IMPROVING WEB PAGE REVISITATION: ANALYSIS, DESIGN AND EVALUATION

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ABSTRACT

Several years of research suggest improvement is needed in how people return to their previously visited Web pages. Web page revisitation is one of the most frequent actions in computer use, so any interface improvements in this area can have a very large effect. Five categories of revisitation research are involved: 1) Characterizations of user behavior; 2) System models of navigation and their impact on the user's understanding; 3) Interface methods for increasing the efficiency of the Back button; 4) Alternative system models for navigation; and 5) Alternative methods for presenting Web navigation histories. Revisitation is a dominant activity, with an average of 80% of page visits being to previously seen pages. The Back button is heavily used, but poorly understood.

Three interface strategies for improving Web page revisitation are described: 1) A gesture-based mechanism for issuing the frequent Back and Forward commands addresses low-level interface issues; it is shown to be both popular and effective; 2) A 'temporal' behavior for the Back and Forward buttons aims to overcome the problems associated with poor understanding of the current behavior of Back, strongly suggesting that revisitation can be improved by providing temporally ordered lists of previously visited pages; 3) Next-generation browsers could integrate the current tools for revisitation into a single utility, thus allowing simple visualization methods to aid users in identifying miniature target pages.

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Every day, millions of people worldwide have problems trying to return to previously visited Web pages. These problems often amount to little more than the minor annoyance of finding that a page has "disappeared'" from those accessible with the Back button. Sometimes, however, extensive searching is necessary to return to a page; for example, users forget to bookmark a "valuable'" page, and they cannot remember how it was originally retrieved. Although the impact of these problems on each individual may be small, it is clear that easing these problems can yield enormous benefits when multiplied across millions of users, and billions of page accesses.

The problems of revisiting Web pages have been examined since 1994, along with designs and evaluations of several systems aimed at improving Web-page revisitation. This article presents an integration and synthesis of this work, in the following order:

1. *User behavior.* Recent results of a Web-use log-analysis show that revisiting pages is a dominant activity on the Web.
2. *System and user models of the current behavior of the Back button.* An easy-to-repeat experiment demonstrates that many users misunderstand the rudimentary behavior of the main interface tool for revisitation—the Back button. Despite this misunderstanding, why is Back heavily used?
3. *Improving the efficiency of the Back command.* The efficiency limitations of the interface mechanisms used to issue the Back command are described, also with an evaluation of a gesture-based shortcut (similar to the scheme recently provided in the Opera Web browser).
4. *Improving understanding and efficiency of the Back model.* An alternative 'temporal' behavior for the Back and Forward buttons is described, with a presentation of the results of its evaluation.
5. *Improving the presentation of revisitation tools.* The implications of the earlier findings demonstrate how the next-generation of Web browsers could integrate and enhance the diverse tools for revisitation that are available in current browsers (Back/Forward, bookmarks, and history lists). This work is ongoing, and preliminary results are encouraging.

USER BEHAVIOR: WHAT DO WEB USERS DO?

Considering that Web browsers are among the most widely used computer applications, there has been only modest research into how they are used. This section briefly summarizes prior analyses of browsing behavior and then describes results from recent studies of what Web users do as they navigate the Web.

Prior analyses: Some researchers detail the demographics of Internet users (e.g., gender percentages, age, occupations, educational attainment, etc.), as well as the demographics of their technologies (e.g., people's connection speed to the Internet and browser selection). The most well-known of these is the 1994-1998 biannual WWW Surveys (http://www.cc.gatech.edu/user_surveys), developed by the Graphics, Visualization and Usability Center at the Georgia Institute of Technology (Kehoe and Pitkow 1996). Recently, sociologists have begun studying Internet use, with a natural emphasis on how Web use changes social structures, rather than focusing on the efficacy of the user interfaces used to navigate the Web (DiMaggio et al. 2001).

Other researchers have analyzed the tasks that people do as they navigate. For example, Byrne et al. (1999) videotaped eight people as they used their browser over the course of their day and codified user behaviors. From this, they developed a task-based taxonomy of browsing, including the six, general Web tasks:

1. Use information—a series of activities in which people use information gathered from the Web,

2. Locate on page—search for particular information on a page,

3. Go to—the act of trying to get the browser to display a particular URL,

4. Provide information—sending information to the browser (e.g., authentication, addresses, search terms),

5. Configure browser—changing the configuration of the browser itself, and

6. React to environment—supplying information or dealing with a problem on demand of the browser.

The authors then proceed to sub-divide these general tasks into more specific ones, and to codify how often they occur. While these results reflect a total of only a few hours of use by a few people, it provides insight into the actual things that people do.

Researchers have analyzed traces (or logs) of users' actions to reveal statistics of use. Some use server-side logs. Since most Web servers collect data indicating when a particular page has been accessed and by what IP address, this is an easy data source to mine. For example, it is relatively simple to analyze logs to expose the frequency of page hits on a Web site. However, server-side logs are limited in that they often do not distinguish well between different users; they collect no data on actual browser use, and they are often missing crucial data. Pirolli, Pitkow, and Rao (1996) and Chi, Pirolli and Pitkow (2000) discuss the problems of extracting meaningful information from server-side logs. Another option is to specially equip the browser so that it logs the users' actions. The advantage of this "client-side

logging" is that it can record the exact history of the user's actions with his or her particular browser.

Perhaps the most well-known, client-side log analyses of Web use are by Catledge and Pitkow (1995) and Tauscher and Greenberg (1997). These studies instrumented the then-popular XMosaic browser to record the pages that users visited and the interface mechanisms used to access them. The participants in both studies were primarily staff, faculty and students in university computing departments. Catledge and Pitkow logged three weeks of use by 107 users in 1995, whereas Tauscher and Greenberg analyzed five to six weeks of use by 23 users in 1995. Catledge and Pitkow revealed that the dominant user interface techniques for visiting pages were clicking on hypertext anchors (52%) and on the Back button (41%). Navigating to pages by typing the URL, clicking Forward, or selecting from 'Bookmarks' were all lightly used, accounting for about 2% each. Tauscher and Greenberg confirmed that link selection and clicking Back are the dominant navigation mechanisms, accounting for approximately 50% and 30% of navigation acts.

Tauscher and Greenberg also analyzed *the recurrence rate* of page visits: "the probability that any URL visited is a repeat of a previous visit, expressed as a percentage." They found that the recurrence rate for the subjects participating in their study was 58%, and a reanalysis of the data from 55 of Catledge and Pitkow's subjects produced a recurrence rate of 61%. This result shows that users had previously seen approximately 60% of pages visited. Tauscher and Greenberg's analysis also reveals that users tend to revisit pages just visited a short while ago, access only a few pages frequently, browse in very small clusters of related pages, and generate only short sequences of repeated URL paths.

In these early studies, people rarely used bookmarks (less than 2% of user actions). However, a later 1996 survey by Abrams et al. (1998) suggested that bookmark use was rising. Some 84% of his respondents had more than eleven bookmarks, indicating that people at least had the intention of returning to key pages. Indeed, Pitkow (1996) reported from a survey of 6619 users that "organizing retrieved information" is one of the top three usability problems of using the Web, reported by 34% of participants.

Our Recent Client-Side Log Analysis of Web Use: While all exemplary studies, the findings of these early studies may not reflect current use of the Web. Things have changed considerably since the mid–90s. Instead of early adopters and technologically savvy 'elite' users, people from virtually all demographic backgrounds use the Web (although not equally). Modern Web browsers have highly polished interfaces with features far beyond those supported by XMosaic. Many Web navigation aids such as search engines and Web directories are now a fundamental part of Web use, yet these tools were either in their infancy or did not exist at the time of the prior studies. The technology itself has changed—broadband connections now give nearly

instantaneous response—a sharp contrast to the "World Wide Wait'" of the early days. The kinds of information accessible on the Web are also completely unlike those of the prior decade. Once an academic repository, the Web is now a massive commercial and populist arena.

METHOD

To update and extend the findings of these previous studies, the Web-browsing activities of 17 Computer Science staff and graduate students were analyzed over a 119-day period from early October 1999 to late January 2000[1]. The use of computer scientists in these evaluation(s) introduces obvious risks of generalizing the results to other communities, but one suspects that computer scientists use the Web for purposes similar to those of most users. Both the Catledge and Pitkow and the Tauscher and Greenberg studies used computer scientists.

The data were gathered through the history and bookmark files that Netscape Navigator (versions 4.5–4.7) maintains. Netscape Navigator was the browser used by the participants in their everyday work, and its user interface features are similar to those of other popular browsers. The browser's history file keeps a list of the URLs the user has visited, the time of the user's last and first visit, the number of visits and the title of each page. The bookmark file stores information about the user's bookmarks and their organization into folders. Copies of these files were obtained through incremental backups that were automatically created every night at the University of Canterbury. To eliminate the chance that participants would modify their behavior due to their awareness that their actions were being logged, participants were asked for permission to retrieve their backup files after the terminating date of the study. That is, participants were asked to have their data mined retrospectively, instead of asking them permission to monitor their future Web uses.

Pages visited per day: The participants made a total of 84,841 page visits, spread across 17,242 different URLs, averaging approximately 42 pages each day. The actual number of pages visited by each user per active day would be substantially higher than this, because the average includes weekends and the Christmas/New Year vacation period during which few participants would have used their browsers at work. Even with this underestimation, these results suggest that people visit almost double the number of pages now than in the mid-90s. That is, the mean of 42 pages per day compares to approximately 14 (Catledge and Pitkow 1995) to 21 pages per day (Tauscher and Greenberg 1997) in the earlier studies.

Percentage of pages that participants had previously seen: The premise behind the Back button, history systems, and bookmarks is that people frequently navigate to pages that they have seen before. As already

mentioned, previous studies have found that the average revisitation rate is between 58-61%. Has this figure changed? To analyze revisitation, the total pages visited were plotted over time by each participant (Figure 1a). The mean total number of page visits by each participant was 4991 (s.d.= 6106), ranging from 281 to 24,309. (Participant 15's heavy Web-use statistics can be explained by his role as a Web-master.) The *distinct* pages visited over time by each participant were then plotted in Figure 1b. Here, the mean number of URLs visited was 1227 (s.d. = 1086), with a range from 74 to 4251. As the figures indicate, the total number of page visits is strongly correlated with the growth of the number of *distinct* URLs visited. Linear regression over all subjects gives a slope of 5.1 and an R-squared value of 0.8837 ($F_{1,940}$=7140, p<0.0001). This slope reflects the revisitation rate for the subject pool: for each new URL added to the set of distinct URLs, four pages are revisited. This revisitation rate is confirmed using Tauscher and Greenberg's formula for revisitation rate:

$$\text{Revisitation Rate: } R = 100 * \frac{total\_visit\_count - total\_URL\_count}{total\_visit\_count}$$

This calculates a revisitation rate of 81%, with individual participant revisitation rates ranging from 61% to 92%—substantially higher than the previously reported values of 58% and 61%.

Use of bookmarks and other shortcuts to pages: One factor behind a high revisitation rate is that almost all participants had one or two pages that they visited far more often than any other. Participant 2, for instance, had visit counts of 4352, 384, 199, and 117 for his top four pages. In general, participants' top three pages accounted for 20% of all page accesses.

Given the high visit counts to particular pages, one would have thought these would be prime candidates for becoming shortcuts. Netscape Navigator supports a variety of shortcut techniques—including the configurable 'Home' button, bookmarks, and the "personal toolbar.'" Netscape's history and bookmark files were analyzed to see whether people created shortcuts to their frequently visited pages. Although most users were found to have shortcuts to their top two pages, few had shortcuts for their third, fourth and fifth most frequently visited pages.

Analysis of the bookmark file showed wide variation in bookmark use: participant 16 had none, while participants 2 and 8 had more than 500 each. The mean maximum size of the subjects' bookmarks collection was 184, but as

**FIGURE 1: GROWTH IN THE TOTAL NUMBER OF PAGES VISITED (A) AND
DISTINCT PAGES VISITED (B) OVER TIME (MM/YY) FOR EACH USE**
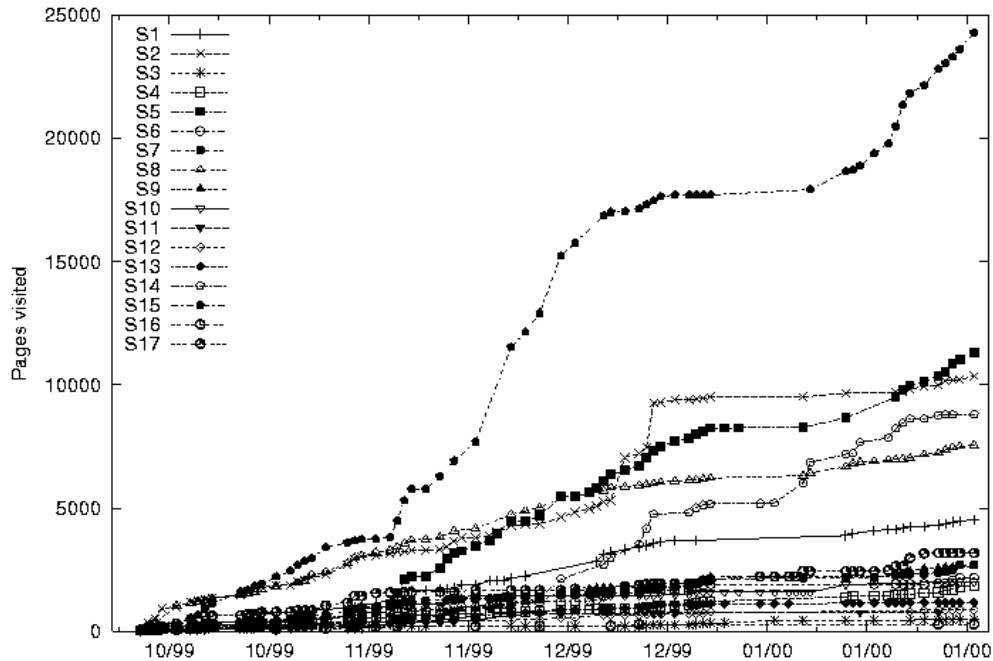
(a) Total pages visited
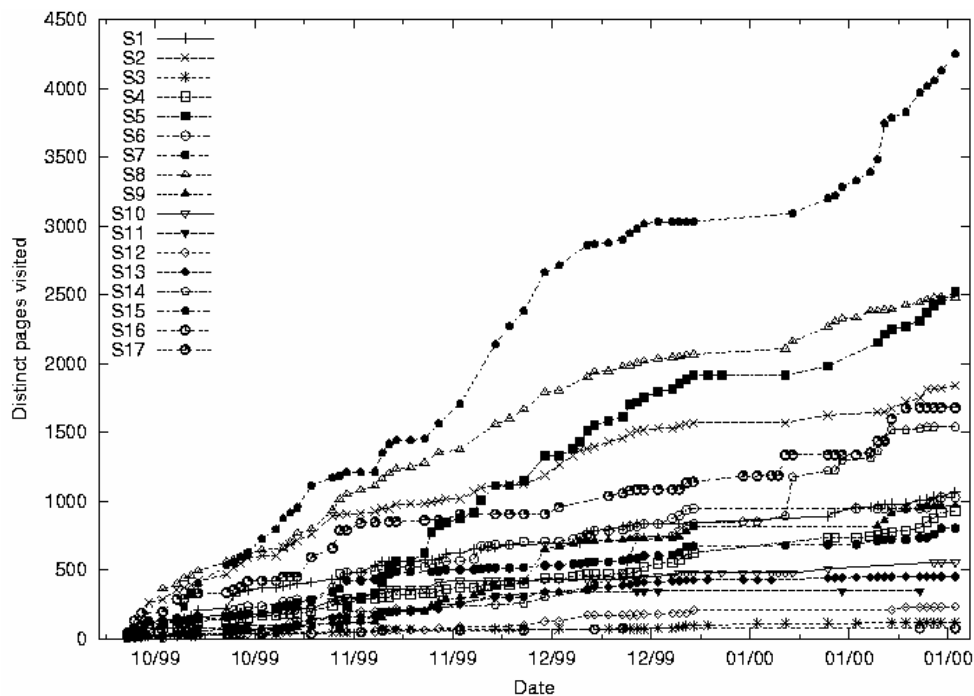
(b) Distinct pages visited.

suggested above, the standard deviation was very high (s.d. = 166). Some people organized the bookmarks into folders, where the mean number of folders used to store bookmarks was 18 (although again the standard deviation is very high—s.d. = 16). We saw that the rate of bookmark addition heavily outweighed the rate of deletion, with averages of 27.6 additions and 3.7 deletions. This imbalance implies that users have, or will have, problems managing the size and organization of their bookmark collections over time. For example, bookmarks in Netscape are normally selected via a pop-up, cascading menu, the length of which depends on the number of "top level" items in the bookmark file. Participant 17 had 130 items in this top-level, which would produce a very cumbersome cascading menu.

Figure 2 plots the number of items in the top-level bookmark structure for three of the subjects over time. The obvious steps in the figure show that participants periodically tried to reorganize their bookmarks to overcome the problem of the menu growing too long; this effect was also noted by Abrams et al. (1998). Rather than deleting items, subjects would typically relocate them to new folders (counted as a top-level item). It is worth noting that the interface mechanisms for managing bookmarks have improved since Netscape 4.5–4.7, possibly easing bookmark management.

The apparent reluctance to delete bookmarks is at odds with the relatively transient nature of Web sites and pages. Two months after collecting the bookmark data, scripts were run that attempted to access each page in the participants' bookmark collections. Any page returning 404 "Not found", 301 "Moved Permanently", or 5xx (host unavailable) was deemed invalid. Approximately 25% of the pages were invalid. This indicates that over time, bookmark collections will become cluttered with useless items.

Proportion of pages that do not have titles: Titles are used by Netscape and Microsoft Internet Explorer in a variety of ways, including labeling items on the Back pull-down menu, default-identification tags in the bookmark and history lists, and labeling the window-manager border. Missing, incorrect and inconsistent titles can frustrate the user's ability to identify pages to which they wish to return (Cockburn and Greenberg 2000).

Some 5% of the distinct URLs visited by the participants did not have an HTML "Title" tag associated with the page. Although there are alternative interface techniques that could be used to aid page identification, such as thumbnail images of the page as in Cockburn et al. (1999); Kaasten et al. (2002) and Robertson et al. (1998), it is likely that text titles will remain an important page-identification cue. There is little that any browser can do to ensure the presence and accuracy of the text titles, but Web-authoring software could promote careful consideration of page titles. Often page-titling facilities are 'hidden' under sub-menus or dialogue boxes, rather than prominently displayed for each newly authored page.

FIGURE 2: NUMBER OF URLS AND FOLDERS IN THE TOP-LEVEL BOOKMARK FILE OF THREE USERS SHOWING DRAMATIC 'PRUNING' OF THE BOOKMARK STRUCTURE, PLOTTED AGAINST TIME (MM/YY)
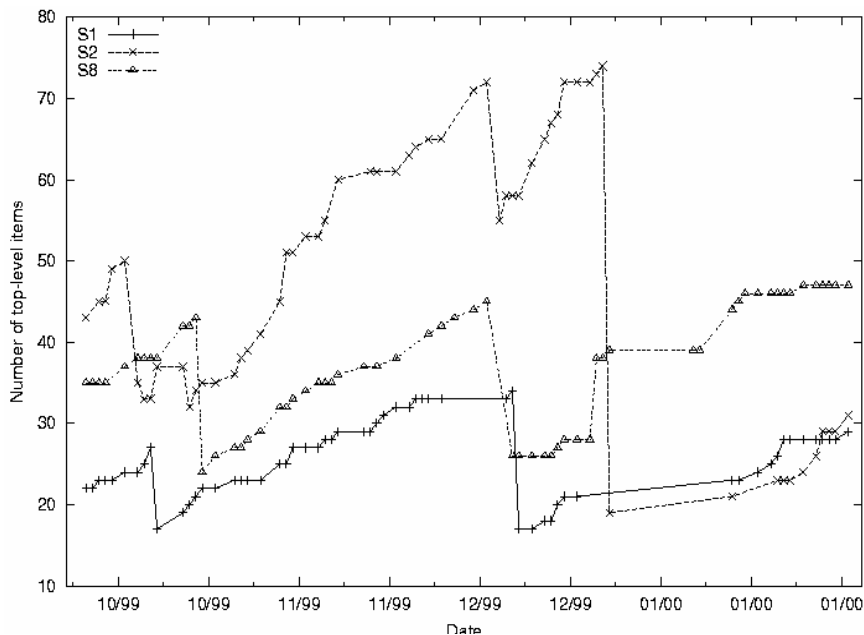
Summary: In summary, the main findings of this log-analysis study are as follows. Web-page revisitation is the dominant activity in Web browsing. On average, users have previously seen four out of every five pages visited. Most participants had one or two pages that they visited far more often than all other pages. Bookmark use was highly varied, with users either making light or heavy use of bookmark collections. Finally, there were two indications that users find bookmark management troublesome: first, 25% of the bookmarks did not refer to legitimate pages when one tried to access them; second, some of the heavy bookmark users appeared to be forced into 'shuffling' bookmarks when their top-level menus became too long.

SYSTEM AND USER MODELS: THE BACK BUTTON

The experimental results summarized in the previous section show the importance of having efficient, effective mechanisms for returning to previously visited Web pages. The Back button is one of the main interface components for returning to Web pages, accounting for approximately 40% of navigational actions, according to Tauscher and Greenberg (1997), yet the easy-to-repeat experiment described below shows that many users misunderstand its behavior. Having described the experiment, it is possible to speculate why the Back button is heavily used despite the common misunderstanding.

Understanding of the Back button: A simple, mass-participation, informal study that takes only minutes to conduct demonstrates how Web users misunderstand the behavior of the Back button.

To run the informal study in a classroom, one can use a Web browser projected onto a large screen, telling the audience that they will be asked to predict whether a page can be returned to using only the Back button, not by using links or other history tools. Have the browser showing a home page that is well-known to the audience, such as the "Computer Science Homepage." Then slowly and clearly use a link to visit a page off the home page—for example, "People in Computer Science." Tell the audience that they will revisit this page shortly. Clearly demonstrate the use of the Back button to return to the homepage. Next, slowly and clearly use a different link to visit another page off the home page. With the browser displaying this final page, ask the students to write on a scrap of paper whether the first linked page ("People in Computer Science") can be returned to using the Back button and only the Back button (no links or history tools). Ask them to write the number of times the Back button will have to be clicked if the page is accessible with Back. Finally, collect the responses. Using paper responses encourages participation, and protects the participants from possible embarrassment in a show of hands. The point is that stack-based behavior of Back means that the page is inaccessible with Back.

A more elaborate version of this experiment was first conducted in 1995, when the Web was still relatively new (Cockburn and Jones 1996). The eleven participants were all computer scientists who used the Web daily. Eight wrongly predicted that the page could be accessed with Back. Since then, we have repeated the experiment as described above many times in large Computer Science undergraduate classes. Approximately 50% of the students—all of whom use the Web in their studies—misunderstood whether pages were accessible with Back, with the most common error being to state that the "People in Computer Science" page can be returned to with two Back clicks.

Stack-based behavior: All major commercial browsers use the same stack-based model for Web-page navigation. In this model, there are two ways—"load" and "revisit"—of displaying pages in the browser. Pages are loaded when the user clicks on a link, types a URL, selects a "Favorite'" page, and so on. The effect of "load" is to add the page to the top of a stack of visited pages. Pages are revisited with the Back and Forward buttons, which move downward and upward through the stack of visited pages. The menus associated with Back and Forward allow users to directly revisit pages on the stack. When the user loads a page after revisiting pages, the new page is added to the stack immediately above the current stack position, and all pages above that stack position are removed. This explains why the "People in Computer Science" page cannot be revisited in the previous example.

Given the notation ® to indicate loading a page (e.g., clicking on a link), and the notation ⇦ to indicate revisiting a page with Back, if the user navigates through pages **a**®**b**®**c**, then the stack contains **{a, b, c̲},** the underscore indicating the page being displayed in the browser. If the user then navigates back to **a** by pressing the Back button twice (**c**⇦**b**⇦**a**) then the stack contains **{a̲, b, c}**. If the user then clicks on a link to page **h** (**a**®**h**), then **b** and **c** are removed from the stack, giving **{a, h̲}**.

What is good about the Back button: The two primary limitations of Back are that many users misunderstand its operation and that not all recently seen pages can be revisited. Yet, despite these limitations, Back is heavily used. There are several factors contributing to Back's success (Cockburn and Greenberg 2000):

- It can allow rapid return to recently visited pages (assuming they are still on the stack).

- It is robust. People can use it, even with a naïve model of the way it works.

- It is cognitively undemanding. Users can backtrack through pages using a simple "click until the desired page is recognized" strategy.

- It is 'ready-to-hand'. Unlike interface features such as the 'History list', which must be explicitly popped up when needed, there is little overhead in accessing Back because it is on constant display.

- It consumes minimal screen real estate.

These beneficial properties have led to the Back button being one of the most heavily used interface components in existence.

Summary: A large proportion of regular Web users misunderstand the stack-based behavior of the Back button. Despite this misunderstanding, they use it heavily, because it has many desirable properties. However, this conflict between heavy use and misunderstanding clearly results in suboptimal use.

The remaining three sections describe the design and evaluation of three approaches for improving human performance with the Back button. The first approach investigates the efficiency of using a shortcut "gesture" action for issuing the Back command. The second evaluates the potential cognitive and motor benefits of changing the stack-based Back model to a complete temporal list, overcoming the problems of pages disappearing off the set accessible with Back. The third investigates the potential benefits of integrating the diverse schemes for Web revisitation currently used in browsers.

IMPROVING THE EFFICIENCY OF THE BACK COMMAND

The mouse-driven cursor is the main input device for Web navigation—to visit a link the user points the cursor to the link, and to revisit a page, the user moves the cursor to the Back button. Fitts' Law (Fitts 1954) predicts the time taken to move the cursor between targets (such as the Back button and the page links), but faster alternatives than mouse-pointing are available.

In recognizing the importance of providing efficient mechanisms for issuing the Back command, both Microsoft Internet Explorer and Netscape Navigator provide keyboard shortcuts, with Internet Explorer using backspace or Alt+left-arrow, and Netscape Navigator using Alt+left-arrow. The main limitation of key-bindings for Web browsing is the overhead in homing the hands between the mouse (used for links) and the keyboard. Homing is necessary for the Alt+left-arrow keybinding, because many keyboards are arranged so that the Alt and left-arrow keys cannot be simultaneously pressed with one hand. Similarly, for right-handed users, the backspace key-binding is awkward because the user must either reach across the keyboard with his left hand, or take his right hand off the mouse. Another shortcut for Back, provided by both browsers, is the context menu that can be popped up by pressing the right-mouse button. Accessing the Back menu item incurs overheads in waiting for the menu to be posted and in the Fitts' Law limitations of pointing to the menu item. Finally, specialized input devices such as the Microsoft Intellimouse Explorer (http://www.microsoft.com/hardware/mouse/ie_info.asp) mouse provide additional buttons for the Back and Forward commands.

These shortcuts are available only to the relatively small proportion of users who buy the devices. From experience, studies and subjects' comments, it appears that the Back command is seldom issued through any interface mechanism other than the Back button. The question, then, is how to improve the efficiency of issuing the Back command, without the low-level costs of target acquisition or of homing the hands between keyboard and mouse.

Inspired by work on gesture-based marking menus (Callahan et al. 1988), in 2001 a gesture-based mechanism for issuing the Back and Forward commands was designed, implemented and evaluated. Similar features were simultaneously released in the Opera (http://www.opera.com) commercial Web browser, and slightly later by the Mozilla Optimoz project (http://www.optimoz.org). Neither of these commercial implementations has apparently been formally evaluated.

With gesture navigation, the user "flicks" the mouse, with the left button held down. A leftward flick navigates Back, a rightward flick Forward. To support gesture navigation within unaltered commercial browsers in this evaluation, a website was constructed where each page contained a Javascript program instructing the browser to navigate Back or Forward

whenever   a   gesture   is   recognized.   (See http://www.cosc.canterbury.ac.nz/~andy/gestureSite/ for an example). Several empirically determined values are used to recognize legal gestures. First, to prevent the script from recognizing a simple mouse click (such as a link selection) as a gesture command, the mouse coordinates must change by at least 35 pixels during the interval between the button being pressed and released. Second, to distinguish between gestures and text selections (both completed by dragging with the left-mouse button), the gesture must be completed within 250 ms.

METHOD

The evaluation compared the effectiveness of gesture navigation with that of the normal Back button across two tasks. Both tasks involved following rehearsed sequences of nine Web pages as quickly as possible, first using the normal browser, and then using gesture features. Multiple rehearsals of the Web paths were used to minimize the impact of learning effects. Tasks were first completed using the Back button, to investigate any deterioration in subjective satisfaction with the Back button after using the gesture system.

Task One compared the effectiveness of the two interfaces in depth-first navigation. The path followed four links on subsequent pages, then backtracked with four, successive Back commands, giving a path **a®b®c®d®e⇦d⇦c⇦b⇦a**. This task represents a directed-search style of Web use, for instance, searching for a faculty member's Web page starting from a university's home page.

Task Two examined the effectiveness of the two interfaces in breadth-first navigation, also called "hub-and-spoke" navigation (Catledge and Pitkow 1995). This style of navigation involves visiting a series of links (or "spokes"), one at a time, off a central "hub" page. Beginning at a "start" page, the subjects followed a link to a main hub page, and then navigated to three spoke links off that page, pressing Back to return to the hub each time. A final Back command returned to the start page, giving a complete path of **a®b®c⇦b®d⇦b®e⇦b⇦a**.

When using the Back button, the mouse-pointing requirements of Task Two are much higher than those for Task One. After selecting each link to a spoke page, the user must point to the Back button, and then point to the next page link. Fitts' Law predicts that the Back button will result in slower task performance. For this reason, a second factor for "amplitude" was introduced in Task Two, allowing an analysis of the degradation of performance as the distance between the Back button and the links on the hub page increased. The links on the hub page were vertically aligned immediately above one another at one of three corners of the Web page— top-left, bottom-left, and bottom-right—to give three levels of amplitude "low,"

"medium," and "high." Mean distances between the Back button and the group of links were 8.5cm, 14cm, and 20cm for the three levels of amplitude.

The twenty participants were all volunteer postgraduate Computer Science students familiar with Web navigation. Each participant's training with the gesture system involved a brief (one or two minute) demonstration of the flick gestures and explanation of the rules determining a valid gesture.

RESULTS

In Task One, the mean task completion times for the normal Back button and gesture systems were 6.1 (s.d.=1.1) seconds and 5.4 (s.d.=1.0) seconds. This is a significant difference (t_{18}=2.7, p<0.05), showing a reduction of 11% in the mean task time when using gestures.

The performance data in Task Two were analyzed using a two-factor analysis of variance with repeated measures. The factors were 'interface type' with two levels (Back button and gesture system) and 'amplitude' with three levels (low, medium and high). The mean time for the Back button was 7.4 (s.d.= 1.1) seconds compared to a mean of 6.1 (s.d=1.2) seconds for the gesture system, giving a significant main effect: $F_{1,18}$=82, p<.001. The gesture system thus reduced the mean task time by 18%.

The mean times for the three levels of amplitude were not significantly different ($F_{2,36}$=1.2, p=0.32). This is unsurprising because amplitude has no effect on task completion time in the gesture system. As expected, the interaction between factors "interface type" and "amplitude" was significant: $F_{2,36}$=6.8, p<0.01. Figure 3 reveals the cause of the interaction—as the amplitude increases, the mean completion times for the Back button increase, but the task times for the gesture system remain relatively constant.

The participants' comments and subjective ratings dramatically amplified the effectiveness of the gesture system, with comments such as "Fantastic," "That's amazing," "Really, really nice," and "Brilliant!" Eighteen of the twenty subjects rated the efficiency of the gesture system more highly than that of the Back button (5-point Likert scale responses). The mean responses for the Back button and gesture system were 2.4 (s.d.= 1.1) and 4.3 (s.d.= 0.8), giving a significant difference: Wilcoxon Signed Ranks, N=17, z=3.5, p<0.01.

Summary: Gesture-based shortcuts for issuing the common Back and Forward commands are already being used in commercial Web browsers. The evaluation summarized here shows that these shortcuts are both efficient and popular. The current Alt+left-arrow keyboard shortcut for Back is inefficient because it requires the user to move a hand between the keyboard and the mouse and because the keys are normally too far apart to be pressed with one hand. Similarly, the "backspace" keyboard shortcut requires right-handed users to either remove their hand from the mouse or to reach across the

**FIGURE 3: MEAN TIMES (AND STANDARD ERRORS) IN TASK TWO
FOR THE NORMAL-BACK AND GESTURE INTERFACES**
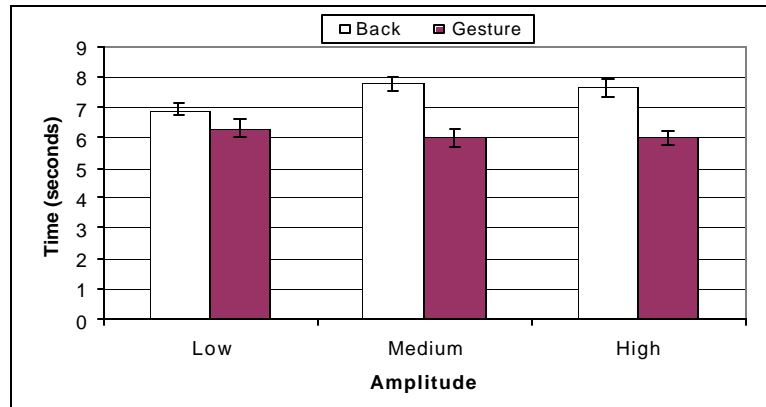
keyboard with their left hand. Gesture solutions, in contrast, are efficient, popular, and available to all users. Full details of this experiment are available in Moyle and Cockburn (2002).

IMPROVING UNDERSTANDING AND EFFICIENCY OF BACK: A TEMPORAL MODEL FOR BACK AND FORWARD

Although the gesture interface appears to provide a more efficient motor mechanism for issuing the Back command, it does nothing to improve the poor understanding of the Back button, as reported earlier. Greenberg and Cockburn (1999) proposed an alternative behavior for the Back button. This "temporal scheme with duplicates removed" aimed to maintain the desirable properties of the stack-based behavior, while overcoming its limitations of poor understanding and of providing an incomplete list of visited pages. The temporal model ensures that all previously visited pages are accessible with Back and Forward and that Back navigates through pages in the order in which they were last displayed in the browser.

Like the stack-based technique, the temporal scheme maintains two semantics of page display (loading and revisiting) that are executed through a visually identical interface. Loading a page causes it to be added to the end of a "main temporal list" (denoted **{a, b, c}**, as for the stack example earlier) that serves a functional equivalent to the stack. When the Back and Forward buttons are used, each revisited page is added to the end of an internal secondary list (the contents of this internal list are denoted by square brackets, for example, **[a, b, c]**), which is not displayed to the user. After revisiting pages with Back and Forward, when the user next loads a page, the secondary list is concatenated to the end of the main temporal list, and any older duplicate pages are deleted. Finally, the new page is appended to the

end of the main temporal list. So, for example, if the user navigates through pages **a⊗b⊗c⇦b⇦a**, then the main temporal list contains **{a, b, c}**, and the secondary list contains **[b, a]**. If the user then clicks on a link to page **h**, then the main temporal list will contain **{a̶, b̶, c, b, a, h̲}**. (The older duplicates of pages **a** and **b**, shown crossed out at the start of the list, have been deleted.)

A recent evaluation of the temporal scheme is summarized below, with full details presented in Cockburn and McKenzie (2002).

METHOD

The evaluation was based around a series of Web-browsing tasks, with the participants using a "new release of Netscape Navigator." Participants were told that the new release "may or may not have modified the behavior of the Back and Forward buttons." The visual appearance, mouse bindings and response time of the stack-based and temporal interfaces were identical to those of Netscape Navigator version 4.72. To construct the interfaces, unparented windows providing exact visual replicas of the Back and Forward buttons were placed over Netscape's actual buttons. When the subjects clicked the imitation Back or Forward buttons, the program modified the state of its stack or temporal list and issued appropriate page display requests to the browser. Back and Forward menus that were visually indistinguishable from those normally produced by Netscape were also supported.

The 34 participants—all Computer Science students who used Netscape Navigator daily in their everyday course work—were randomly assigned to either the stack or the temporal interface. Each evaluation lasted approximately one hour. No training or instruction on the behavior of the Web browser was given.

The experiment consisted of repeating six tasks in three different Web sites (one created specially for the experiment, one based on http://www.boeing.com, and one based on http://www.cs.waikato.ac.nz). Only two of the tasks are described in this paper—the *parent revisitation task* and the *cross-site distant revisitation task*.

The *parent revisitation task* examined the subjects' ability to return to a parent (or home) page from a relatively deeply nested page. In the Boeing site the task was: "You are at the page describing the 747 international aircraft. Return to Boeing's Homepage." Both the stack and the temporal interfaces allowed the users to solve the task with a single selection from the Back menu, but otherwise the stack system would require three Back clicks, whereas the temporal system would need either four or six (depending on earlier actions). It was therefore predicted that the stack interface would be more efficient.

The *cross-site distant revisitation* task examined the subjects' ability to revisit a temporally distant page. An example of the task is: "You are at the

page describing Boeing's 747-freighter commercial aircraft. Return to the Waikato University page 'Introduction to Computer Science' that you were at approximately half an hour ago." In theory, the temporal system is more efficient than the stack-based system because it allows the page to be selected directly from the Back menu. With the stack, however, the page would have been popped off the stack, requiring users to switch from backtracking with Back to navigation using links. Finally, if users used the cognitively lightweight "click Back until the desired page is seen" strategy, then the temporal scheme would succeed, but only after between 12 and 27 clicks! It was uncertain which interface would allow more efficient completion, with the main interest being simply to observe the solution strategies that were used.

RESULTS

In the *parent revisitation task*, the mean task completion times with the stack and temporal interfaces were 6.2 (s.d.= 2.2) and 10.6 (s.d.= 6.2) seconds, providing a significant difference: unpaired T-Test, $T_{100}=4.8$, p<.01. Similarly, the mean action counts for the stack and temporal interfaces were significantly different at 2.4 (s.d.= 1.3) and 4.1 (s.d.= 2.8) actions: $T_{100}=3.8$, p<.01. As predicted, then, the longer paths with the temporal interface made it less efficient for returning to parent pages.

The *cross-site distant revisitation task* provided an interesting contrast between the interfaces. The results revealed highly varied solution strategies in both interfaces. Although the overall means were similar for both interfaces, some users solved the task quickly, while others struggled. The mean solution times for the stack and temporal interfaces were 15.5 (s.d.= 6.5) and 16.2 (s.d.= 12.0) seconds, and the corresponding action counts were 7.2 (s.d.= 4.4) and 8.4 (s.d.= 8.9). Neither of these comparisons provides a statistically significant difference. Analyzing the ways in which participants solved the task provides interesting insights into opportunities for enhancing the efficiency of Web browsers. The intention here is not to determine whether the two interfaces are statistically different, but rather to observe patterns of behavior that result in efficient and inefficient navigation.

Use of the Back menu (supported by both the normal stack and temporal interface) was strongly correlated with the efficiency of task completion (Spearman rank correlation between action count and menu use, r_s=0.83, p<.01). The mean number of moves used by the 23 participants who used the Back menu was 3.0 (s.d.= 2.4), compared with 20.7 (s.d.= 7.8) for the 11 participants who did not. Task times were similarly biased, with means of 11 seconds (s.d.= 4.5) and 28 (s.d.= 9) for menu and non-menu users. The correlation between action count and menu use holds for both the stack (r_s =0.89) and temporal (r_s =0.86) interfaces. Figures 4(a) and 4(b) show the time and number of moves (y-axis) used to complete the task plotted against a sorted order of participants (x-axis). The x-axis is a sorted order of

FIGURE 4: TIME AND ACTIONS TAKEN TO COMPLETE THE CROSS-SITE DISTANT REVISTATION TASK USING THE STACK AND TEMPORAL INTERFACES

(a) Time

(b) Actions
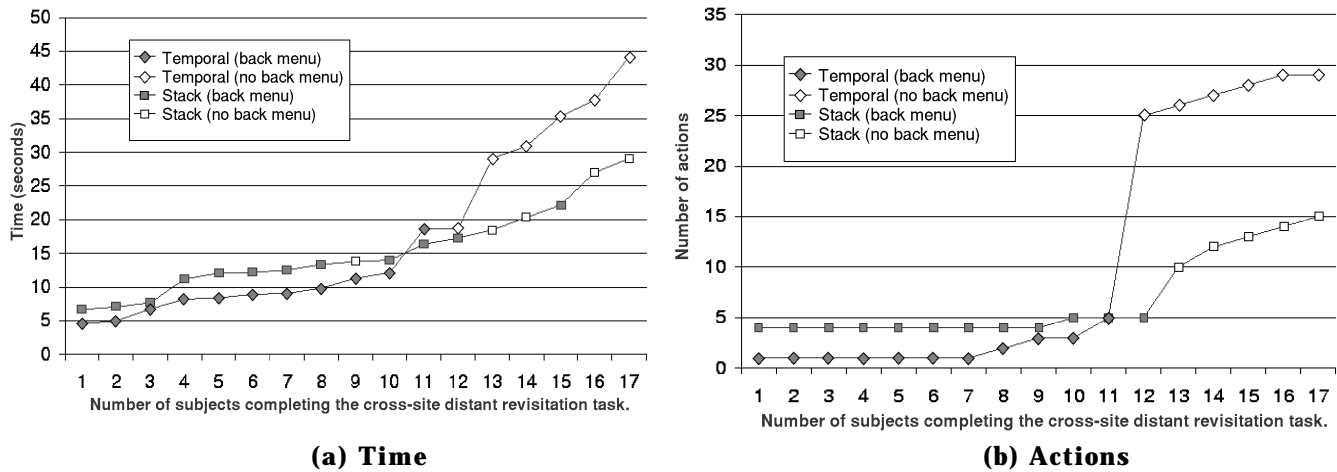
participants completing the task. Filled shapes show Back menu users; unfilled ones show users who did not use the Back menu.

Figures 4(a,b) show that the temporal system allowed most of the participants to solve the task rapidly (when compared to the stack users), but that the least efficient temporal users were dramatically slower the worst stack users. The figures also show that all 11 efficient users with the temporal system used the Back menu, and that none of the inefficient users did so.

One final problem, noted by many of the participants who used the Back menu in either system, was that Web pages are often hard to identify from the text displayed in the Back menu. The text shown in the Back menu is extracted from the HTML <TITLE> tag associated with the page. As noted earlier, this information is often unavailable, truncated or poorly reflective of the page contents. Other mechanisms for aiding page identification are discussed in the following section.

Summary: The observation that participants solved the distant navigation task most rapidly when using the Back menu is potentially important. It suggests that Web page revisitation could be made more efficient, if browsers encouraged users to make greater use of "direct page access" methods such as the Back menu, rather than relying on multiple clicks of the Back button. These ideas are also pursued in the following section.

**FUTURE DIRECTIONS: IMPROVING AND INTEGRATING REVISITATION TOOLS**

Further work includes investigations of enhancements to the temporal scheme that aim to improve the effectiveness of direct page access mechanisms. This work is motivated and informed by the findings of the studies reported above.

Current Web browsers support many tools for Web-page revisitation, including the Back and Forward buttons, bookmarks and pop-up history lists. These tools can be beneficially integrated into one revisitation resource. The use of simple visualization techniques is also being investigated to aid Web page identification within these tools.

Several interfaces, collectively called WebView, have been constructed to experiment with these concepts. The common features of all WebView prototypes are as follows:

- They interact with unaltered versions of Netscape Navigator. Figure 5, for example, shows an implementation of WebView, in which the complete temporal list of pages is added to the drop-down menu associated with the Back menu. The top-left dogear encodes visit counts, and the bottom-left dogear shows that the page is bookmarked. WebView automatically adapts to navigational actions made in Netscape, and Netscape responds to user actions in WebView.

- They visually represent the complete temporal list of previously visited pages, therefore integrating History and the temporal behavior of the Back and Forward buttons.

- They display zooming thumbnail representations of all pages visited in the browser. The small thumbnails, automatically captured whenever a new page is displayed in the browser, expand whenever the user points the cursor over them.

- The thumbnails include such identification cues as "dogears" that encode information about the number of visits to a page and whether the page is bookmarked, as shown in Figure 6.

Several systems have used thumbnails to depict Web pages, including MosaicG (Ayers and Stasko 1995), PadPrints (Hightower et al. 1998), and Glabster (Kaasten 2001). Recently Kaasten et al. (2002) formally evaluated the effectiveness of various cues to Web-page identification, with results indicating that people are able to identify pages more accurately from thumbnail images than from titles or URLs. It seems reasonable to expect that automatically captured, Web-page thumbnails, such as these, will soon appear in commercial Web browsers.

FIGURE 5: A *DOGEARED* THUMBNAIL

FIGURE 6: A VERSION OF THE WEBVIEW PROTOTYPE WITH ZOOMABLE THUMBNAILS INTEGRATED INTO THE BACK/FORWARD MENUS
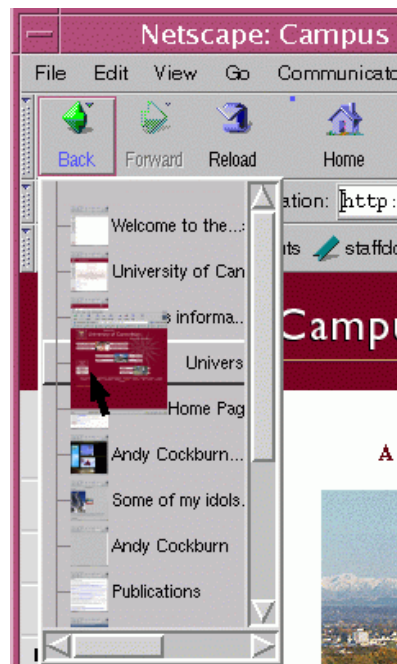
A PILOT STUDY OF WEBVIEW

To gain preliminary insights into WebView's usability, and to direct this development work, a preliminary evaluation was performed (Cockburn et al. 1999). Seven volunteer participants, all graduate Computer Science students, received a very brief introduction to WebView's interface prior to completing a simple navigational task with WebView. They then repeated the task without WebView (using Netscape Navigator). The evaluated version of WebView was similar to that in shown in Figure 6, but it was displayed in a separate window rather than embedded within the Back menu.

To prepare for the task, the participants were asked to navigate from the "Computer Science Homepage" to a "Teaching Page," then back to the "Computer Science Homepage" and down through links to "People," then "Academic Staff," and finally "Wal's Page." Using the notation described earlier, this path is **a®b®a®c®d®e**, giving a stack content of **{a, c, d, e}**, and a temporal list content of **{b, a, c, d, e}**. Note that page **b** has been popped off the stack, but it is displayed in WebView's temporal list. The timed task involved returning to the "Teaching Page" from "Wal's Page." With WebView, the page was immediately accessible on the temporal list, and it could be revisited with a single click. With Netscape, however, the participants had to click Back three times to return to the "Computer Science Homepage" (or use the Back menu) and then select the link to the "Teaching Page."

All participants completed the task more rapidly with WebView, with mean times for Netscape and WebView of 9.6 seconds and 2.6 seconds respectively (paired T-Test, $t_6=2.7$, $p<.05$). Five of the seven participants were enthusiastic about the system, three of them extremely so, one stating "It'd be great to have a system like this." The two unenthusiastic participants were primarily concerned about the redundancy introduced by having two different ways of navigating (the "Netscape way" and the "WebView way"). Integrating WebView's support into the browser, as shown in Figure 6, should overcome this concern.

Participants were then asked Q1 "If available, how likely would you be to use a system like WebView?" and Q2 "How useful were thumbnail images in recognizing pages?" with responses rated on a five-point scale from 1–"Not at all" to 5–"Very." The mean response to Q1 was relatively high at 3.9. It was surprising, however, that the mean response for the usefulness of the thumbnail images was low at 2.7. When asked to comment on the thumbnails, several participants stated that they would probably be more useful when navigating through unfamiliar sites. Participant 4 added that the thumbnails were not useful because the task was introduced verbally, using the same names for the pages as was displayed in the title text identifying each page.

One participant made an interesting observation that he "didn't like the thumbnails jumping about while navigating." When a new page is loaded,

WebView redisplays the temporal list, causing all thumbnails in the display to move down one position. These redisplay problems were not anticipated. One current design solution is to use rapid animation to move items to their new location, rather than abrupt redisplaying of them. Similar, animated techniques are now common in many rapidly appearing/disappearing graphical user interface components, such as pop-up menus.

The most recent WebView research demonstrates a variety of interface schemes aimed at rationalizing and improving the diverse facilities for revisiting Web pages currently used in browsers. The pilot study indicated that under favorable conditions these mechanisms could be successful, but extensive further work is necessary to determine how they scale to prolonged heavy use. This will be the focus of further work.

OVERALL SUMMARY

This article has provided an integration and synthesis of the findings from eight years of research on understanding and improving Web browsers' support for revisiting Web pages. The findings in five categories of revisitation research were presented: characterizations of user behavior; system models of navigation and their impact on the user's understanding; interface methods for increasing the efficiency of the Back button; alternative system models for navigation; and alternative methods for presenting Web navigation histories. Major results and observations presented above include the following:

1. Web-page revisitation is a dominant activity in Web use, with more than 80% (on average) of Web page visits being to pages previously visited by the user.

2. Most users have one or two pages that they visit much more frequently than all other pages.

3. Some users make very heavy use of bookmarks and incur problems with managing them.

4. Many users misunderstand the stack-based behavior of the Back button, even though they use it regularly.

5. Gesture navigation features in which users "flick" the mouse to issue the common Back and Forward commands are both efficient and popular. They overcome the need to continually move the cursor away from the page links or to home the hands between the mouse and the keyboard, when using Back. These features are now included in some commercial browsers.

6. The evaluation of an alternative behavior for the Back and Forward buttons suggests that revisitation can be improved by providing a complete, temporally ordered list of previously visited pages. This

observation has potentially important implications for the development of navigation features in the next generation of Web browsers.

7. The WebView prototype system demonstrates how temporal lists could be used to integrate the diverse Web-revisitation tools in current browsers. It also demonstrates how the problems of page identification (prevalent in current browsers) can be eased through simple, visualization techniques.

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[1] The full details of this study are available in Cockburn and McKenzie (2001).