Automating Web-Navigation Support Using a Cognitive Model

by

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in

4th International Conference on Web Intelligence, Mining and Semantics

Report No: IIIT/TR/2014/-1

Centre for Software Engineering Research Lab
International Institute of Information Technology
Hyderabad - 500 032, INDIA
June 2014
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ABSTRACT

Reducing cognitive overhead is one way to ensure fast and easy web-navigation for users. We present here an automated navigation-support tool for websites. Whenever a user visits a website for searching some information, the tool will suggest relevant links to click, where they can find desired information on that website. The tool is based on a new cognitive model CoLiDeS+Pic, which combines two related models, CoLiDeS+ and CoLiDeS+Pic. The model computes semantic similarity between the user goal and the website information using latent semantic analysis technique. It also takes into account the path adequacy, performs appropriate backtracking if required, and uses semantic information from pictures. In the current implementation, the tool is not fully automated because the semantic features of pictures have to be obtained manually. To evaluate the effectiveness of the tool, we conducted an experiment with tool support and multi-tasking as independent variables. Statistical analysis showed a significant positive impact of the tool support for time needed to perform search tasks, disorientation in navigation and task-accuracy. The navigation performance in time and disorientation of the users and answering questions are improved when provided with the tool support. Multi-tasking had no effect on time needed or answering questions, but we observed an unexpected positive effect on disorientation, suggesting that perhaps the participants were more motivated to perform primary task due to the assigned secondary task (monitoring a video at the same time), which resulted in less disorientation.

Categories and Subject Descriptors

General Terms
Algorithms, Design, Experimentation, Human Factors, Performance

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WIMS'14, June 2–4, 2014, Thessaloniki, Greece.  
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ACM 978-1-4503-2538-7/14/06$15.00.  
http://dx.doi.org/10.1145/2611040.2611077

Keywords

1. INTRODUCTION

Navigation is a key aspect of the World Wide Web (WWW), in general as well as for specific websites. If the user interface of a website is good, it reduces the cognitive overhead on the users while searching for desired information on the website [1], which results in fewer mouse-clicks and facilitates faster navigation. However, due to a lack of web-design standards, sometimes the navigation becomes difficult and confusing to the users [2]. For example, there is no standard place for the sign-in process on a web page. In some websites we find it on the upper-left corner, while in others it may be on the right corner. Bad navigation structures and unclear menus also contribute to the user confusion.

There are different elements of web-navigation like selecting hyperlinks, backtracking using the back button and form submission [3]. Among these, evaluating and selecting hyperlinks is a key element. It is also observed that the position of hyperlinks affects their selection by a user. For example, if the link is visible only after scrolling down, it is less likely to be selected by the user. In this paper, we focus on the selection process of hyperlinks and propose a methodology for automating navigation support.

Looking from the perspective of Cognitive Science, there exist different models to simulate web-navigation. These models not only help in predicting the navigation patterns of the target user, but can also be used for providing support to a user for web-navigation. Some such cognitive models are Linked Model of Comprehension-based Action Planning and Instruction taking (LICAI) [4], Comprehension-based Linked Model of Deliberate Search (CoLiDeS). LICAI simulates the user navigation behavior, while CoLiDeS also adds a parsing phase to the model, in which the user divides the web page into high-level semantic regions and then focuses on one of them. The extensions of CoLiDeS model are CoLiDeS+ and CoLiDeS+Pic. Some other models are Scent-based Navigation and Information Foraging in ACT Architecture (SNIF-ACT), and Method for Evaluating Site Architectures (MESA) [5,6]. These last two models simulate the navigation on the entire World Wide Web.

Here we consider the CoLiDeS model and its variants, as we focus on the navigation of a specific website. The CoLiDeS model divides the user navigation behavior into four stages: parsing, focusing, elaboration/comprehension and selecting a hypertext link on a page [7]. Though CoLiDeS model only takes into account the semantic similarity between the information of the hyperlinks and user’s goal, an extension to this model known as CoLiDeS+ [8] also considers the structural dimension, i.e., path adequacy. Path adequacy refers to the semantic similarity between
the navigation path the user traversed so far during the session and the user’s goal. Furthermore CoLiDeS+ includes backtracking when forward search fails. Another variant of the CoLiDeS model is CoLiDeS+Pic, which also considers the semantics from pictures [9]. However, CoLiDeS+Pic does not take into account the structural dimension, i.e. path adequacy.

In this paper we propose an automated support tool which is based on the combination of CoLiDeS+ and CoLiDeS+Pic model. The new model is termed as CoLiDeS++Pic. We chose this combination to get the advantage of both the structural dimension and the availability of information from the semantic features of pictures. Thus, it should give better results compared to the individual models. Basically, given a website and a certain goal, the tool offers on-line suggestions on every page for the most relevant hyperlink to be clicked on, so that the user can find the desired information. This should help in better information-seeking performance such as faster and more goal-directed navigation and more accurate answers to the search questions.

The tool could be helpful for different user groups Visually-impaired persons, who use screen readers to access the website contents in a sequential manner, take a long time to reach to their goal. If they could be made aware of the hyperlinks to be clicked on, it should reduce cognitive load and save their time considerably. The tool can also be used by elderly people who have memory problems, or naive internet users who do not have much experience with the process of navigation. Users doing multi-tasking could use the tool for increasing cognitive capacity for navigation; we will explicitly examine the role of multi-tasking here.

The structure of this paper is as follows - we first discuss the different automated navigation support systems currently available and the motivation for developing a support system based on a cognitive model. Then the design, algorithm and implementation of the proposed tool are discussed. Next the results of an empirical evaluation of the tool are presented in the context of multi-tasking.

2. RELATED WORK

There are different approaches to provide navigation support to the user. In order to provide better web-navigation to blind people. Zajicek et al. (2007) developed a tool, which provides a list of links, headings and a summary of the web page using information retrieval techniques and effective search mechanisms [10]. However, they reported that the summaries were not reflecting the whole web page content.

Another method for providing support is by recording the browsing steps and allowing them to replay [11]. This approach will be useful only when the user wishes to revisit a website. Other similar studies provide facilities for automatically retrieving dynamical web pages [12], automating repetitive browsing tasks [13], and analyzing the previous usage patterns [14, 15].

An implementation of a constructivistic approach for web-navigation is proposed by Zeiliger et al. [16]. Basically they gather, represent, structure and create navigational objects with a graphical user interface. The objects are represented in the form of a map, which could be used to navigate. This approach is limited by the fact that map-enhanced browsers also lead to the disorientation problem, that is the sense of being ‘lost’ in information space. A similar graphical approach to represent the previously visited pages is employed by [17, 18].

A tool called WebWatcher provides support to the user by employing knowledge about which hyperlinks are likely to lead to the target information [19]. The training is done by logging user’s successful and unsuccessful searches. However, according to the authors, the results are still far from perfect. Another tool Letizia uses heuristic approach to learn users’ interest through their behavior [20]. It keeps track of user’s behavior and navigation history to find out what could be interesting to the user.

ScentTrails [21] is another approach of providing support by merging browsing and searching techniques, and using information foraging theory [23]. Based on information scent, the relevant links on the web page are highlighted, leading to the user goal. In contrast to ScentTrails, we focus only on within-website navigation, and use navigation path adequacy, backtracking and semantic information of pictures.

The tool we are proposing is different from the ones mentioned above, as it can be applied to navigating through a website, which is visited by the user for first time. It is based on the implementation of cognitive models of web-navigation simulation, since it is observed that cognitive models could be effectively used for providing navigation support [22] and also uses information scent as driving force [25].

Our tool does not implement any map-based architecture and does not require any initial training. However, augmenting the tool with features like text-to-speech conversion and recording navigation paths in order to allow them to replay will make our tool more useful.

3. DESIGN AND IMPLEMENTATION

Our tool is based on a new cognitive model CoLiDeS++ which is derived from CoLiDeS+ and CoLiDeS+Pic. This combination could be termed as CoLiDeS++Pic, as it considers both semantic and structural knowledge. The model uses Latent Semantic Analysis (LSA) to determine information scent between the user goal and the content of hyperlinks on a given web page. According to Pirolli and Card (1999), information scent is a measure of the value, cost or access path of information sources obtained from proximal cues (hyperlinks in our case) [23]. In general, a higher information scent will stimulate users to follow that cue and click on the corresponding link.

LSA is an unsupervised machine learning technique that builds the semantic space representing the given user goal, as well as the content of a hyperlink combined with the semantic features of the picture(s) present on that particular web page. The technique includes computation of term frequency (number of times a word occurs in the document) and inverse document frequency (words occurring less frequent but more relevant). Then the cosine similarity is computed using dot products of the two term-frequency vectors (one for the user goal and the other for the hyperlink information) [24, 25]. A hyperlink is selected if its information scent is above a threshold value.

CoLiDeS++Pic also uses the concept of path adequacy and backtracking [8]. Path adequacy refers to the semantic similarity between navigational path (current hyperlink including the previous selected hyperlink(s) and semantic features of pictures) and the user goal. If the information scent is not increased for the current selection as compared to the previous one, then path adequacy is calculated. Thus, the hyperlink with lower similarity will be considered if it increases path adequacy. If no such hyperlink is found, backtracking (moving back to the previous page) is performed. It is important to note here that the semantic features for pictures are obtained manually by a feature-generation task. In this task, participants are asked to list semantic features corresponding to a given picture, and then features that are common across the participants are selected. (See Van Oostendorp et al., 2012 [9] for a detailed description of this procedure.) Figure 1 shows the basic workflow of the tool. The user first receives the website URL and goal as inputs.
The suggested link is obtained by running the tool, which basically implements CoLiDeS++Pic. If the user achieves the goal on the suggested link, the process stops, else further suggestions are given by the tool. The detailed algorithm for obtaining suggested links is given in Appendix. For LSA computation, we use the LSA server of University of Colorado and their semantic space of first-year college students [26]. We present here an example of the implementation applied on the mockup website we used in the experiment. The user goal is “Lymphatic System contains immune cells called lymphocytes, which protect our body from antigens. They are produced by lymph nodes. Name at least three locations in the body where lymph nodes are present”. At level 1, one out of four given links needs to be selected. The cosine values for each of the links, representing the semantic similarity between the user goal and the hyperlink text along with the semantic features of the picture present on the webpage are calculated. The link ‘Circulatory System’ with highest LSA value is selected. At level 2, again the LSA values are calculated. As the LSA values are not increased, the path adequacy (PA) is calculated. The PA of first link (Circulatory System + Cardiovascular System) compared to the goal is .284, and second link (Circulatory System + Lymphatic system) compared to the goal is .308, so the second one is chosen. Thus, we get “Lymphatic System” as the suggested link which is the correct link to achieve the goal. Table 1 shows the LSA values at different levels.

<table>
<thead>
<tr>
<th>Level 1</th>
<th>LSA Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory System</td>
<td>0.251</td>
</tr>
<tr>
<td>Nervous System</td>
<td>0.251</td>
</tr>
<tr>
<td>Digestive System</td>
<td>0.270</td>
</tr>
<tr>
<td>Circulatory System</td>
<td>0.273</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level 2</th>
<th>LSA Value</th>
<th>Path Adequacy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiovascular System</td>
<td>0.238</td>
<td>0.284</td>
</tr>
<tr>
<td>Lymphatic System</td>
<td>0.242</td>
<td>0.308</td>
</tr>
</tbody>
</table>

Note: bold links are selected by the system

4. EMPIRICAL EVALUATION

In order to evaluate the tool for its efficiency in providing navigation support to the users, we performed the following experiment in which participants received support (or no support) and were doing a secondary task (or not).

4.1 EXPERIMENT DESIGN

As mentioned earlier, the tool could be useful for various user groups. One such user group is the internet users doing multi-tasking. We expect that the users with the tool support will perform better, particularly when doing multi-tasking. To induce multi-tasking scenarios, we introduced a secondary task of monitoring a comedy video during navigation.

Our experiment followed a 2x2x4 factorial design, where the first two factors (tool-support and multi-tasking) were between-subject variables, and the third factor (levels of task) was within subject.

Forty computer science and technology students of IIIT-Hyderabad, 34 males, 6 females, (Mean age=27.14, SD=6.75) participated in the experiment on a voluntary basis. They had no specific prior knowledge with regards to the website content (physiological base of human body). They were randomly assigned to one of the four groups: Group 1 (No tool support no multi-tasking), Group 2 (No tool support but multi-tasking), Group 3 (tool support but no multi-tasking), and Group 4 (tool support with multi-tasking). Each group had 10 participants. For the experiment, we took the same mockup website as in [25] due to the availability of semantic features for pictures present in the website. We created two versions of the website: one with no hints for the links to be selected, and the other one with highlighted arrows pointing to the link where users can find the answer for the given task. Participants were told that the link suggestion was an advice, and that they were free to make another decision. This support was automatically obtained by running the navigation support tool at the back-end.
Figure 2 and 3 show the two versions of the test website. Group 1 and Group 2 were given the first version website while Group 3 and Group 4 were given the second one with highlighted link suggestions. There were eight search questions for which the participants were asked to find the answers. These questions were equally divided into four levels based on the number of web pages to be browsed. Level 1 tasks required only two web pages (including home page) to be visited. Level 2, Level 3, and Level 4 tasks required 3, 4, and 5 web pages respectively. For example, a question for Level 3 is: "Name the three layers of tissue that form the heart wall?" (Answer - Navigation Path - Home: Introduction > Circulatory System > Cardiovascular System > Heart

Participants of Group 1 and Group 3 were asked to find answers to the questions with no secondary task running in parallel. The other two groups were asked to monitor a comedy video while they were completing the main tasks. To ensure that the participants would pay attention to the video, these participants were told that at the end of the session they would be asked questions about the video.

4.2 EXPERIMENT RESULTS

We measured the performance of the participants in terms of total time, accuracy and disorientation. Total time was the time taken by participants to complete each task. It is based on the interval between presenting the question and submitting the answer. Accuracy was assigned a score of 1 if the participant reached the correct page and answered correctly, 0.5 if they reached the correct page but the answer was wrong, and 0 if they failed to reach the correct page. Mean accuracy over all eight tasks was computed (score range 0-1). We also calculated disorientation as a measure of deviation from the shortest path to solve the assigned task. It was measured based on the ratio of the visited and the optimal node counts [27] as follows:

\[ L = \sqrt{\left(\frac{N - S}{S} \right)^2 + \left(\frac{R}{N} - 1\right)^2} \]

where \( R \) is the minimum number of pages needed to visit in order to finish the task, \( S \) is the actual number of pages visited, \( N \) is the number of distinct pages visited and \( L \) is the disorientation. As users become increasingly lost the value of \( N/\min S \) tends to be 0 and also \( R/N \) tends to be 0, while for users who are not lost the ratios tend to be 1. When both ratios are combined into one measure (L) we get a more accurate picture of Lostness. A higher value of L means less goal-directed navigation behavior with many revisits and detours.

We calculated values of total time, task accuracy and disorientation for all the participants in each group. In order to simplify presentation of the results we leave out the effect of levels, however it is considered in the statistical analyses.

The average total time taken by the participants in each group is shown in Figure 4. As we can see, the time taken in the no-support groups is higher compared to the support groups, suggesting that the tool helps in saving time. But multi-tasking has a minor effect with respect to the support and no-support conditions. In order to statistically verify these results we did a mixed-design ANOVA with tool-support and multi-tasking as between-subject factors, and the level of tasks as a within-subject factor. We found a strong positive effect of tool-support, \( F(1, 36) = 16.54, p<.001\), while there was no significant effect of multi-tasking on the total time or on the interaction.

Figure 5 shows that the accuracy level is higher in the support condition compared to the no-support condition. The results of a similar mixed-design ANOVA showed a significant difference in accuracy between the support and no-support conditions, \( F(1, 36) = 16.54, p<.001\), while there was no significant effect of multi-tasking and its interaction with tool-support, \( F < 1\).

The last parameter for measuring performance was disorientation. The means of disorientation are shown in Figure 6. These means show that disorientation was less in the support condition. The participants did deviate less from the correct navigation path when provided with the hints. The statistical analysis, again a mixed-design ANOVA, showed that the effect of support on disorientation was highly significant, \( F(1, 36) = 18.99, p<.001\). The effect of multi-tasking was also significant \( F(1, 36) = 5.35, p<.05\), however the disorientation was unexpectedly higher in the no-multi-tasking condition. The interaction of the multi-tasking and support variables was not significant.
5. CONCLUSION

We presented here a navigation-support tool based on a new cognitive model CoLiDeS++Pic. The model is derived from two models CoLiDeS+ and CoLiDeS+Pic, taking into consideration the advantages of both. Given a specific goal, the tool provides navigation hints to the user. It uses semantic similarity between the user goal and the website hyperlinks, and so does not require any past experience or navigation history for providing hints. Furthermore it uses the navigation path, a backtracking mechanism and semantic information available from pictures. At present, the tool is automated except for the module for features extraction from pictures. But this could be incorporated using metadata and keywords for pictures in the future.

The validation experiment reported here shows that when the users are provided with the tool suggestions (by the highlighted arrows), their performance in terms of accuracy, (dis)orientation and time needed to perform the search tasks is improved. However, we found no negative effect of multi-tasking, but only a positive effect on disorientation. It may be that our secondary task was not taxing enough for working memory. Even in the no-support conditions, the differences in the accuracy or the total time needed were minimal between multi-tasking and single-tasking situations. This effect is in line with a study reported in [28], where it is suggested that interruption is not always as deleterious to productivity as one might expect - although it creates more stress (which we did not measure). Regarding the positive effect of multi-tasking on disorientation, we conjecture that this might be due to the participants having a higher motivation for doing their search tasks. In subsequent studies, we plan to use a stricter and more taxing secondary task.

This study was a first step to determine the empirical value of the CoLiDeS++Pic model in terms of behavior of participants. In next steps we have to compare the value of CoLiDeS++Pic to existing models like CoLiDeS+ and CoLiDeS+Pic. In subsequent analyses of the current data, we will also compare different cognitive models (CoLiDeS+, CoLiDeS+Pic and CoLiDeS++Pic) for their effectiveness: we will do this by examining the match of the respective models behavior with user navigation patterns [see 8, 9]. In previous research it was determined that CoLiDeS+Pic was more effective, in the sense of predictability of human navigation, than CoLiDeS [9]. The question is now whether CoLiDeS++Pic is even more effective than CoLiDeS+Pic.

It is significant to note here that we also tested our tool (not reported here) with few real-time websites (after excluding the semantics of pictures consideration), where it worked well and provided useful and usable suggestions to the user. We plan to quantify these results on real-time websites in the future.

The tool can be helpful to a wide variety of internet users. For example, it can be useful for visually-impaired people when augmented with text-to-speech facility. We predict that people having memory problems and new internet users can also benefit from the tool. In future, we plan to validate the tool support for these use cases. Further questions to be examined are: what happens when a set of related websites is used, and also when the model fails, in the sense that no solution to the search goal is found; what feedback should be given to the user, and so on. We will address these questions in our further studies. Overall, we claim that making use of a cognitive model for navigation support is a promising research area.

6. REFERENCES


Following is our algorithm for the navigation-support tool:

1. Take the User goal and website url as inputs (level n=0)
2. Extract all hyperlinks of the website url
   a. If the hyperlink does not have any text (when the hyperlink is on a picture or on a flash-based object), then the url of the hyperlink [page name: last word of the url] shall be elaborated along with the semantic features of the picture.
   b. Elaborations are done using LSA near-neighbor analysis. Minimum frequency and minimum cosine value are kept as 50 and 0.5 respectively.
3. User goal versus hyperlink and picture features elaborations: LSA computation is done using the online website [23]. If the similarity measure of a hyperlink is > 0.8 times the highest similarity measure, then it is also considered as a prediction by the model.
   a. If more than one hyperlink have the maximum LSA value (nearly the same), Path Adequacy needs to be taken into consideration. Go to step 4.a
   b. If LSA value is very low for all the hyperlinks (threshold value 0.2) backtracking need to be done. Go to step 4.b
   c. If LSA value is not increased (compared to the previous LSA when repeated through step 5) then Path Adequacy need to be calculated. If Path Adequacy is also not increased, needs to backtrack. Go to step 4.
4. Path Adequacy computation: User goal versus hyperlink elaborations, picture feature elaborations and previous path(s) [hyperlink text and picture elaborations]: Perform LSA computations. If the similarity measure of a hyperlink is > 0.8 times the highest similarity measure, then it is considered as a prediction by the model.
   a. The link that increases Path Adequacy is considered for selection. If there are multiple candidates, the link with highest LSA value (computed in step 3) is selected.
   b. If no link increases path adequacy then an impass occurs, and backtracking is done (Now level n = n-1). Go to step 2 with URL at n-1 level. If n-1=0 this implies no path for user goal. Backtracking should be restricted to path-x (where x=2) only.
5. The user is provided with the suggestion (which link to click) and asked if this achieved his or her goal.
6. If user has not yet found the requested information - Steps 2 to 5 are repeated given user goal and URL of the link provided in step 5. Now level n= n+1.

Output: Adequate path(s) to reach the user goal.