CoSearch: A System for Co-located Collaborative Web Search

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ABSTRACT
Web search is often viewed as a solitary task; however, there are many situations in which groups of people gather around a single computer to jointly search for information online. We present the findings of interviews with teachers, librarians, and developing world researchers that provide details about users' collaborative search habits in shared-computer settings, revealing several limitations of this practice. We then introduce CoSearch, a system we developed to improve the experience of co-located collaborative Web search by leveraging readily available devices such as mobile phones and extra mice. Finally, we present an evaluation comparing CoSearch to status quo collaboration approaches, and show that CoSearch enabled distributed control and division of labor, thus reducing the frustrations associated with shared-computer searches, while still preserving the positive aspects of communication and collaboration associated with joint computer use.

ACM Categories
H5.3 [Information interfaces and presentation]: Group and Organization Interfaces - computer-supported cooperative work.

General Terms
Design, Experimentation, Human Factors

Author Keywords
Web search, collaborative search, CSCW.

INTRODUCTION
Although computers have become more plentiful in recent years, shared-computer use remains common in many settings. For example, in U.S. public schools, the ratio of students to computers is 3.8 to 1 [23], and the number of Internet-enabled computers available in U.S. public libraries is 3 for every 5,000 people [24]. In developing countries, these ratios can be even more skewed. For example, in rural schools in developing countries, the student-to-computer ratio can be as high 10 to 1 [17]. Even when resource constraints are not a factor, the social and pedagogical benefits of face-to-face collaboration and shared viewing of information can be a compelling reason for collaborators to share a single computer [20]. For example, in a recent survey of 204 Microsoft employees, 87.7% reported engaging in "backseat driver" searches where they watched over another person's shoulder and suggest query terms to try or links to click [12].

Web search is one of the most common online activities [19], and is often undertaken in shared-computer settings. For example, students work together on homework and family members jointly plan vacation travel. However, sharing a computer for Web search can be frustrating and inefficient when individual collaborators disagree on which queries to issue or links to follow.

We conducted interviews with educators and others who frequently observe shared-computer Web searches, and, based on these interviews, identified several limitations of current collaborative search practices. Informed by the findings of this formative study, we created CoSearch, a system for facilitating collaborative Web search among people gathered around a single computer. CoSearch leverages cheap or pervasive devices within the environment, such as mice and mobile phones, to provide a richer searching experience for all group members. We selected mobile phones as a target platform because they are widely available, even in resource-constrained environments. In the U.S., 76% of the population have mobile phones [2]. Furthermore, 61% of the world's mobile phone users are in developing countries [3], with India having the fastest growing market in the world [25]. We also present the results of a formal evaluation of CoSearch's utility for co-located collaborative Web search, and show that CoSearch enables distributed control and division of labor, while maintaining the communication and collaboration levels associated with shared computer use.

RELATED WORK
Commercial search engines and Web browsers focus on single-user scenarios. However, researchers investigating search activities have found significant effects of collaboration on the information retrieval behaviors of users in domains such as schools [10, 21], libraries [22] and offices [5, 7]. For example, Twidale *et al.* [22] observed the collaborative information retrieval activities of library users

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at a university and identified several common types of collaborative search practices, including 'joint search', in which a group gathers around a single computer.

Prior work has proposed systems for *remote* collaboration on Web tasks, such as browsing (*e.g.*, GroupWeb [4]) and searching (*e.g.*, SearchTogether [14] and S^3 [12]). In contrast, CoSearch is designed for collaborative Web search in a *co-located* setting, *i.e.,* when several people are gathered around a single computer.

Some prior work has explored supporting co-located users on searching and browsing tasks. ARIADNE [22] supports co-located collaborative search of databases through visualization of a user's search process that can be shared with others. TeamSearch [15] supports co-located search of digital photo collections by groups seated around an interactive tabletop display. Maekawa *et al.*'s system [11] automatically divides a single Web page into multiple components distributed among the handheld devices of co-located collaborators for group browsing in a mobile setting. WebSplitter [6] generates personalized views of Web pages for multiple co-located users based on the currently available devices (*e.g.,* laptops, PDAs, etc.). WebGlance [16] enables multiple PDAs to control a Web browser on a shared display. Unlike CoSearch, however, WebGlance only permits one-way PDA-to-shared-display message passing, and focuses on browsing rather than specifically supporting search tasks.

The design of CoSearch, which centers around a single computer while leveraging devices commonly available in the environment, such as mice and mobile phones, was inspired by related work involving technologies that exploit multiple devices for co-located collaborative activities. Inkpen *et al.* [8] conducted a study comparing pairs of children solving puzzles using a standard workstation versus one that provided each child with a mouse and cursor. They found significant pedagogical benefits of the distributed control the two-mouse/two-cursor setup enabled, including the reduction of off-task behavior. Pawar *et al.* [17, 18] also explored a multiple-mouse/multiple-cursor configuration for computer-aided learning in rural schools in developing countries. Their evaluations also showed benefits of this 'Multimouse' setup, including increased student motivation, engagement, and learning.

FORMATIVE STUDY

In order to verify the prevalence of co-located collaborative Web search and understand the needs of co-located searchers, we conducted semi-structured interviews with seven people who work in settings where sharing computers is common. We interviewed three teachers, two librarians, and two researchers in the field of technology for developing regions. The teachers included an elementary school teacher from a low-income public school, an elementary school teacher from a middle-income public school, and a secondary school teacher from a high-income private school. Of the two librarians, one worked in a large urban public library and one worked in a small suburban public library. Of the two researchers, one was based in Bangalore, India, and one was from a U.S. university.

In each interview, we asked a set of open-ended questions that were customized for each occupation. The questions were designed to learn more about the collaborative search habits of people in schools, libraries, and the developing world, such as the frequency of co-located collaborative search, the types of people who participate, the within-group roles they take on, the types of search tasks they collaborate on, the motivations for searching collaboratively, and the physical setup of resources used.

Demographics and Tasks

The librarians and teachers both reported that students frequently perform co-located collaborative Web searches by sharing a single computer. They emphasized that students (elementary and secondary) prefer to work and play collaboratively, and teachers are often trained to encourage collaboration in classrooms. One librarian explained that this type of activity is "generational" and stated that she rarely saw students in her library using computers in isolation unless they were checking email. Regarding collaborative Web search in particular, the librarians reported observing this activity daily among youths of all socio-economic backgrounds, including high-income, low-income, and homeless. These interviewees reported observing a typical group size of two or three collaborators, mainly due to logistic issues (*i.e.*, the arrangement of computing resources in libraries and schools makes it difficult for larger groups to sit around a single workstation comfortably) or management issues (*i.e.*, controlling off-task behavior is increasingly difficult in larger groups). Interestingly, these interviewees believed that because of the social and pedagogical value in group activity, larger groups would appear were it not for these limitations. During collaborative Web searches, the interviewees reported that one student would typically control the shared computer's input devices while the others made verbal suggestions about query terms to use or actions to take. Occasionally, students would spontaneously switch control of the input devices; in some classrooms this was enforced by the teacher so that each student would benefit from learning how to interact with a Web browser. In classrooms, teachers themselves periodically participated in the collaborative searches by suggesting navigation actions or query terms to individual groups (or to the class by writing terms on the board). Most often the searches students conduct collaboratively are informational (*e.g.*, finding facts about a particular person for a project).

Librarians also reported that seniors and new immigrants frequently participate in co-located collaborative Web searches, mainly because they are unfamiliar with technology. These searches are mediated by library staff or more skilled family members. Library staff are trained to avoid taking over input devices while collaboratively searching so that their collaborators can become

comfortable with the technology. Instead, staff members typically guide the search by making query suggestions (verbally or on paper) or navigation suggestions (by pointing). While students tend to collaborate mostly on informational searches, seniors and new immigrants also participated in transactional (*e.g.*, paying bills) and navigational tasks (*e.g.*, finding sites with job postings).

Both of the developing-regions experts that we interviewed remarked that the lack of internet access and Web content in local languages are currently major impediments to the adoption of Web-based technologies in developing regions, particularly in rural and low-income communities. However, both were optimistic that these resources would become increasingly available in the near future and expressed confidence that, were this the case, then a tool to support collaborative search would be valuable due to recognized resource constraints in developing regions (it is not unusual for four to six people in such locales to share a computer for work or play). Therefore, the responses from these interviewees pertained to their observations of co-located collaborative work and play in general, rather than Web search specifically, in these regions. They identified three categories of people who perform co-located collaborative work and play: students, rural people (sharing a computer at a local kiosk or telecenter), and low-income small business employees (*e.g.*, travel agencies with five employees forced to share a single computer). For students, our interviewees stated that co-located collaborative practices were comparable to those of students in developed regions, but with more students sharing each computer. In regards to rural people at local kiosks, their observations were similar to those of the librarians, in that computer use in these cases was often mediated by the kiosk operator. Finally, for small businesses employees, shared computer use is similar to that of students, but also includes scenarios where collaborative tasks are not conducted simultaneously, but rather sequentially on the same machine.

Limitations of Current Practice

Several limitations of current co-located collaborative search practices emerged as common themes during our interviews:

Difficulties Contributing. This can apply to the person controlling the mouse and keyboard (the 'driver') or the other collaborators (the 'observers'), depending on their relative assertiveness. Meek drivers can become occupied carrying out commands from assertive observers, reducing their own chance to contribute ideas. Conversely, domineering drivers often use their access to the input devices to control the search, ignoring or inadvertently discouraging participation from their collaborators.

Lack of Awareness. Dominating group members can overshadow the attempted contributions of others, leading to reduced awareness of others' skills and suggestions.

Lack of Hands-On Learning. Group members without access to the computer's input devices are deprived of the opportunity to increase their expertise interacting with search technologies.

Pacing Problems. Differences in reading speed among group members can make shared computing frustrating (*e.g.*, when drivers scroll too fast or slow, or navigate away from pages before observers have finished reading them).

Referential Difficulties. One of the benefits of collaborating around a shared display is the joint context it provides. However, for group members situated further from the display, it can be difficult to refer to this shared information (*e.g.*, because they cannot reach the display to point).

Single-Track Strategies. Common group-work strategies, such as division of a task into subtasks, are not possible with current computer-sharing practices.

Information Loss. Groups can have difficulty keeping track of their findings. For example, because shared-computer searches often occur on public computers or computers belonging to only one group member, it can be difficult for others to keep a record of what was accomplished.

COSEARCH

Based on our investigations of peoples' collaborative search practices and needs, we developed CoSearch, a tool that provides explicit support for groups of co-located people to search the Web when gathered around a single computer. Our primary design goal for CoSearch was to enhance the experience of co-located collaborative Web search in settings where computing resources are limited (*e.g.*, schools, libraries, or developing regions), by enabling distributed control and division of labor while maintaining group communication and awareness levels. We leverage devices commonplace even in resource-constrained environments, such as mobile phones and mice, to provide a more productive and engaging experience for group members who don't have access to the shared computer's keyboard and mouse. In the remainder of this section, we describe the functionality and features of CoSearch.

In the most basic CoSearch usage scenario, a group can gather around a single computer running the CoSearchPC application (Figure 1) with several mice connected to it. While schools, libraries, and rural communities in developing countries are typically unable to afford many computers, extra mice are quite cheap. In CoSearchPC, each group member's mouse controls a unique cursor (distinguished by color); multi-cursor functionality is obtained via the Microsoft Windows MultiPoint SDK. Individual cursors can serve as proxies for on-screen pointing, an important aspect of communication that can be difficult for group members that are far from the shared display in status-quo scenarios. Users can optionally use the shared keyboard to enter their names in the Identity Region in order to clarify which cursor color is associated with which group member.

Figure 1. CoSearchPC, with annotations identifying key UI features.

When the user with the keyboard enters a query in the search box, the results appear in the Results Pane. Any group member can click on any search result using her own cursor. Clicking a result causes a new tab to appear in the Page Queue, color-coded according to the user who opened it. New tabs are sent to the back of the Page Queue (*i.e.*, the page shown in the Browser Pane does not change as new tabs are added to the queue so as to prevent disruption to other group members possibly still viewing the current page). Clicking on any tab in the queue selects it, bringing its associated page to the forefront in the Browser Pane. Any group member can also click on links within the page in the Browser Pane, adding the link's target to the back of the Page Queue in a color-coded tab. The Page Queue is designed to address the problems of drivers being overwhelmed with suggestions from observers and observers having their suggestions ignored by drivers, by creating a persistent, unobtrusive way for all group members to indicate items they are interested in exploring.

There is a Notes Region at the bottom of the Browser Pane, where users can type notes about the current webpage. By clicking the Save button, the current page's title, URL, and Notes Region contents are added to the Summary Region. The "E-mail Summaries" button prompts the users to enter their email addresses and sends the entire summary to each of them in order to provide each group member access to the products of their collaboration. The Notes and summary-sending features are designed to address the issue reported by our interviewees that group members often have difficulty keeping track of shared sessions' findings.

If group members have Web-enabled mobile phones (as is becoming increasingly common even among school-age children and teens - in the U.S., 75% of teens age 17 and 42% of teens age 13 have mobile phones [1] - and people in developing countries [3]), then CoSearch offers a richer set of collaboration features. As in the basic case, one computer would run CoSearchPC, but it would also be Bluetooth-enabled, achieved with the addition of an inexpensive ($15) Bluetooth USB dongle. In this scenario, one group member can use the PC's mouse and keyboard, while the others can connect to the PC over Bluetooth (via the protocols developed in [9]) using their mobile phones, which would each be running the CoSearchMobile application (Figure 2). Upon connection, phone users' identity information is automatically entered into the CoSearchPC's Identity Region based on metadata already

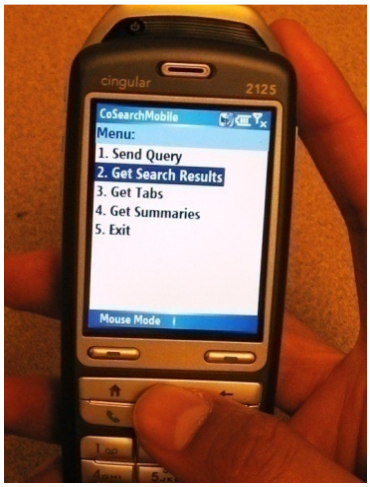

Figure 2. CoSearchMobile (main menu).

stored on most phones. Each group member would still have her own cursor on the PC, controlled by her phone. By selecting "Mouse Mode" from the CoSearchMobile main menu, users can move the PC's cursors via the phone's joystick or keypad, thus mimicking all the functionality provided by multiple mice in the basic usage scenario.

In addition to using their phones to control their cursors on the PC, CoSearchMobile users can download content onto their phones via Wi-Fi using the "Get Search Results" menu option (which downloads the list of results currently in CoSearchPC's Results Pane) or the "Get Tabs" option (which downloads the list of tab titles from the Page Queue). They can view these lists on their phone's display, and then select any item to open the associated Web page in their phone's browser. This ability to view Web pages on mobile displays is intended to allow group members to explore different aspects of the same search and/or enable individuals to read the same Web page at their own pace. Selecting a Web page from a mobile phone also causes that page to be added to the Page Queue (in a tab, color-coded for that user) so the other collaborators maintain awareness of what that group member is viewing. If phone users browse to new pages and encounter information they want to show the group, they can choose the "Share" command, which adds a tab containing their phone browser's current page to CoSearchPC's Page Queue.

CoSearchMobile users can also choose the "Send Query" option from the main menu, which allows them to enter query terms using the phone's keypad, and send them to CoSearchPC in a manner analogous to short message service (SMS). These queries (along with any queries entered by the user controlling the PC's keyboard) are color-coded according to the issuing user and are added to the CoSearchPC Query Queue. As with the Page Queue, the Query Queue provides a means for all group members to indicate search keywords they would like the group to try, without interrupting the current exploration. The "driver" can click on any item in the Query Queue in order to execute that query, causing its results to appear in the Results Pane. Executed queries remain in the queue, in order to help the group remember what they have already investigated and to enable fast re-access of result lists.

At the end of a search session, CoSearchMobile users can choose the "Get Summaries" menu option, which downloads the contents of the PC's Summary Region to their phones, so that they can refer to them in the future.

The addition of devices (mice or phones) in CoSearch is intended to allow "observers" to engage more directly with technology, so that they can share in the pedagogical benefits of doing so that only "drivers" experience with current shared-computing scenarios. Furthermore, the combination of CoSearch's features, such as the Query and Page Queues, and the ability to browse and share pages from the phones' displays, is intended to enable division of labor, a collaboration strategy not possible with traditional shared-computer use. However, by keeping the PC's display as the gathering point for queries, pages, and notes, we aim to preserve the shared context and focus that facilitate collaboration and communication among shared computer users. Finally, the color-coding scheme used throughout CoSearch (for cursors, Query Queue entries, and Page Queue tabs) is designed to address the lack of awareness about individual group members' contributions often experienced in shared computing scenarios.

EVALUATION

We conducted a study to assess how well we achieved our primary design goal of creating a tool that enables distributed control and division of labor while maintaining group communication and awareness levels. We compared CoSearch to the experience of collaboratively searching around a single, shared computer to determine whether CoSearch succeeded in addressing the limitations of this scenario. We also compared CoSearch to the experience of collaboratively searching using separate co-located computers, in order to verify that the introduction of additional devices in CoSearch had not inadvertently reduced some of the collaborative and communicative benefits associated with current computer-sharing practices to separate-workstation levels. We also evaluated the basic usability of CoSearch. We chose to evaluate only the mobile phone version of CoSearch as it, in effect, subsumes the multi-mouse version and offers richer interaction.

Participants

We recruited 36 paid participants (12 groups of three people each). The participants included 21 males and 15 females ranging in age between 12 and 76 years old (mean = 36).The group compositions ranged from sets of teens and college-aged people who were friends or siblings (4 groups), one child or teen with two adults who were either parents, grandparents or friends (6 groups), and adults with one elderly parent and another adult friend (2 groups).

Methodology

Each group was seated in a room containing three computers (with 21" monitors and UXGA resolution) side-

by-side. We asked each group to think of three topics of mutual interest that they could jointly research. Topics chosen included activities they wanted to participate in together, upcoming joint travel or purchases, or subjects they all wanted to learn about. We also asked groups to determine which member would be most likely to operate the keyboard and mouse if they were to gather around a single computer to work together. The person elected became the "driver" and sat at the middle computer throughout the study, flanked by the two "observers."

Each group jointly searched the Web under three conditions (counterbalanced via Latin Square design). In the 'Shared' condition, the subjects used a single computer. In the 'Parallel' condition, each of the group members operated one of the computers. In the 'CoSearch' condition, the middle computer ran CoSearchPC, and the two observers each used CoSearchMobile on i-mate SP5 Smartphones.

At the beginning of the Shared and Parallel conditions, the groups were instructed that they were going to jointly search the Web (either using a single computer or multiple computers, respectively). They used Internet Explorer 2007. At the beginning of the CoSearch condition, subjects were given a tutorial in which two experimenters demonstrated the features of CoSearchPC and CoSearchMobile. The subjects were then given a few minutes to experiment with CoSearch and ask questions of the experimenters as needed.

Each group was sequentially given two timed tasks to accomplish using each condition's setup. The first task was always one of three tasks that we had defined prior to the study (the tasks were also counterbalanced to eliminate ordering effects). These tasks were designed to resemble common tasks identified by the interviewees from our formative study, and involved finding the answers to questions about U.S. history and geography. To improve ecological validity, the second task in each condition was one of the three tasks the groups had formulated at the beginning of the study. Groups were given one task at a time and instructed to jointly search the Web until they accomplished it. To keep the study under a reasonable length (two hours) and avoid exhausting our participants, we allotted a maximum of 7 minutes for each task, but did not inform the groups of this limit so as not to induce unnecessary stress. If a group had not completed a task after the 7 minute period, we asked them to stop the search.

All actions in CoSearch were automatically logged. Two experimenters also observed and took notes. After completing both tasks for a condition, subjects filled out questionnaires. At the end of the study, each participant completed a questionnaire comparing all three conditions.

RESULTS

Our results showed that CoSearch succeeded in facilitating high levels of group communication and collaboration (comparable to the Shared condition and superior to the Parallel condition), while also enabling division-of-labor and more individualized control, thus reducing frustrations associated with the Shared condition. Users were able to learn and use CoSearch's features, and had positive reactions to the system, although users with more SMS experience were able to use CoSearchMobile more effectively than novices. The rest of this section discusses the findings in greater detail.

Analysis Details

Due to the diversity of our study participants, we wanted to examine the effects of expertise (with search and SMS) on our findings. When examining the effects of search expertise on our findings, we split the participants into a *Less-Experienced* group (19 participants made up of two self-rated novices, 2 below average and 15 average searchers) and a *More-Experienced* group (17 participants made up of 16 above average and one expert searcher). We also used self-ratings to partition based on SMS skills: 11 participants reported *Never* sending text messages, 16 participants *Occasionally* sent text messages, and 9 participants *Frequently* sent text messages.

We conducted several statistical analyses of our questionnaire and log data. For Likert scale questions (1=strongly disagree, 5=strongly agree), we conducted Friedman tests with follow-up pairwise Wilcoxon tests (with LSD corrections). We also conducted individual Friedman tests (and follow-up Wilcoxon tests) for each subgroup that we identified (*e.g.*, we conducted separate Friedman tests for less-experienced searchers, and separate Friedman tests for more-experienced searchers). To make comparisons between any two subgroups that we identified (*e.g.*, between less- and more-experienced searchers in any given condition) we used Mann-Whitney *U* tests. To make comparisons across any three subgroups (*e.g.*, between those who never, occasionally or frequently send SMS messages) we used Kruskal-Wallis tests with follow-up pairwise Mann-Whitney *U* tests.

For ranking questions from the final questionnaire, we used one-sample Chi-Square tests to evaluate whether there were differences in the overall proportion of participants selecting any of the three setups as Rank 1 (best), 2, or 3 (worst). Follow-up comparisons between pairs of setups used Holm's sequential Bonferroni corrections. As with the Likert questions, we conducted separate Chi-Square tests on the ranking questions for each subgroup we identified. To compare across subgroups on the ranking questions, we used two-way contingency table analyses.

One group's data was excluded from the analysis because they did not complete the entire study due to eye strain experienced by one member.

Overall Preference

15 participants chose the Parallel setup as their favorite, 11 chose CoSearch, and 7 chose the Shared setup. These differences, however, were not statistically significant.

Communication

There was a significant difference in users' ranking of setups in terms of impact on communication (χ^2 (2,

N=32)=11.31, p<.01), with pairwise follow-up tests showing that the Shared and CoSearch setups were ranked as better for communication significantly more frequently than the Parallel setup (χ^2 (1, N=19)=11.84, p<.01 and χ^2 (2, N=15)=8.07, p<.01, respectively). Participants' comments about the Parallel setup (*e.g.*, "No communal feeling of teamwork", "Had no communication with my partners") also indicated less communication in that condition.

Although there were no differences in perceived communication levels between the Shared and CoSearch conditions, there was a significant difference in the participants' feelings of being ignored (χ^2 (2, N=33)=12.25, p<.01) with participants feeling significantly more ignored in the CoSearch condition than in the Shared (CoSearch median=3, Shared=2, p<.01). Note that participants also felt marginally significantly more ignored in the Parallel condition than in the Shared (Shared median=2, Parallel=2, p=.053). We then evaluated the effect of position, and found that in all three conditions the people in the observer positions felt significantly more ignored than the drivers (Shared driver median=1, Shared observer median=2, z=-2.53, p=.01; Parallel driver median=1, Parallel observer median=1, z=-3.17, p<.01; CoSearch driver median=1, CoSearch observer median=3, z=-3.35, p<.01). The fact that observers felt more ignored than drivers in the Shared condition is not surprising since this was a limitation of this scenario noted by our interviewees. In the Parallel condition, this is likely because of the greater difficulty participants on the outer computers had communicating than those in the center (one observer commented "I was aware of the person next to me, but unaware of the person 2 seats over"). However, for CoSearch this was surprising, but could be explained by a finding from our log files that showed that queued items (*i.e.*, queries and web pages) posted by observers sometimes went unnoticed by drivers. That is, since the driver is ultimately the person who can bring items from the Query and Page Queues into focus, when the driver fails to do this it can lead to the observers feeling ignored. Only 55.3% of observer-queued queries were executed and 10.88% of observer-queued web pages were viewed by drivers in our study.

Collaboration

In ranking the three setups in terms of which enabled the group to collaborate most effectively, there was a significant difference (χ^2 (2, N=32)=8.69, p=.01), with pairwise follow-up tests showing that participants felt their groups were able to collaborate more effectively in the Shared and CoSearch conditions than the Parallel condition (χ^2 (1, N=19)=8.90, p<.01 and χ^2 (1, N=16)=6.25, p=.01, respectively). However, we found that the subpopulations of more-experienced searchers and observers felt more frustrated in the Shared condition than their counterparts. More-experienced searchers ranked the Shared condition as significantly more frustrating to use than less experienced searchers (Pearson χ^2 (1, N=17)=6.80, p<.01), likely due to the frustrations experienced by these searchers at conveying promising directions to others in the Shared setup. Also, observers in the Shared condition felt significantly more frustrated than drivers (z=-2.16, p=.03), likely due to their limited access to the mouse and keyboard. One observer commented that searching in the Shared condition "Made me want my own computer!" In contrast, there were no differences in frustration levels between any of these subpopulations in the CoSearch condition.

We also asked participants to rate their awareness of other group members' activities, and found significant differences (χ^2 (2, N=33)=20.49, p<.01). Follow-up tests revealed that participants were more aware of what other group members were doing in the Shared condition than in the CoSearch condition (p=.01), but also more aware in the CoSearch condition than in the Parallel (p=.04). In the CoSearch condition, there was a significant effect of SMS-expertise on participant awareness (χ^2 (2, N=33)=5.98, p=.05), with follow-up tests showing that people who occasionally send text messages were significantly (z =-2.32, p=.02) more aware of what the other group members were doing in this condition than people who never texted. There were no differences between people who frequently and occasionally send text messages. This suggests that the lack of awareness in the CoSearch condition could have resulted from some people's inexperience with mobile phones causing them to become overly pre-occupied with interfacing with the phones rather than participating in the group search. As mobile phones and texting become more pervasive, particularly among some of CoSearch's target demographics (*e.g.*, kids and teens), this inexperience should become less problematic for CoSearch users.

Participation

We asked the participants several questions pertaining to their perceived contribution levels. Drivers felt significantly more active in their participation in all three conditions than observers (Shared driver median=4, Shared observer median=2, z=-2.34, p=.02; Parallel driver median=4, Parallel observer median=4, z=-2.61, p<.01; CoSearch driver median=4, CoSearch observer median=4, z=-2.66, p<.01). This was expected in the Shared condition considering the driver was in control of executing all of the group members' suggestions, and reasonable in the Parallel condition since the driver was better able to communicate with the other group members than the observers were with each other. In the CoSearch condition, this could be the result of the Bluetooth and Wi-Fi lag observers experienced with the phones (see 'CoSearch Usability'), or of some observers' inexperience with phones and text messaging preventing them from contributing to the search as much as drivers. For example, observers could participate by adding items to the Query and Page Queues via CoSearchMobile and each did so an average of 2.7 and 4.4 times, respectively, during their 14 minutes of CoSearch use; however, the drivers, using the mouse and keyboard, each added items to the Query Queue and Page Queue more frequently (a mean of 5.2 and 8.9 times each, respectively).

In terms of specific contributions, there were significant differences in subjects' answers to the following questions:

- 'I helped the group by suggesting query terms to use' (χ^2 (2, N=33)=20.00, p<.01). Shared median=4, Parallel=3, CoSearch=4.
- 'I helped the group by suggesting search results to visit' (χ^2 (2, N=33)=17.82, p=.00). Shared median=4, Parallel=3, CoSearch=4.
- 'I helped the group by identifying important content within specific Web pages' (χ^2 (2, N=32)=11.14, p<.01). Shared median=4, Parallel=3, CoSearch=4.

Pairwise follow-up tests show that participants felt they were able to help the group by suggesting query terms and search results significantly more in the Shared and CoSearch conditions than in the Parallel condition (p<.01 for all pairs). In contrast, participants felt they were able to help the group by identifying important content within Web pages significantly more in the Shared condition than in both the Parallel and CoSearch conditions (p<.01 and p=.02, respectively). The low scores for the Parallel condition on all three of these questions are likely attributable to the low communication levels reported by participants in this condition relative to the Shared and CoSearch conditions, as well as the observed difficulties some searchers (particularly novices) had approaching search tasks in this more independent setting. In the CoSearch condition, the small screens on the phones may have made it difficult for some participants to identify important content within specific web pages.

Task Outcome

For the fixed tasks that we predefined according to our formative study interviews, there were no significant differences in efficiency or quality (correctness of answers) of the groups' search results across conditions. However, this was likely a ceiling effect, since few groups were able to complete these tasks within the allotted time. The fixed tasks were challenging to stay true to the types of tasks our interviewees described, and time limits were necessary to keep the study under two hours. Because of the diversity of the group-selected tasks, it was not possible to compare the effect of condition on those tasks' outcomes.

CoSearch Usability

We asked participants to comment on the general usability of CoSearch for group Web search. On a 5-point Likert scale, participants rated CoSearch neutral (median=3) in terms of its general ease of use. However, when we compared more-experienced searchers to less-experienced searchers on this measure, more-experienced searchers rated CoSearch significantly easier to use than less-experienced searchers (more-experienced median=4, less-experienced median=3, z=-2.12, p=.03). Therefore, we expect that with increased search experience, and more experience with CoSearch itself (considering participants were only given a short tutorial and a few minutes to try out all of the features), CoSearch should become easier to use.

Overall, participants agreed that the different colors representing individual group members in CoSearch were useful (median=4.5). Some participants commented that this feature was one of the 'best things' about CoSearch (*e.g.,* "Color cursors felt intuitive and natural"). Participants also agreed that the Query Queue feature was useful (median=4) and it was easy to add a query to the Query Queue via CoSearchPC (driver median=4) and via sending a text message from CoSearchMobile (observer median=4). Half of the participants commented that this feature was one of their favorite things about CoSearch because everyones' "Ideas were readily visible" and "[it's] interesting to see what other people search for."

Participants agreed that CoSearch's color-coded tabs were useful (median=4) because "it is clear who is searching for what." Selecting a search result, which opens a new tab in CoSearchPC, was also reported as easy to do by both drivers (median=4), and observers (median=4). However, more-experienced searchers found this feature significantly easier to use than less-experienced searchers (z=-2.60, p<.01) likely because of their familiarity with tabs featured in many new Web browsers.

Only .18 notes per group were added to Web pages during the study. However, some participants commented that "Being able to make notes about the websites you were researching" was one of the 'best things' about CoSearch. In fact, while searching in the other conditions some participants took notes about particular web pages by using a pen and paper or text editor on the computer. Similarly, only .45 summaries per group were saved using the Save Summary feature. Again, several participants commented that being able to "save pages that were good" for later use was one of the best things about CoSearch. Some participants also wanted a way to remember or send themselves the information they found during their searches within the other conditions. For example, prior to ever seeing CoSearch, one participant in the Shared condition asked if there was a way to send the results to themselves as "that would be the next step." Since notes in CoSearch are designed to be persistent even if a Web page is closed, and saved summaries are intended for easy future retrieval of information, these features may be used more in longer or more realistic tasks (*e.g.*, school projects).

Observers could view Web pages on their mobile phones either by using the phone's joystick to remotely operate their cursor or by using the "Get Search Results" or "Get Tabs" options from the CoSearchMobile menu. The remote-cursor option was generally more difficult due to Bluetooth-related lag in moving the cursor, resulting in fewer instances of these events. Nevertheless, observers reported that it was generally easy (median=4) and useful (median=4) to select a page to view in their mobile phones, and did so because they wanted to read a page at a different pace than other group members (median=4) or because they wanted to explore different content than the other group members (median=4).

Observers could also explicitly 'Share' pages of interest with the group through CoSearchMobile. Pages opened by selecting from the lists of search results or open tabs, or by clicking on links with CoSearchMobile, are automatically shared with the group, so this feature is mostly useful when an observer navigates within his phone and finds a new page to share. Wi-Fi lag for loading Web pages on the phones may have resulted in the low number of Share events recorded during the study (.96 pages were Shared per observer). However, this feature was reported as one of the 'best things' about CoSearch by both observers (*e.g.,* "You could contribute to the screen with searches you did on your mobile phone") and drivers (*e.g.*, "[observers] could refer me to a site they found").

Finally, we asked participants (on a 5-point Likert scale, 5=strongly agree) if and where they would potentially use CoSearch were it available. Participants responded that they would likely use CoSearch at work or school (median=4), but less at home (median=3.5). This is encouraging since 64% of our participants said that they currently collaboratively search the Web at school or work and our target audiences include students and people in resource constrained environments (*e.g.*, workplaces with limited computers such as those observed in developing regions).

The most-cited 'worst things' about CoSearch were:

- *Bluetooth and Wi-Fi lag times*. 55% of participants commented about their frustrations trying to control the cursor with the phone via Bluetooth (*e.g.*, "Sluggish mouse") and waiting for pages to load on phones over Wi-Fi (*e.g.*, "The lag of the web page loading times").
- *Small screens and keypads on phones*. 42% of participants complained about difficulties viewing web pages on the Smartphones' small screens (*e.g.*, "Hard to browse a page on the mobile phone because so little of the whole page is seen") and using the phones' small keypads (*e.g.,* "The phone buttons are too small").
- *Lack of experience using phones.* Several of the older participants (37% of those aged > 25 years) noted this as one of the worst things about CoSearch (*e.g.,* "I feel like technology has passed me at lightning speed" and "this is definitely for the text-messaging generation").

DISCUSSION

Overall, our study demonstrated that CoSearch succeeded in addressing the limitations of shared-computer searching, while preserving high levels of camaraderie among groups, despite the presence of additional devices. Our results showed that, overall, our participants preferred the Parallel setup for group Web search the most, followed by CoSearch, and least of all the Shared setup. Although participants enjoyed having their own computers in the Parallel condition, CoSearch is designed for situations when it is not possible for each user to have his own computer (for social or economic reasons), and thus it is encouraging that users preferred CoSearch over the Shared condition.

Participants reported that their communication levels in the CoSearch condition were on par with those in the status-quo Shared condition and better than in the Parallel condition. Participants commented that CoSearch enabled "everyone [to] share their ideas," "communicate their ideas," and "submit search topics without having to yell at the person on the computer." However, in terms of group awareness, the Shared condition fared better than CoSearch (and both were better than Parallel). CoSearch could be improved in this respect by providing additional feedback (such as auditory cues) to drivers when observers queue queries and pages, in order to increase awareness of these events. Also, limited SMS expertise may have impacted the awareness levels of CoSearch phone users, though this should become less problematic with SMS use on the rise.

Participants also reported that their collaboration and contribution levels in the CoSearch condition were on par with those in the status-quo Shared condition and better than in the Parallel condition. Many commented about the distributed control CoSearch enabled their groups to achieve during their collaboration. For example, both drivers and observers commented that CoSearch enabled them to "have more of a say in what's going on on the screen," "[go] at my own pace" and "select my own links." Participants also commented about the distribution of labor CoSearch facilitated, such as "we could search many offshoots of the same topic at once," "brows[e] three different pages at once," and "input more ideas on how to find the answer". Observers felt like less active participants than drivers in all three conditions, although CoSearch did reduce the frustrations of observers (and more-experienced searchers) compared to the Shared condition.

In terms of usability, most people were able to quickly learn and use each of the CoSearch features, even with only a brief introductory tutorial. Participants were generally in favor of the key CoSearch features such as the colors representing group members, the Query and Page Queues, and the ability to control the cursor and view Web pages with the mobile phones. And, although few groups used the Notes and Summaries features of CoSearch, many participants were enthusiastic about these and may make more use of them in more natural settings.

Testing CoSearch with participants with diverse technical skills showed that those with more search and SMS skills could use the system more effectively, suggesting CoSearch may be more appropriate for some populations identified as shared computer users in our formative study (*i.e.*, students) than others (*i.e.*, senior citizens).

The major frustrations noted about CoSearch were technological limitations with the Smartphones and Bluetooth/Wi-Fi. That is, the small screen and keypad sizes of the phones made it difficult for some participants to use CoSearchMobile. The lag experienced with moving the cursor with the phone over Bluetooth and loading Web pages onto phones via Wi-Fi also may have prevented users

from experiencing the potential usefulness of these features. However, as mobile phones and related technologies become increasingly more advanced, easy to use, and efficient, these technological limitations should diminish.

To summarize, participants reported better overall communication, collaboration, and contribution levels in the CoSearch and Shared conditions than in the Parallel. However, the Shared condition induced greater frustrations with certain subpopulations (*e.g.*, observers and more-experienced searchers) than CoSearch due to the limited efficiency and lack of individual control with the Shared setup. In fact, these are likely the key reasons why participants preferred the Parallel setup for group Web search, despite the poor group dynamics it engendered. Thus, since recognized resource constraints often make it infeasible for every person to have his own computer, CoSearch can be an effective enhancement to shared computing for group Web search.

CONCLUSION

In summary, this paper reported on three contributions:

1. A set of interviews providing data on current practices of several demographics regarding co-located collaborative Web search, and identifying limitations of those practices.

2. The CoSearch system, which leverages abundant devices, such as mice and mobile phones, to address the limitations of current shared-computer search practices.

3. An evaluation showing that CoSearch achieved its goal of preserving communication and collaboration while facilitating distributed control and division of labor, and revealing how the system could be further improved.

Economic constraints, coupled with the social and pedagogical benefits of shared-computer use, suggest that workstation-sharing will remain a trend in computing for the foreseeable future. Systems like CoSearch, which enhance the experience of shared-computer use for common task scenarios (such as joint Web search) have the potential to positively impact shared-computer users, such as students, families, and developing-world communities.

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