Proceedings of the Annual Meeting of the Cognitive Science Society

Title

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Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 27(27)

ISSN

1069-7977

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Publication Date

2005

Peer reviewed

Toward Modeling Contextual Information in Web Navigation

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Abstract

Existing cognitive models of web navigation mainly address the process of assessing relevance ('information scent') of screen objects to user's goals. Recent research shows that users decisions are based not only on the assessed relevance of the currently available screen objects, but also on relevance of objects that were encountered in earlier steps of the navigation session. We propose the concept of 'path adequacy', that is the semantic relevance of a navigation path, to be used in augmenting an existing cognitive model of web navigation. It is argued, based on theories and models of text comprehension, that path adequacy models the role of contextual information in assessing the relevance of incoming information. Then, we show that the augmented model is able to simulate some aspects of task execution and generate navigation support. The generated navigation support had a positive impact on users' performance in realistic web navigation tasks. Finally, some aspects regarding the validity of the proposed model and its practical relevance are discussed.

Introduction

Several attempts to model cognitive processes involved in web navigation are based on the assessed semantic relevance of screen objects to users' goals ('information scent') (Kitajima, Blackmon, & Polson, 2000; Pirolli & Fu, 2003). In a previous study we found out that not only semantic but also spatial processes are employed in web navigation tasks (Juvina & van Oostendorp, 2004). Based on this and also on other findings (Chen, 2000; Howes, Payne, & Richardson, 2002; Wen, 2003), we assume that assessing relevance of a particular screen object to user's goal depends not only on user's knowledge about that particular screen object but also on the contexts of a navigation session, i.e. what has been done up to that moment, where the current position is represented in the information space, how close to the target the user perceives herself etc. In this study, we argue for considering 'path adequacy', that is the relevance of a navigation path to the user's goal, beside 'information scent', in modeling web navigation. This would be a first step in modeling the role of contextual information in selecting specific navigation actions.

The next section introduces the model of web navigation that we propose, its cognitive grounds and practical relevance. Then a study is described, which attempted at validating the model and examining its practical relevance. Results of this study are commented and further developments of the model are suggested.

Cognitive Models of Web Navigation

There are various approaches in cognitive modeling of web navigation behavior. Pirolli and Fu (2003) developed SNIF-ACT (Scent-based Navigation and Information Foraging in the ACT architecture), a computational cognitive model that simulates users performing web tasks. Their model predicts navigational choices, i.e., where to go next and when to stop (leave the website) based on the concept of information scent. Information scent is calculated as a mutual relevance between the user's goal and link texts based on word occurrences and co-occurrences in the Internet. Kitajima, Blackmon, and Polson (2000) introduced CoLiDeS – a *Co*mprehension-based *Li*nked model of *De*liberate *S*earch. CoLiDeS measures relatedness of a particular screen object to the user's goal (information scent) based on three factors: semantic similarity, frequency and literal matching. Semantic similarity is calculated based on co-occurrences between words and documents with the aid of an algorithm called Latent Semantic Analysis (LSA). Miller and Remington (2004) model the common situation in which link labels are not fully descriptive for their targets or users are not knowledgeable enough to accurately assess the relevance of link descriptions to their goals. Their model, called MESA (Method for Evaluating Site Architectures), does not give an account for how link relevancies are assessed, but takes them as input. It rather focuses on effectiveness of various link selection strategies, given various link relevancies and site structures.

CoLiDeS+

We have made few amendments to an existing cognitive model of web navigation, namely CoLiDeS (Kitajima, Blackmon, & Polson, 2000), and we have conducted a study to refine the model and check its validity. The altered model has been labeled CoLiDeS+, to indicate that it is a working version, shares the main assumptions with the original CoLiDeS, and is intended to eventually be an augmented model.

CoLiDeS compares the user's goal with link texts on web pages using Latent Semantic Analysis and selects the link that best matches the user's goal. The selected link is clicked on and the process of judging link relevance (information scent) and selecting a link is repeated until the user's goal is attained or the user gives up. CoLiDeS+ brings in the concept of "path adequacy" as a complement to the concept of "information scent". Path adequacy is the semantic similarity between a navigation path and a user's goal. A navigation path is a succession of links that have been selected prior to a particular moment in a navigation session. A high similarity means that the path is likely to lead toward the targeted item. Previous research found significant positive correlations between path adequacy, spatial ability and task success, respectively (Juvina & van Oostendorp, 2004). Path adequacy and information scent are both calculated based on semantic similarity, although they model different aspects: information scent models the value of incoming information and path adequacy models the value of past selections. Users are assumed to base their selections based not only on goal-relevance of incoming information but also on whether a candidate selection is consistent with past selections or not. Therefore, in CoLiDeS+ selecting a link on a specific web page is a function of goal description, link description and path description.

CoLiDeS models mainly the ideal situation of forward linear navigation; backtracking steps are considered erratic actions. When no particular object on the current page sufficiently matches the user's goal, an impasse is said to have occurred. Solutions to impasses are only described and not computationally modeled by Kitajima, Blackmon and Polson (2000). However, backtracking and impasses seem to be natural in web navigation and rather frequent (Cockburn & McKenzie, 2001; Wen, 2003). Therefore they need to be modeled within the same framework as forward linear navigation. Miller and Remington (2004) propose navigation strategies to deal with ambiguity of link labels or with users' errors in judging link relevance.

CoLiDeS+ tries to incorporate navigation strategies. First, it maintains a developing representation of the information space being navigated and it remembers past selections. Then it tries to prevent impasses by checking at each step for latent impasses based on path adequacy. A latent impasse occurs when path adequacy does not increase after selecting a link and it is a possible reason to switch the path. It is called latent because it only signals a possible path switch and it causes considering concurrent paths. If a concurrent path with a better adequacy is found, the current path is switched toward the concurrent one. If impasses still occur, CoLiDeS+ reacts with a strategy that we called "next best" and it is to some extent similar with the opportunistic strategy of Miller and Remington (2004). "Next best" means that not only the link with the highest similarity to the user's goal is considered but also links with lower similarities provided that they contribute to an increase in path adequacy. And eventually the options of backtracking one or more pages or going to index pages are available.

A short description of the algorithm used by CoLiDeS+, presented below, shows how task execution is simulated and how the concept of path adequacy is considered in addition to link relevance (see also figure 1):

- A task description is taken as input and assumed to be equivalent to the user's goal.
- A web page is attended to, parsed in several areas, and a particular area is focused on (e.g. a menu).
- Menu entries are comprehended (based on how semantically similar to the user's goal they are) and one entry (the one that is most relevant to the user's goal) is selected and acted on (e.g. clicked on).
- A new page is attended to and if the target information cannot be found, the cycle is reinitialized.
- The selected element is retained in a memory structure that maintains user's navigation paths.

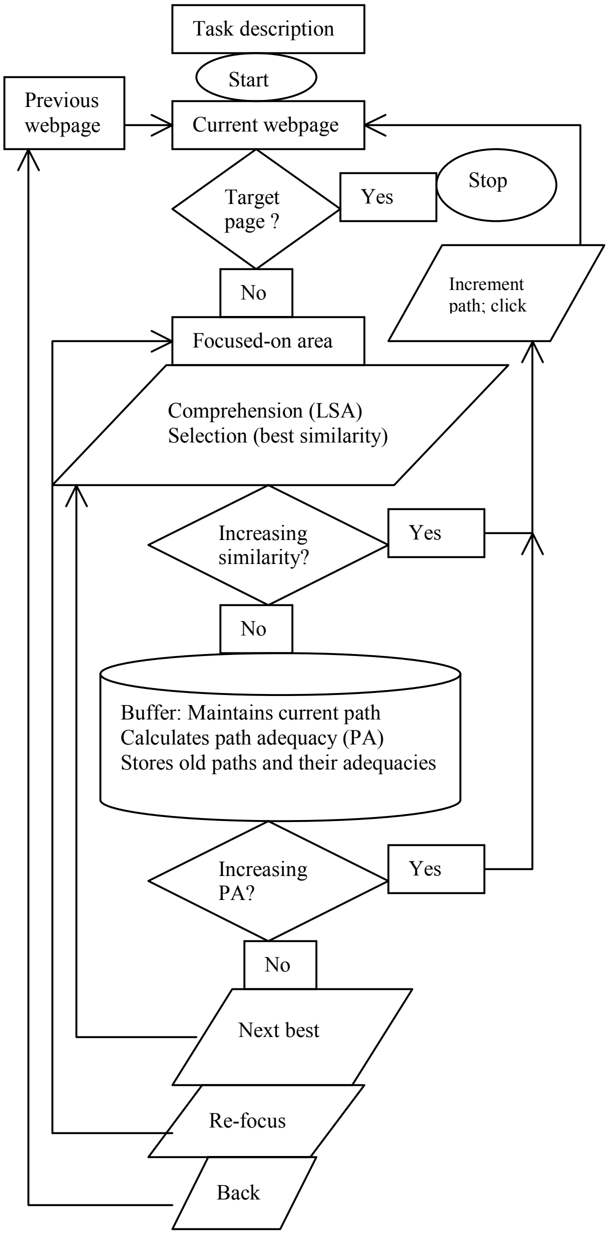

Figure 1. A simplified diagram of the algorithm that implements the CoLiDeS+ model

- Starting with the second cycle, a navigation path is available to be taken into consideration when screen objects are checked for their goal relevance. A metric called *path adequacy* is calculated as a semantic similarity between a path and the user's goal. Selections of screen objects to be acted on are made if they contribute to an increase in path adequacy.

- Otherwise an impasse is declared and dealt with by considering "next best" options, changing the focused-on area and backtracking.
- If the focused-on area happens to be a search engine, keywords are generated by the LSA *nearest neighbors* module (terms that are semantically most similar to the user's goal), and the engine's results page is treated as any other web page.
- The algorithm stops when the current page contains the target information.

Cognitive grounds. CoLiDeS is based on a text comprehension theory; a similarity in basic principles is assumed between the process of reading a text and navigating through an information space. We maintain the analogy between text comprehension and web navigation but specify some particular aspects of the latter.

As the reader proceeds through a text, s/he constructs an episodic memory representation of the incoming information and uses background knowledge from semantic memory (van den Broek, Rapp & Kendeou, 2005). Since human attentional resources are limited, only a small part of the reader's memory is active at a given moment, i.e. only a small amount of knowledge resources can be employed in current processing. What determines which concepts are activated? According to the authors of *the Landscape model of reading* (van den Broek, Young, Tzeng & Linderholm, 1999) there are several sources of activation: the text element that is currently being processed, the preceding recently processed knowledge, the knowledge processed in earlier phases of a reading session, and the reader's background knowledge. Since the web navigation tasks that we modeled are goal-directed, we consider the user's goal as the primary source of activation. Thus, in CoLiDeS+, information can be actively involved in current processing because: (1) it is the current goal, (2) it is attended to (incoming text elements), (3) it has some residual activation carried over from previous cycles of processing (previously encountered text elements), (4) it is required for understanding of current information, and (5) it is strongly associated with an already active knowledge element.

Existing models of cognition (e.g. ACT-R, Landscape) assume that concepts can be activated to different degrees. CoLiDeS+ has not yet a complete implementation of this assumption. It only gives priority ranks to various sources of activation and this results in some sources of activation having a bigger influence than others. For instance, user's goal is more important as a source of activation than information previously encountered. The attended text element is first assessed in the view of user's goal. Only when the result of this assessment is not straight forward previously attended text elements come into play to disambiguate the relationship between the current text element and the user's goal. This ranking mechanism can also give a simple account for decay effects. Thus, background knowledge and previously encountered information is likely to have less influence than the currently attended information on the current processing. Our particular ranking of various sources of activation is tailored to the type of tasks we are simulating. In a web based information search task, already encountered information has been assessed as partly useful or useless. We only use selected text elements, so they were judged as having some relevance, but the most relevant elements are not there yet, and are expected to be found in the incoming information. This is why incoming information has received a higher rank as an activation source.

As mentioned in the text comprehension literature, readers sometimes import concepts that are not mentioned in the current sentence. Employing background knowledge from user's long term memory in the current processing happens either because there is an explicit need for that knowledge or the prior knowledge is strongly associated with the current knowledge (van den Broek, Rapp & Kendeou, 2005). In web navigation the role of domain expertise (prior knowledge and experience) has been empirically established (e.g. Juvina & van Oostendorp, 2004). CoLiDeS uses a LSA semantic space to model user's knowledge representation. A particular semantic space (corresponding to a particular user population) is used to represent concepts and relationships between them (semantic similarities). Based on this representation, a text element can be "comprehended", i.e. it is possible to specify the concepts of the semantic space that are most associated with it.

An LSA semantic space is not a perfect model of user's background knowledge but it is useful in building computational models (Kintsch 1998). LSA allows an objective estimation of the strength of association between knowledge elements; this estimation is essential in calculating the amount of activation that is spread between various knowledge elements. CoLiDeS+ relies crucially on a knowledge representation that allows comprehension of incoming information. An attended text element (e.g. a link label) is represented in the semantic space and it can be computed if the current link label is semantically connected to the current goal. If the connection is not strong enough, the processor employs contextual information, i.e. text elements that have been previously attended to and selected (navigation path). The semantic space allows determining if the new text element is connected to the previous information that has been selected. If this is the case the current text element receives an extra activation from the path elements and contributes itself to the *cohort activation* (van den Broek, Rapp & Kendeou, 2005) of the whole new path (including the new element). The new path as a whole can now be stronger related to the goal (*path adequacy* is higher) than the old path. If this is the case, the new element is integrated in the path and (if the goal is not fully attained) the user proceeds further to attend to new information. If the added element makes the path less connected to the goal, it is rejected, and other options are considered. The semantic space provides a reference frame to represent all of these connections and to estimate their strength.

Practical relevance. CoLiDeS has been used to identify and repair web usability problems (Blackmon, Kitajima & Polson, 2003). With the amendments proposed here and with future improvements, such a model could be used in supporting navigating users more actively and in real time. A cognitive model could be running few steps ahead and prompt the user with a reduced number of options that are likely to be relevant for the task at hand. For some categories of users suggesting relevant actions to users could be essential for a satisfactory web experience. For example, blind users access the web by the aid of "screen readers" – tools that read out loud the web content and options. Since using the web naturally involves revisits to certain pages (Cockburn & McKenzie, 2001), blind users would have to repeatedly listen to large amounts of menu options and contents. Therefore, tools are needed to assist users in selecting the relevant information. One of the solutions proposed by Di Blas, Paolini and Speroni (2004) is to bring in linguistic models, and we propose cognitive models to be brought in.

Experimental Setup

An empirical study examining the predictive and ecological validity of the CoLiDeS+ model was conducted. We hypothesized that CoLiDeS+ would be able to simulate real users navigation behavior and the navigation support generated based on simulations would have a positive influence on users navigation behavior and task performance. This positive influence was expected to be bigger for users with a deficit of spatial ability, since CoLiDeS+ took over the job of representing a complex information structure and remembering past selections.

Six realistic web tasks were built based on the collection of cases gathered by Morrison, Pirolli, and Card (2000) and indications of Kitajima, Blackmon, and Polson (2000) related to size and elaboration of task descriptions. Each task had an associated web site.

The six tasks were simulated with CoLiDeS+ prior to the actual navigation sessions. The results of simulations were successful paths, i.e. successions of links leading to the target pages, and "dead-ends", i.e. pages that are not linked with target pages, making it necessary for the user to backtrack. Based on these results of the simulations, two types of suggestions were generated: link suggestions – when a link contained in a successful path was visible on the screen, the user received the suggestion *Click on* <link label>; path switch suggestions – when a 'dead-end' page was downloaded, the user got the suggestion *Go back*.

Participants (students, sufficient web experience, non-domain and non-internet experts) were randomly assigned to two conditions: a control condition in which 15 participants had to perform as many of the six tasks as possible in 45 minutes, and a 'support' condition in which 14 participants did the same while receiving the generated navigation support (suggestions). These participants were instructed in advance that suggestions were generated by a robot, they were meant to help with task execution, and they were not mandatory: participants could follow them or not at their discretion. Suggestions were provided in the auditory modality. This way of delivering navigation support can be implemented in combination with screen readers for improving the web access of visually impaired users.

Solutions to tasks were reported on paper by the participants and evaluated afterwards for correctness. The average duration of tasks per participant was calculated by dividing the total navigation time (45 minutes) to the number of tasks attempted. An overall estimate of task performance was calculated by dividing the total correctness score to the average duration of tasks. The natural logarithm of this ratio was taken to correct for a skewed distribution. Participants' spatial ability was tested with a mental rotation task (Juvina & van Oostendorp, 2004). Navigation actions of participants were automatically recorded with a web logging software (Scone).

Results

The first outcome was that CoLiDeS+ was able to generate successful paths and "dead ends". However, the way it navigated the websites was not as straight and forward as suggested by Kitajima, Blackmon, and Polson (2000). It made extensive use of 'next best' trials, refocusing, and backtracking. The number of steps to solutions was even higher than the actual users took. In general, the model took different decisions than the actual users did, but, due to the mechanisms of solving impasses, the correct paths and dead-ends were correctly identified. The main explanation for the differences between the model and the actual users is the weakness of the LSA technique. The "general reading" semantic space available at http://lsa.colorado.edu was used. Perhaps a more specialized semantic space would have given better results. These results show that LSA is limited as a tool to model user's relevance assessments. However this limitation exists for users as well. This is why contextual information and navigation strategies to deal with impasses are needed.

Providing navigation support made a significant difference in users' navigation behavior and task performance. The number of navigation steps was lower in the support condition than in the control condition ($t=3.86$; $p=0.001$). It took an average of 30 steps to execute a task in the control condition and only 19 steps in the support condition. The average duration of tasks was shorter in the support condition than in the control condition ($t=2.16$; $p=0.039$). It took an average of 10.26 minutes to complete a task in the support condition and 12.49 minutes in the control condition. Task performance was significantly higher in the support condition (mean=1.16) than in the control condition (mean=0.68) ($t=2.16$; $p=0.04$).

As expected, the correlation between spatial ability and task performance was significant for the control condition ($r=0.64$; $p=0.01$) and not significant for the support condition ($r=0.15$; $p=0.60$). Participants were divided in two groups with high and low spatial abilities (the median of test scores was taken as a cutting point). The difference in task performance induced by navigation support was checked separately for low and high spatial ability participants. Results are depicted in figure 2. One can see that the difference induced by the navigation support is bigger for participants with low spatial ability (t=2.27; p=0.044) than for participants with high spatial ability (t=0.73; p=0.48).

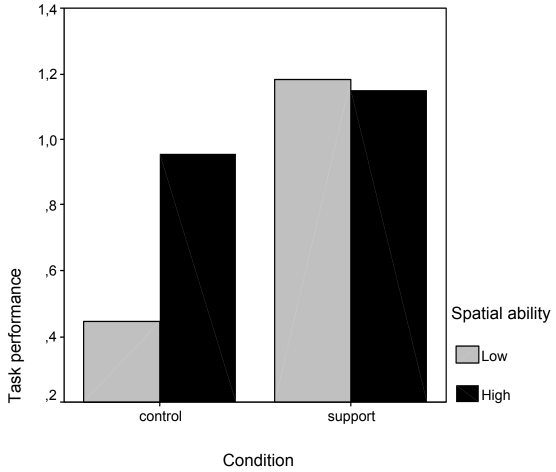

Figure 2. The effect of providing navigation support on task performance for users with low and high spatial ability

Conclusions

The technique used by CoLiDeS+ to model user's assessments of relevance (LSA) was rather weak, i.e., it modeled a rather bad assessor. For instance, the similarity between *hotel* and *sleep* (0.24) was lower than the similarity between *hotel* and *wait* (0.34). This is why CoLiDeS+ had to make extensive use (more than actual users) of its mechanisms of preventing and dealing with impasses before finding solutions. These mechanisms were based on path adequacy – a measure of contextual information involved in user navigation. This result shows that using contextual information as a complement of judging semantic relevance of incoming information is essential for users' success in web navigation tasks.

When CoLiDeS+ simulations were offered as navigation support, users performed the given tasks in fewer steps, faster and with better results. It seems that the offered navigation support prevented users to spend time and cognitive resources with those kinds of navigating actions that are not directly effective but are usually employed in order to accurately represent the information structure (exploring how information nodes are linked and where the relevant information is placed). As other researchers have found (Cockburn & McKenzie, 2001; Howes, Payne, & Richardson, 2002; Wen, 2003), real users do engage in seemingly useless navigation actions in order to get acquainted with the context of a particular piece of information, which is eventually useful in judging the value of that particular information. By making use of path adequacy CoLiDeS+ gives an account for this type of behavior.

The correlation between spatial ability and task performance was once more replicated in this study. It indicates that users' ability to mentally represent and manipulate information spaces is crucial for web navigation tasks. However, when provided with the kind of navigation support that CoLiDeS+ generated, users' performance did not depend any more on their spatial abilities. Users with low spatial abilities had a higher performance increase due to navigation support than users with high spatial abilities. Since in a previous study (Juvina & van Oostendorp, 2004) we found a positive correlation between spatial ability and path adequacy, we decided to include the navigation path in the CoLiDeS model, and we expected the new model to account to some extent for spatial cognition involved in web navigation. This expectation was confirmed. Users with low spatial abilities are probably less able to represent the information space and remember past selections and this is why they benefit considerably when the cognitive model is doing this job for them. We consider this result to be an additional proof that CoLiDeS+ gives an account not only for the process of assessing relevance of screen objects to users' goals but also for the ability of users to represent and manipulate an information space.

A cognitive model running few steps ahead and providing users as they navigate with filtered information relevant to their goals has various possibilities of application. We have suggested the use of such a model together with screen readers for improving the web experience of visually impaired users. In fact such a model can be used whenever users' cognitive or perceptive limitations interacts with information overload. The model takes over part of the user's burden in representing and processing information.

Search engines use a different approach: they try to find target pages and return them to the user. Target pages are identified by their title, URL, and a short description. In contrast, the model-based navigation support that we propose prompts the user with possible ways to reach her target by following the existing links on the web page that she is currently inspecting. Information is left in its initial context and the users natural way to look for information (Pirolli & Card, 1999) is preserved.

Discussion and further developments

CoLiDeS+ is a process model of web navigation, which describes the step-by-step process by which information presented on the screen is attended to and processed in order to perform various types of web tasks. It is originated in established theories and models of text comprehension.

The Construction - Integration theory of text comprehension (Kintsch, 1998) postulates a construction phase in which a mental representation is constructed from textual input, reader's goals and prior knowledge, and an integration phase which establishes coherence of the constructed representation. Construction is local (context-free) whereas integration is global (context-dependent). Human comprehension is regarded as a top-down and bottom-up process (Kintsch, 2005). CoLiDeS (the original source of CoLiDeS+) only implements a top-down feature: assessing an incoming text element in the view of user's goal. By adding contextual information we made the model more consistent with its theoretical assumptions. Contextual information is essential in comprehension of particular text elements especially for text elements with equivocal or metaphorical meaning. Lack of supportive sentence context may lead to fast reading but poor comprehension (Budiu and Anderson, 2004). In web navigation, contextual information allows users to build a representation of the information space that is being navigated and this representation, in turn, supports locating and integrating relevant pieces of information.

Link labels have various degrees of ambiguity (due to either bad design or user's comprehension limits). Users are generally able to disambiguate an ambiguous term by integrating it in context (Kintsch, 1998). Budiu and Anderson (2004) demonstrated that when a word seems inappropriate, a rich sentence context can help people grasp the intended meaning of that word.

Using a LSA semantic space instead of a propositional representation is beneficial since it allows automation. However, a LSA semantic space is only an approximation of a user's background knowledge and it makes the model less accurate in details. We believe though that the model remains valid in general principles, since LSA only models the sub-symbolic part of CoLiDeS+, i.e. the strengths of associations between concepts. We have shown that the model is able to give an indirect account for spatial cognition, user behavior and task performance. The fact that LSA models a bad assessor does not affect the validity of the symbolic part of CoLiDeS+ (navigation rules and strategies). However, a better way to represent user knowledge should be employed in the next versions.

So far in our simulations we have used the whole path from the beginning of the task to the current step. This was justified by the fact that the number of steps to solutions was rather small. However, there are theoretical and empirical reasons for limiting the amount of elements that are active at a particular moment. In text comprehension, it is estimated that one sentence is carried over to the next cycle (Kintsch, 1998). Other approaches limit the total amount of available activation rather than the number of elements. We will try to identify meaningful segments in a navigation path which could be based on path switches.

In the current version, all the previously selected text elements are taken into account with an equal weight. Differentiation based on recency or frequency were not considered necessary since paths were rather short and repetition of a link label in a path is a rather rare event. However, an appropriate decay mechanism needs to be implemented if more complex tasks are modeled.

CoLiDeS+ was conceived with the aim of building model-based navigation support. For this reason, some of the methodological criteria of cognitive modeling are (at least at this stage) relaxed. The simulation of user behavior is not complete. For example, the model does not have a mechanism to identify target content pages. Such a mechanism would be extremely difficult to build and it is not really necessary for our intended use of the model. The model is meant to work alongside the user and suggest links that are – according to its "judgment" – relevant to a given goal. The user is free to take these suggestions or not. If a target page has been attained the user would presumably recognize it without any intervention of the model.

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