Large High Resolution Displays for Co-Located Collaborative Intelligence Analysis

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ABSTRACT

Large, high-resolution vertical displays carry the potential to increase the accuracy of collaborative sensemaking, given correctly designed visual analytics tools. From an exploratory user study using a fictional intelligence analysis task, we investigated how users interact with the display to construct spatial schemas and externalize information, as well as how they establish shared and private territories. We investigated the spatial strategies of users partitioned by tool type used (document- or entity-centric). We classified the types of territorial behavior exhibited in terms of how the users interacted with the display (integrated or independent workspaces). Next, we examined how territorial behavior impacted the common ground between the pairs of users. Finally, we recommend design guidelines for building co-located collaborative visual analytics tools specifically for use on large, high-resolution vertical displays.

Author Keywords

Large high-resolution displays, co-located collaborative sensemaking, visual analytics, territoriality.

ACM Classification Keywords

H.1.2 [User/Machine Systems]: Human Information Processing – Sensemaking; H.5.3 [Group and Organizational Interfaces]: Collaborative computing, Computer-supported cooperative work.

General Terms

Experimentation, Human Factors, Design.

1 INTRODUCTION

Collaborative visual analytics has been a growing research area within the visual analytics community due to the ability to integrate social and group dynamics into the analytic process [1, 2]. Additionally, the use of large displays for collaborative applications has been expanding in recent years, particularly with tabletop and projector-based displays [3, 4]. However, large, high-resolution displays composed of vertical LCD displays expand upon the large display surface by easily displaying whole documents at standard magnification levels. This allows users to place detailed views of documents (as opposed to thumbnails or labels) into spatially meaningful representations, which can then be used to easily recall information through physical navigation, as well as semantically organize the display space [5]. These properties of large, high-resolution displays have been shown to improve user performance on many tasks ranging in difficulty from simple pattern matching and route tracing to cognitively demanding sensemaking [5, 6].

Although large, high-resolution displays have proven to be beneficial to single users, their potential benefits for co-located collaborative sensemaking tasks have yet to be thoroughly examined [7]. We seek to understand how large displays can be leveraged by visual analytics tools to improve co-located collaborative sensemaking for intelligence analysis-type tasks. To do this, we will first examine how analytic tool choice impacts the use of the large display space. Next we will examine how different levels of shared display space impact the sensemaking process. By answering these questions, we will be able to discuss how designers can develop visual analytics tools for co-located collaborative sensemaking on large, high-resolution displays, specifically for intelligence analysis.

2 RELATED WORK

Co-located collaborative sensemaking has been studied in various domains [8-10]. However, user requirements vary across domains due to the specific nature of the work. The competitive workplace culture of intelligence analysts means that collaboration occurs only informally, if at all [11, 12]. Therefore, it is important to design tools and environments with little overhead required to commence collaboration [13].

Although pair dynamics exist between domain experts and tool experts [14, 15], we seek to better understand the collaborative process between equally knowledgeable collaborators, such as between co-workers working on a joint investigation. This notion of working together on a shared computer display is known as Single Display Groupware (SDG) [16], and has been studied extensively in the past, starting with early systems in the late 1980s and early '90s [17-19]. In subsequent work ([20, 21]), Stewart et al. investigated SDG systems further. Additionally, they conjectured that the "very limited screen space" "may result in reduced functionality compared with similar single-user programs" [21]. This concern can be alleviated by increasing the display screen's physical size, and subsequently resolution, to provide adequate virtual and physical space for SDG systems.

Design decisions that enhance individual work often hinder group work, and vice versa. Previous groupware interfaces have either supported group work through consistent view sharing, known as "What You See Is What I See (WYSIWIS)," or the

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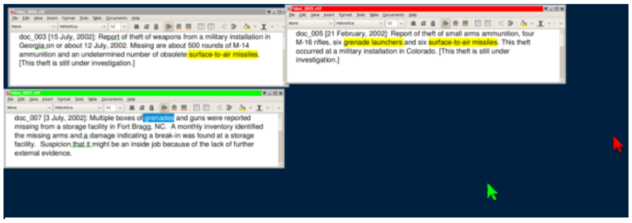

Figure 1: Two mice with two active windows.

individual user through more relaxed view sharing [22]. As Gutwin and Greenberg state, "the ideal solution would be to support both needs – show everyone the same objects, as in WYSIWIS systems, but also let people move freely around the workspace, as in relaxed-WYSIWIS groupware" [23]. We believe that a balance can be reached between these tensions by allowing users to work on a large, high-resolution vertical display equipped with multiple input devices where they can work individually while maintaining awareness of their collaborator's actions.

Large displays come in many different form factors. These include, but are not limited to, LCD or projector displays, and vertical or horizontal displays. One factor in deciding which display to use is whether or not the display provides adequate space for personal, shared, and storage territories to form as the participants see fit [24].

Territoriality and other co-located design issues have been studied on tabletop displays using systems such as Lark [25] or Cambiera [26]. The tabletop display used to study these systems was 2' x 3' with a resolution of 1024x768 pixels. Some study participants commented they "felt cramped, wanting a higher-resolution and physically larger display for document reading" [3]. Thus this particular physical set-up does not provide "appropriate table space" to define territories [27]. Because the current tabletop technology is limiting not only due to these concerns, but also the risk of neck fatigue and the inability to reach far across the display, vertical displays appear to be better suited to long collaborative analysis sessions.

These large vertical displays can range from wall-sized projector displays (15' x 5.4' in size with a resolution of 14 megapixels) to desktop LCD displays (4x2 grid of 30" LCD monitors with a total resolution of 32 megapixels) [4, 5]. Both of these set-ups are large enough to support the physical space Scott et al. claims supports the development of territories [27]. Although the projector display is much larger than the LCD display, its resolution is much lower. Therefore, the higher resolution LCD display is better suited to close-proximity document viewing.

Given the choice to use a large, high-resolution vertical LCD display, the next decision to make is the number of input devices (mice and keyboards) to use. Stewart et al. found that two input devices (one per person) are preferable in SDG systems because they increased interaction and kept both participants "in the zone" [20]. Although it has been shown that multiple input devices allow for more parallel work but less communication [4], mult-input devices allow for more reticent participants to contribute to the task [28]. Because we sought to keep users in the "cognitive zone" [15], we chose to implement two mice and keyboards, one for each user, to enable them to contribute to the collaborative sensemaking task simultaneously.

3 STUDY DESCRIPTION

We conducted an exploratory user study to observe the co-located collaborative sensemaking process on large, high-resolution displays.

In order to observe a wider range of user behavior, we chose two different types of tools to study: *entity-centric* and *document-centric*. An entity-centric tool focuses on the connections between specific entities (people, locations, organizations, etc.) within documents without displaying the entire document text, while a document-centric tool simply provides the whole text of the document. We chose these two contrasting tools under the hypothesis that the document-centric tool would better take advantage of the display space, due to the ability of LHRDs to provide detailed views of information while maintaining spatial representations, even though entity-centric tools have performed well in single-user studies [5, 29, 30].

Additionally, we allowed territories to develop naturally by providing two mice and two keyboards (one per user) that could operate independently. Using two mice and keyboards allowed the users to choose how much of their time was spent working jointly or independently. Each mouse could maintain its own active window, and two windows could be active simultaneously [**Figure 1**].

3.1 Research Questions

We set out to answer the following research questions:

- How does the choice of analytical tool impact the use of display space in a co-located collaborative environment?
- How does "sharedness" (closeness of collaboration) between two co-located individuals impact sensemaking?
- How do large, high-resolution displays facilitate co-located collaborative sensemaking for intelligence analysis?

3.2 Participants

We recruited eight pairs of participants (J1-J4 used Jigsaw; D1-D4 used the document viewer). Six of the eight pairs were students and the other two pairs consisted of research associates and faculty, and all pairs knew each other prior to the study and had previous experience working collaboratively. There were four all male groups, one all female, and three mixed gender. Each participant was compensated $15 for participation. As a form of motivation, the verbal debriefing solutions formed by the teams of participants were scored and the participants received an additional financial award for the four highest scores.

3.3 Workspace Set-Up

The teams of users sat in front of a 108.5 in. x 35 in. display consisting of a 4x2 grid of 30" LCD 2560x1600 pixel monitors totalling 10,240x3,200 pixels or 32 megapixels [**Figure 2**]. The display was slightly curved around the users, letting them view the majority, if not all, of the display in their peripheral vision. A single machine running Fedora 8 drove the display. A multi-cursor window manager based on modified versions of the IceWM and x2x was used to support two independent mice and keyboards [31]. Thus, each user was able to type and use the mouse simultaneously and independently in the shared workspace [**Figure 1**]. A whiteboard, markers, paper, and pens were also available for use because these external artifacts were explicitly requested during the pilot study. Each participant was provided with a rolling chair and free-standing, rolling table top holding the keyboard and mouse so that they could move around if they chose to do so. The desks and chairs were positioned side-by-side in the central area of the display space.

3.4 Analytic Tools

As mentioned previously, we chose to investigate two different types of analytic tools. This is by no means an exhaustive survey of visual analytic tools, but this design decision allowed us to observe a wider range of display usage and collaborative behavior than if we had only observed one category of tools.

3.4.1 Jigsaw

Jigsaw [29, 30] is a system that has been designed to support analysts in the sensemaking process. Jigsaw visualizes document collections in multiple views based on the entities (people, locations, etc.) contained within those documents, making Jigsaw an *entity-centric* visual analytics tool. It also allows textual search queries of the documents and entities. Jigsaw can sort documents based on entity frequency, type, and relations, and this information can be displayed in a variety of ways, including interactive graphs, lists, word clouds, and timelines. There is also a recently added Tablet view within Jigsaw where users can write notes, draw connections between entities, and create timelines. Because of the complexity of Jigsaw, participants were given a thirty minute tutorial prior to the start of the task.

3.4.2 Document viewer

To gain a better understanding of collaborative sensemaking behavior, we chose a different style of tool to observe in addition to Jigsaw. We chose a basic document viewer, AbiWord [32], which allows for manually highlighting individual documents sections, editing existing documents, and creating text notes. Teams using this document viewer were also provided with a file browser in which they could search for keywords across the document collection. This document viewer is a *document-centric* tool because it only displays the raw documents (with optional highlighting added), as opposed to also including information about the document contents. Participants were given a five minute tutorial for this tool.

3.5 Task and Procedure

After the tutorials on Jigsaw or the document viewer with a sample set of documents, each team was given two hours to analyze a set of 50 text-only documents and use the information gathered to predict a future terrorist attack on the United States. The scenario used in this study comes from an exercise developed to train intelligence analysts and consists of a number of synthetic intelligence reports concerning various incidents around the United States, some of which can be connected to gain insight into a potential terrorist attack. This same scenario was also used in a previous study evaluating individual analysts with Jigsaw [29].

3.6 Data Collection

Following the completion of the scenario, each participant filled out a report sheet to quantitatively assess their individual understanding of the analysis scenario, then verbally reported their final solution together to the observers. The rubric for evaluating the participants' verbal and written solutions was based on the strategy for scoring Visual Analytics Science and Technology (VAST) challenges [33]. The participants earned positive points for the people, events, and locations related to the solution and negative points for those that were irrelevant or incorrect. They also received points based on the accuracy of their overall prediction of an attack. The joint verbal debriefing was scored to produce the group's overall score. The individual reports filled out by the participants were compared against their teammate's to calculate similarities and differences.

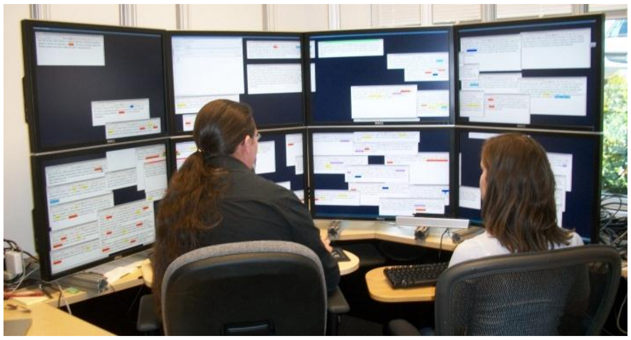

Figure 2: Two users seated in front of the large, high-resolution set-up equipped with two mice and keyboards used in the study

Additionally, individual semi-structured interviews were conducted where each participant commented on how they solved the scenario, how they arranged information on the display, and how they felt the collaboration affected their ability to solve the scenario.

During each study session, an observer was present taking notes. Video and audio of every scenario, debriefing, and interview was recorded. We also collected screenshots in fifteen second intervals, logged mouse actions (movements and clicks), and logged active windows.

3.7 Data Analysis

We used the overall solution correctness scores to identify any significant differences based on which analytic tool was used (this relationship was not significant). Additionally, we compared the individual solution reports generated by each pair's participants to calculate their shared knowledge as it pertained to the solution of the scenario, calculating the amount of common ground in the solution.

The screenshots were combined with answers from the semi-structured interviews to identify what organizational strategies were used on the display, if any. We also referenced the screenshots to observe the use of display space throughout the study and to "play back" the study session along with the recorded video. Finally, the screenshots were used to calculate the amount of empty space, or whitespace, on the display to quantify display usage.

The video was coded to calculate the percentage of time the pairs spent closely collaborating during the session, using a coding set established by Isenberg et al., where close collaboration involves active discussion, working with the same documents, or working on the same specific problem, and loose collaboration involves working on similar problems from different starting points, different problems, or one participant is disengaged from the task [3]. We also transcribed the video in order to quantify verbal cues that were linked with different territorial behaviors.

We used the mouse data to further establish territorial boundaries that existed between the participants, if any. We

Figure 3: Geographical document clustering

accomplished this by counting the number of mouse button-down events that occurred in each screen of the display for each participant. Using this information, we could see which screens were used by one participant, both, or none. The mouse data was also used to calculate the percentage of clicks in each display screen to identify where each participant primarily interacted with the display.

4 Display Space Usage

To answer our first research question (*How does the choice of analytical tool impact the use of display space in a co-located collaborative environment?*), we analyzed how the groups, partitioned by analytic tool used, used the large display space to externalize information to aid their sensemaking process.

4.1 Information Organization

As a result of the document-centric nature of the document viewer tool, all document viewer groups (D1 – D4) displayed all 50 documents on the display screen. They did not have access to the advanced features, such as connecting entities across documents, which Jigsaw provides. Instead, their only method of learning the contents of the document collection was to read every document. After reading the documents, all document viewer groups arranged the documents on the display, only closing document once they were deemed irrelevant to the solution.

The Jigsaw groups (J1 – J4), however, did not find the need to use the entire display space. They were able to complete a sizeable amount of their investigations through Jigsaw's different analytic views. Participants in these groups only opened one or two documents at a time in Jigsaw's document viewer. Three out of four Jigsaw groups used Jigsaw's Tablet view to record connections between people, places, and events, while the fourth team used paper to accomplish this. The groups that chose to use the Tablet view spatially arranged information in this virtual space.

4.1.1 Document Viewer Clusters

All document viewer groups clustered the documents using an overall organizational scheme. Two groups formed clusters based on relevance (e.g. people, organizations, events occurring in multiple documents). One group organized their display space geographically, mentally superimposing a map of the United States on the large display, with foreign countries located where the Atlantic Ocean would be. The final group created multiple timelines on the display to track the evolution of events or track individuals.

The clusters formed by the document viewer groups expanded across the entire display [**Figure 3**]. Because of the large display space, participants were able to display all 50 documents simultaneously, eliminating the need to form clusters based on thumbnails of documents. Entity highlighting, which the groups had to accomplish manually, was completed by all groups even though the groups were not guided by the proctor on how to complete their investigation.

Clusters were marked on the display by containing adjacent or overlapping documents, and were separated from different clusters by whitespace on the display. In this manner, the document viewer groups transformed the "unused" portion of the display to aid their cognitive process regarding accessing information externalized to the display.

4.1.2 Jigsaw Clusters

The Jigsaw groups that chose to use the Tablet view formed clusters, but these were composed of entities, not entire documents, and were contained in the Tablet view, as opposed to expanding across the entire display.

The main difference between the document viewer groups' clusters and the Jigsaw groups' clusters is the information represented at each data point. The document viewer groups clustered entire documents, whereas the Jigsaw groups clustered entities (people, locations, organizations, etc.) and drew explicit links between connected entities which were labelled with their relationship, such as:

"*Muhammad J., who is an alias for George W., is a member of Al-Queda and is friends with Kamel J*." [**Figure 4**]

This was a much more formal method of clustering than was seen in the document viewer groups due to the labelled connections between nodes.

It should be noted that the Jigsaw groups did not utilize their whitespace as the document viewer groups did. They did not spatially organize the different Jigsaw views into any meaningful arrangements, as evidenced through interview questions regarding their display usage. For the Jigsaw groups, the whitespace between views was merely empty and unused space. These groups, however, did use whitespace in the same manner as the document viewer groups within the Tablet view to separate clusters of entities.

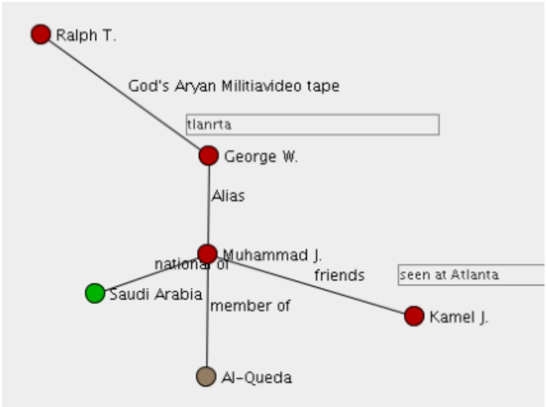

Figure 4: Group J4: zoomed in Tablet view showing connections between entities.

4.1.3 Note-taking

Two types of notes were recorded on paper, whiteboard, or the Tablet view (Jigsaw only). The first type was composed of only document numbers and arrows connecting them. Groups used these types of notes to maintain a record of documents that were connected through a sequence of events, as well as documents of particular interest or suspicion.

The second type of notes contained connections between entities or events that the participants had established. These included the travel history of individuals, lists of suspects, their aliases, and allegiances, as well as notable or suspicious events. Overall, these notes contributed to hypotheses concerning the fictional terrorist plot the participants were attempting to uncover.

Although there was no significant difference between the total number of notes taken by groups partitioned by tool type, this brings to light the need for participants to keep track of related documents, important documents, and possible suspects, to name a few. The document viewer groups were limited in their ability to record information on the display because they were not equipped with a virtual whiteboard like the Jigsaw groups.

4.2 Externalization

All teams externalized information, although the methods of externalization and what was externalized differed between groups based on the analytic tool used. In addition to notes explicitly written by the participants, users persisted information on the display in order to reference it later in their investigation. Due to the technological affordances of each tool, participants naturally kept separate document windows open for various documents, whereas Jigsaw's Document Viewer automatically replaces previously viewed documents with the current document. Because of this Jigsaw feature, additional effort would be required to persist detailed document contents. As a result of this added difficulty, Jigsaw participants did not keep documents opened on their display that could be accessed through physical navigation. Jigsaw groups only revisited documents through virtual navigation.

Document Viewer groups, however, naturally arranged the text documents on the display in spatial schemas. In addition to this being an organizational strategy, displaying the documents reduces the effort required to recall document contents from memory. Participants using this tool pointed significantly more at the screen than participants using Jigsaw [**Table 1**].

Additionally, all groups used the physical location of information on the screen to re-find documents or information [**Table 1**]. All but one group re-located information by using spatial references more than using a search function on the computer to locate the entity or document in question.

In further support of the theory that pairs of collaborators use a large, high-resolution display as a form of external memory, regardless of analytical tool used, all groups referenced documents by their spatial location and contents more than by document title. For example, participants used words such as "here" or "there" to indicate position, often accompanied by a pointing gesture towards the indicated region of the display:

"There are some surface-to-air missiles up there."

Occasionally, documents were referenced by their name:

"[Document] 35 is just right above it."

While all groups referenced the location of information, the Jigsaw groups externalized less persisted information on the display. The document viewer groups used the large display as a continuous analytical environment where meaning could be imparted through spatial proximity, whereas the Jigsaw groups used the display as a mere place to hold their analytical tools. This lack of meaning of the display for Jigsaw groups was

Table 1: Partitioned by tool used (J: Jigsaw; D: Document Viewer), scores calculated using the VAST challenge rubric, score similarity, average amount of whitespace, total number of notes taken, number of times participants pointed at the display, number of times participants re-found information through computerized searches or by spatial reference, and number of times participants referred to documents by the document name or by spatial location.

Group	Total Score	Report Similarity	Average % Whitespace	Notes Taken	Pointing Count	Re-find by Search	Re-find Spatially	Doc. Refer by Name	Doc. Refer Spatially
J1	11	8	86.77%	140	76	4	11	4	16
J2	-1	4	55.60%	90	43	6	7	2	20
J3	-2	3	86.84%	121	122	3	2	2	5
J4	-7	-17	27.24%	91	97	0	7	2	19
D1	13	2	61.23%	44	211	8	27	11	74
D2	-1	-26	50.88%	153	95	1	12	4	33
D3	10	4	54.80%	24	115	0	3	1	27
D4	14	10	51.64%	147	165	4	11	3	44

evidenced through the post-study interviews, where the document viewer groups described the layout of the display and the Jigsaw groups made no mention of it.

Table 2: Characteristics of integrated and independent workspaces.

Integrated Workspaces	Independent Workspaces
Few apologies, if any	Apologies when other's workspace is "invaded" (indicates "personal space")
Information passed freely across the screen	Information moved to the central shared space when sharing it
Plural possessive pronouns ("our")	Singular possessive pronouns ("my" and "your")
Mouse clicks more evenly distributed across the display	Mouse clicks biased towards each person's side of the display

5 TERRITORIALITY

To answer our second research question *(How does "sharedness" (closeness of collaboration) between two co-located individuals impact sensemaking?)*, we analyzed the territoriality and collaboration styles of the pairs, partitioned by groups that viewed the display an entirely shared space and those that viewed it as containing shared and individual partitions.

5.1 Collaboration Style Characteristics

We classified the groups into two collaboration styles based on how they shared the display space. These styles were Integrated Workspace [**Figure 6**] and Independent Workspace [**Figure 5**]. The characteristics of these styles can be seen in [**Table 2**]. The classification of groups was based on the dialog between participants, how they transferred documents across the display, mouse click distributions, and video coding of the closeness of collaboration using an established set of codes [3].

Integrated groups tended to use plural possessive pronouns such as "our" in speech, such as "we know that…" even if only one person had read the document containing the referenced information. The independent groups, on the other hand, used singular possessive pronouns, such as "my" or "your" to reference the same kind of information. For example:

Independent Workspace: *"You are not stealing **my** document!"*

Integrated Workspace: *"I like these three people as **our** suspects."*

Figure 6: An integrated workspace group working to solve a joint problem

As seen in [**Table 3**], groups that used the large, high-resolution display as an integrated workspace tended to collaborate more closely and score higher on the intelligence analysis scenario.

5.2 Shared Display Space

For those groups that adopted an integrated workspace, the mouse clicks were evenly distributed clicks across the display [**Figure 7**], while the independent workspace groups showed partitions of shared and individual territories [**Figure 8**]. Even though boundaries were never formally vocalized, they could still be detected by analyzing the mouse data collected.

Once the independent workspace groups subconsciously established individual and shared boundaries, they apologized whenever they inadvertently crossed the imaginary lines they had drawn or interfered with the other person's actions.

"Sorry, did Georgia display in your window?"

Although rare, there were instances where participants explicitly chastised their partner for invading their personal territory and the documents contained in it:

"Why are you looking at my documents?!"

In order to pass documents or windows across the display when shared and individual territories were established in the independent workspace groups, participants dragged windows to the shared territory and allowed the other participant to drag the window from the shared territory to their own individual area. In integrated workspace groups, participants did not hesitate to drag documents or windows across the entire display, unhampered by an invisible barrier.

It is not surprising that the amount of shared display space is closely linked to the amount of close collaboration between the participants. Without individual territories in which the participants could work on separate threads of the investigation, they tended to work together to solve the scenario. The independent workspace groups, on the other hand, often secluded themselves on "their side" of the display to pursue hypotheses, eventually coming back together to discuss their findings. The territories afforded different styles of collaboration. The closely collaborating groups scored much higher on the scenario, and also reported more similar solutions than those groups that collaborated loosely. This phenomenon is tightly linked with how successful the participants were at attempting to achieve and maintain common ground.

Figure 5: An independent workspace group working on separate threads of the investigation

Table 3: Partitioned by collaboration style, overall score earned, similarity of individual reports, and percentage of time spent in close collaboration.

Group	Collab. Style	Total Score	Report Similarity	% Close Collab.
J1	integrated	11	8	93.39%
D1	integrated	13	2	98.11%
D3	integrated	10	4	89.69%
D4	integrated	14	10	98.78%
J2	independent	-1	4	45.82%
J3	independent	-2	3	67.24%
J4	independent	-7	-17	42.04%
D2	independent	-1	-26	54.75%

5.3 Common Ground

Broadly, common ground is "the knowledge that enables [collaborators] to communicate and, more generally, to coordinate their activities" [34].

Specifically, common ground features include explicitly and implicitly shared objects and events. The explicitly shared objects (e.g. physical artifacts, visuals, audio) are the focus of the communication. Communication is an important part of establishing common ground through the process of "grounding" to ensure that a successful transaction has taken place [35]. The implicitly shared objects are the surroundings that compose the environment, such as background noises and artifacts scattered throughout the room. Common ground also includes the level of attention a collaborator pays to certain objects and their thoughts and interpretations about the data [34].

5.3.1 Process Common Ground

Participants used verbal communication to confirm that information had been received and that they were on the "same page" as each other:

Participant A: *"Do we have him written down too?" (Points at a name in a list)*

Participant B: *"We do."*

They continue to check a few more names and double check that they have taken notes on the individuals.

Plural pronouns (e.g. "we," "our") were often used to denote common knowledge, although this rule was not strictly followed (emphasis added):

Participant A: *"**We** saw something about 150 thousand, right?"*

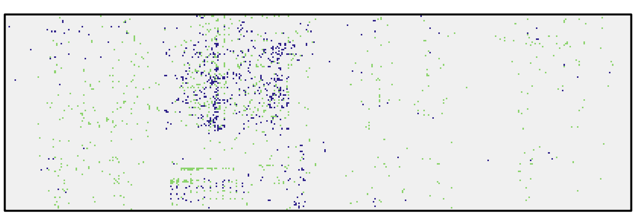

Figure 7: Group D1: mouse clicks distributed across the display with no clear boundaries

The integrated workspace groups tended to communicate more and use plural pronouns than the independent workspace groups that worked more quietly and used more singular pronouns. Higher levels of communication as well as discussion of common knowledge functioned to allow participants to maintain an awareness of the other person's thoughts regarding current hypotheses.

5.3.2 Solution Common Ground

Common ground throughout the process of solving the intelligence analysis scenario translated to common ground across the solutions reported by the individual participants in each group. Similarity scores, calculated by summing the common entities and hypotheses reported and subtracting what was only reported by one participant, can be found in [**Table 3**].

Integrated workspace groups tended to have more similar reports than individual workspace groups, indicating that more common ground was established between groups that treated the large, high-resolution display as an entirely shared space.

The similarity of individually reported solutions is linked with the correctness of the overall solution, which indicates that groups that came to a joint solution were more accurate with their final hypothesis than those whose solutions diverged from one another.

In summary, increased "sharedness" increases the accuracy of collaborative sensemaking for intelligence analysis using large, high-resolution displays. The groups that worked closely together and did not maintain private partitions on the display were more successful in correctly completing the fictional analysis scenario.

6 Discussion

Our analysis of research questions one and two, regarding display usage and collaborative strategies, and general observations made during the study allows us to answer our third and final research question (*How do large, high-resolution displays facilitate co-located collaborative sensemaking for intelligence analysis?*).

Having a large, high-resolution display as a workspace allowed the pairs to work in a co-located setting with ample room to sit side-by-side without bumping chairs into each other. This, combined with the high resolution of the display, which allowed many documents to be displayed in their entirety, gave users the flexibility to establish shared, individual, and storage territories in various capacities [24]. However, we discovered that groups that tended towards an entirely shared display space were more successful in their analysis.

We also noted that analytical tools designed to naturally expand into the display space allowed the participants to externalize information to the display in meaningful schemas in order to

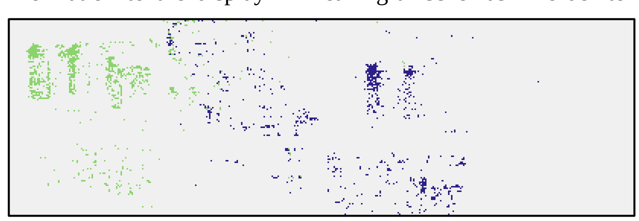

Figure 8: Group J2: mouse clicks with clear boundaries established

more easily recall information later. Participants were able to use the large display to re-find information using spatial references. This spatial reference was often accompanied by physical pointing to the display. Thus, large, high-resolution displays are useful for co-located collaborative intelligence analysis by providing this intuitive data representation space.

Through our observations of this study, as well as knowledge of other existing display configurations for co-located collaborative intelligence analysis, we recommend that large, high-resolution vertical displays be used for this specific domain application.

We feel that these displays offer the opportunity for ad hoc collaboration in the real world. Collaboration only occurs in the real world when overhead is low [13]. Large, high-resolution vertical displays used as everyday individual workstations may be able to aid in reducing this overhead. For instance, a co-worker can stop by an employee's office to inquire about the status of a joint investigation. The co-worker can then pull up a chair and a mobile tray containing a wireless mouse and keyboard next to the employee, flip a switch, and begin collaborating. In addition to providing an easy way to engage in simultaneous work on the same computer, using a large, high-resolution display makes file transferring as simple as dragging a document across the display, eliminating the need to email files or save them to a shared server.

7 Design Guidelines

Few, if any, co-located collaborative visual analytics tools are designed with the affordances of large, high-resolution vertical displays in mind. We offer the following suggestions for designing tools for intelligence analysis on large displays.

1. Allow information to easily be persisted on the display/analytical environment, either in full form or thumbnails. This will allow information to be easily recalled and referenced through spatial position and grouped into clusters based on spatial proximity.
2. Support clustering and flexible reorganization of schemas. This prevents users from maintaining an incorrect spatial representation because the overhead for rearranging the display space is high.
3. Promote shared territoriality instead of maintaining individual or private partitions. This encourages communication and sharing of knowledge, which in turn increases the likelihood of obtaining and maintaining common ground.
4. Design tools to support multiple mice and keyboards to allow users to work simultaneously within the application. This can be achieved through using a multi-window approach [31] or a specially designed toolkit [36].

These guidelines are not meant to downplay the importance of entity extraction and representation. Entity-based systems become important when document collections become large, as they are a method of data reduction. Even though a 32-megapixel large, high-resolution display can easy display the entire contents of 50 short text documents, this display would be unable to do the same for thousands of documents. It is for this reason that we encourage developers to maintain entity representations, but place a larger focus on being able to display persisted document contents that users deem important.

8 Conclusion

Through our analysis of an exploratory user study on co-located collaborative intelligence analysis, we have identified several guidelines for designing collaborative visual analytics tools for use on large, high-resolution vertical displays. In order to establish these guidelines, we analyzed how the users interacted with the large display as well as how they collaborated with each other.

By understanding how two different types of visual analytics tools (document-centric and entity-centric) enable and encourage externalization of information as well as spatial schemas, we were able to link tool capabilities with sensemaking performance. By understanding how users partition territories on a large, high-resolution display and converse with each other, we were able to link higher levels of "collaborativeness" and higher accuracy and common ground.

It is our hope that these recommendations will inspire tool designers to build tools specifically designed for collaborative use on large, high-resolution displays. We believe that large displays have the potential to increase the frequency of collaboration in real-world settings due to the innate affordances of the technology.

We wish to pursue this line of research further by conducting an ethnographic study of professional intelligence analysts to further determine user requirements for collaborative sensemaking in this domain. Specifically, we wish to determine how large, high-resolution displays can be used to benefit these analysts.

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