them stay aware of their partner's related items and items with common features. The results of this study implied that for the group territory design in MDEs, separated individual sections that map personal territories could allow the group territory to better support awareness of partners' activities.

> Finding 3: Automatically and constantly integrating a large amount of individual information could make the group territory overwhelming and less effective; synthesizing individual work needs to account for complexity to the task.

Prior research has examined the linking of common work to encourage the expression of individual thoughts and the coordination of collaborative activities [32]. Duplicating a shared view (e.g., strict WYSIWIS) may not offer enough value to sensemaking tasks [50, 53]. VISGRAINS provides two different ways to link individual work: connecting related items from the personal territories when performing actions (CON) and merging all items from the personal territories generating a layout automatically (MER). In this experiment, MER led to worse task performance than CON and PAR. MER groups found the fewest key items for the questions, spent the longest time on the task, and gave it the highest difficulty rating. Though both CON and MER link individual work, the higher level of interference and weak awareness with MER reduce its effectiveness. The dynamically integrated group work and constantly updated visualization did not show benefits in supporting awareness and communication. Presenting all information at once complicates the group territory and reduces its benefits in supporting awareness. Its auto-arrangement of items from personal territories also make the group territory less similar to personal workspaces and break the WYSIWIS relationship between personal and group views. Many prior systems consider promoting close-coupled collaboration by making the group views to automatically associate individual work [6, 8, 17, 32]. Such designs need to consider that merging sensemaking activities on large amounts of data and showing connections in force-directed graphs may introduce an extra level of complexity and make the group territory less interpretable. MDE designers need to consider the interpretability of the combined individual artifacts and how the connections add value to the sensemaking tasks, especially when the sensemaking systems automatically merge individual work.

> Finding 4: Separated views and non-connected individual items in a group territory encourages the establishment of sensemaking roles (PAR); the group territory highlighting connections between items in personal territories encourage joint discussion (CON).

Communication centered face-to-face collaboration and led to closer coupled collaboration [27, 32]. Furthermore, closely coupled collaboration is considered to improve sensemaking outcomes [26, 54]. This study's results reveal that sensemakers with different group territory paradigms communicate and exchange information in different manners. A prior study suggested that sensemakers establish roles as foragers and sensemakers when collaborating with shared displays [52]. In the present study, participants in the PAR condition passed more cards to their partner's workspace (as the forager) and let the latter lead the task (as the sensemaker). This phenomenon was less intensive in CON groups. The connections in CON bridged the personal territories and provided extra information that needed to be interpreted together. Instead of establishing roles and communicating by exchanging cards, the CON groups discussed the answers by looking at the group territory together. This is in line with prior studies that found that group territories serve as a focus of attention and support discussion [5, 32]. Reflecting on these results, it is argued here that when designing a group territory to support sensemaking collaboration, group territories can be segmented based on ownership if sensemakers have different roles or expertise in the task (e.g., sensemaker and forager [52], voyagers and voyeurs [23]). For peer sensemakers who contribute equally, a group territory connecting related items from personal territories could better support closely-coupled collaboration [51].

9 CONCLUSIONS AND FUTURE WORK

This study examined three paradigms for how group territories can affect co-located sensemaking in a multi-display environment. The PAR paradigm presents individual work separately in a group territory without connection. The CON paradigm incorporates separated individual sections in the group territory, but connects related items from personal territories. The MER paradigm merges group work together into one integrated visualization. The three group territory paradigms are exemplified by an MDE-based sensemaking system, VISGRAINS, which supports information searching, creating search representations, and organizing retrieved information. The three paradigms were compared using a co-located Twitter analysis task. The results showed that separating individual work in a shared peripheral display ensures individual control over the workspace. Splitting the visual sections in a group territory is beneficial in monitoring and staying aware of others' work. Automatically integrated individual work and constantly updated connections in the group space may reduce the use of a group territory to maintain awareness and discuss sensemaking outcomes. Incorporating visualization algorithms and techniques that automatically and repeatedly lay out data representations from different sensemakers need to consider their negative effects on control, awareness, and communication. In contrast, separated views encourage the establishment of sensemaking roles, while group territories with connections between items in personal territories support discussion with a shared visualization. The design knowledge gleaned from evaluating VISGRAINS seeks to advance the MDE designs for co-located sensemaking. Group territories in MDEs are essential to the effectiveness of individual work, workspace awareness, and communication. The knowledge from this study can be applied to future collaborative systems which support co-located analysis of large textual datasets. With the growing importance of social media in acquiring situation awareness, systems for collaborative crisis/event monitoring, community studies, review summarization, and public opinion analysis can apply proper group territories to better support sensemaking collaboration.

Moving forward, future research seeks to solve the limitation of this study and extend the findings into broader applications. This study examined co-located sensemaking with the team size of two, with which the group territory only connects individual work in a simplified pairwise condition. Future work will explore group territory design to support bigger sensemaker groups and investigate design options to visualize work from more individuals. The VISGRAINS consists of a tabletop and a vertical peripheral display, which is just one setting of the multiple-display environment. Group territories on different display types (e.g., computers, tablets, and AR/VR devices), in different display configurations (e.g., shared views on tabletops and duplicated views in personal territories), and with transitions of user locations (e.g., working separately then co-present in one workspace) require further examination. The task explored in this study is a Twitter analysis task that only consists of key sensemaking steps. However, other sensemaking tasks could require sensemakers to consider different forms of data and information (e.g., pictures, data sheets, charts, etc.) and perform more complex activities (e.g., intersecting data groups, reasoning, diagramming, etc.). Future work will explore how different individual actions on different data forms could be visualized in a group space to support more complex collaborative activities. This research considers control, awareness, and communication as three key collaboration components that are affected by group territories. It will be interesting to examine these factors in other collaboration scenarios (e.g., some team members join the sensemaking remotely, team members work asynchronously, or the team is completely distributed) to explore how a group territory affects sensemaking collaboration in different time-space settings.

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