WeSearch: Supporting Collaborative Search and Sensemaking on a Tabletop Display

Meredith Ringel Morris
Microsoft Research
Redmond, WA, USA
merrie@microsoft.com

Jarrod Lombardo
Averro
Bellevue, WA, USA
jarrod@network-science.net

Daniel Wigdor
Microsoft Surface
Redmond, WA, USA
dwigdor@microsoft.com

ABSTRACT
Groups of users often have shared information needs – for example, business colleagues need to conduct research relating to joint projects and students must work together on group homework assignments. In this paper, we introduce WeSearch, a collaborative Web search system designed to leverage the benefits of tabletop displays for face-to-face collaboration and organization tasks. We describe the design of WeSearch and explain the interactions it affords. We then describe an evaluation in which eleven groups used WeSearch to conduct real collaborative search tasks. Based on our study's findings, we analyze the effectiveness of the features introduced by WeSearch.

Author Keywords
Interactive tables, surface computing, tabletop computing, collaborative search, Web search, sensemaking.

ACM Classification Keywords
H5.3. Information interfaces and presentation (e.g., HCI): Group and Organization Interfaces: *computer-supported cooperative work*.

INTRODUCTION
Web search is often considered a solitary activity, but there are many situations in which groups of people share an information need, and may benefit from the ability to search the Web collaboratively in both education [1, 15, 33] and workplace [5, 9, 19] scenarios.

Several researchers have begun to introduce technologies that support collaborative search tasks. For example, SearchTogether [18] is a browser plug-in that facilitates remote collaboration on Web search. Unlike the designers of SearchTogether, however, our focus is on supporting collaborative search among *co-located* group members. For example, business colleagues may need to find information related to a question that arises during the course of a meeting; students working together in the library on a joint homework project may need to find materials to include in their report; and family members gathered in their home may wish to explore topics such as researching joint purchases, planning an upcoming vacation, or seeking medical information to assist a loved one.

CSCW 2010, February 6–10, 2010, Savannah, Georgia, USA.

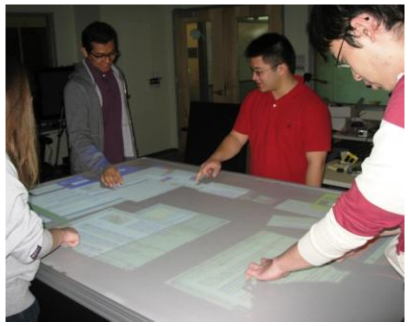


Figure 1. A group of students conducts a collaborative Web search using the WeSearch tabletop application.

Proposed systems for supporting co-located collaborative Web search generally provide each group member with her own device, sometimes supplemented by a shared display. For example, CoSearch [1] provides a mobile phone for each user, plus one shared PC display for the group. Cerchiamo [24] provides a dedicated PC for each of two collaborators that shows role-specific content, plus a shared wall display providing joint information. Maekawa et al. describe a system [16] which divides a Web page into sections and puts one section on each user's personal mobile device. WebGlance [22] lets a group browse the Web together by providing an interface on each user's PDA that controls a browser shown on a large wall display.

These prior systems' rationale for providing each group member with a personal device is to enable all group members to participate and work in parallel. This is necessary because traditional PCs (and many large wall displays) permit only a single mouse or keyboard to interact at a time, which can result in frustration for the group member who is not "driving" the input devices [1]. However, providing separate devices for each co-located group member has some drawbacks, such as reduced awareness [1], which may be particularly problematic for collaborative search applications, where awareness information has been found to be valuable [18, 23].

Multi-touch tabletop technologies (*e.g.*, [2, 7]) provide a promising platform for co-located collaborative search applications. Such technologies enable simultaneous participation by all group members, while providing a shared display to facilitate awareness. Indeed, groups already gather around traditional tables in many of the situations in which the needs for collaborative search arise (in business meetings, in classrooms and libraries, and at home), making next-generation, interactive tables a logical venue for supporting information-finding tasks. Tables' large size affords spatially organizing content, which also makes them well-suited to search and sensemaking tasks.

A few researchers have begun to explore the harmony between tabletops and information-seeking tasks, although they have focused on specialized domains. TeamSearch [17] provides a visual query language to support tabletop search over a tagged image database. The Personal Digital Historian [29] also supports image search, by filtering a tagged collection based on who is shown in the photo, where it was taken, or when it was taken. Físchlár-DT [31] enables partners to collaboratively explore a collection of video clips on a tabletop display, and Cambiera [13] supports investigation of a database of news clips associated with the VAST visual analytics challenge.

In this paper, we introduce WeSearch, a system designed to support collaborative Web search (and subsequent sensemaking) for groups of up to four co-present users gathered around a multi-touch tabletop display. We first articulate design criteria specific to tabletop search systems, and introduce user interface features to address those criteria. We then describe an evaluation of WeSearch, in which student, co-worker, and family groups conducted real-world search tasks. We discuss the findings from our study, reflecting on the effectiveness of each of WeSearch's features.

WESEARCH

In order to explore the potential for interactive tabletops to support collaborative Web search, we developed WeSearch. WeSearch is a tabletop application which supports collaborative Web search, browsing, and sensemaking among groups of up to four people.

Design Criteria

When designing WeSearch, our goal was to leverage the affordances of tabletops that would benefit collaborative search tasks. Examples of such affordances include high levels of awareness from sharing a single display and the affordances of large horizontal surfaces for spatially organizing content [21].

Prior work on collaborative Web search tools for the PC informed our system's design. In their work on SearchTogether [18], Morris and Horvitz identify three traits that are important for facilitating collaborative search tasks. *Awareness* of other group members' activities, facilities for supporting *division of labor* among group members, and facilities for *persistence* of a search session in order to facilitate asynchronous collaboration and resumption of multi-session, exploratory search tasks. Morris and Horvitz also noted that, in initial evaluations of SearchTogether, participants requested richer *sensemaking* [25] support. Studies of the CoSense system [23] reiterated the importance of sensemaking support for collaborative Web search tools.

Research from the surface computing community has shown that there are several challenges in adapting horizontal surfaces to productivity tasks [20]. Text entry on tabletops is one challenge [35]; virtual keyboards are not nearly as efficient as their physical counterparts, and appropriate alternative techniques are still a subject of ongoing research [12]. Clutter is also a challenge of adapting search and sensemaking applications to tabletops, since displaying content for multiple users on a single display is a constant challenge for single display groupware systems [32]. The clutter issue is further compounded by the information-intensive nature of Web search tasks, as well as by the tendency of tabletops to utilize projected displays; XGA (1024 x 768) is still the predominant projector resolution, so while most tabletops are larger than PC monitors, they may in fact have fewer pixels. Orientation is also a challenge for tabletop system designers [30], since what's right-side-up for some group members is upside-down for others; Web search exacerbates this challenge, since text-heavy applications are particularly challenging to use from odd viewing angles [34].

In light of these findings from the collaborative search and tabletop communities, our design goals for WeSearch were:

- Support *awareness* among group members.
- Support *division of labor* among group members.
- Enable the shared search to *persist* beyond a single session.
- Support *sensemaking* as an integral part of the collaborative search process.
- Provide facilities for *reducing the frequency of virtual-keyboard text entry*.
- Reduce *clutter* on the shared display.
- Address the *orientation challenges* posed by text-heavy tabletop applications.

Next, we describe the features of WeSearch, and explain how they address these design goals.

System Description

Since collaborative search and sensemaking are data-intensive tasks, we designed WeSearch for a large-form-factor surface, 4x6 [10] (Figure 1). 4x6 is a custom-built, standing-height interactive tabletop measuring 4 feet wide by 6 feet long (1.2 m x 1.8 m). The display is top-projected by two tiled XGA projectors, for a total display resolution of 1024 x 1536 pixels. The table is illuminated from beneath by infrared light, and touch inputs are detected by a vision system.

The 4x6 table can receive multiple, simultaneous touch inputs, but cannot associate inputs with a particular group member. Users can freely rotate all objects; because our tabletop hardware is not user-differentiating, we use

Figure 2. A WeSearch session. Each group member has a color-coded toolbar in which they can enter queries or urls, and a marquee containing awareness information. Spread around the table are several browsers, clips, and containers.

objects' orientation as a proxy for identity (*i.e.*, whether an object is right-side up for the North, South, East, or West edge of the tabletop). Because of the readability issues concerning text on tabletops [34], orientation of text-heavy documents such as Web pages seems like a reliable proxy for the identity of the currently-interacting user, and is consistent with how users utilize orientation of objects to denote ownership [14, 27].

Toolbars

When WeSearch initializes, it displays four color-coded toolbars (one per group member), one along each edge of the tabletop (Figure 2). If desired, these toolbars can be repositioned and re-oriented through direct-touch manipulations. The color of a user's toolbar is associated with him in other aspects of the user interface.

Touching the toolbar's text field opens a virtual keyboard that enables users to enter urls or query terms. Tapping the toolbar's "go" button opens the WeSearch browser (Figure 3a) to that url (if the terms begin with "http" or "www") or opens a search engine page containing search results for the terms entered.

Browser Controls

We have designed the WeSearch browser with the needs of touch-based interaction in mind. The browser can be moved, rotated, and scaled using direct touch manipulations [8]. Because touches on the browser are by default interpreted as manipulations, we augment the browser's border with buttons to enable additional actions (pan, link, and clips), shown in Figure 3. A future implementation of WeSearch might remap these buttons to gestures; we chose to sidestep the issue of gesture selection by using buttons which are held with one hand while the browser is manipulated with the second hand. The buttons must be held to maintain the mode in order to reduce errors [28]. Horizontal and vertical scrolling are accomplished by holding the "pan" button with one hand while using the other hand to pull the Web page's content in the desired direction, and link-following is accomplished by holding the "link" button with one hand while tapping the desired link with the other.

Clips

Holding a browser's "clips" button divides the current web page into multiple smaller chunks (Figure 3b); a user can grab a chunk with his other hand and drag it beyond the borders of the browser, where it will become a separate entity that we call a *clip*. Upon releasing the "clips" button, the browser page returns to its undivided state. In order to divide a Web page into clips, WeSearch parses the DOM (document object model) of each page when it is loaded; we then create clip boundaries surrounding DOM objects such as paragraphs, lists, and images. The ability to divide a page into clips supports division of labor and readability by enabling different group members to claim responsibility over distinct portions of a page's contents, which can then be individually rotated into a proper reading orientation; clips also support clutter reduction – the small chunks of relevant content can remain open on the table and the parent page can be closed. Our clips build upon prior work demonstrating the value of micro-mobility of content on tables, such as DocuBits [4], which enabled easy transfer a screen-captured chunk of text documents or images between a tabletop and associated supplementary displays.

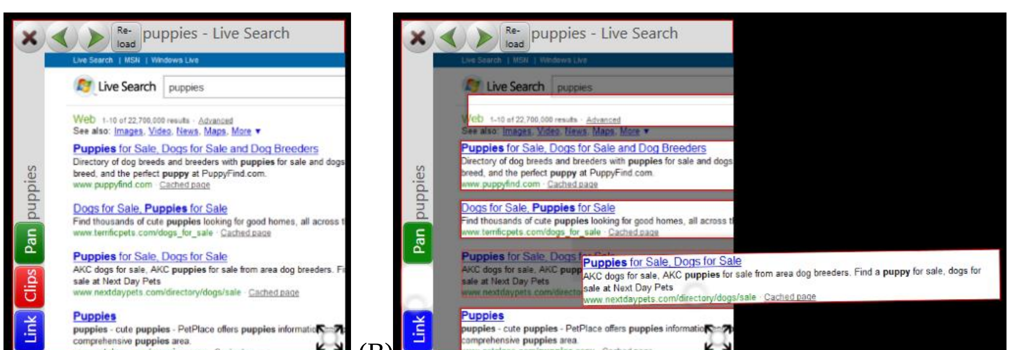
(A)  (B)

Figure 3. (A) The WeSearch browser provides a panel of kinesthetically-held buttons to distinguish between direct manipulations (translation, rotation, and scaling), and actions such as panning, link-following, and dividing a page into clips. (B) When the clips button is held, a webpage is automatically divided based on the underlying DOM. The resulting *clips* can be pulled out of a page and treated as individual objects.

Figure 4. A clip tagged by both the green and red users.

Figure 5. The clips-search function creates four types of clips directly from query terms: related keywords, Web search results, images, and news article summaries.

Clips can be moved, rotated, and scaled in the same manner as browser windows. Like browsers, clips are augmented with a "link" button that, when depressed, interprets touches as clicks on links rather than direct manipulations. Clips are also augmented by a "tag" button; pressing this opens a virtual keyboard, and the user can augment a clip with tags. Tags are displayed on the clip in the color of the user who entered them (Figure 4). We included the ability to augment clips with tags in order to support sensemaking as a key part of the task.

Clips-Search

In addition to creating clips by pulling chunks out of Web pages in WeSearch browser windows, users can also create clips directly by pressing the "clips" button in lieu of the "go" button after they have entered query terms into their toolbar. This sends the query to a search engine via its public API, and automatically creates four piles of five clips each in front of the user (Figure 5) one containing the most relevant images for the query, another containing snippets describing related Web pages, a third containing news article summaries on that topic, and a fourth containing suggested related query keywords. The clips-search button provides another easy way for groups to divide labor amongst themselves, if each chooses to take responsibility for a different content type.

Marquee

Another component of the WeSearch interface is the *marquee* region of each user's toolbar (Figure 6). The marquee displays a slowly flowing stream of text and images that reflect the group members' activities: query terms used, titles of pages opened in browsers, and clips created. The marquee is visually similar to an interface current [11], but the marquee's content is generated automatically based on users' actions, while objects must be manually added to interface currents. The colored borders surrounding marquee items indicate which user's

Figure 6. Each toolbar contains a marquee, where search terms, page titles, and clips from all group members slowly scroll past for awareness and readability. Terms from the marquee can be reused via dragging onto the search box.

activities each item represents. Scroll buttons at either end of the marquee enable the user to manually rewind or fast-forward the display, in order to review the content. The marquee addresses the issue of awareness of group members' activities, as well as offering a solution to the challenge of reading text at odd orientations by giving each group member a right-side-up view of key bits of textual material from other team members.

Marquee items are interactive. Pressing and holding a marquee item causes the corresponding original clip or browser (if still open) to become highlighted in the pressing user's color and to blink, offering a method of mitigating the clutter issue by simplifying the process of finding content within a crowded UI. Marquee items (and clips) also provide another opportunity to reduce the frustration of virtual keyboard text entry: users can drag items out of the marquee and onto the toolbar's text area, in order to re-use the text they contain; clips can also be used in this manner. For example, the "keyword suggestion" clips created by a clips-search can be dragged directly onto the textbox in order to save the effort of manually re-typing those terms.

Containers

Another type of sensemaking support WeSearch provides, in addition to the ability to create and tag clips, is the ability for clips to be organized in *containers*, which a user can create via a button on the toolbar (Figure 7). The ability to create collections of material from disparate websites has been demonstrated by prior systems such as Dontcheva *et al.*'s system [3], Hunter Gatherer [26], and Google Notebook. We expand on this concept by offering containers designed for use in multi-user, direct manipulation environments, and augmented by features such as the ability to "search by example."

WeSearch offers several container variants, which organize clips in different manners, such as via lists, grids, and free-form positioning. The virtual keyboards can be used to specify a title for the container. Containers can be translated, rotated, and scaled through direct manipulation interactions on their background, and clips can be added and removed from containers via drag-and-drop.

Search by Example

In addition to providing a mechanism for organizing a group's clips, containers also facilitate discovering new

Figure 7. Clips can be organized within containers. Containers also provide a "search by example" capability, suggesting search terms related to a group of clips along the container's bottom edge (in this case, the terms "top breed").

information via their "search by example" functionality. Every time a clip is added to or removed from a container, the *search preview* region at the bottom of that container updates, to indicate what query the system thinks is suggested by the container's current clips (Figure 7). Pressing the "search" button adjacent to the preview executes the search, opening the search results in a new browser window. The suggested queries are generated by analyzing what terms (excepting stopwords) a group of clips has in common; if there are no common terms, the algorithm instead composes a query by choosing a salient term from each clip; saliency is determined by heuristics including the frequency with which a term appears and whether the term is a proper noun. This functionality helps to reduce the need for tedious virtual keyboard text entry.

Metadata

WeSearch automatically associates several types of metadata with clips, structured around the six journalistic interrogatives:

- *Who*: The identity of the user who created the clip.
- *What*: The content type of the clip (text, image, etc).
- *Where*: The URL of the Web page the clip is from.
- *When*: The timestamp of the clip's creation.
- *Why*: The tags associated with the clip.
- *How*: The query keywords used to find the clip (or to find its parent Web page).

Exportable Record

These metadata are used to create a record of the group's search session. This record is saved as an XML file, with an accompanying XSL file that enables the records to be viewed in any standard Web browser. Figure 8 shows a sample record, viewed after a WeSearch session on a group member's PC. Pressing the "save" button on a toolbar creates this record, as well as creating a session file that captures the current application state, enabling the group to reload and resume the WeSearch session at a later time. This supports our design goal of persistence by providing

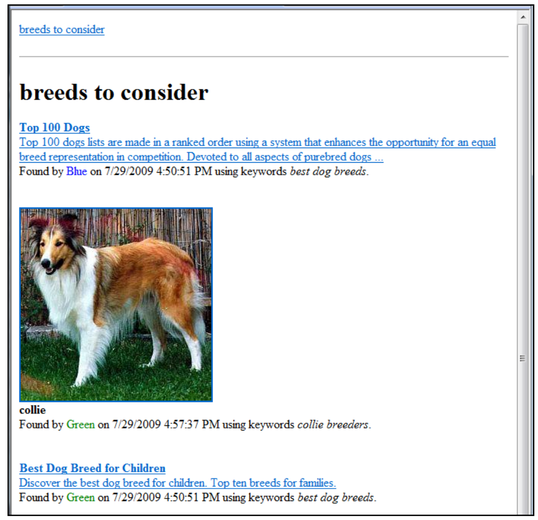


Figure 8. WeSearch exports the session record as XML with an accompanying XSL file that enables users to view the record from any Web browser for post-meeting reflection and sensemaking.

both persistence of the session for resumption by the group on the table at a later time, as well as persistence in terms of an artifact (the XML record) that can be viewed individually away from the tabletop computer. The metadata included in the record also supports sensemaking of the search process by exposing detailed information about the lineage of each clip (*i.e.*, which group member found it, how they found it, etc), as well as information about the assignment of clips to containers.

EVALUATION

We conducted an evaluation of WeSearch in order to learn more about how groups would use a tabletop collaborative search system, and whether the features we included in light of our design criteria were effective.

We decided to conduct an observational study rather than a formal experiment, since there is no clear baseline condition to compare to, as there are currently no other tabletop Web search systems of which we are aware. Comparing to a naïve system (such as running a standard Web browser on a table) would yield little additional insight, as we already understand the shortcomings of such systems based on our own experiences, prior work on tabletop systems, and prior work on collaborative search (and chose our design criteria based on those issues!).

We decided to recruit groups who had an existing shared information need, in order to observe the use of WeSearch for real, ecologically valid tasks. Questions we hoped to address through our evaluation included:

- What types of search tasks would groups want to conduct using an interactive tabletop?
- How will groups use the WeSearch application; what types of work styles and group dynamics does it engender?

- Were WeSearch's interface features effective in achieving our design goals?

Participants

We recruited 44 participants (11 groups with four members per group) from outside our institution. In one of the groups, two members had an unexpected absence, resulting in 42 participants total. Group members had prior relationships – three were family groups (each consisting of two adults plus children), three were groups of college students taking classes together, and five (including the two-member group) were groups of colleagues who worked together. Participants' ages ranged from 10 to 54 years. 43% were female. Participants did not have backgrounds in computer science, usability, or related fields. When asked to describe their Web search skills, 1 self-rated as a novice, 19 as average, and 22 as above-average.

Methodology

Sessions began with a "group interview," during which the experimenter asked the group members to describe a shared information need that is typical in their interactions with one another. They were then asked to describe how their group would normally go about investigating this information need (*i.e.*, what tools would they use, how would they divide up the task, etc.). The tasks groups chose were:

- Select the location for their company's next offsite meeting (colleagues: administrative assistants)
- Conduct background research on a plaintiff in a pending court case (colleagues: paralegals)
- Learn about local businesses who might be in need of financial services (colleagues: bankers)
- Research and describe antimicrobial peptides for identifying bacteria (colleagues: food scientists)
- Compile a list of commonly reported problems with a piece of technology commonly utilized by their customers (colleagues: technical support technicians)
- Shop for a new home computer (family)
- Plan an upcoming ski trip to Colorado (family)
- Plan an upcoming trip to Montana (family)
- Research treatments for Alzheimer's disease (students)
- Learn about art classes they might take together (students)
- Plan a trip to Austin, Texas (students) (Note that this student group was unable to agree upon their search task, so we prompted them with a variant of the travel planning task used in Paul & Morris' collaborative sensemaking study [23].)

After the initial interview, groups completed a tutorial, in which an experimenter demonstrated each of WeSearch's features, and participants were able to try using each feature. Participants were also free to ask the experimenter for assistance during the study (for instance, if they forgot how to access a particular feature).

After completing the tutorial, groups were given 30 minutes to use WeSearch to conduct the joint search task they had specified during the group interview. All interactions with WeSearch were logged automatically. Sessions were video recorded, and each session was observed by three experimenters who took notes.

At the conclusion of the session, group members individually completed questionnaires soliciting feedback on their experience using WeSearch.

RESULTS

Participants reported that WeSearch was easy to learn (median score of 6 on a 7-point Likert scale), and was helpful in completing their chosen task (median = 5). In this section, we revisit the seven challenges we designed our system to address, and examine how they impacted the WeSearch experience based on log, observation, and questionnaire data.

Awareness

WeSearch was designed to support awareness among group members through (1) use of a single, shared display and (2) the *marquee* feature, which displays other group members' query terms and clips in a slowly moving stream atop each user's toolbar.

Participants strongly agreed that seeing everyone's content on the shared display was a useful aspect of the system (median = 6), and reported generally high awareness of other group members' activities (median = 5). Additionally, several users commented on the benefits of the shared tabletop form-factor. For example, when asked to compare using WeSearch to their current method of finding information as a group, one user commented that she liked how WeSearch's shared display offered the ability to "glance over and see that someone found something interesting," another said she liked "being able to see other people's pages & searches at the same time," and another reported liking that "we are able to see what each person is working on and can expand on that particular idea."

The marquee feature proved successful in facilitating additional awareness, particularly of the search terms other group members had typed. One user described her experience with the marquee by noting, "I found search terms coming up that I did not anticipate and this improved the value and speed of the searches," and another reported that "seeing other people's search queries reminded me of things to search for." During the sessions, we observed many instances where the marquee sparked awareness and discussion. For example, among the group searching for a location for a company offsite meeting, one participant questioned another, "Why did you put 'weddings'?" when she saw that term scroll past in her marquee, and learned that her colleague thought wedding venues might also have catering facilities appropriate for corporate meetings. The marquee made one of the bankers aware that his partner was searching for businesses in an area he didn't anticipate, causing him to comment, "oh, you did 'city of <anon>'?"

when he saw her search terms in his marquee. One of the paralegals commented in surprise when he noticed a colleague's search term, "McDonald's," appear in the marquee, and his colleague explained that the plaintiff had in the past sued that restaurant chain. One participant commented that he felt that the collaborative aspect of the system was most clear in the marquee feature, due to the awareness it provided him of the keywords other participants were using. Another participant removed search terms that seemed most useful from the marquee and arranged them in a pile near his toolbar, in order to help him keep track of which directions of the group's investigation appeared most promising. However, participants also commented that they felt the marquee sometimes became too cluttered; in particular, they felt that the clips that appeared in the marquee took up too much space, and were not as valuable as the search terms, since clips were already easily visible by glancing at the tabletop.

Division of Labor

One motivation behind the design of WeSearch's clips feature was to facilitate division of labor among group members. We envisioned that group members might divide up responsibility for portions of a web page, for instance, by dividing it into several clips and each claiming some, or that users might find the different clip types returned by the clips-search feature (news, images, web results, and keyword suggestions) to be a convenient way to allocate different media types among themselves. However, groups did not use clips to divide labor in this manner, but rather used clips mainly for sensemaking and clutter reduction.

However, the large, shared display provided by WeSearch seemed to adequately support division of labor by providing each group member with space to interact and facilitating conversation and awareness through co-presence and co-visibility. All groups followed a divide-and-conquer strategy for their search task, wherein group members each were assigned sub-tasks (either by a de facto "leader," or by each volunteering for a particular task); group members then communicated orally to resolve questions, update others on the status of their subtask, and to share and compare key findings.

Persistence

WeSearch provides persistence of information through the ability to save and reload the table's state, and the ability to export an XML record containing metadata about containers and the clips they contain, such as who found each item, what terms they used to find it, what tags were added to it, and a link back to the url where each clip originated. Because our evaluation took place during a single session, participants did not have the opportunity to make use of this record feature, although we did show participants their record webpage at the end of the session, to get their reactions. Participants strongly agreed that the ability to export a record for later viewing away from the tabletop was a valuable feature (median = 6). Despite the fact that the task was only occurring during a single session, 9 of the 11 groups used the "save" button at least once during the task, in order to export their record and capture the table's current state, further emphasizing the value users attribute to persistence features.

Sensemaking

WeSearch offered several features designed to support an integrated search and sensemaking cycle, including the ability to create clips representing the key portions of web pages, the ability to tag clips, and the ability to organize clips in various types of containers.

Participants appreciated the ability to create clips, although they preferred creating clips by selecting chunks of pages in their browsers rather than through the clips-search feature, which created clips directly from search terms. They rated the ability to break up pages into clips as significantly more useful (median = 6) than the ability to do a clips-search directly (median = 5), as confirmed by a Wilcoxon test ($z = -2.54$, $p = .01$). Participants frequently broke pages into clips (previewing the available clips by using the browser's "clips" button 74.7 times per group, and removing from the browser 38.3 clips per group, on average), but rarely executed a clips-search (only 2.2 times per group, on average). The relative unpopularity of the clips-search feature seemed largely to be a clutter issue, with participants commenting that the number of clips created at once via the search feature was overwhelming (the feature by default created 20 clips relevant to the current query); for example, one user noted, "clips-search … added too much clutter to the table."

While making clips from web pages was quite popular, participants rarely chose to add tags to their clips – only 2 of the 11 groups used this feature at all; the slowness of text entry with virtual keyboards may have contributed to the disuse of the tagging feature. Several participants also suggested improving upon our current clip feature by enabling manual demarcation of clips (such as by circling a region of the page with one's finger), in addition to the automatic, DOM-based chunking that our system used.

The ability to organize clips in containers in order to help make sense of the information the group had discovered was popular among our participants. All groups created at least one container, with an average of 5.7 per group. Of the four container types, the list format was the most popular; however, several participants requested the ability to change a container's organizational style on-the-fly (rather than have to choose a style a priori), so that they could preview what their content looked like organized in varying fashions (lists, grids, etc.).

While we had anticipated that containers would be used for sensemaking at the group, rather than individual, level, this was not typically the case; participants seemed to feel ownership over the containers they had created, and typically each group member had one (or more) containers of his own. The exceptions were two of the family groups – in one, one of the parents created a container and instructed the other family members that each should place clips related to his favorite candidate laptops inside it; in the other, one of the children created a container about weather conditions in Montana and instructed the other family members to "throw any clips you find for weather stuff here." Generally, however, participants felt awkward about using a container someone else had created, apologizing when they did so (such as when one participant exclaimed "oops, I was naming your container!") or asking for explicit permission, such as when one colleague asked another "can I use your bucket?" Groups that followed this "individual sensemaking" trend typically followed up with a round of collective sensemaking, where they discussed what was in each container; for example, near the end of the task one of the administrative assistants declared "now it's time to compare [containers]."

The metadata (*who*, *what*, *where*, *when*, *why*, and *how*) that was automatically associated with each clip and exposed in the exported session records was designed to support individual sensemaking and reflection away from the tabletop; however, since our experiment took place during a single, around-the-table session, we did not have the opportunity to evaluate that sensemaking feature.

Text Entry

As expected, participants reported that entering text (query terms, urls, tags, etc.) using our tabletop's virtual keyboards was slower and less pleasant than using traditional keyboards, expressing disagreement with the statement "typing on the virtual keyboard was easy" (median = 3), and providing several comments to that effect, such as "take the keyboard off the table and make it separate hardware. Typing was a bottleneck to my efficiency."

WeSearch attempted to mediate this problem by facilitating easy reuse of text, such as by enabling reuse of terms appearing in the marquee and clips, and by the "search by example" feature that suggests search keywords based on the set of clips in a container. Participants made use of the search by example feature, though not extensively; 7 of the 11 groups used it at least once, with an average of 2.8 uses per group.

The ability to reuse items appearing in the marquee was a very popular alternative to typing, and enabled group members to leverage text entry work already done by their teammates. Groups used this feature an average of 16.8 times each (66.2% of all words entered in the query box were from re-used, rather than typed, text), and participants strongly agreed that the ability to reuse text from the marquee was helpful (median = 6). For example, when the group of administrative assistants was searching for a location for their company's offsite meeting, one woman said to another "thanks for typing 'conference'" as she pulled that term from her marquee and appended it to her own query. Another participant had begun typing a long keyword when he saw it appear in his marquee because another group member had typed it already – "why am I typing this when it's on the marquee?" he said, abandoning typing and adding the marquee text to his query instead.

Clutter

WeSearch allowed participants to extract clips containing the most relevant content from web pages so that the pages themselves could be closed, thus reducing clutter on the tabletop. Our system also employed a large form-factor table with a tiled projector system in order to alleviate space issues. Nonetheless, clutter remained one of the most problematic aspects of the WeSearch experience, prompting tense dialogue between participants such as "will you move your stuff?", "you're taking up my space, man", and "I'll just start stealing Dad's space." These remarks also reflect participants' sense of ownership over a portion of space, reconfirming Scott *et al.*'s findings regarding territoriality on tabletop displays [27]. Participants strongly agreed that the table was too cluttered during the activity (median = 6), and 18 participants (43%) mentioned clutter as a problem in their free-form questionnaire responses. Common suggestions made by our participants on the post-task questionnaire included the ability to group items and mark them for simultaneous deletion (*i.e.*, deleting an entire pile of clips at once), and allowing users to hide or minimize their toolbars (which are currently always visible in WeSearch).

Orientation

As mentioned in the "Awareness" section, the marquee appeared to successfully address the issue of reading text at odd orientations by providing a user-oriented view of the search terms other group members were typing. However, WeSearch permitted clips and browser windows to be freely rotated via two-fingered manipulations in order to permit the use of orientation for communicative purposes, as suggested by Kruger *et al* [14]. Participants frequently performed rotations unintentionally (while scaling or moving documents), and spent time trying to return browser windows to straight orientations – even slight angles seemed to annoy our participants, several of whom requested that browsers and clips should "snap" to align with table edges rather than be fully rotatable (such as in [30]). One participant captured this sentiment on his questionnaire, indicating that we should "change the sensitivity to rotation. I spent too much time having to continually readjust the rotation."

DISCUSSION

In light of our findings, we revisit the questions that motivated our evaluation:

What types of search tasks would groups want to conduct using an interactive tabletop?

In our study we had the opportunity to observe groups of several types (families, students, and colleagues) conducting collaborative searches on topics of interest to them. Our post-study questionnaire also asked participants to discuss any other information needs they had where they might want to use a system such as WeSearch. In addition to providing examples of several specific productivity tasks (*i.e.* job or school-related joint research tasks) and family-oriented tasks (*i.e.* shopping, travel planning, entertainment planning) involving collaboration among groups of peers, several participants also suggested that a collaborative tabletop search system might be valuable in situations where a professional and a customer work together, such as a librarian and a student finding information together, or a salesperson helping a client to explore various product options together.

How will groups use the WeSearch application; what types of work styles and group dynamics does it engender?

WeSearch supported natural transitions between closely- and loosely-coupled (*i.e.,* parallel) work styles, with groups typically dividing a search task into sub-tasks on which members worked in parallel, with interwoven discussion of items of interest to the group at large, such as interesting results discovered.

Were WeSearch's interface features effective in achieving our design goals?

Awareness: WeSearch adequately supported awareness among group members; the marquee feature, in particular, provided heightened awareness of the query terms used by other group members, which stimulated discussions about search strategy among group members.

Division of Labor: While the clips feature did not support division of labor as originally envisioned, the tabletop environment itself, which supported individual action and shared communication, was adequate for enabling effective division of work among group members.

Persistence: The system's record-exporting and state-saving features received positive reactions from our participants.

Sensemaking: WeSearch enabled group members to integrate their search and sensemaking activities seamlessly. The ability to create clips and to organize them in containers was highly valued, although tagging capabilities were underutilized.

Text Entry: The ability to reuse existing text rather than re-typing everything on virtual keyboards was highly appreciated, although participants still found the occasions when they needed to use the virtual keyboards to be frustrating. Augmenting the tabletop with physical keyboards (perhaps fixed in place around the bezels of the display so that they don't add to the clutter problem) might address this frustration. Since text entry was a key frustration for users, we expect that offering physical keyboards may change work styles from what we observed; however, evaluating WeSearch without physical keyboards offered value in understanding how to optimize productivity systems for this common hardware configuration, such as by maximizing text reusability.

Clutter: The ability to create a clip and then close the web page it came from helped to reduce clutter somewhat. Despite this, clutter remained a key frustration when using WeSearch due to the large number of documents participants explored during their search tasks. Further clutter reduction techniques, such as ZoomScapes [6], might prove valuable. A higher-resolution display would also reduce clutter, since objects could be legible at a smaller size. Note that popular commercially-available tabletops such as DiamondTouch [2] and Microsoft Surface would not be appropriate for collaborative search and sensemaking tasks due to their small sizes (since the custom table we used in our study was over twice as large as these technologies and still suffered from clutter issues). We note that a common suggestion made by participants of allowing the toolbar to be minimized would reduce its benefits for awareness, and so alternative clutter-reduction approaches would be preferable.

Orientation: While the marquee provided group members with a way to see other users' text at a right-side-up orientation, group members were more concerned with maintaining a right-side-up orientation for items that belonged to them – the freedom to reorient objects freely confused them and they did not seem interested in the communicative benefits of orientation; rather, they indicated a strong preference for forced rectilinear orientations for text-heavy objects such as web browsers.

In light of these findings, we believe that WeSearch effectively illustrates the potential of interactive tabletops as a platform for collaborative search tasks, by easily facilitating awareness and division of labor, which PC-based collaborative search tools struggle to enable [1, 18], and by offering interface solutions to challenges specific to the tabletop form-factor, such as text-entry and clutter. Note that by choosing a holistic evaluation, we were unable to evaluate alternative designs for any particular UI innovation introduced by WeSearch; while such assessments would also be beneficial, we leave them to future work.

CONCLUSION AND FUTURE WORK

In this paper, we investigated whether interactive tabletops could be an effective platform for facilitating collaborative Web search. The contributions of this work included: (1) Identifying seven design criteria for successful tabletop search systems, based on a review of literature from both the collaborative search and tabletop communities; (2) WeSearch, a system that addresses these design criteria through a combination of novel interface features; and (3) An evaluation of WeSearch, in which 42 participants (in 11 groups) performed real-world search tasks, thereby providing data on the effectiveness of WeSearch's interface features as well as on how groups work together using this new type of system.

We found that WeSearch's marquee feature enhanced awareness of group members' search terms, clips and containers supported sensemaking as an integral part of the search process, and text-reuse and report-exporting features were highly valued. The main obstacles to a smooth tabletop search experience were hardware-based: larger, higher-resolution tabletops would alleviate clutter issues, and the integration of physical keyboards would provide a more positive text-entry experience.

The success of WeSearch in facilitating co-located collaborative search shows the potential for tabletop computers to serve this need. Our design criteria, system, and study findings provide a first step toward adapting the properties of tabletop displays for group Web search tasks.

REFERENCES

1. Amershi, S. and Morris, M.R. CoSearch: A System for Co-located Collaborative Web Search. *CHI 2008*, 1647-1656.
2. Dietz, P. and Leight, D. DiamondTouch: A Multi-User Touch Technology. *UIST 2001*, 219-226.
3. Dontcheva, M., Drucker, S., Wade, G., Salesin, D., and Cohen, M. Summarizing Personal Web Browsing Sessions. *UIST 2006*, 115-124.
4. Everitt, K., Shen, C., Ryall, K., and Forlines, C. DocuBits and Containers: Providing e-Document Micro-mobility in a Walk-Up Interactive Tabletop Environment. *Interact 2005*.
5. Fidel, R., Bruce, H., Peitersen, A., Dumais, S., Grudin, J., and Poltrock, S. Collaborative Information Retrieval. *Review of Information Behavior Research 1*, 1 (2000).
6. Guimbretiere, F., Stone, M., and Winograd, T. Fluid Interaction with High-Resolution Wall-Size Displays. *UIST 2001*, 21-30.
7. Han, J. Low-Cost Multi-Touch Sensing through Frustrated Total Internal Reflection. *UIST 2005*, 115-118.
8. Hancock, M., Vernier, F. D., Wigdor, D., Carpendale, S., and Shen, C. Rotation and Translation Mechanisms for Tabletop Interaction. *Tabletop 2006*, 79-86.
9. Hansen, P., and Jarvelin, K. Collaborative Information Retrieval in an Information-Intensive Domain. *Information Processing and Management 41*, 5 (2005), 1101-1119.
10. Hartmann, B., Morris, M.R., Benko, H., and Wilson, A. Augmenting Interactive Tables with Mice & Keyboards. *UIST 2009*.
11. Hinrichs, U., Carpendale, S., and Scott, S. D. Interface currents: supporting fluent face-to-face collaboration. In *ACM SIGGRAPH 2005 Sketches*.
12. Hinrichs, U., Hancock, M., Collins, C., and Carpendale, S. Examination of Text-Entry Methods for Tabletop Displays. *IEEE Tabletop 2007*, 105-112.
13. Isenberg, P. and Fisher, D. Collaborative Brushing and Linking for Co-located Visual Analytics of Document Collections. *Eurographics/IEEE-VGTC Symposium on Visualization (EuroViz 2009)*, 1031-1038.
14. Kruger, R., Carpendale, M.S.T., Scott, S.D., and Greenberg, S. Roles of Orientation in Tabletop Collaboration: Comprehension, Coordination and Communication. *Computer Supported Cooperative Work, Volume 14, Issue 5-6*, December 2004, 501-537.
15. Large, A., Beheshti, J., and Rahman, T. Gender Differences in Collaborative Web Searching Behavior: An Elementary School Study. *Information Processing and Management 38*, 3 (2002), 427-443.
16. Maekawa, T., Hara, T., and Nishio, S. A Collaborative Web Browsing System for Multiple Mobile Users. *PERCOM 2006*.
17. Morris, M.R., Paepcke, A., and Winograd, T. TeamSearch: Comparing Techniques for Co-Present Collaborative Search of Digital Media. *IEEE Tabletop 2006*, 97-104.
18. Morris, M.R. and Horvitz, E. SearchTogether: An Interface for Collaborative Web Search. *UIST 2007*, 3-12.
19. Morris, M.R. A Survey of Collaborative Web Search Practices. *CHI 2008*, 1657-1660.
20. Morris, M.R., Brush, A.J.B., and Meyers, B. A Field Study of Knowledge Workers' Use of Interactive Horizontal Displays. *IEEE Tabletop 2008*, 113-120.
21. Morris, M.R. Supporting Effective Interaction with Tabletop Groupware. *Stanford University Technical Report (Doctoral Dissertation)*, April 2006.
22. Paek, T., Agrawala, A., Basu, S., Drucker, S., Kristjansson, T., Logan, R., Toyoma, K., and Wilson, A. Toward Universal Mobile Interaction Shared Displays. *CSCW 2004*, 266-269.
23. Paul, S. and Morris, M.R. CoSense: Enhancing Sensemaking for Collaborative Web Search. *CHI 2009*, 1771-1780.
24. Pickens, J., Golovchinsky, G., Shah, C., Qvarfordt, P., and Back, M. Algorithmic Mediation for Collaborative Exploratory Search. *SIGIR 2008*, 315-322.
25. Russell, D.M., Stefik, M.J., Pirolli, P., and Card, S.K. The Cost Structure of Sensemaking. *CHI 1993*, 269-276.
26. schraefel, m.c., Zhu, Y., Modjeska, D., Wigdor, D., and Zhao, S. Hunter-Gatherer. Interaction Support for the Creation and Management of Within-Web-Page Collections. *WWW 2002*.
27. Scott, S.D., Carpendale, M.S.T., and Inkpen, K. Territoriality in Collaborative Tabletop Workspaces. *CSCW 2004*, 294-303.
28. Sellen, A., Kurtenbach, G., and Buxton, W. (1992). The prevention of mode errors through sensory feedback. *Human Computer Interaction*, 7(2). p. 141-164.
29. Shen, C., Lesh, N., Vernier, F., Forlines, C., and Frost, J. Building and Sharing Digital Group Histories. *CSCW 2002*, 324-333.
30. Shen, C. Vernier, F., Forlines, C., and Ringel, M. DiamondSpin: An Extensible Toolkit for Around-the-Table Interaction. *CHI 2004*, 167-174.
31. Smeaton, A.F., Lee, H., Foley, C., and McGivney, S. Collaborative Video Searching on a Tabletop. *Multimedia Systems Journal*, 2006, Vol. 12, No. 4, 375-391.
32. Stewart, J., Bederson, B., and Druin, A. Single Display Groupware: A Model for Co-present Collaboration. *CHI 1999*, 286-293.
33. Twidale, M., Nichols, D., and Paice, C. Browsing is a Collaborative Process. *Information Processing and Management 33*, 6 (1997), 761-783.
34. Wigdor, D. and Balakrishnan, R. Empirical Investigation into the Effect of Orientation on Text Readability in Tabletop Displays. *ECSCW 2005*, 205-224.
35. Wigdor, D., Penn, G., Ryall, K., Esenther, A., Shen, C. Living with a Tabletop: Analysis and Observations of Long Term Office Use of a Multi-Touch Table. *Tabletop 2007*.