AutoWeb: Automatic Classification of Mobile Web Pages for Revisitation

Jie Liu **Wenchang Xu** **Yuanchun Shi**
Key Laboratory of Pervasive Computing, Ministry of Education
Department of Computer Science and Technology, Tsinghua University, China
{liujiejesse, wencxu}@gmail.com, shiyc@tsinghua.edu.cn

ABSTRACT
Revisitation in mobile Web browsers takes more time than that in desktop browsers due to the limitations of mobile phones. In this paper, we propose AutoWeb, a novel approach to speed up revisitation in mobile Web browsing. In AutoWeb, opened Web pages are automatically classified into different groups based on their contents. Users can more quickly revisit an opened Web page by narrowing down search scope into a group of pages that share the same topic. We evaluated the classification accuracy and the accuracy is 92.4%. Three experiments were conducted to investigate revisitation performance in three specific tasks. Results show AutoWeb can save significant time for revisitation by 29.5%, especially for long time Web browsing, and that it improves overall mobile Web revisitation experience. We also compare automatic classification with other revisitation methods.

Author Keywords
Mobile Web; automatic classification; revisitation.

ACM Classification Keywords
H.5.2 **[Information Interfaces and Presentation]**: User Interfaces – Graphical User Interfaces.

General Terms
Human Factors, Design, Algorithms

INTRODUCTION

With the popularity of smart phones and the improvement of wireless connection, people tend to spend more time surfing the Internet on mobile devices. Mobile Web browsing experience is affected by many factors, such as small screens, low CPU performance and variable latency of wireless networks [21].

Small screen makes it difficult to get a normal view of what is displayed and it also affects the accuracy of input via pen taps or direct finger touches [4]. When users want to revisit an opened Web page, they scroll history lists or bookmarks back and forth or just tap back button several times. It takes extensive scrolling to target an intended Web page if many pages are opened. Users can also type related characters in the URL field to locate previous page in the pull-down suggestion list. But this search-based revisitation only applies to the pages that can be recalled clearly, such as frequently or recently accessed pages.

To get an overview of opened Web pages quickly, representation of history list should be re-designed. Mobile browsers can not show as many entries of history list in one screen as desktop browsers. To solve this problem, we can narrow down search scope in history list. If opened Web pages are classified into different groups based on their content, users can view all groups quickly on small screens. When a user wants to revisit a previous Web page, s/he can first choose the group that shares the same topic with the intended Web page, and then in this group find the target. Revisitation becomes topic-specific and needs less movements and scrolling. In addition, navigation pattern changes from one level to two levels.

If we apply classification to mobile browsers in the same way as desktop browsers [15, 16, 27], users have to classify opened Web pages manually, which in turn increase the input complexity on users' side. Classification can be performed by browsers themselves instead. We design AutoWeb (Figure 1) to automatically classify opened Web pages into different groups according to their contents.

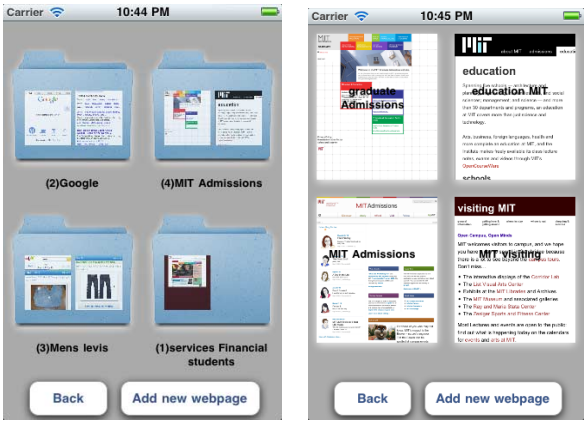

Figure 1. Revisitation in AutoWeb
(Left: Groups Level, Web pages are classified into groups. Right: In-Group Level, similar Web pages are in one group)

MobileHCI'12, September 21− 24, 2012, San Francisco, CA, USA.

The rest of paper is organized as follows. Following a review of relevant literature, we describe a pilot survey to find out the frequency, methods and other aspects of mobile Web revisitation. Then we explain the design and evaluation of AutoWeb. After that, we give a detailed explanation about three experiments to investigate revisitation experience in three tasks in comparison with traditional history list and search-based revisitation. We conclude the paper with discussion and future work.

RELATED WORK

Various studies have been conducted to investigate mobile Web browsing and revisitation. We discuss related work from both human and technique aspects.

Human Factors in Mobile Web Browsing

Performing tasks on mobile browsers place heavy cognitive demands on users' short-term memory because of limited screen size, scrolling capabilities, and slower processing [2]. Shrestha [21] found that participants had frustrating experience using mobile browsers as they spent significant time in navigation by extensive scrolling and full concentration on browsing rather than actual content. Scrolling the long history or bookmark list also takes much time for revisitation.

Users form mental models to help them make connections among disparate bits of information [19]. With a small screen size, users have difficulty in activating a mental model for interpreting the information and in placing information within the existing mental model [2]. Besides the screen size constraint, AutoWeb also introduces another mental model issue. Since AutoWeb automatically classifies Web pages into several groups without users' intervention, how to guide users to match their mental models to the right group needs much consideration. In later sections, we'll discuss some approaches to address it.

Mobile Web Browsing Activities

For active mobile Internet users, mobile Web browsing and searching are the dominant information access methods [10] and are intended to support task-specific usage [2]. Church *et al.* [6] conducted a large-scale study of mobile Web use and indicated that browsing accounts for the majority of information access activities.

As with the content of mobile Web browsing, Sohn *et al.* [22] did a diary study and claimed that *trivia*, *directions (navigation)* and *point of interest (local services)* are the most cited information needs. Church *et al.* [5] classified Web content by topics and found that the most popular mobile topics were *local services* and *travel & commuting*. Heimonen [10] came up with a similar result, which *trivia*, *work/studies/hobbies*, *public transportation (navigation)* were top three frequent categories. Considering the proportions of each kinds of Web content, we design several sets of tasks and simulate usage scenarios in daily life to evaluate AutoWeb's revisitation performance.

Revisitation Methods

Revisitation occurs frequently when users browse Web pages. Early studies show that from 58% [23] to 81% [7] Web pages visited by users have been previously accessed. Recently, Weinreich [28] suggested revisitation frequency dropped to 43.7%. Zhang *et al.* [30] measure revisitation in tabbed browsing and rated the effective revisitation frequency at 59.6%. All the researches above are about conventional revisitation on desktop browsers. To our knowledge, there is no similar research on mobile Web browsing. Hence, we conduct a pilot survey to find out revisitation frequency on mobile Web browsing.

Usually, users resort to history lists, back button and bookmark for revisitation. But these tools can only help to revisit Web pages in a specific context. Many studies [3, 7, 13] show that users seldom use Web history to visit Web pages for lack of clear description of entries. The back button comprised 30% [24] of revisitation action. But it is only useful for short-term revisitation. Up to 94% of users [1] utilized bookmarks to revisit and organize information over several Web pages. Users have to manage bookmarks themselves, and more efforts are taken as bookmarks increase.

Users can also use search-based methods for mobile Web revisitation. Users can directly type related characters in the URL fields to locate previous Web pages in the pull-down list, or use a search engine to find the information again. These methods put a heavy burden on users' cognition and memory. They only apply to the Web pages that can be recalled clearly, such as frequently or recently accessed pages. Moreover, extensive typing is needed, which is not efficient for software keyboards on small screens.

Many novel tools try to facilitate revisitation. Thumbnail images of Web pages tend to reduce contained text beyond readability and have visual cues to remind users of the Web pages they accessed previously. Session Highlights [11] arranged thumbnails in chronological order besides browser. Visual Snippets [25] presented a compact representation of Web pages to support both the identification of new relevant Web pages and the re-finding of previously viewed pages. AutoWeb also uses thumbnails to help users recall opened Web pages. MacKay *et al.* [15, 16] and Wang *et al.* [27] designed browser plugins to support multi-session tasks. Users create a task group, add several Web pages related to a specific task to this task group and manage the tasks manually. This method costs lots of operations on users' side, so it's inappropriate for mobile browsing.

Automatic Classification Algorithms

Many algorithms have been proposed for automatic classification in information retrieval field. These algorithms can be categorized into two types, link-based analysis algorithms and content-based analysis algorithms. Link-based analysis algorithms use hyperlink information inside Web page source. If one page has a link to another

page, these algorithms infer that these two Web pages are relevant to each other. But linkage information cannot show the sematic meaning of Web pages [9]. Content-based analysis algorithms employ information retrieval methods to extract keywords from a set of Web pages and calculate the similarity among them. It is more accurate than the link-based analysis algorithms [17]. Hence, we adopt the content-based analysis algorithm for automatic classification in AutoWeb.

In consideration of constrained resources on mobile phones, complex classification algorithms are not appropriate for slow CPU frequency and small amount of RAM. It also introduces noticeable latency that affects browsing experience. TF-IDF algorithm [14, 26] only uses simple mathematical operations and consumes acceptable computing resources. We customize TF-IDF algorithm to achieve satisfactory classification accuracy and speed.

PILOT SURVEY

Before we design AutoWeb, some prerequisite facts need to be confirmed. The frequency may not fall in line with that on conventional desktop browsing. We should know whether users revisit Web pages often on mobile devices like that on PCs. Unfortunately, to our knowledge, previous researches mainly focus on desktop Web browsing and no available reference we can refer to. Hence, we conduct a pilot survey to find the answer.

We recruited 45 paid participants from our university and a residential area nearby, in which 31 participants (68.9%) were male. Ages ranged from 19 to 35 years (*mean*=23.5, *SD*=4.1). They took different occupations, including undergraduates, graduates, teachers, businessmen, managers and IT employees. All participants used smart phones like iPhone or Android phones in daily life. They were all experienced mobile Web users with at least one year for mobile Web browsing.

The browsing events on their phones were captured for one week with their consent. We measure revisitation frequency by using a traditional approach. It is rated by using the number of repeated page loading events divided by the total number of page loading events [24, 30]. The methods used for revisitation were also logged. In total, 33750 loading events were logged. One Web browsing session is defined as a continuous browsing phase in which no intervals between two consecutive loading events exceed one hour. Revisitation span is the number of page loading events before the last revisitation.

The number of opened Web pages for each browsing session is 27.6 on average (SD=15.3). Revisitation frequency on mobile browsing is 45.8% (SD = 14.3%) with 15458 repeated loading events. It means that users revisit about 13 Web pages during one browsing session. It is relatively high. The acceleration of revisitation introduced by AutoWeb will contribute to improving mobile browsing experience.

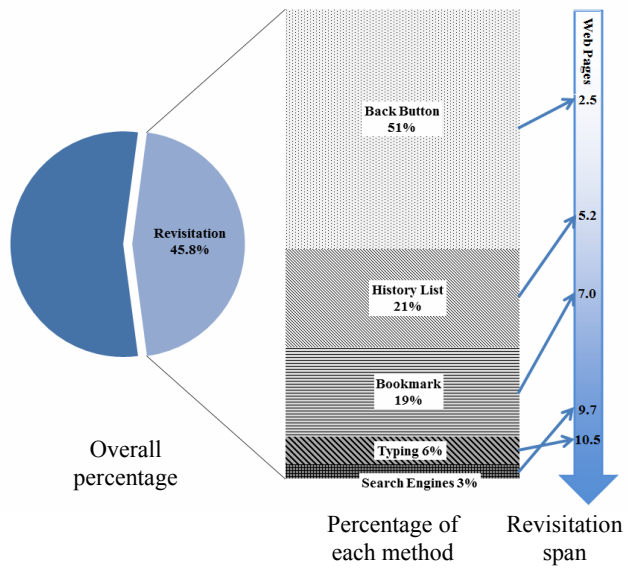

Figure 2. Revisitation Frequencies and Spans in Mobile Web Browsing

We also present the usage frequencies and revisitation spans of bookmark, history list, back button, typing in the URL field and search engines in Figure 2. Participants relied heavily on back button for revisitation, and the frequency of using bookmark and history list is similar. It differs with previous study results on desktop browsers as mentioned in *Revisitation Methods* section, in which back button comprised 30% of revisitation action and history list is seldom used. In the informal interview after the survey, some participants said that they thought back button was an easy tool to re-find Web pages that were recently accessed. So they used back buttons often.

Typing in the URL field and search engines were rarely used. Some participants said they could remember only a few frequently used URLs and mainly typed homepages' URLs. If they typed some other keywords in the URL field, they need to scroll the long suggestion list and pay much attention to find the target link.

From the perspective of revisitation span, we can find a rough negative correlation between revisitation frequency and span. The more often a revisitation method is used, the less revisitation span it has. It indicates that users tend to use simple operation and less taps or touches in mobile Web revisitation. We suggest the reason why mobile Web revisitation differs with that on desktop is the inherent limitations of mobile devices, which are slow input speed and low accuracy, small display size and etc.

AUTOWEB

We design AutoWeb to achieve the goal of speeding up revisitation in one browsing session. In AutoWeb, we use two levels to represent opened Web pages. Groups Level holds all groups of topics, and In-Group Level contains opened Web pages in each group sharing the same topic.

Considerations in Design

We choose iPhone as the platform. A recent report in May, 2011 reveals that iPhone tops first in mobile phones' network traffic in 10 out of 13 main countries [8]. In addition to iPhone's popularity in mobile Web browsing, it is easy for development using Xcode and distribution via App Store.

To help users identify Web pages quickly with less mental effort, an appropriate page representation is necessary. As mentioned in *RELATED WORK*, thumbnails are helpful for supporting re-finding Web pages [25]. We use a hybrid way by combining thumbnails and texts. Thumbnails give users visual cues and provide large touch areas for selection. Keywords used for classification are also displayed on thumbnails to help users match their mental models. In Group Level, we use the folder as the metaphor for a group of classified Web pages. Smaller thumbnails also appear in the folder to indicate the content of this group.

As with the order of each opened Web page, some alternatives are based on alphabet, recency and frequency of visits [29]. Recency is a strong reuse pattern [23] for Web browsing. It requires less cognitive efforts when users search for newly visited sites on top of the list [12]. Therefore, we adopt the recency-based approach to sort groups and Web pages in each group.

To guide users match their mental models with automatic classification results, several methods are introduced to help address this issue. When a Web page is loaded, a pop-up window will show the keywords of this Web page for one second to give users first expression (see part ① in Figure 4). At Groups Level, Web page thumbnails in the folder icons and the keywords below provide cues for recall. At In-Group Level, larger thumbnails with keywords in the center also help to match users' mental models (in Figure 1).

Clustering Algorithm in AutoWeb

Clustering is a computation intensive task. In consideration of limited computing resources on mobile phones, an efficient clustering algorithm is necessary.

We use vector-space model (VSM) to represent each Web page source as vectors in a multidimensional Euclidean space. The frequency of each word is counted. AutoWeb uses TF-IDF algorithm [26]. Term frequency $TF(d,t)$ is the number of times term t occurs in document d, which is $n(d,t)$. So, $TF(d,t)=\frac{n(d,t)}{\sum_{\tau} n(d,\tau)}$.

For Inverse document frequency $IDF(t)$, if D is the document collection and D_t is the set of documents containing t, $IDF(t)=\log\frac{|D|}{1+|D_t|}$.

Web page source is in a relatively structured format. HTML tags and metatags indicate different significance of terms. So we assign weights to them. Title, keywords and description in metatags weigh the highest. The first level headings have a medium weight, and bold words, headings in second level and below weigh the lowest. Hence, in vector space, the coordinate of document d in axis term t is given by $d_t = w_t TF(d,t) IDF(t)$, where w_t is the weight of t. Let $\vec{d}$ represent document d in vector space, then each Web page can be represented as $\vec{d} = \{i : w_i TF(d,i) IDF(i)\}$.

After calculating TF-IDF value of an incoming Web page source, we apply single-pass incremental clustering to it. Although for each calculated Web page, its D and D_t may change by 1. This doesn't affect the clustering result greatly. So we don't re-calculate IDF values for the consideration of efficiency. The similarity of incoming Web page with existing pages in each cluster is computed. We calculate inter-document similarity $s(\vec{d}_i,\vec{d}_j)$ using cosine measure, which is $s(\vec{d}_i,\vec{d}_j)=\frac{\vec{d}_i\vec{d}_j}{|\vec{d}_i||\vec{d}_j|}$.

If the similarity value is above a given threshold, this Web page belongs to this cluster. If more than one cluster pass the threshold, all these clusters will contain this Web page so as to increase the hit rate of revisitation. A new cluster will be created when no existing clusters go beyond the threshold.

Classification Procedure

When users input a URL or touch a link, a request for a Web page is issued. After getting the requested Web page, AutoWeb extract Web source and parse it in several steps.

Figure 3 shows the detailed procedure of clustering. We parse the source for text components using Document Object Model (DOM). Given the limited computing resources on mobile phones, we choose the most significant parts of text components, which are titles, keywords,

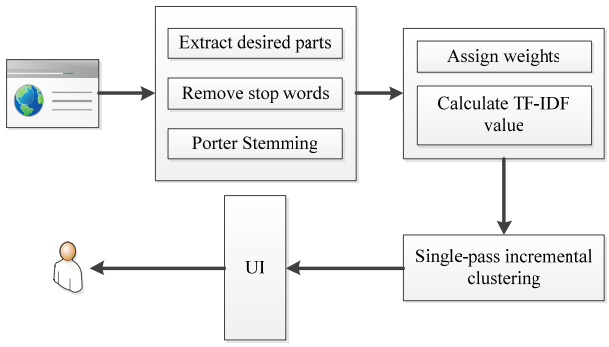

Figure 3. The Procedure of Clustering Web Pages

description, bold words and headings. We remove stop words in these components. Porter Stemming algorithm [18] is employed to map words to the same stem. Then we assigned different weights to different components and calculate TF-IDF values for each selected terms in this Web page. After single-pass clustering, results are stored and ready for revisitation. Users interact with the system by a designed UI as illustrated in Figure 1.

User Interface

We also take the UI design into account. Since AutoWeb features automatic classification, at the bottom of the main window there are two buttons, one for viewing current Web page in the same group of topic and the other one for viewing all groups. Figure 4 illustrates the user interface of AutoWeb. When a user wants to revisit a previous Web page sharing the same topic, s/he just simply touches the same-topic button to enter In-Group Level and view all the Web pages that belong to the same group. If more than one group hold this Web page, all Web pages in these groups will be shown. The user can select the desired Web page to revisit by touching the thumbnail image. If a user wants to shift to a different topic performed earlier, s/he touches the all-topics button and enters Groups Level. AutoWeb shows all groups with one folder for one group. Below the folder shows the keywords this group holds. By picking a folder with the desired topic, the user steps into that folder and choose a specific Web page. So at most three steps are taken to target a desired Web page and no extra interaction such as text input is necessary.

Accuracy of Automatic Classification

We evaluated the system by processing Web pages related to four kinds of most frequent activities [5, 10], that is *local services*, *travel*, *trivia* and *work/studies/hobbies (shopping)*.

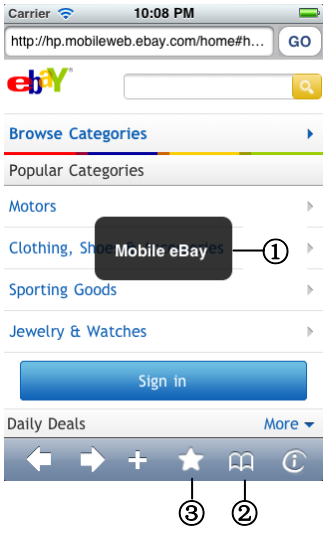

Figure 4. UI of AutoWeb.
(①Pop-up Window, lasts for 1 second ② Same-Topic Button, ③All-Topics Button)

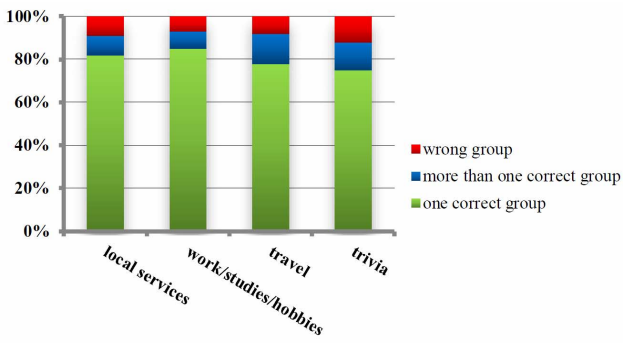

Figure 5. Classification Accuracy in Each Activity

We did these activities in AutoWeb with at least 50 related Web pages opened for each activity independently. We recorded the numbers of Web pages that were classified into one correct group, more than one correct group, and wrong group in each activity. In the case that the Web page was classified into several groups but not all these groups should hold this Web page, we considered it was classified into wrong group. We measured classification accuracy from users' perspective rather than using F-measure, Purity or other theoretical measures. Since in AutoWeb, it's users that judge whether previous Web pages are classified into correct group. For each opened Web page, if a user can find it in a folder at a time, it is regarded as a time of correct classification.

Figure 5 shows the results of evaluation. In every activity, about 80% of Web pages can be correctly classified into one group of topic. Plus more than one correct group classification, the accuracy is 92.4%. Still there are 7.6% of Web pages that were not placed into correct groups. We analyzed these Web pages and found that they contained few feature keywords and less descriptive titles, which were difficult for classification. This is the drawback suffered by content-based analysis algorithms. We'll study the effect on revisitation caused by classification missing in experiment 2 of the user study.

USER STUDY SETUP

The goal of our user study is to find out whether AutoWeb is helpful, in what condition, to what extent AutoWeb facilitates the revisitation and the difference between other methods. We conducted three experiments.

Study Design

We compare AutoWeb with a conventional mobile browser. Elapsed time of each revisitation in AutoWeb starts from touching revisitation button, goes on by stepping into Groups Level and In-Group Level (maybe some iterations for classification miss), ends by choosing an intended Web page. The times that participants step into wrong groups were also logged. We define Miss Ratio as the rate that the times of entering wrong In-Group Level divided by the total times of entering In-Group Level.

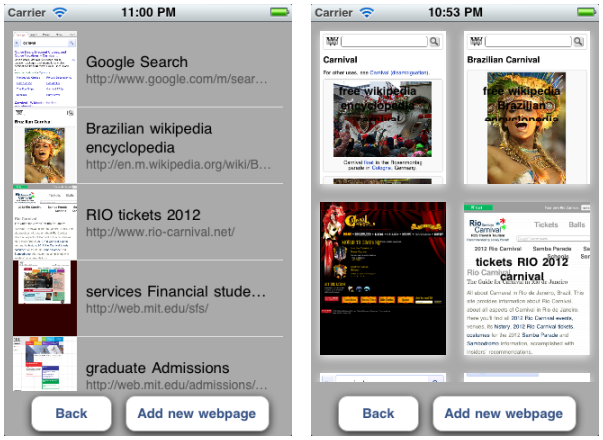

Figure 6. Two Representations of Opened Web Pages (Left: PlainWeb, Right: AutoWeb, In-Group Level)

Mobile Safari is a built-in browser in iOS devices. But due to the limitation of software authority, browsing events in Mobile Safari cannot be logged. So we also implement a traditional mobile browser called PlainWeb to log events (in Figure 6, left picture), which only has back button and traditional history list for revisitation. History list in PlainWeb also adopts recency order and a hybrid Web page representation with thumbnails and texts. The elapsed time of revisitation begins with touching the history button and ends with finishing finding a target Web page.

Participants

We recruited 26 participants (9 females). They all took part in previous pilot survey. Ages ranged from 21 to 32 years (*mean* = 22.4, *SD* = 4.5). 12 participants were students affiliated with computer science, 4 with electronic engineer and 3 with economics. Other participants were 2 teachers, 2 salesmen and 3 IT employees. They are active mobile Web users with iPhone. Before experiments, all participants were instructed how to use AutoWeb and PlainWeb. They practiced browsing Web pages with these browsers for at least half an hour until they got used to them.

EXPERIMENT 1

Tasks Design

Web content varies so greatly that it affects the results of automatic classification. To conduct the experiment in a controlled way, we design three typical sets of tasks according to existing studies about mobile browsing content [5, 10] to simulate the daily use of mobile browsing. These tasks are about *local services*, *shopping*, *trivia* and *travel*, which are the most frequent activities in mobile browsing.

All participants fulfilled these three tasks in sequence using both AutoWeb and PlainWeb. Web pages accumulate over each task. 13 participants used AutoWeb first, and the others used PlainWeb first to receive counterbalanced results.

Task 1 Make a Shopping Plan

This task focuses on local services and shopping. We design a scenario where participants make a shopping plan for this weekend.

First, participants required to find the latest fashion trends (such as jeans, suits) using Google. Then they searched it in the on-line shopping sites (such as amazon, eBay) to find the price and discount. After that, they searched shopping centers in New York, compared them and chose the favorite one. After finishing the previous steps, they should write down the name and price of desired clothing, the shopping center's location and other related information.

Task 2 Answer Questions

This task is to perform trivial information retrieval activities. There are eight questions focusing on the worldwide mobile network and iPhone, such as the most recent mobile network traffic in America, the market share of iPhone, the quantity of apps that had download from App Store, the number of countries had deployed 3G wireless network, and iPhone's share of mobile network traffic.

Task 3 Create a Travel Itinerary

This task is about travel. We put participants in the scenario that they are planning a trip to Rio, Brazil.

First, they should find the price of flight from New York to Rio on different airlines, compare and choose a proper one. And then, they searched for hotels in Rio and booked a room. There would be an annual carnival held in Rio during the stay. So they wanted to learn more about the carnival on Google and Wikipedia. After that, they decided to prepare a costume for the carnival. So they modified the shopping plan to buy a costume. After finishing previous steps, they should write down the information of flight, hotel and carnival, name and price of costume, shopping center's location and other related information.

Results

After participants accomplished all tasks using AutoWeb and PlainWeb, we transferred log files from phones to a desktop computer for analysis. We measure the average revisitation time. Classification accuracy differs in a small range, which is 91.1%-91.7%. The average revisitation times for each participant is 44.2 (*SD* = 7.5) in AutoWeb, and 38.4 (*SD* = 8.1) in PlainWeb. We use two-way ANOVA to analyze which factor may affect revisitation performance. We also interviewed several participants for their comments.

We investigate the average revisitation time in different tasks and browsers. The average revisitation time is the average time participants spent in re-finding one opened Web page. We explore each participant's average revisitation time using AutoWeb and PlainWeb. The hypothesis is: Participants revisited Web pages faster when using AutoWeb.

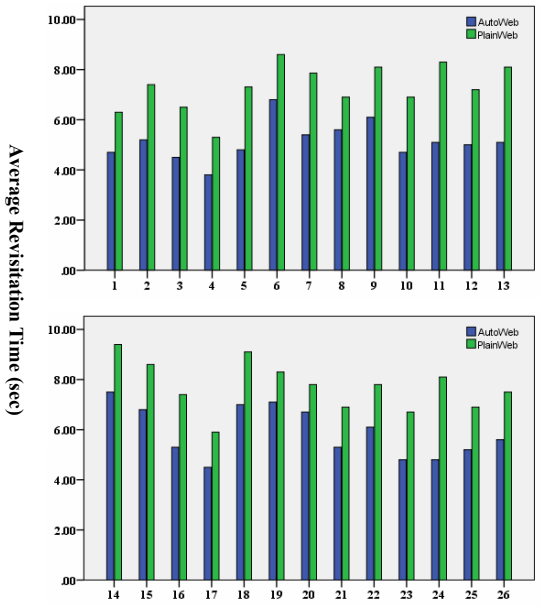

Figure 7. Average Revisitation Time for Each Participant

Figure 7 illustrated every participant's average revisitation time in two passes. There is a significant difference in AutoWeb and PlainWeb in terms of average revisitation time ($F(1, 24)=6.53$; $p<.001$). It conforms to the hypothesis. The result suggests that participants were able to revisit previous Web pages more quickly using AutoWeb. The average revisitation time of AutoWeb is 5.52sec (*SD*=.96sec), while the average revisitation time of PlainWeb is 7.83sec (*SD*=1.10sec). AutoWeb saves up to overall 29.5% revisitation time.

User Experience

We also investigated participants' browsing experience with AutoWeb and PlainWeb. After finishing these three tasks, Participants filled out a questionnaire to rate some aspects of AutoWeb and PlainWeb in Likert scale[1]. We collected and calculated the ratings for each browser. Standard t-test comparison cannot be used because Likert scale responses are not normally distributed. We use Mann-Whitney U Test to make pairwise comparisons between AutoWeb and PlainWeb.

As with ease of use, AutoWeb received a mean rating of 4.13, while PlainWeb received 4.08. There is no obvious difference in ease of use between these two browsers. As with the question, "Which browser do you like", AutoWeb received a mean rating of 4.50, and PlainWeb receive 3.12. Mann-Whitney U Test show a significant differences between AutoWeb and PlainWeb (z=4.13, $p<.001$). It reveals that participants prefer AutoWeb.

[1] Likert scale responses range from 1 to 5, where 1 stands for strongly disagree and 5 stands for strongly agree

Discussion

In the informal interview, we want to explore how participants felt about revisitation during browsing and how their mental model works when they use AutoWeb.

Several participants mentioned that, at the beginning of each pass, "I didn't find the benefit of AutoWeb. I can easily revisit a Web page use PlainWeb with the cue of thumbnails (at the beginning)." When participants opened more Web pages, "When I began to write down the results, I came to realize that AutoWeb is helpful. Because by PlainWeb, I had to scroll up and down several times in the history list to find my target. Especially in Task 3, when I have to go back to Web pages opened in Task 1, it took great pains to scroll down so many times to find them.". "Using AutoWeb, I only scroll down few times to find the folder, and in the folder, find the page at once." Their browsing experience in different browsing stages falls in line with the revisitation time in different stages. AutoWeb can easily manage a large number of opened Web pages and speed up revisitation.

As with the mental model, we are interested in the way how participants find the target with the help of the cues we provide. Some participants said, "The pop-up window gave an overview of the Web page and I got an idea of keywords in this page." When searching in the Groups Level, "I first skimmed over the thumbnails in the folder icon. If folder icon didn't contain all the thumbnails, I would look at the text below." One participant said, "After several times of revisitation, I almost remembered the folders' names and locations. So before I began to find a Web page, I knew where to find it."

EXPERIMENT 2

AutoWeb relies on automatic classification to facilitate revisitation. Classification accuracy is crucial to reducing revisitation time and improving browsing experience. AutoWeb proves to be faster for revisitation at a relatively high accuracy in experiment 1. In this experiment, we want to discover the relationship between classification accuracy and revisitation time in a quantitative way. Furthermore, how different classification accuracies affect browsing experience will be discussed.

Experiment Setup

23 out of 26 participants who took Experiment 1 took this experiment. Participants were not instructed to open specified Web pages. They can access any Web pages related to these topics. They surfed the Internet for at least one hour.

Results

By analysis of log files, we calculated miss ratio (MR) and corresponding average revisitation time (ART). The overall trend is that ART increases as MR increases (Figure 8). In the experiment, MR ranged from 7.4% to 14.1% while ART ranged from 4.5 sec to 8.7 sec. In previous experiment 1,

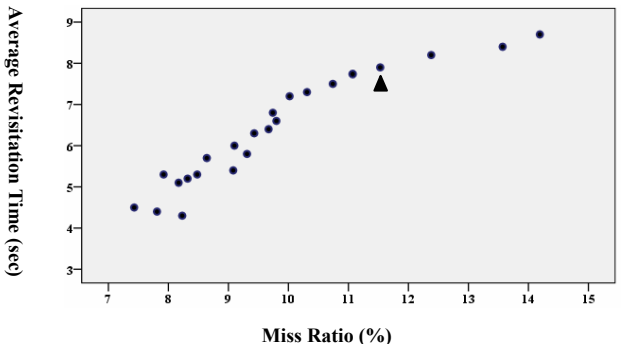

Figure 8. Average Revisitation Time at Different Miss Ratio

ART in PlainWeb is 7.83sec. In Figure 8, when MR is 11.53%, ART is 7.9 sec (marked by a triangle). Hence, we can get an empirical conclusion that to keep ART in AutoWeb lower than that in PlainWeb, we should control MR fewer than 11.53%. 74% participants are under 11.53% about MR. In most conditions, AutoWeb can speed up the revisitation in daily use.

Interview and Discussion

In the informal interview after experiment, we wanted to know what measures participants would adopt if a classification miss occurred and how they felt about this more freely browsing.

The measures taken by participants to handle miss issues differed. Some participants told that they just went back to the Groups Level and found another proper folder, stepped into it. There would be some iteration to find a target Web page. One participant said, "When I didn't find the Web page, sometimes I would scroll up and use a similar one or one that can lead me to the target." Someone said, "If I didn't' find it at the second time, I would give up and open a new Web page instead".

A participant said that when using traditional mobile browsers before, in order to narrow down the search scope in history list, he would recall approximately the last accessed time. AutoWeb released him from memory burden. He could just choose one group of Web pages by the hints to find an intended Web page.

AutoWeb also changes the way of mobile browsing. A participant told us that when using AutoWeb, she paid more attention to the topic of Web pages. The whole procedure of browsing became more topic-specific. She would sometimes touch same-topic button to enter In-Groups Level and see Web pages that shared the same topic. It could remind her of the pages that she didn't pay much attention to before. She would also step into Group Level to get a whole view of topics.

During the experiment, we noticed that there was some difference in the pattern of browsing using two browsers. In PlainWeb, when searching for information by search engines, participants would touched one link in the search result Web page, stepped in and browsed it. In current Web page, they would follow another link to other pages. After tracing down several pages, they went back to the search results page, touched a second link and browsed it. They searched information in depth. In AutoWeb, a number of participants opened several link pages continuously. Then they browsed them one by one. They searched information in width. They said that in this way they would focus on the topic and make comparison between similar Web pages more quickly.

EXPERIMENT 3

In order to compare automatic classification with other revisitation methods such as search-based navigation, we conduct another experiment to investigate the difference.

We integrate other revisitation methods, namely back button, history list, bookmark, typing in the URL field and search engines, into AutoWeb and installed the software in participants' own iPhones for daily use. We recruited 12 participants from experiment 2 and conducted a one-week log study. After collecting log files, we calculated the revisitation frequency of each method for each participant (in Figure 9).

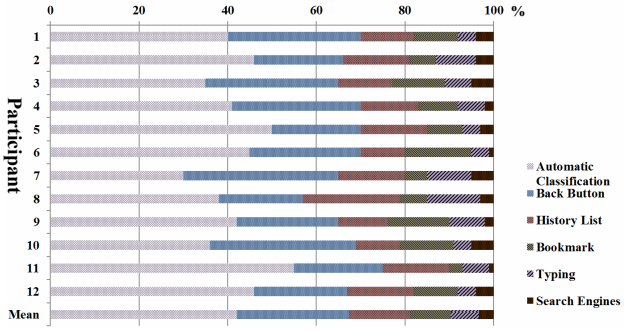

Figure 9. Comparison of Each Revisitation Method

In the experiment, participants preferred to use the automatic classification method to revisit Web pages at the frequency 42.0% (*SD* = 6.6%). Back button (*mean* = 25.4%, *SD* = 5.5%), history list (*mean* = 13.8%, *SD* = 3.1%), and bookmark (*mean* = 9.2%, *SD* = 3.6%) were used less than those in previous plot survey. Interestingly, typing in the URL field (*mean* = 6.4%, *SD* = 2.6%) and using search engines (*mean* = 3.2%, *SD* = 1.4%) were similar with those in pilot survey. This indicates that automatic classification replaces about half of the usage of back button, history list and bookmark, while has little effect on the long revisitation span methods, like typing in the URL field and search engines.

Back button is the second most frequent revisitation method. Some participants said that back button is indispensable since it takes only few operations to find the Web pages which are one or two pages before the current one. But

sometimes they might touch the same-topic button instead if these consecutive pages share the same topic. Similarly, they would touch the all-topics button instead of history list or bookmark to find a Web page that is in a relatively longer revisitation span.

We also investigate the difference that participants use the same-topic button and all-topics button. The majority of participants (10 people) would like to click on the all-topics button and navigate to previous Web pages, but two participants prefer to search for a related page first and then touch the same-topic button to find similar pages. They said this method can save time in choosing the topic folder.

DISCUSSION

Results presented in user study confirm that AutoWeb is easy to use and facilitates the revisitation for browsing mobile Web pages. AutoWeb introduces the concept of automatic classification according to Web contents into mobile browsers. This method proves effective and conducive to revisitation.

The essence of automatic classification in AutoWeb is to narrow down the searching scope of opened Web pages. However, in some extreme situations, AutoWeb won't work well. If all Web pages share the same keywords, all of them will be classified into one group. Users can only search in one folder for a desired Web page. Then AutoWeb degenerates to a traditional mobile browser that uses history list to hold accessed entries. If every Web page doesn't share the same keyword with each other, one topic group will hold only one opened Web page. In this worst case, AutoWeb won't speed up the revisitation. Users will take more steps in revisitation on the contrary. But in practice, for a relatively long time browsing and common activities, these extreme situations seldom happen in our evaluation and user study.

As to classification algorithm itself, to our knowledge, there is no algorithm that can automatically classify all Web pages correctly. Taking the limited computing resources of mobile phones into consideration as well, the efficiency of algorithms is more crucial. In the design of AutoWeb, we got an idea to design client/server architecture. If we move the heavy computing burden to a powerful server and adopt more complicated and accurate algorithm, we can get a better classification result. But the communication latency will increase so as to affect user experience. Moreover, the server gets every request from users, so privacy will be another issue. The practical method is to provide some remedy tools when automatic classification fails to put Web pages into right groups. Our goal is to speed up the revisitation on the whole and make the loss of classification miss at the very least.

We use two levels to represent classification results. If AutoWeb also support long-term revisit, many Web pages would be classified into one group. So Web pages at In-Group Level may also need to be classified into different groups. Two levels may not be enough. But the increase of levels also increase the complexity of guide and navigation, it also increase recognition burden on users' side. How to strike a balance between the number of levels and ease of use needs further study.

The user study also has some limitations. Firstly, we only implement AutoWeb on iPhone due to its dominance in mobile network traffic [8]. Other platforms, such as Android and Symbian should be implemented in future. Secondly, since each participant only took hours to finish experiments, experiment time was relatively short. Hawthorne Effect[2] may exist. So we need carry out a long-term study to verify the result.

CONCLUSION AND FUTURE WORK

We have introduced a novel approach for revisitation on mobile browser by automatic classification of Web pages. Due to the limitations on mobile devices, revisitation takes more time than that on desktop computers. We use automatic classification method to classify opened Web pages into different topics of groups. It helps users to narrow down searching scope and to reduce extensive scrolling.

We have presented results from a pilot survey to find that revisitation occurs frequently on mobile Web browsing. We have described the design and implementation of AutoWeb. The consideration in design was explained in detail. We also described the UI design and the process of operation. We evaluated classification accuracy of the system. The results proved satisfactory. In most cases, AutoWeb can classify Web pages correctly at the rate of 92.4%.

We have presented a user study in detail. In the controlled experiment, we design three tasks which are most frequent activities on mobile browsing. We found that AutoWeb can facilitate revisitation a lot and save up to overall 29.5% revisitation time. Users also got a better revisitation experience and preferred AutoWeb other than PlainWeb. In the semi-open experiment, how classification accuracy and miss rate affect revisitation was discussed. We find average revisitation time increases as miss ration increases. In most conditions, AutoWeb can facilitate the revisitation in daily use. We also conducted an experiment to find the difference between automatic classifications with other revisitation methods.

Future work includes adding the features that users can intervene in classification process for more satisfactory results such as manually adding or moving an opened Web page to a desired group. The system should learn from users' choice and adjust the classification results accordingly. More practical remedy tools in case of classification miss should be

[2] Hawthorne effect is a form of reactivity whereby subjects improve or modify an aspect of their behavior being experimentally measured simply in response to the fact that they are being studied, not in response to any particular experimental manipulation.(Wikipedia.org)

provided in AutoWeb. Besides, an appropriate number of levels for representation should be investigated.

ACKNOWLEDGMENTS

This work is supported by the University Doctorial Research Foundation, No. 20100002110052 and the Nokia - Tsinghua University Joint Research Funding.

REFERENCES

1. Abrams, D., Baecker, R. and Chignell, M. Information archiving with bookmarks: Personal web space construction and organization. *Proc. CHI 98*, pp. 41-48
2. Albers, M.J. and Kim, L. User web browsing characteristics using palm handhelds for information retrieval. *In Proc. IPCC/SIGDOC 2000*, pp. 125-135.
3. Aula, A., Jhaveri, N., and Käki, M. Information Search and Re-access Strategies of Experienced Web Users, In *Proc. WWW 2005*, pp. 583-592.
4. Borodin, Y., Mahmud, J., and Ramakrishnan, I.V. Context Browsing with Mobiles - When Less is More. In *Proc. MobiSys 2007*, pp. 3-15
5. Church, K., and Smyth, B. Understanding the Intent Behind Mobile Information Needs. In *Proc. IUI 2009*, pp. 247-256
6. Church, K., Smyth, B., Cotter, P., and Bradley, K. Mobile information access: A study of emerging search behavior on the mobile Internet. In *ACM Trans. Web, 2007, 1(1).*
7. Cockburn, A. and McKenzie, B. What do Web Users do? An Empirical Analysis of Web Use. In *International Journal of Human-Computer Studies, 2001(54)*, pp.903-922.
8. Device Essentials. http://www.comscore.com/Press_Events/Press_Releases/2011/6/comScore_Introduces_Device_Essentials
9. Dourisboure, Y., Geraci, F., and Pellegrini, M. Extraction and classification of dense implicit communities in the Web graph. In *ACM Trans. Web 2009;3(2)*
10. Heimonen, T. Information Needs and Practices of Active Mobile Internet Users. In *Proc. Mobility 2009*.
11. Jhaveri, N. and Räihä, K. The Advantages of a Cross-Session Web Workspace. In Proc. *CHI extended abstracts on Human factors in computing systems, 2005,* pp. 1949-1952
12. Kaasten, S. and Greenberg, S. Designing an integrated bookmark/history system for web browsing. *In Proc. WCGS, 2000*.
13. Kellar, M., Watters, C. and Shepherd, M. A Goal-Based Classification of Web Information Tasks. In *Proc. the American Society for Information Science and Technology, 2006, 43(1),* pp. 1–22.
14. Liu, J., Yu, C., Xu, W and Shi. Y. Clustering web pages to facilitate revisitation on mobile devices. In *Proc. IUI 2012*, pp. 249-252
15. MacKay, B. and Watters, C. Building support for multi-session tasks. *In Proc. CHI 2009*, pp. 4273-4278.
16. MacKay, B. and Watters, C. Exploring multi-session web tasks. *In Proc. CHI 2008*, pp. 1187-1196.
17. Nikolaev, K., Zudina, E., and Gorshkov. A. Combining anchor text categorization and graph analysis for paid link detection, In *Proc. WWW 2009*.
18. Porter, M., An algorithm for suffix stripping. 1980 http://tartarus.org/~martin/PorterStemmer/
19. Redish, J., C. Understanding Readers. In *Techniques for Technical Communicators*. *1994*. pp. 15-41
20. Setlur, V., Rossoff, S., and Gooch, B. Wish I Hadn't Clicked That: Context Based Icons for Mobile Web Navigation and Directed Search Tasks. In *Proc. IUI 2011*, pp. 165-174
21. Shrestha, S. Mobile Web Browsing: Usability Study. *In Proc. Mobility 2007*, pp. 187-194
22. Sohn, T., Li, K., Griswold, W. and Hollan. J. A diary study of mobile information needs. In *Proc. CHI 2008*, pp. 433-442.
23. Tauscher, L., and Greenberg, S. How People Revisit Web Pages: Empirical Findings and Implications for the Design of History Systems, *International Journal of Human-Computer Studies, 1997, 47(1),* pp.97-137.
24. Tauscher, L. and Greenberg, S. Revisitation patterns in World Wide Web navigation. In *Proc. CHI 1997*, pp. *99-106.*
25. Teevan, J., Cutrell, E., Fisher, D., Drucker, M. S., Ramos, G. Visual Snippets: Summarizing Web Pages for Search and Revisitation. In *Proc. CHI 2009*, pp. 2023-2032.
26. TF-IDF algorithm. http://en.wikipedia.org/wiki/TF-IDF
27. Wang, Q., and Chang H. Multitasking Bar: Prototype and Evaluation of Introducing the Task Concept into a *Browser, In Proc. CHI 2010, pp. 103-11.2*
28. Weinreich, H., Obendorf, H., Herder, E. and Mayer, M. Not Quite the Average: An Empirical Study of Web Use. In Trans. Web 2008; 2(1).
29. Yoong-En, T., and Seong, D.S.K. Visual History Mechanism on Mobile Internet Browser. In *Proc. Mobility, 2007*, pp. 372-379.
30. Zhang, H. and Zhao, S. Measuring Web Page Revisitation in Tabbed Browsing. In *Proc. CHI 2011*, pp. 1831-1834.