A Comparison of Two Display Models for Collaborative Sensemaking

Haeyong Chung, Sharon Lynn Chu, Chris North
Department of Computer Science, Virginia Tech
2202 Kraft Drive, Blacksburg, VA 24060, USA
{chungh | sharilyn | north}@vt.edu

ABSTRACT

In this paper, we investigate how a distributed model of sensemaking, spread out over multiple displays and devices, impacts the sensemaking process for the individual and for the group, and whether it provides any feasible opportunities for improving the quality and efficiency of sensemaking efforts. Our study compares the use of two display models for collaborative visual analytics, one based on the model of the personal displays with shared visualization spaces and the other based on the distributed model whereby different displays can be appropriated as workspaces in a unified manner by collocated teams. Although the general sensemaking workflow did not change across the two types of systems, we observed that the system based on the distributed model enabled a more transparent interaction for collaborations, and allowed for greater ‘objectification’ of information. Our findings have significant implications for how future visual analytics systems can be designed to motivate effective collaborative sensemaking.

Categories and Subject Descriptors
H.5.2. UI, H.5.3 Group and Organization Interfaces

General Terms
Design, Human Factors.

Keywords
Collaborative sensemaking, visual analytics, multiple displays, display ecology.

1. INTRODUCTION

The ongoing advances in modern display and computer technology have the potential to dramatically change dominant paradigms of how our computing environments are used to analyze large amounts of information. The current proliferation of mobile devices and large high-resolution displays offers new opportunities for both personal and collaborative sensemaking. If multiple displays and devices could function in a unified manner, would the sensemaking process be distributed in such a way as to generate advantages with the results? How would such a ‘distributed’ model compare to the current model where group sensemaking occurs within the boundaries of a single display?

In this paper, we understand sensemaking broadly as a process in which information is foraged, organized, synthesized, and analyzed to generate a productive conclusion or to initiate new questions or new lines of inquiry [13]. Prior literature has highlighted several benefits that the use of multiple displays and devices, varying in affordances can provide to data analysis and sensemaking. For instance, the multiplicity of devices exploits the human capacity to use spatiality and physicality to make sense of information [18]. The separate and common discrete spaces of the various devices also facilitate the division of tasks across different displays and among team members [9].

In contrast to this multi-display environment, the situation that is currently most common to groups is to engage in sensemaking within the confines of individual computers with shared focus and simultaneous control of information provided by a cloud service such as *GoogleDocs*. While this represents a tremendous improvement over past models of users working on isolated devices without access to a common view of information, we believe that there are even greater benefits to be gained from allowing sensemaking to occur within an ‘ecology of display and devices.’ Our work investigates the benefits that users may derive for the process of sensemaking from the use of devices that not only provide shared focus and simultaneous control, but also work together to allow users to distribute cognitive resources across physical space. To this end, we compare the use of two systems, *VizCept* [3] and *VisPorter* which will be described in detail later. The systems support the above mentioned collaborative sensemaking environments respectively.

2. RELATED WORK

We extend the prior research work for visual analytics tools supporting external representations of information, multiple display environments (MDE), and user studies for co-located collaborations around displays. ‘Sandbox’ in the nSpace suite is designed to support an open analytic workspace where users can move digital objects and organize on the display space for external representations [17]. Andrews et al. expanded the benefits of the external representation to sensemaking tasks on personal large displays [1]. ‘Entity Workspace’ supports capabilities for merging multiple users’ findings by collaboratively creating visualizations [2].

Our work is also related to existing MDE systems, which facilitate moving and sharing information objects spatially, across displays. Wigdor et al. designed an interaction technique called the World in Miniature (WIM) to move information from a tabletop to two wall displays [16]. Nacenta et al. surveyed techniques to transfer objects from one device to another, emphasizing on spatial interaction in MDE [12]. Multibrowsing [10] allows users to arrange Web content among heterogeneous displays including personal laptops and wall displays. Seifert et al. developed more advanced content sharing with spatial organization on the tabletop through direct interactions of mobile devices [14]. Last but not least, Geyer et al. [4] designed a multi-display system for

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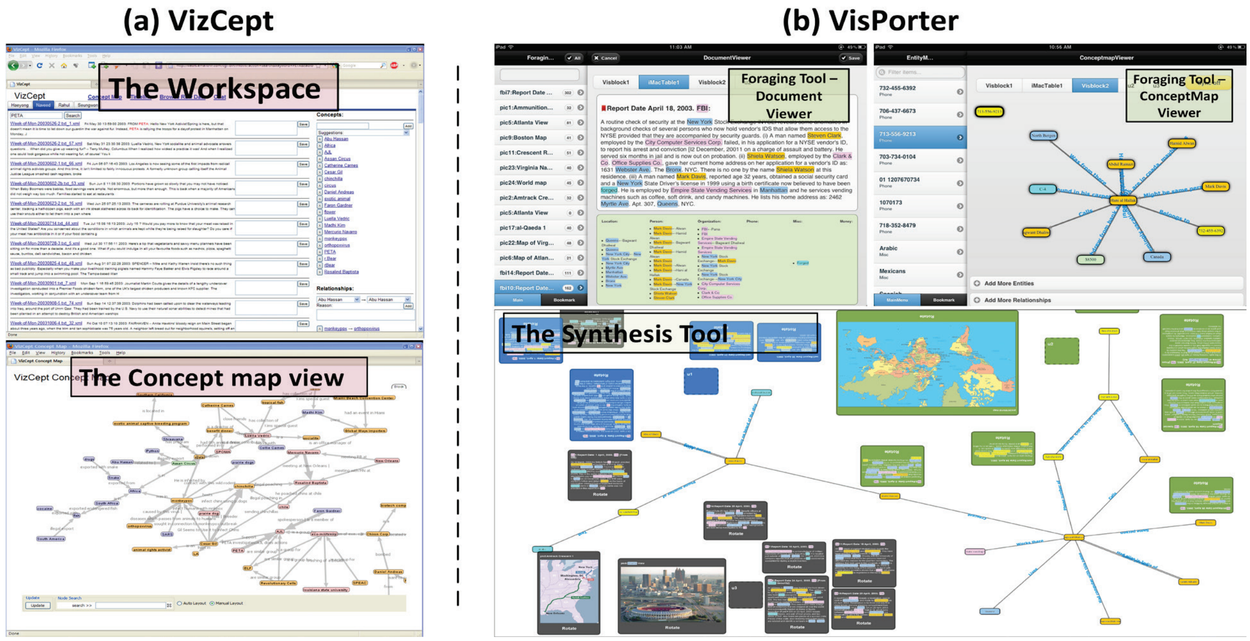

Figure 1. The two collaborative sensemaking systems used in our comparative studies.

collaborating sketching through multimodal interfaces on multiple displays, emphasizing spatial properties in the workspace.

There are user studies which inform design implications for our multi-display visual analytics system. Isenberg et al. [8] addressed the types of collaboration styles that are adopted during collocated collaborative visual analytics. Inkpen et al. explored how various display factors impact co-located collaboration [7]. Ha et al. investigated how input devices affect collaboration on a tabletop display [6].

3. PROPOSED DISPLAY MODELS FOR COLLABORATIVE SENSEMAKING

We now describe the design of our prototype multi-display visual analytics systems, *VizCept* and *VisPorter*, which epitomize the two contrasting models of shared visualization spaces on single displays and unified multiple devices respectively. The two systems are based on a common framework that we first explain, before progressing to describe the particulars of each system.

VizCept and *VisPorter* are visual analytics systems designed to support co-located collaborative analysis of textual data by providing shared focus of information through concept maps. Both tools emphasize seamless transition between individual and collaborative analysis, which is an important foundational concept in group work support [5]. *VizCept* and *VisPorter* consist of two types of sensemaking tools: the foraging tools and the synthesis tools. Each of these is primarily designed to support different stages of the sensemaking process. These two tools match the two loops in the Pirolli & Card's model of the sensemaking process directly [13]: the Foraging and Sensemaking Loops. It has been shown that the division of the sensemaking process into these two loops can be beneficial for collaborative sensemaking, but that the two loops are highly interconnected [15]. Both systems include the following common features:

Foraging tools. The *Workspace* of *VizCept* (Fig.1a) and the *Foraging tool* of *VisPorter* (consisting of the *Document viewer* and the *ConceptMap viewer* in Fig.1b) are the main components for data exploration, providing keyword searching and document content browsing. In *VisPorter*, each document is automatically parsed for entities using the *LingPipe* library [11] and the extracted entities are highlighted in different colors based on entity type, such as organization, people, location, money, phone numbers, etc. (Fig.1b upper left). The Foraging tool and the Workspace also allow the user to specify the relationship between the entities.

Synthesis tools. The *Concept map view* (Fig.1a bottom) of *VizCept* and the *Synthesis tool* (Fig.1b bottom) of *VisPorter* enable the visualization of global concepts and relationships that collaborating users have discovered. This visualization is shared among all team members. Nodes in the visualization represent concepts or entities, while relationships among concepts are represented as directed edges with descriptive labels. The colors of nodes represent different users or types of entities.

3.1 *VizCept*: Shared Visualization Spaces

VizCept [3] is designed such that each user may use individual (or multiple) devices such as laptops, tablets, or personal large displays. Collaborating users share and construct visualization through shared workspaces on individual displays (Fig.2a). The system does not allow for any direct cross-device interaction. An analogy can be drawn with the popular *GoogleDocs* model whereby each user accesses the shared document on her own device, while able to see updates by others in real time. The characteristics of *VizCept* are described below:

Interaction: The user interacts with the system through a conventional tethered interface such as a keyboard and mouse on the user's personal computer.

Concept mapping: Each user contributes to creating a global concept map allowing them to understand the entire plot. The concept map helps to track valuable information in a one-screen view. Navigation strategies, such as pan and zoom, or the manual/automatic layout (force-directed) of the concept map can be applied individually on a shared concept map. The shared concept map provides awareness of the progress of the other users and the connection between one user's own work and the work of the rest of the group (Fig.1a bottom).

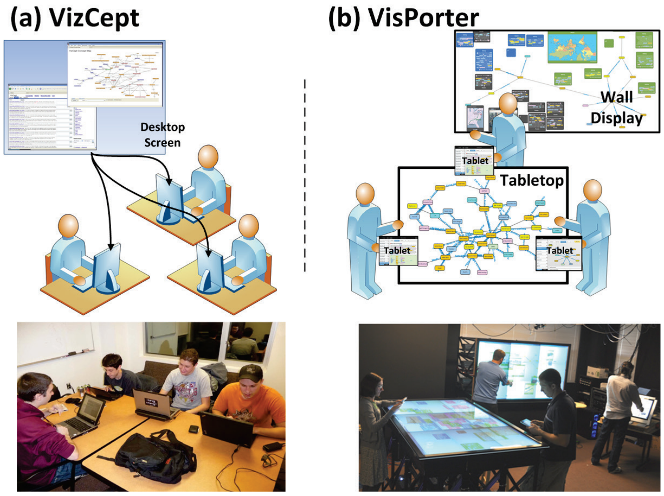

Figure 2. Two display models for collaborative sensemaking.

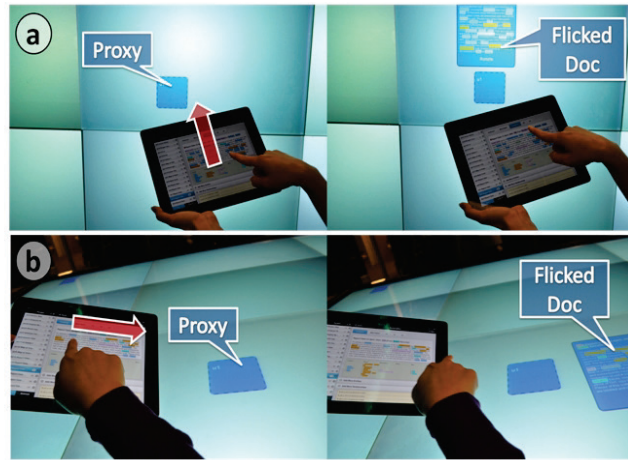

Figure 3. Swipe and drop the document onto the shared displays to (a) Wall Display and (b) Tabletop display.

Scalability: *VizCept*'s multiple coordinated views (separate documents, pictures, concept maps, etc.) help users see different aspects of the same dataset on a single screen. However, multiple views and visual scalability of concept maps remain limited to a single display and are confined to the computation capability of one single device.

3.2 *VisPorter*: Multiple Displays Unified

VisPorter is designed to facilitate information sharing between multiple displays using the physical reference of the displays in the real world. For instance, to transfer information from one device to another, users refer to the physical position of the target display. One can thus spatially distribute entities, concept maps and documents across different displays, then organize, and investigate them further on individual or shared displays (Fig.2b). In *VisPorter,* information can be individually analyzed on one device and also shared with other collaborators and devices. The characteristics of *VisPorter* are described below:

Display: While all tools run on a single individual device/display in *VizCept*, analysis can be carried out across multiple individual (e.g., smart phones, tablets, laptops, etc.) and shared displays (e.g., tabletops, powerwall, etc.) in *VisPorter*. However, the Foraging tool (Fig.1b top) is adapted to run on personal devices instead of on the shared devices. The Synthesis tool conversely allows users to take better advantage of large screens by organizing documents and concept maps spatially on the screen and by enabling the integration of various results from multiple users and devices (Figure 1b bottom).

Interaction: *VisPorter* enables cross-device sharing of information through lightweight touch and gesture interactions. Users can throw a piece of information to someone who is nearby or to a large screen with the flick or tap of a finger (Fig.3). Similarly, gesture-based techniques are used to move an information object between the Foraging tool and the Synthesis tool. In such a transfer, the position where the object is dropped can be determined by one of the four swiping directions (i.e., up, down, left and right). On the other hand, if users want to transfer it between two Foraging tools, the flicked document is saved in the Bookmark viewer of the recipient's Foraging tool.

Moving documents or entities between two displays running the Synthesis tool is carried out through device proxies and simple gestural interactions, and thus relies on the physical locations of users and devices. Other available displays in the room are represented on any particular display by a proxy (Fig.3). The display proxy provides a spatial reference for each specific display and is the spatial target position to which objects need to be 'flicked' for transfer. The proxies can be dragged and dropped on the screen space manually for users to be able to determine a 'flick' position, but they are sensitive to optical motion-tracking systems which enable devices to know when they are in mutual proximity.

Concept mapping: Users can create personal concept maps on the ConceptMap viewer (Fig.1b upper right) and then later merge them with the larger concept map on the Synthesis tool (Fig.1b bottom). The tap-hold gesture is used to transfer an entity or concept map across the devices. So, multiple users can construct sub-concept maps independently on their personal devices (*iPad*) and combine them with the Synthesis tool of the shared display (e.g., wall or tabletop displays).

Scalability: In *VisPorter,* users are able to extend the device they are currently using with other displays and devices by moving objects (e.g., document, concept map, etc.) on one of their devices to another. The key characteristic differences between *VizCept* and *VisPorter* as described above are summarized in Table 1.

Table 1. Design characteristics of the two systems.

Design Characteristic	*VISCEPT*	*VISPORTER*
Display	Individual devices at a time (laptops, tablets, personal large displays)	Multiple personal devices and shared displays (tabletops + wall displays)
Interaction	Desktop-bound mouse and keyboard, enabling only virtual navigation (zooming/panning)	Enabling spatial, gestural and physical navigation through touch-based interaction
Visualization(Concept maps)	Shared information, individualized concept map layout	Individual information + Individual layout; Shared information + Shared layout
Information Sharing	Automatic online updates	Online controlled/manual updates + Direct transfer of information and concept maps
Scalability	Limited to one screen/device	Users flexibly extend a screen space with other nearby screens
Awareness/ Progress indicator	Through shared concept maps	Visual scanning of associated displays; other users' actions and displays in use

4. STUDY DESCRIPTION

We carried out two exploratory studies for the two different configurations (*VizCept* and *VisPorter*) of collaborative sensemaking described in the previous section, and compared qualitative results obtained regarding the sensemaking and analytic processes from the two studies. For the two studies, we recruited 11 teams with three members each (total of 33 participants, 4 female and 29 male). All participants were graduate students in engineering departments at Virginia Tech. Although the participants were not intelligence analysts, they had basic knowledge of how to approach analytic problems from graduate level Information Visualization classes and were familiar with data analysis procedures. Prior user studies in collaborative visual analytics have also made use of participants not formally trained as data analysts [8, 15]. As information around us grows exponentially, data analysis and sensemaking are no longer processes restricted to formal domains. The study tasks were common enough that they did not require any specialized knowledge.

Three teams were assigned to the study of the use of *VizCep*t. In this situation, the participants were asked to use individual devices (*iPad*s or laptops) collaboratively (each participant had only one device). Eight teams were assigned to the study for the use of *VisPorter*, whereby each participant had one *iPad* and could access the shared displays such as a touch-enabled *iMac*, a tabletop and a wall display at all times during the analysis. Both the tabletop and wall display are made of nine tiled back projection displays arranged as a large 4ft by 6ft (3840x2160, 82.5 inch diagonal) horizontal or vertical surface screen with a PQ Labs' 32-points multi-touch overlay.

An intelligence dataset was used as a sensemaking scenario. The task assigned to the participant teams was to identify the terrorist plots hidden within the dataset, which consists of approximately 41 documents. Additionally, we added 25 pictures related to important entities to the original dataset.

The study was conducted with all teams for 1.5 to 2 hours as follows: All the members of a team were asked to come to a laboratory to perform collocated, synchronous analysis of the dataset. After a demographics questionnaire and tutorial session, the team started a 1-hour to 1.5-hour-long analysis task using the devices allocated in their assigned condition. The participants were asked to complete an answer sheet for a hypothesis solution with supporting evidence, including details (who, what, where, and when). After the analysis session, each participant was given a post-questionnaire to complete regarding their experience with the system and about the analytic workflow they used to arrive at their solution. A group interview was subsequently conducted with all team members.

All analysis sessions were recorded (video and audio). Observation notes were taken by a researcher who remained in the experiment room. Screen activity was recorded for all work carried out using the Synthesis tool of *VisPorter* on the wall, tabletop and *iMac* displays; screenshots were taken at 30-second intervals. Additionally, all interview results and conversations during the collaborative analysis sessions were audio recorded and transcribed by the authors.

We employed a mixture of the multiple types of data for the analysis. Two authors first consolidated their observation notes, interview transcripts, and post-questionnaire collected from the two studies by discussing and collating them on the whiteboard. Based on this process, they generated a set of key insights regarding the sensemaking process. They then conducted a validation procedure of those key insights by revisiting all other types of relevant data including video and audio recordings of the sessions to find proof for those activities in each display usage model. For instance, the authors identified users' preference for physical navigation in information foraging across multiple displays as a key insight and they then analyzed multiple teams' actual behaviors for physical navigation in recorded videos. If data from the various sources supported one of our key insights, the insight was considered to be supported. If data did not support a key insight, that insight was contradicted or not supported. We present in this paper the key insights that remained as supported after all data sources had been analyzed.

5. FINDINGS

The analytic workflow of *VizCept* was partially identified in [3]. Based on post-session questionnaires, observation notes, and interviews, we found that team members in both the *VizCept* and *VisPorter* conditions generally used a common analytic workflow consisting of five stages (Fig.4). Nevertheless, there were interesting differences within each of the five stages of the process. We present the key insights of the differences between the two study conditions within each stage below:

Stage 1: Work and Data Division. This first stage generally consisted of the team working together and coordinating the data across the different members or displays. We observed the notable difference in work division between the use of the two systems in relation to the process of how it was achieved.

Using *VizCept*, the teams relied only on communication methods that were external to the system to reach a consensus, for instance, verbal communication (i.e. oral negotiation, discussions of which information object belongs to which group) or textual means (i.e. Internet chats and annotations). In contrast, *VisPorter* generated a physical way of dividing work and data. The physical spaces of the different displays were used to divide and organize information. For example, pieces of data were assigned to specific screen spaces of the different displays. Team members, on top of data pieces, then were assigned to different displays. For instance in one team, the tabletop, wall and *iMac* displays were divided among each of the three team members and were used as individual workspaces in addition to the individual *iPads*. After discussion, the team then assigned the categories of data to a suitable large display based on their contents and entities for further analysis by the associated member.

Stage 2: Individual and Collaborative Information Foraging. Information foraging entailed participants searching for keywords in the documents, reading them and identifying new concepts and relationships. Under both study conditions, the participant first read the documents loaded into the system individually, and after all team members were somewhat acquainted with the dataset, the team began discussing documents related to specific topics.

In the case of individual foraging, the two compared conditions differed in terms of how participants marked relevant information objects for later use in analysis. With the *VizCept* condition, either

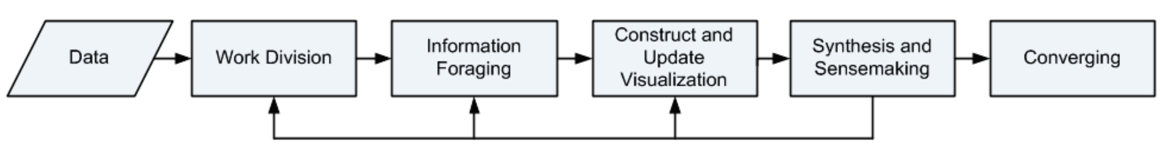

Figure 4. A common collaborative sensemaking workflow for the two multi-display systems.

notes were added to the important documents found as annotations or the bookmarking feature was used. In the *VisPorter* condition however, the participant used the space provided by the shared displays to support external memory of information for their own reference (self-referencing). For example, participants transferred documents from their *iPads* to the tabletop when the document included entities that were hard to remember, such as exotic names and phone numbers, in order to reference them later when they came across these entities in different documents. Also, *VisPorter* users showed a clear preference for physical navigation to forage for information or specific documents across the displays, rather than searching keywords on the individual *iPads.*

With group information foraging, the two conditions differed in the way that insights about information objects were shared. Using *VizCept*, information sharing was initiated with oral file referencing to other team members, as in Stage 1. In other words, participants verbally referred to specific document IDs to ask another user to review the document. Using *VisPorter*, documents were flicked onto shared displays for the purpose of offloading information. Interestingly, this created opportunities for chance collaborative moments. For instance, one participant flicked a document (for self-referencing) on the tabletop. He thereafter slid that same document directly to another participant during collaboration. Opportunistic interactions also occurred because participants did not need to focus on memorizing the object IDs, but only on the task of organizing the data and making sense of it.

Stage 3: Constructing and Updating Shared Visualizations.

Both systems use concept maps to represent associated thoughts from multiple users visually. On top of their concept maps, team members contribute to the buildup of the shared global concept map by creating, merging and refining entities and relationships based on their findings.

One key difference between *VizCept* and *VisPorter* is that the former shares all objects added to a global concept map instantly and indiscriminately. This immediate sharing of concept maps had two contrasting effects: on the one hand, some members were hesitant to add premature results and concepts with the concern that they would redirect the seemingly disconnected analyses and thus, hinder a productive line of investigation [3]. On the other hand, the immediate update feature helped to create common ground among team members. For example, one participant found that no one else had added any concepts related to her concepts for more than 30 minutes. That prompted her to question whether her line of inquiry was wrong and to try and find the reasoning behind the objects that the other members were adding

In contrast to *VizCept, VisPorter* allows the participant to retain concept maps on individual devices locally (Fig.1 ConceptMap View) while concept maps on shared displays are global (Fig.1 Synthesis Tool). In the *VisPorter* condition, we saw a more refined process of concept mapping through which the participants first narrowed down their initial concept maps on their individual devices and only selectively flicked parts of their concept maps onto the global concept map on the shared display. Furthermore, in the *VisPorter* condition, assignments of concept map data to particular displays were again evident based on data type, display size and device capabilities.

Stage 4: Synthesis and Sensemaking. Synthesis involves participants integrating and combining multiple insights from all team members and developing a common series of insights. Based on the results of this stage, users decide whether they must return to one of the previous stages or proceed to the final hypothesis.

With *VizCept*, the formation of common insights was an additive process whereby insights from individual members were brought together through the concept maps and verbal communication (oral explanations and internet chats as before). Verbal communication was most often used in a process to validate individual findings. On the other hand, with *VisPorter,* synthesis occurred in a collaborative process that provides more awareness of others' activities and integrated cycles of common insight formation and presentation. For example, the *VisPorter* teams manipulated document objects or concept map nodes working together while using external representations of information as references to make sense of their global concept map on different displays.

Stage 5: Converging. In both models, convergence occurred when improvements to the concept maps were completed or when it was time to arrive at a common conclusion regarding the solution of the plot. In the *VizCept* condition*,* all of the teams allocated 'presentation' time to each member to relate her conclusions/story. Each member explained her cluster in the global concept map, as everyone gathered around the particular participant's device or screen. After all presentations, a common final story was agreed upon. In the *VisPorter* condition, this stage was brief as participants engaged in discussions to find common ground throughout the whole analytic process. So, the more formal 'presentation' mode was less obvious. The physical space and engagement in spatial organization of documents/concept maps, afforded by multiple displays, changed analysts' approach to convergence by tightly integrating the information synthesis, sensemaking and presentation stages.

6. DISCUSSION

VizCept embodied a model of collaborative sensemaking whereby users perform joint work by having shared focus and simultaneous individual control of the dataset on single devices. However, the collaborative sensemaking is mostly confined to the single shared space on the individual screen and verbal communication. *VizCept* did have certain positive effects. For example, the system's capabilities for merging collaborators' thoughts/findings in a global concept map, and in single screens, facilitated monitoring the work of their partners. *VisPorter* conversely embodied a model whereby users collaborate using varied interconnected devices that separate individual and shared work with physical constraints. It enables people to distribute knowledge and ideas around the physical space where the displays take on meaning. The key differences in the use of the two systems for sensemaking that we elucidated from our study are summarized in Table 2.

Our focus is not on the performance of the teams or the specific solutions that the teams discovered using the systems. We were more interested in how the process of sensemaking would differ between the uses of the two contrasting models. Two common characteristics of the sensemaking processes that occurred under the *VisPorter* condition are particularly interesting. The greater emphasis on physicality in the model exemplified by that system led to (i) transparency in interaction, whereby users appropriated information objects to be shared and received in a direct, transparent and rapid manner, focus of attention on the material being handled, and (ii) to a process that we call the 'objectification' of information [18]. Objectification refers to how participants assigned meaning to devices. They assigned thought objects to particular devices, and used these 'physical carriers' to expand their thinking. This concept is related to the idea of 'distributed cognition'. For instance, after organizing related information on a particular display, the physical display device was regarded as a physical representational proxy for the group of information during discussions. The device became the information. An illustration of this physical referencing is the frequent pointing gestures towards one display as the team members discussed a specific fictitious person in the plot (whose information were gathered on that display). In other words, objectifying all the information related to the fictitious character as a physical display allowed them to chunk all the attributes of the character as a single unit, and physically reference that unit, while deliberating the character's role on the plot.

Table 2. Key differences between the two models

Stage	*VISCEPT*	*VISPORTER*
Work division	External communication methods (speech, text chats)	Accountability for actions and physical assignment of data and members to specific shared displays
Individual information foraging	Annotations to documents/bookmarking	Flicking documents onto displays, Physical navigation
Group information foraging	Mostly individual with oral file referencing to team (e.g., document ID)	Opportunistic collaboration; flicked documents for self-referencing are also used for collaborations
Updating shared visualizations	Greater noise; hesitancy; opportunities for common ground	More refined; selective sharing of only important information
Sensemaking and Synthesis	Additive effect of individual insights; verbal communications	More awareness of others 'activities and integrated cycles of common insight formation and presentation
Converging	'Presentation' mode	

7. CONCLUSION

In this paper, we investigated how the current paradigm of collaborative sensemaking differs from a prospective ecological model where all the devices in an environment develop roles and relationships for sensemaking tasks. The chief contribution of our work is to provide a qualitative comparison of two systems built for co-located collaborative sensemaking tasks that use different display and input arrangements. We found that the overall sensemaking process remains the same, but many differences exist in the processes employed within each stage of the process. A key benefit that the ecological model (*VisPorter)* brought about was in the greater opportunity for 'objectifying' information that the physicality and spatiality of the system afforded. The differences between the two models inform the design of new sensemaking tools or future groupware about how people leverage spaces in ubiquitous display/device scenarios. Our findings have not only significant implications for how future systems can be designed to motivate better collaborative sensemaking, but we also hope that it will generate discussion in the visual analytics community regarding the potential of new display and interaction approaches.

8. ACKNOWLEDGEMENT

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