A Comprehension-based Model of Web Navigation and Its Application to Web Usability Analysis

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CoLiDeS, a comprehension-based cognitive model of Web navigation, offers a theoretical explanation of the impasses users often encounter during information search and retrieval from the WWW, and also identifies the determinants of success cases. In this model, acting on a single Web page screen object is regarded as the outcome of a multi-step process:

- **parsing the current display containing up to about 200 screen objects into five to ten top-level schematic objects;**
- **focusing on one of these top-level schematic objects;**
- **comprehending and elaborating the screen objects within the focused-on area; and then**

- **selecting one of the actual screen objects as the target for the next action, the object whose representation bears the highest degree of semantic similarity to the user's goal.**

Keywords: Web navigation, usability, comprehension-based cognitive model, information retrieval, semantic similarity, scent, hierarchical site structure, attention management, action planning, forward search, impasse.

1 Introduction

According to published findings, users find typical Web navigation tasks to be very difficult and have low success rates, even when they are first taken to a particular Web site containing the information sought (Spool et al., 1999). The pragmatic goal of our research program is to improve users' success rates in finding information on typical Web sites. To accomplish that goal we are currently engaged in a three-prong research program:

- developing a theoretical model;
- conducting extensive empirical testing of the model, combining controlled laboratory research and usability testing of real-world Web sites; and
- building tools and tutorials for Web site developers.

Due to space limitations, this paper will focus on describing the theoretical model, a comprehension-based, simulation model of Web site navigation derived from earlier models of Kitajima & Polson (1995; 1997). Our strategy in this paper is to highlight the ingredients of success, providing integrated, detailed explanations of what is known about the attributes of Web pages that support successful navigation.

We plan to ultimately build a theoretically based design methodology practical enough for Web site developers to put to wide use (Wharton et al., 1994), but even now developers will find valuable uses for our model. Empirical results (Larson & Czerwinski, 1998) and guidelines summarising successful design practice and usability research findings (see http://www.useit.com/alertbox/ — last accessed 2000.06.10) typically focus on one attribute of a site design at a time and may be contradictory when applied to particular site designs. A theoretical model can be a powerful tool for mediating such tradeoffs by showing how two or more attributes interact to determine usability of a Web page, collection of pages, or Web site. A model can also be a powerful tool for reasoning about design decisions for which there are no relevant empirical data or guidelines.

The key claim of the model presented in this paper is that comprehension of texts and images is the core process underlying Web navigation. Comprehension processes build and compare the mental representations of screen objects on a Web page in preparation for selecting and clicking one particular hyperlink or image. The primary assumption of the model is that users act on the hyperlink, image, or other screen object they perceive as being most similar to the representation of their current goal. By similarity we mean semantic similarity — similarity of meaning.

2 The CoLiDeS Model

The model we have developed to understand cognitive processes of users navigating the Web is called CoLiDeS, an acronym for *Co*mprehension-based *Li*nked model of *De*liberate *S*earch. CoLiDeS extends a series of earlier models developed by Kitajima & Polson (1995; 1997) and the entire series of models is based on Kintsch's construction-integration theory of text comprehension (Kintsch, 1998). Previous models in the series simulated both performing/learning by exploration (Kitajima & Polson, 1997) and skilled use in complex applications hosted on systems with graphical user interfaces (Kitajima & Polson, 1995). CoLiDeS shares with its predecessors assumptions about the underlying cognitive architecture, comprehension processes, and action planning processes.

All models in the series, CoLiDeS included, are based on the claim that both exploration and skilled use involve serious problems of attention management. In contrast to previous models in the series, CoLiDeS incorporates more complete and realistic attention management mechanisms. These attention management mechanisms provide a principled explanation of how the user focuses on a subset of the screen objects and selects one screen object (e.g. a pull-down menu or hypertext link) on a Web page.

The four cognitive processes most central to the CoLiDeS model are *parsing*, *focusing on*, *comprehension*, and *selection*. Section 2.1 explains how *parsing* builds mental representations of Web pages. Section 2.2 portrays how *selecting* the next action depends upon *comprehension* of a set of screen objects. As Section 2.3 shows, *focusing on* a subset of the screen objects on a Web page guides both the comprehension and action selection processes. Section 2.4 examines patterns in the entire sequence of actions — the entire click stream — selected by a particular user to accomplish her goal.

2.1 Representation of the Screen Objects on Web Pages

CoLiDeS assumes that each object on the screen — action graphic, iconic link, hypertext link, navigation bar item, or paragraph, for example — is represented as a screen object if it is a meaningful unit and/or a target for action. A Web page can contain from 100 to 200 screen objects competing for a user's attention. Users manage this complexity by scanning and constructing a schematic representation of a page that contains from 5 to 10 top-level schematic objects — referred to here as 'parsing the page'.[*] Parsing the page into top-level schematic objects is critical to avoiding getting lost in the complexity of a Web page.

A mixture of bottom-up and top-down processes determines the collection of schematic objects defined by a page. Bottom-up processes utilize low-level perceptual features that guide how the user parses the Web page into visually related regions. Top-down processes are controlled by a user's knowledge of the conventional elements of a typical page for a given Web site or type of Web site

[*] Tullis (1998) used nine standard elements that appeared on each page when he worked on redesigning the Internet at Fidelity Investments. The number we describe in the paper is an approximate value that we derived from his experience and from the similarity of his nine standard elements to the conventional page elements defined by best-practice guides to Web site design. The number is also in accord with the number of items that can be held in working memory, classically estimated at seven plus or minus two.

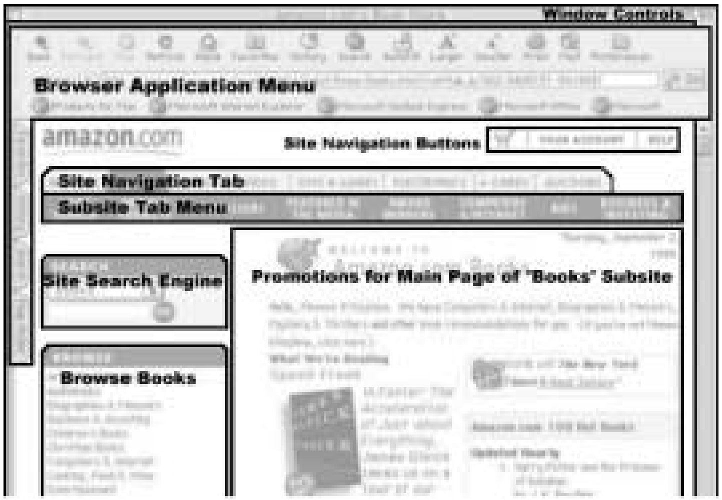

Figure 1: An example of standard elements for on-line bookstores.

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and by the user's knowledge of print conventions that enable the user to scan the configuration of heading texts to identify meaning-related units. Consistent or enforced interface conventions enable users to quickly grasp an accurate schematic representation for individual pages in a Web site (Tullis, 1998). Frequent Web users can assume the existence of many top-level schematic objects, such as site and subsite navigation bars, browser application menus and window controls, site search engine, and advertising banners and promotions.

Each top-level schematic object encompasses a cluster of screen objects. The top-level parsing always employs schematic objects for its representation. Each schematic object can be regarded as a conceptual label that distinguishes it from the remaining regions on the page. Each top-level schematic object, in turn, contains a collection of lower-level schematic objects and/or actual objects. Examples of actual objects include text links, navigation buttons and other image links, text discourse communicating content, brief texts used for banners, and images, such as a site logo or images of products for sale.

Figure 1 shows how a frequent user of a particular online bookstore might parse its home page by applying both knowledge-driven top-down processes and perception-driven bottom-up processes. The user would be apt to identify such schematic objects as window controls and the browser menu, because such features are consistently present in any Web browser application familiar to the user. Another easily identifiable area is the interactive window for the site search engine. Experienced users will probably define a browse area containing a list of related links, for example, the area labelled 'Browse Books' in Figure 1.

Such site-specific areas as site navigation buttons and a site navigation tab consistently appear at the same position on every page of this particular Web site, as shown in Figure 1. The site navigation tab conjointly displays both an upper menu of sub-sites and a lower menu with crucial navigation options for one particular sub-site or for the site home page. Users familiar with e-commerce sites will also tend to distinguish a promotion area encompassing an assortment of featured products the business hopes the customer will buy. In Figure 1, the site navigation tab area, a schematic object, contains only actual screen objects, text links with the labels WELCOME, BOOKS, etc. In contrast, the promotion area contains both another level of schematic objects — more specific promotion areas — and an assortment of actual objects — text links.

2.2 Action Planning Processes Guided by User's Goal

This section describes the comprehension process and the selection process applied to a given set of alternative objects. This set of objects can be a set of schematic objects, as illustrated by the superimposed labels of Figure 1, or they can be a set of actual screen objects, as shown by the hyperlinks nested under 'Browse Books' in Figure 1. Kitajima & Polson (1995; 1997) have defined the comprehension and selection processes. Elaboration plays a central role in the comprehension process by extracting information from the user's long-term memory store of knowledge to augment the representations of the goal and the set of objects. The user then selects the next action on the basis of the elaborated representations.

2.2.1 Elaboration of Goal, Schematic Objects, and Actual Objects

To plan the next action the user must comprehend and compare what the probable consequences would be for selecting various screen objects as candidates for action. To decide how selecting any given screen object might contribute to accomplishing the user's current goal, the user elaborates candidate objects. The user interprets the intended meaning of screen objects and their associated texts by relying on the extensive amount of knowledge in long-term memory (LTM), which stores both domain knowledge and knowledge of interface conventions.

The elaboration process can be applied to the current goal as well as to schematic/actual screen objects, as the following examples clarify:

Elaborate goal: The concise goal representation, *browse books on chaos theory*, might be elaborated with a subgoal in a richer representation, such as *browse books on chaos theory by [the subgoal of] selecting a link that matches chaos theory, which is a mathematical formalism for describing complex indeterminate physical systems.*

Elaborate schematic object: Similarly, the schematic object 'Button Bar' in the Browser Application Menu might be represented after elaboration as a series of buttons for controlling various display properties, such as fonts, size, and style. The ability to elaborate this schematic object comes from knowledge acquired from experience with typical button bars in browser applications and/or other computer applications.

Elaborate actual object: In the same vein, the user could elaborate the actual object represented by the image  with the word 'Larger' printed beneath it, constructing the elaborated representation "a button which can be clicked to enlarge the size of the font displayed in the browser window by one unit". The elaboration of the intended meaning comes from knowledge associated with the interface convention combined with the semantic meaning of the image  joined with the word 'Larger' printed under the image.

2.2.2 *Selection by Constraint Satisfaction*

Each of the elaborated schematic/actual objects is related to some degree with the elaborated goal. Furnas (1997) and Pirolli & Card (1999) use the term *scent* to describe the degree of relatedness. This metaphor evokes the image of a user searching for information by following a trail, repeatedly pursuing whatever object currently provides the highest degree of scent. In the CoLiDeS model three independent factors interplay conjunctively to define the degree of relatedness:

- The degree of similarity between the elaborated object's representation and the elaborated goal.
- The frequency with which the user has encountered a particular object on a particular navigation path.
- Whether the representation of the unelaborated current goal has a literal matching with the actual object.

CoLiDeS assumes that the competition among the objects based on these three factors be resolved by the constraint satisfaction process incorporated into Kintsch's (1998) construction-integration architecture. Each schematic/actual object is related to the current goal in degree of similarity, frequency, and literal matching. Each screen object is also related to each of the other screen objects in degree of similarity, frequency, and literal matching. Thus, when the selection is performed there exists a very complicated network of relationships with multiple measures of relatedness. The constraint satisfaction process deals with the competition among the various degrees of relatedness, enabling the user to single out the objects closest to the user's current goal.

Similarity: The model assumes that the degree of similarity between schematic or actual objects and the current goal is defined by their distance in a semantic space. We use Latent Semantic Analysis (LSA) to compute the degree of similarity within a particular semantic space. As Landauer & Dumais (1997) explain, LSA is a data analysis technique that generates a high dimensional space, typically a space with about 300 dimensions. LSA applies singular value decomposition, a mathematical procedure similar to factor analysis, to a huge terms-by-documents co-occurrence matrix. Each word can be represented as a vector in the 300-dimensional space.

The vector of each word varies according to the knowledge of the user, and the LSA Web site, http://lsa.colorado.edu/, currently offers a variety of LSA semantic spaces, most importantly an encyclopaedia space and five spaces representing the general reading knowledge typical of users in grades 3, 6, 9, 12 or first-year college. These grade-defined spaces are constructed by incorporating the appropriate texts from the Touchstone Applied Science Associates, Inc. (TASA) corpus, which provides a variety of texts, novels, newspaper articles, and other information that has typically been read by students who have attained these age-grade levels.

In LSA analyses any cluster of terms is represented as a linear combination of the constituent vectors. The degree of semantic relatedness between two terms or documents is measured by the cosine value between the corresponding two vectors. Cosines are analogous to correlations. Each cosine value lies somewhere between +1 (identical) and -1 (opposite), and near-zero values are unrelated. By using LSA, it is possible to measure the relationship between the representation of a user's goal and the representation of each screen object.

Frequency: The model assumes that the screen elements on frequently navigated paths are more likely to be selected. For example, a frequent user of Web sites with site navigation tab menus would have a propensity to navigate a Web site using the site tab menu. Analogously, a person who had often used site search engines would be more apt to focus on the search window than someone who had previously located information primarily by browsing.

Literal Matching: When the representation of the current goal literally matches the representation of the schematic or actual object, partially or completely, the number of matches is counted when selecting an object from the screen.

2.3 Attention Management Mechanisms

CoLiDeS assumes that attention management mechanisms are crucial for guiding the user toward acting on a particular screen object. Immediately after being transported to a new Web page, the user parses the page, generates a schematic representation of the display — illustrated by the collection of top-level schematic objects in Figure 1. A particular schematic object rapidly grabs the user's attention. If there are lower-level schematic objects nested under the *focussed-on* top-level schematic object, then the user parses the top-level schematic area as a representation of lower-level schematic objects. Then one of these lower-level schematic objects grabs the user's attention, making available the information in that area. By this point, if not before, the user is *focusing on* an area that contains actual objects, meaning screen objects on which the user can act. The user then comprehends and compares these actual objects in relation to the current goal and selects one object as a target for the next action.

If, for example, a user wants to enlarge the font size for the page, her attention must be successively drawn to a series of particular schematic/actual screen objects as follows:

- *Parse* the home page, representing it as 5–10 top-level schematic objects, and *focus on* the Browser Application Menu to make available the information contained in the area.

- *Parse* the Browser Application Menu area, consisting of multiple schematic objects — Tab Menu (vertical at left edge), Button Bar, Address Bar accompanied by a Go To Button, Status Bar, and Featured Sites Bar — and *focus on* Button Bar, a particular lower-level schematic object, to make available actual objects to act upon.

- *Comprehend* the set of button objects and *select/click* the button object with the image (intended to mean 'increase font size') with the clarifying text label 'Larger' printed beneath the image.

As shown in this simple example, the interplay of *focus on* with the other three processes is crucial to determining which screen object is acted upon. If the user first focuses on the Browser Application Menu and then on the Button Bar, the user is apt to accurately comprehend the consequences of clicking the '/Larger' button and select that action. At present CoLiDeS models both the *focus on* and *select* processes using constraint satisfaction to resolve competition among objects related by varying degrees of similarity (LSA cosines), frequency, and literal matching. The difference between the two processes is that *select* results after comprehending actual screen objects that are competing potential targets for action and *focus on* results after scanning and representing top-level schematic objects that compete for the user's attention.

2.4 Outcomes of Action Sequences

So far the discussion has been limited to analysing a single action at a time, a single click in the user's click stream. This section enlarges the perspective to the full sequence of actions, analysing patterns in the entire click stream required to accomplish the user's goal. Two prototype patterns can be distinguished. The first pattern is forward search, in which the user moves smoothly forward step by step towards the goal. The second pattern is an erratic navigation path, exhibiting backtracking to previously visited pages and/or detours resulting from confrontations with one or more impasses.

Forward search: This is an action sequence that avoids impasses. Obviously this is the ideal pattern Web site designers should aim to support, and CoLiDeS offers insights into how to increase the percentage of typical users who can accomplish their goals with forward search.

Impasses: Forward search can fail when no screen object is similar to the user's goal — no target of action is available that can satisfy the similarity, frequency, or literal matching measures. This situation presents an impasse that results in the user backtracking, taking detours, and becoming lost in the site. To resume forward search and move towards accomplishing her goal, the user must first find a way to solve the impasse.

An example of pure forward search is shown in Figure 2 and discussed in detail in Section 3.1. Causes of impasses and methods of solution are described in detail in Section 3.2.

3 Simulation of Web Navigation: Browse Books at Online Stores

In order to demonstrate how the CoLiDeS processes are performed, this section describes simulations of Web navigation by CoLiDeS. The task we consider is a task commonly performed by both frequent and novice Web users: browsing for a narrow class of items at an online shopping site. More specifically, the simulated task was locating and browsing books on chaos theory at online bookstores. The success case described in Section 3.1 was accomplished with flawless forward search. In contrast, Section 3.2 analyses impasses frequently confronted by users attempting the same or similar tasks at various e-commerce sites. The success case illustrates how CoLiDeS simulations can help designers gather evidence that a particular site design enables pure forward search for a sample of prototypical user goals. The analysis of impasses shows how useful CoLiDeS simulations can be for identifying usability problems on a particular Web site.

3.1 Success Case: Pure Forward Search

Figure 2 displays a CoLiDeS simulation that exemplifies pure forward search. For this simulation the user was assumed to be familiar with site navigation tabs and to have general reading knowledge equivalent to the average college freshman. In addition, the user is assumed to have previously acquired sufficient knowledge of chaos theory to construct the following well-elaborated subgoal for the goal of browsing books on chaos theory:

> I am searching for a link for chaos theory. Chaos theory is the hottest scientific theory since relativity, a new paradigm in the realm of mathematics, mathematicians' and scientists' breakthrough discovery of order in chaos, and a mathematical formalism for describing complex, indeterminate physical systems in complicated equations. Chaos theory overturns deterministic theories of classical physics, showing that systems obeying precise laws can behave in a random fashion, and showing the emergence of order from disorder and the generation of random patterns from chaos and uncertainty.

This goal was entered into the LSA analysis to compute the cosines displayed in steps 2.6 and 2.8 of Figure 2. These cosines measure the degree of similarity between the user's goal and the relevant text labels that appear on Web pages the user visited to complete the task.

Figure 2 outlines a ten-step trace (see steps 2.1 to 2.10 in Figure 2) of the simulation of the success case. The same two-part cycle is repeated five times during the simulation. Each cycle begins when a new Web page appears in the browser, and CoLiDeS parses the page into top-level schematic objects and focuses on one of the top-level schematic objects (odd-numbered steps). To complete the cycle CoLiDeS comprehends the set of actual screen objects nested within the top-level schematic object and selects the object that is semantically most similar or identical with the user goal (even-numbered steps). The action of selecting a link transports CoLiDeS to a new Web page and the start of a new cycle. For each step, the highlighted object is the one CoLiDeS has focused on or selected.

Figure 2: Simulation of 'Browse books on chaos' at Amazon.com.

3.2 When Forward Search Fails: Impasses and Their Solution

Impasses are commonly encountered while searching for information or products on the Web, and the difficulty of solving an impasse frequently results in the user abandoning the site without completing the task, yielding no sales for e-commerce sites and frustration for the user. This section will first describe how users try to cope with impasses and then analyse two distinct types of impasses. One type of impasse is due to inadequate scent for the target item on Web pages visited along the trail (Larson & Czerwinski, 1998; Pirolli & Card, 1999). Another type of impasse can be traced to flaws in the hierarchical structure of a particular Web site (Dumais & Landauer, 1984; Phillips et al., 1985; Landauer, 1995).

3.2.1 How Users Respond to Impasses

Forward search breaks down if a user cannot find any link that is sufficiently similar to the user's goal, leaving the constraint satisfaction process with no target of action that satisfies the similarity, frequency, or literal matching measures. Under such conditions the user's goal often offers little, if any, guidance.

There are several possible actions in this case:

- The user can shift attention and focus on another schematic object on the page, attempting to find an acceptable forward move. For example, scanning the headings may have attracted the user to focus on the actual objects in one area of the page, but the heading may have been misleading or misinterpreted or there may have been two or more objects with a similar degree of scent. The user may then search for an acceptable link under a different heading printed on the same page.

- The user can backtrack to a previously visited Web page, most commonly by clicking the browser application back button one or more times. For example, if the user was surprised by the new Web page that appeared as a result of her last click, backtracking can erase the effects of her mistaken prediction.

- A more complex alternative is to focus on a subset of the navigation links on the page and try to elaborate the links using information from other sources, such as the site architecture and/or general search strategies for the Web. For example, if the user has been browsing for information in a hierarchically structured site and has reached a dead end, the user may abandon browsing and try the site search engine. Alternatively, the user may revise her model of the site architecture and conclude she has previously been searching for the information in the wrong place, deciding to browse for the desired information in a different part of the hierarchical structure instead.

Successful solutions for impasses can thus require extensive knowledge of the Web site architecture (something only frequent users of the particular site have) and/or well developed search strategies for the Web (something only expert Web users have).

3.2.2 *Causes of Impasses: Inadequate Scent*

As the success case in Figure 2 shows, CoLiDeS estimates information scent by measuring the LSA cosine value of the correct link(s) in relation to the cosine values for competing links that could potentially lead the user astray. LSA cosines increase with richness of meaning, clarity, specificity, and lack of ambiguity — generally correlated with increased text length — for either the user goal or the text labels attached to the hyperlinks the user is considering. We have done cognitive walkthroughs (Wharton et al., 1994) of many Web sites using representations of user goals that are realistic for these Web sites and measuring the LSA cosines between each of these goals and the texts for each of the link labels available on the page. Several distinct sources of inadequate scent have emerged.

- Users encounter inadequate scent — and, therefore, more impasses — on Web pages that use short and/or ambiguous link labels. Various alternative link label texts — with or without link titles — can be objectively evaluated by comparing their LSA cosines in relation to the spectrum of typical user goals for a particular Web site.

- If all the link labels on a Web page are highly general, none of the LSA cosines for link labels may exceed 0.20 and five or six low-scent link labels (ranging from 0.10 to 0.20) may compete for the user's attention. In such a case the user experiences difficulty finding any link worth clicking on the page. When link labels are very general, they are slightly similar to just about everything but not very similar to anything in particular. The antidote is greater specificity that makes individual links distinct from each other.

- Sometimes a link for a featured item has high specificity but lacks adequate scent nevertheless, because the link label text uses a technical term or brand name with little or no meaning for most users. CoLiDeS or potential customers can select the correct link by literal matching, but only if they happen to know the precise technical term or brand name. To repair the inadequate scent the Web site designer can add link label and/or link title text describing the featured item in terms common within the LSA semantic space for general reading knowledge of typical users.

- When the highest cosines on the Web page deceptively lure the user to follow unproductive search paths, it generates an unusually difficult kind of impasse to solve. For example, we tested several medical/health Web sites using the query of a real user seeking information about diabetes. On one home page LSA cosines indicated that the user's attention would be pulled strongly towards a set of disease conditions. Five of the ten links nested within that area had cosines ranging from 0.33 to 0.46, but none provided more than an indirect path to some cross-referenced information on diabetes. The best link to diabetes information, unfortunately, was 'Library' with a cosine of only 0.03.

- Although some users arrive at a Web site with well-formulated goals and abundant relevant knowledge, others do not. Opportunely, LSA can accommodate any and all varieties of user goals, even rambling, ill-informed user goals that reduce scent and presumably raise the frequency of impasses. For example, we repeated the simulation of browsing for books on chaos theory with less elaborated and minimally elaborated goal representations, showing that each reduction in elaboration produced substantially lower LSA cosines. LSA could enable simulations to explore how to design a Web site that interacted with users to gradually expand the user's goal elaboration and goal-related knowledge, thereby potentially improving the success rate for users who arrive at a Web site with poorly elaborated goals.

3.2.3 Causes of Impasses: Flaws in Hierarchical Structure

Online bookstores — like most complex Web sites — have a hierarchical site structure several layers deep. To find books on a particular subject the user must drill down to a terminal node by selecting link labels for increasingly narrower categories. The browsing path down through any hierarchical structure is liable to present several types of hazards:

- The top-level categories may be so general that none are more than weakly similar to a particular subject, reducing the probability that the user will select the correct link, i.e. the link that leads to the correct terminal node. This situation of inadequate scent has already been covered in Section 3.2.2.

- The Web site designers may have misclassified either the terminal node or some middle level of the hierarchy, so that picking links closest to the user's goal may not lead to the correct terminal node.

- Even if an information architect says the terminal node is optimally categorised, the real issue is whether there is enough information scent at each click along the trail to ensure that the user can get to the correct terminal node. According to amazon.com, the primary classification for 'Chaos & Systems' is under 'Mathematics', but there would be no success case in Figure 2 if Amazon.com had not also decided to nest 'Chaos & Systems' under 'Physics'. The LSA cosines suggest that many users would click 'Evolution' to get to 'Chaos & Systems', so cross-classifying 'Chaos & Systems' under 'Evolution' and perhaps additional subjects would be effective for further reduction of the incidence of user impasses.

- The terminal nodes in the hierarchy may not be sufficiently specific, so that the terminal node retrieves an unreasonably large number of books. This happened when the simulation was run on a competing online bookstore site, where 'Physics' turned out to be a terminal node, presenting the user with the task of browsing 6519 books.

- There may not be a terminal node that closely matches the user's goal. For the case at hand, there may be no terminal node for books on chaos theory, not because the terminal nodes are not sufficiently specific but because that particular terminal node was not used.

To the naïve Web user, search engines may seem to present a superior alternative to browsing through hierarchically organised Web sites, but key word searching has its own set of hazards. If the user enters key words describing the particular subject — such as 'chaos' and 'theory' — into the site search engine, the search engine may or may not return results similar to those the user finds by browsing.

4 Useful Applications of CoLiDeS

4.1 Theoretical Understanding of Key Usability Guidelines

The CoLiDeS model offers a theoretical explanation of existing, agreed-upon usability guidelines that have been developed independently. Three well-known, agreed-upon usability guidelines are briefly considered in this section as examples of guidelines that can be explained by CoLiDeS.

4.1.1 User Navigation Is Goal Driven, Dominated by Local Decisions

Usability experts have noted that users' behaviour on Web sites is very goal driven and that users focus immediately on scanning the content area of the Web page, ignoring navigation aids and resisting constructing a representation of the site structure unless required to solve impasses. CoLiDeS claims that the major determinate of successful navigation is the quality of the descriptions of the consequences of clicking on a link. The most promising measure of users' accuracy in predicting the consequences of clicking on a link appears to be the LSA cosines between link label texts and a spectrum of representative user goals. To enable users to navigate by forward search, the Web site designer must ensure that clicking the link with the highest LSA cosine consistently carries the user closer to meeting her goal.

4.1.2 Link Labels Must Be Clear, Not Ambiguous, to Users

Unambiguous link labels facilitate smooth forward search, enabling users to accurately predict where they will end up if they click on a link. Adding clear verbal labels to an icon reduces the ambiguity inherent in icons without verbal labels (Nielsen & Sano, 1995; Rogers, 1986; Vaughan, 1998). Higher success rates in finding information are correlated with longer link labels (7–12 words), because long link labels generally carry more information and are less ambiguous than the short labels more typically found on Web pages (Spool et al., 1999). An alternative to long link labels is to retain short link labels and add link titles containing important supplementary information (a maximum of 60–80 characters) that becomes visible to the user when the cursor lands on the link label (Nielsen, 2000). CoLiDeS uses LSA to assess which links are highly similar to any given user goal, and ideally just one link label will be similar to the goal. In a case where multiple links on a Web page are similar to the user's goal, the Web site designer should ensure that selecting any of the competing links — not just one 'correct' link — will carry the user towards accomplishing the goal.

4.1.3 Lower Success Rate for Web Sites Organised in a Deep Hierarchy

The impasses outlined in Section 3.2 illustrate many reasons why searches through hierarchical spaces so often fail. Descriptions of top-level objects in deep hierarchies are very general and unlikely to provide much scent (Larson & Czerwinski, 1998) for any user's goal, especially an unelaborated one. In contrast, in a broad, shallow structure, a larger number of more specific headings appear on a Web page, raising the probability of a close semantic match to a user's goal. In a well-designed site scent increases as the user moves deeper into the hierarchy and closer to accomplishing her goal. For the elaborated goal in Section 3.1, for example, 'Science & Nature' (third level down) has a cosine of 0.41, 'Physics' (fourth level down) has a cosine of 0.57, and 'Chaos and Systems Theory' (fifth level down) has a cosine of 0.76.

A modest change in the probability of selecting the correct link at each level has a major impact on the overall success rate. A separate advantage of breadth is reducing the number of levels the user must drill through. If the user has an 90% probability of picking the correct link at each level then drilling down through two levels results in an 81% (0.9^2) overall chance of success, but drilling down through six levels reduces the overall probability of success to 53% (0.9^6). Just as important, a user trying to solve an impasse is less likely to get lost when backing up through two levels than when backing up through six levels.

4.2 Way to Resolve Tradeoffs Among Guidelines

Individual guidelines for Web site design have an inherent limitation: there are always contradictions and tradeoffs among guidelines, and also among the empirical results of usability studies. A unique contribution of a model like CoLiDeS is to provide guidance in balancing the tradeoffs and resolving the contradictions. For example, the guideline that stipulates long labels (Spool et al., 1999) can contradict the guideline recommending designing text to be concise and highly scannable (Nielsen, 2000). CoLiDeS offers a resolution of the contradiction. CoLiDeS emphasises scannability for the text the user relies upon to parse a Web page, but unambiguous, high-scent, long text labels when the user is comprehending a set of actual objects and selecting one for the next action.

4.3 Insight into Forward Search Success Cases

CoLiDeS provides a well-integrated, intuitive theoretical foundation for explaining the determinants of successful navigation by pure forward search. The best defence against usability problems is a good offence: CoLiDeS can help designers test a particular site design to determine whether user goals can be accomplished with pure forward search — the ideal scenario that would increase success rates for information searches on the Web.

4.4 Key Design Goal: Higher Information Retrieval Success Rates

Empirical usability studies have reported dismal success rates for information search and retrieval on the Web (Nielsen, 2000; Spool et al., 1999). Problems with inadequate scent and flaws in hierarchical site structures present serious usability problems for information search and retrieval, and this paper has demonstrated how CoLiDeS can explain these problems and suggest solutions. In addition, CoLiDeS can simulate solutions to impasses, although that complex topic is beyond the scope of this paper. If we can increase our understanding of the ways users wiggle out of impasses, it may be possible for designers to create second-chance search paths when minimum-path forward search is out of reach.

References

Dumais, S. T. & Landauer, T. K. (1984), "Describing Categories of Objects for Menu Retrieval Systems", *Behavior Research Methods, Instruments and Computers* **16**(2), 242–8.

Furnas, G. W. (1997), Effective View Navigation, *in* S. Pemberton (ed.), *Proceedings of CHI'97: Human Factors in Computing Systems*, ACM Press, pp.367–74.

Kintsch, W. (1998), *Comprehension: A Paradigm for cognition*, Cambridge University Press.

Kitajima, M. & Polson, P. G. (1995), "A Comprehension-Based Model of Correct Performance and Errors in Skilled Display-based Human–Computer Interaction", *International Journal of Human–Computer Interaction* **43**(1), 65–99.

Kitajima, M. & Polson, P. G. (1997), "A Comprehension-based Model of Exploration", *Human–Computer Interaction* **12**(4), 345–89.

Landauer, T. K. (1995), *The Trouble with Computers: Usefulness, Usability and Productivity*, MIT Press.

Landauer, T. K. & Dumais, S. T. (1997), "A Solution to Plato's Problem: The Latent Semantic Analysis Theory of Acquisition, Induction, and Representation of Knowledge", *Psychological Review* **104**(2), 211–40.

Larson, K. & Czerwinski, M. (1998), Web Page Design: Implications of Memory, Structure and Scent for Information Retrieval, *in* C.-M. Karat, A. Lund, J. Coutaz & J. Karat (eds.), *Proceedings of CHI'98: Human Factors in Computing Systems*, ACM Press, pp.25–32.

Nielsen, J. (2000), *Designing Web Usability*, New Riders Publishing.

Nielsen, J. & Sano, D. (1995), "SunWeb: User Interface Design for Sun Microsystem's Internal Web", *Computer Networks and ISDN Systems* **28**(1/2), 179–88.

Phillips, D. A., Hearty, P. J., Latremouille, S., Treurniet, W. C. & Whalen, T. E. (1985), "Behavioural Research in Telematics", *Canadian Psychology/Psychologie Canadienne* **26**(3), 219–30.

Pirolli, P. & Card, S. (1999), "Information Foraging", *Psychological Review* **106**(4), 643–75.

Rogers, Y. (1986), Evaluating the Meaningfulness of Icon Sets to Represent Command Operations, *in* M. D. Harrison & A. Monk (eds.), *People and Computers: Designing for Usability (Proceedings of HCI'86)*, Cambridge University Press, pp.586–603.

Spool, J. M., Scanlon, T., Schroeder, W., Snyder, C. & DeAngelo, T. (1999), *Web Site Usability: A Designer's Guide*, Morgan-Kaufmann.

Tullis, T. S. (1998), A Method for Evaluating Web Page Design Concepts, *in* C.-M. Karat, A. Lund, J. Coutaz & J. Karat (eds.), *Proceedings of CHI'98: Human Factors in Computing Systems*, ACM Press, pp.323–4.

Vaughan, M. (1998), "Testing the Boundaries of Two User-centred Design Principles: Metaphors and Memory Load", *International Journal of Human–Computer Interaction* **10**(3), 265–82.

Wharton, C., Rieman, J., Lewis, C. & Polson, P. (1994), The Cognitive Walkthrough Method: A Practitioners Guide, *in* J. Nielsen & R. L. Mack (eds.), *Usability Inspection Methods*, John Wiley & Sons, pp.105–140.

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