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# Task demands and memory in web interaction: a levels of processing approach

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## Abstract

The Levels of Processing principle holds that the strength of the encoded memory trace depends on the mental operations carried out during goal-pursuit. Therefore, memory should be better for web elements that are more deeply processed. Participants ( $N = 24$ ) accomplished several information finding tasks with printed web pages in two conditions: navigation-orientation and content-orientation. The results support the prediction and show marked differences between the two tasks in how the locations and features of task-relevant and -irrelevant elements are remembered. In explaining the results, the levels of processing principle is bound to a wider model of perception, attention, and memory in web interaction. It is argued that the memory test tapped explicit memories that are not recruited in the rapid on-line control of attention but rather in higher-level operations such as planning and error recovery in interaction. Implications are proposed for the design of memorable user interfaces, adaptive hypertext, and notifications.

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*Keywords:* Memory; Hypertext; Levels of processing; Navigation; Content

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## 1. Introduction

Although reading this text appears to occur without considerable effort, several complex cognitive processes are actually carried out: eyes are directed to fixate words in the correct order, words are recognized, sentence structure and grammar interpreted, references to previous sentences analyzed, anaphors and metaphors resolved, surface feature memories encoded, propositional textbases constructed, and situational models

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built. After reading the text, you will probably have a good idea on the gist of the text and perhaps on what page some particular piece of information can be found. If, instead, you were only interested in, say, evaluating the validity of the statistical analysis, the task characteristics would change dramatically—you only needed to skim over the main text and look for the method and results section, perhaps write down a model of our experimental design and obtained results, and conduct the evaluation. In this case, if asked later, you would probably not be able to give a summary of the argumentation structure of the text. However, you would probably know some *F*-statistics or graphs and their locations. The purpose of this thought experiment is to demonstrate that task-goals determine the way information is selected and processed, and these processing characteristics in turn determine what is subsequently remembered. A similar argument can be extended to tasks carried out in human–computer interaction (HCI): The way *elements* in a user interface (e.g. links, text, figures, etc.) are processed affects the extent and quality of remembrance. The purpose of this paper is to test this idea and investigate its importance in the context of web interaction.

There are reasons to hypothesize that memory and remembering are particularly important in web interaction. Tauscher and Greenberg (1997) found that 58% of an individual's pages are revisits, and new pages are constantly added to the repertoire of visited pages. Sequences of repeated URL paths are short, and only few pages are frequently revisited. In a follow-up study done by Cockburn and McKenzie (2001), it was found that revisiting is even more frequent, involving 81% of page accesses. The fact that we have to remember a vast repertoire of pages that nevertheless are rarely visited, places a burden on memory. Upon a revisit, memory is recruited in at least three stages of interaction: First, in forming a goal of revising a page, we need to recollect what was on that page. Second, planning how to navigate to that page demands access to representations of episodic memories of interaction with that web site. Moreover, executing this navigation relies on procedural memories.

However, if it was true that different web tasks had different impacts on memory, it would be important for designers to know exactly how remembering and forgetting are dependent on task-characteristics. With this information in mind, web sites could be designed to provide the most efficient support to information finding activities.

In this paper, two common *orienting tasks* in web interaction—navigation- and content-orientation—are compared from the memory point of view. *Navigation-orientation* is here conceived of as finding a particular page from the network of web pages by means of finding the correct link on the current page. *Content-orientation* means attending to the textual information (content) on the target page. Both are important subcomponents of commonly performed information gathering activities in the Web (O'Day and Jeffries, 1993). For example, Byrne et al. (1999) recorded verbal protocols during normal, uninstructed browsing activities.<sup>1</sup> Clustering of the activities suggested a division of tasks to six classes: (1) use of information (reading, viewing, listening, saving, displaying to

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<sup>1</sup> Two caveats of that study must be noted here. First, as noted by the authors themselves, 10 participants were selected from the university community and results may not thus generalize to the majority of web users. Second, Byrne et al. do not provide any inferential statistics to support their comparisons between different categories, which makes their conclusions tentative at best.

others, duplicating, printing), (2) locating information on page (something ‘interesting’, related concept, tagged information, specific string, image), (3) going to a page (following hyperlink, back/forward, bookmarks, history list, or direct URL input), (4) providing information (search string, shipping address, survey response), (5) configuring browser (adding a bookmark, helper setting, cache size setting, window resizing, scrolling), and (6) reacting to application environment (responding to a dialog, display change, reload). Most time was spent on the first, second, and third task types, which provides support for the supposition that navigation and content-orientation are representative of web interaction. Moreover, the results justify the selection of orientation tasks from the ecological validity point of view (Norman, 1980).

### 1.1. Levels of processing

In order to predict memory effects of the two tasks, content- and navigation-orientation, a theoretical framework called the levels of processing is adopted. *The levels of processing* (LOP) framework was put forward 30 years ago by Craik and Lockhart (Craik and Lockhart, 1972; Lockhart and Craik, 1990). Since then, it has been enormously influential. The central notion in LOP is that the *depth of information processing* determines the durability of the memory trace. In a typical LOP experiment (Watkins, 2002), when subjects are presented with words and required to respond on an orienting question (e.g. shallow orientation: ‘Is this word in uppercase?’, or deep orientation: ‘Does this word refer to an animal?’), and memory is subsequently tested, it is consistently found that memory is strongest for words subjected to a deep orienting task. According to later revisions of the framework, this deep level of processing produces memory traces that are *distinctive* from other traces and *organized* in a more elaborate network of associations strengthening the trace, supporting *accessibility* to larger variety of retrieval criteria, and being more *resistant to interference* (Craik, 2002). Deep level-of-processing thus results in what is called *robust encoding* (Lockhart, 2002). “... deep processing provides the schematic context within which episodic details are related to each other and to more abstract representations of significance and purpose” (Craik, 2002, p. 314). By contrast, *shallow* processing is processing of words based on their surface (e.g. phonemic and orthographic) features, and it leads to a fragile memory trace that is susceptible to rapid forgetting. To summarize, the processes of perception, attention and comprehension constitute memory-encoding operations and successful retrieval is a corollary of match between the encoding and retrieval conditions.

To apply LOP in the analysis of navigation- and content-orientation, they are characterized as *matching tasks* (Paap and Cooke, 1997). In a matching task, the user has some prior description of the target in his working memory and must determine whether the target lies in the center of attention. Because targets usually reside within dedicated regions on the page, attention has to be first directed to those regions. Within an attended region (e.g. a navigation panel), sets of elements (e.g. links) must be processed in some order. If the target lies in the attended subset of elements, the search task can be terminated. If not, attention must be shifted to another subset of elements. At the stage of processing individual elements, content orientation is *semantic* in nature, thus having resemblance with deep processing. For example, according to Kintsch’s (1986) model of

cognition in reading, three representations are built during reading. The *surface feature* memory is a transient account of exact wordings and their surface visuo-spatial properties. The *textbase* is a representation of propositions built in the process of comprehension, and the *situational model* is built to represent the situation described in the text. Navigation-orientation, by contrast, is more *lexically- and perceptually-based*, requiring less elaboration and no construction of a situational model. Navigation orientation is thus closer to shallow processing.

## 1.2. Hypotheses

LOP predicts that memory for user interface differs between the two orienting tasks. Because navigation involves scanning of the whole page for potential targets, enhancement in memory for surface features of page elements is expected. But, because processing of individual elements is shallow, memory for semantic features should be poorer. On the contrary, content-orientation should result in good memory for semantic features of content elements.

How about memory for locations of web elements? Guthrie and Kirsch (1987) claimed that locating information such as facts, names, or numbers in text, is a reading task requiring comprehension that is distinct from text recall in two respects: “(1) cognitive processes that control reading comprehension and locating information are expected to be different; (2) the frequency of engagement in comprehension and locating are expected to be independent” (p. 220). Piolat et al. (1997) argued that positional information is encoded and retained during reading: readers are very accurate in making corrective gazes to those words or sentences that needed to be studied again (Kennedy and Murray, 1987), indicating a transient memory upheld during reading for locations of individual words. In a study addressing the question more directly, Rothkopf (1971) asked subjects to read 3000-word texts and later tested their memory for content and location of words in the passage, and performances in content and position tests were correlated. Theriault and Raney (2002), however, showed that the effect is rather weak and probably related to surface memory rather than propositional or situational memory. The *reference frame* employed in locating a piece of information is poorly understood (Piolat et al., 1997). That is, it is not known if the borders of the display, salient features of the page, or what is used as frames of references in finding words. In sum, location is at least weakly and transiently encoded in content-orientation, but it is not known how this extends to navigation that is more surface-oriented than reading. An experimental condition in the present experiment directly addresses this question.

## 2. Method

The present experiment is carried out utilizing the *incidental learning paradigm*; that is, participants carry out navigational and content-related tasks not knowing that their memory is later tested. Afterwards, memory for the titles of the pages, visual and semantic features, and locations of elements are tested in a surprise test. From the results, memory accuracy for task-relevant and task-irrelevant elements, and task-targets (e.g. the link that

was clicked) and neighbor elements (e.g. links close to the target) are examined. Testing learning without intent is ecological, because, in HCI, user's goal is seldom to memorize interface elements, but to accomplish some content-related goal. Moreover, orienting tasks provide strict control over stimulus processing, because they provide an independent variable (IV) that can be operationally defined, described in functional processing terms, and, through monitoring participants' responses during the orienting task, can provide some check that the designated processing is being performed (Craig, 2002; Lockhart, 2002).

### 2.1. Participants

Twenty-six students were recruited from an introductory course in cognitive science arranged by the Open University of Helsinki. Twenty-four students were run in a single classroom session. Two participants were excluded from data analysis because of inability or unwillingness to follow instructions. To replace their data, two other students were later tested in similar conditions. All participants were native speakers of Finnish. Mean age of participants was 32.6 (SD = 10.81), and their average WWW experience was 6.1 years (SD = 1.62). Ten of the participants were male, and the rest female.

### 2.2. Materials

Six web pages were sampled from the *fi* domain. All pages were composed of common HTML elements such as text, links, headings, tables, images, etc. organized in a prototypical visuo-spatial configuration (as judged by the experimenter). In all six pages, two major regions could be identified: the main information content and the navigational framework. The main information content was always located centrally on the page and consisted of headings, text, tables, and images. The navigational framework, on the other hand, involved hyperlinks organized by grouping, distinctive positioning, and layout.

The following criteria were used in selecting and preparing the materials: (1) In order to minimize the possibility of prior experience with the page, educational and student life-related pages were excluded. (2) In order to be fully comprehensible and representative of the WWW, pages using non-standard design solutions (e.g. Flash) were excluded. (3) In order to equalize the amount of screen estate and data ink given for the two tasks, pages with marked biases in that balance were excluded. (4) To ensure legibility in the printed handout, a minimum of 12-point on-screen font size was forced. (5) The whole page was to fit on one screen without scrolling.

A screenshot was taken from each of the selected page and reduced to fit to a landscaped A4.

Two paper *handouts* were prepared: one for the *incidental learning phase* and another for the *test phase*. In the first handout, *the study handout*, each of the six pages contained a picture of a web page on left, consuming about 70–80% of the space, the title of the page printed on top, and six short task descriptions printed on right. In content-orientation, task descriptions involved finding a piece of information or a filling in information to a form. The content tasks were in accord with Shneiderman's (1997) typology of information finding activities. Of Shneiderman's tasks, specific fact-finding, or known item search

(e.g. Find the phone number of Bill Clinton), extended fact-finding ('What kinds of music is Sony Publishing', or 'Which satellites took images of the Persian Gulf War?'), but not open-ended browsing ('Is there a relationship between carbon monoxide levels and desertification.') or exploration of availability ('What information is there on Grateful Dead band members?') were utilized. *Content targets* (i.e. the correct answers to the task descriptions) were mostly textual elements (i.e. headings, captions, or text) and only rarely buttons, links or figures embedded to text. The navigation task descriptions involved finding a link (*the navigation target*) that was always located in the navigation regions.

In preparing the printed task descriptions, special care was taken to ensure that the tasks could not be solved solely using verbatim or visual memory, but required at least synonym matching or even deeper semantic analysis. That is, there was no 1-to-1 match between the task description and the target. This reflects the fact that users rarely have an exact description of the target in mind but have to decide on other basis whether the description matches to an attended item. Tasks were designed to be challenging enough so that all six would not be accomplished in the given time of 90 s. Examples of tasks and correct solutions are given in Fig. 1.

In the second handout, *the test handout*, the first page had few empty lines and a question "Please write down as many titles from the web pages you can. You have 2 minutes for this task" (*The title memory test*). The following six pages consisted of the *feature memory test*. Each page contained eight test items, each with four alternatives and a box for marking confidence for the decision. Confidence range was from 1 (guess) to 7 (absolutely certain). One of the alternatives was always right, one was only semantically correct (i.e. the text was correct), but visually incorrect (e.g. it was presented in incorrect color, font, or format), one was only visually correct but semantically incorrect, and one was incorrect both semantically and visually. This division allowed us to make interpretations from recognition performance to surface vs. semantic memory. The idea is that the kinds of errors made would reveal what features are represented poorly in memory. Of the eight test items, half were *navigation items* and the other half *content items*. Within both four-item sets, half of the items were target elements (i.e. actually searched for in the learning phase) and half neighbor elements (i.e. elements lying in the same subregion). Adhering to the Gestalt grouping principles, a neighbor element had to reside within the same common (sub)region, be presented in the same font and color than the target, and not be separated by other elements lying between it and the target. The instruction printed on top of the page was: "One of the 4 shown elements was actually on the page. Which one? Circle your answer and mark your confidence (1 to 7)."

The final six pages consisted of the *location memory test*, one page for each web page in the same order as in the study phase. On each of the six pages, the title of the studied web page was printed on top, an *empty* browser window on left (same size than in the study phase, but with the browser window empty), and 16 elements cropped from the page were placed on right. Again, half of the items were from the navigation task, half from the content task, and within both sets half of the items were targets and the other half neighboring elements. Different test items were used in the feature memory test.

All handouts were printed in full color. The language used was Finnish.

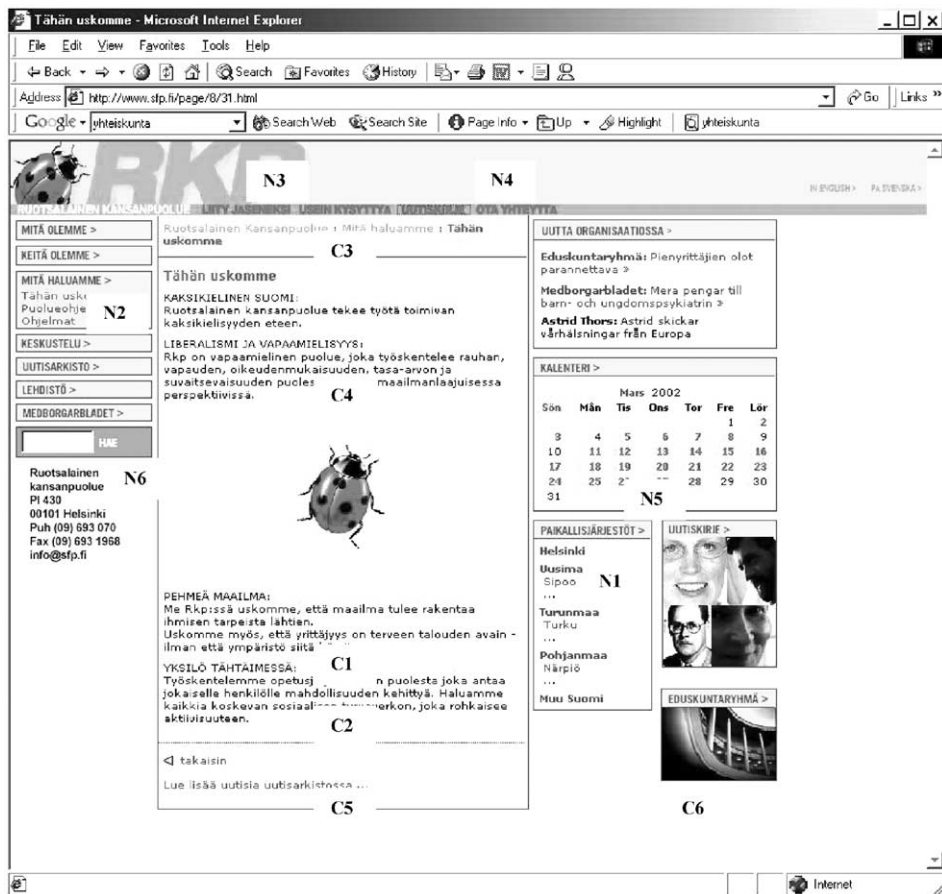


Fig. 1. A WWW page used in the experiment (original in color). In the content-orientation condition participants' task was to find and circle from the page: (C1) RKP's [a political party] relation to nature, (C2) RKP's relation to social security, (C3) meaning of the abbreviation RKP, (C4) RKP's relationship to equality between men and women, (C5) more news headlines, and (C6) RKP's parliamentary faction. In the navigation-orientation condition, the tasks were to find: (N1) RKP's local organizations, (N2) the party program, (N3) information on party membership, (N4) contacting the party, (N5) party's activities on 27th March 2002, and (N6) more information on a particular representative. The target locations are marked to the figure.

### 2.3. Procedure

The experiment was administered in a classroom for a class of 24 students. Possibility of seeing other's answers was minimized. One experimenter managed timing and the other monitored participants. Name, age, WWW experience in years, and the number of hours spent using the web were collected before the experiment. The study handouts containing materials were then distributed to the participants.

Then, using an overhead projector and a non-experimental user interface, participants were instructed and demonstrated on how to perform the task. Because of the focus on

incidental learning, participants were not told the real purpose of the study, but that the purpose was to study the effects of interface design on finding information efficiently. Consequently, they were asked to do every task ‘as quickly and accurately as possible’. They were then told to go through the six problems in the given order and, using their pens, to mark their answer to the browser window. In the navigation-oriented tasks, participants were given a description of six links that they had to find and circle (the target) from the page. In the content-oriented tasks, participants were given description of six content-related questions and they had to circle the answer (the target) from the page. Some of the tasks involved ‘filling in’ information to a form on the web page, and this was done by writing with the pen to the fields and ‘pressing’ the ‘Submit’ button by circling it. If a participant would not be able to solve the problem, s/he would continue to next problem. If the participant was able to solve all problems, s/he would put his/her pen down to the table. Ninety seconds were given for each page after which the experimenter told them to turn page. After going through the six pages, study handouts were collected back.

After the incidental learning phase, participants were given the test handouts. In the first page (the title memory test), participants were asked to write down the titles of all web pages they had been seen in the previous phase. Two minutes were given for this task, after which the experimenter instructed the participants on the following two memory tests. In the feature memory test, the task was to go through the eight test items on the page and for each item select the one out of four options that had appeared on the page. As described above, the options were different in respect to their surface and semantic features. For each item, participant had to mark confidence of his/her selection to a box.

In the location memory test, 16 items cropped from the original page were presented on the side of the handout page, and the task was to mark on an empty browser window the location in which the participant thought it had appeared originally. The task was to mark the number of the element to the location he/she remembered it was presented originally.

In both memory tests, the test pages appeared in the same order as in the study handout. Participants were given as much time as they needed for both feature and location memory tests.

#### 2.4. Design

The dependent variables (DVs) indicating overall task performance were the number of tasks accomplished in time (90 s) and the number of correct, incorrect, and omitted responses. *Task* (the task-orientation performed for this web page in the first handout: content- vs. navigation-orientation) was the independent variable. For the title memory test, DV the number of correctly recalled titles.

In the feature memory test, the DVs were the recognition accuracy and confidence, and the IVs were *Task*, *Element Type* (type of the test item in question: navigation vs. content), *Element Location* (location of the test item in relation to the to-be-found targets: target vs. neighbor), and *Feature Type* (type of the feature tested for the test item: surface vs. semantic). In the location memory test, *Task*, *Element Location*, and *Element Type* were the IVs. In the location memory test, angular error was also used as DV.

In order to control for order effects, the presentation order of the six web pages was counterbalanced across participants by rotation. Order of Tasks was counterbalanced analogously. This counterbalancing yielded  $(6 \times 2)$  12 experimental sets.

### 3. Results

#### 3.1. Task performance

The number of tasks accomplished (min 1, max 6) in the given 90 s did not differ between the Task conditions,  $t(23) = -1.57$ , *ns*. Neither did the number of correct answers, wrong answers, or omissions (failing to answer a question), all  $|t|s < 1.78$ . Therefore, it is unlikely that the found differences between conditions in memory performance (reported below) would trivially reflect differences in how many or how correctly tasks were accomplished or the amount of time spent per task.

#### 3.2. Title memory

On average, 2.75 (SD = 1.36) page titles were correctly recalled in the title memory test.

#### 3.3. Feature memory

*Scoring.* Feature memory was tested using the feature recognition test where two kinds of errors could be made in selecting the correct option from four alternatives: surface and semantic. Because of the two by two feature options in the test, recognition scores were given so that the maximum recognition accuracy was  $(2 + 2)$  4 points, yielding a chance level of 1 point. In other words, the errors made were subtracted from the maximum score for the corresponding error types (surface or semantic). For each web page, confidence scores were summed for all cells in the experimental design, yielding a score range of 4–28.

*Results.* A four-way (Task  $\times$  Element Type  $\times$  Element Location  $\times$  Feature Type) Repeated Measures Analysis of Variance (RM-ANOVA) was run using the *alpha-level* 0.05. A significant main effect of Element Type was found  $F(1, 23) = 6.15$ . Content elements were better remembered ( $M = 2.15$ , 95% CI  $\pm 0.24$ ) than navigation elements ( $M = 2.48$ , 95% CI  $\pm 0.20$ ).<sup>2</sup> The main effect of Element Location was significant  $F(1, 23) = 11.25$ . Accuracy was better for target elements ( $M = 2.51$ , 95% CI  $\pm 0.24$ ) than for neighbor elements ( $M = 2.12$ , 95% CI  $\pm 0.16$ ). As expected, the interaction effect Task  $\times$  Element Type was significant,  $F(1, 23) = 12.67$ : In the navigation-orientation, navigation elements were better remembered than content elements; and vice versa in the content-oriented task. The more complex interaction effect Task  $\times$  Element Location  $\times$  Element Type was also significant,  $F(1, 23) = 11.06$ . Task-targets were equally well

<sup>2</sup> Tukey's Honestly Significant Difference (HSD) is used throughout this paper for calculating confidence intervals (CIs).

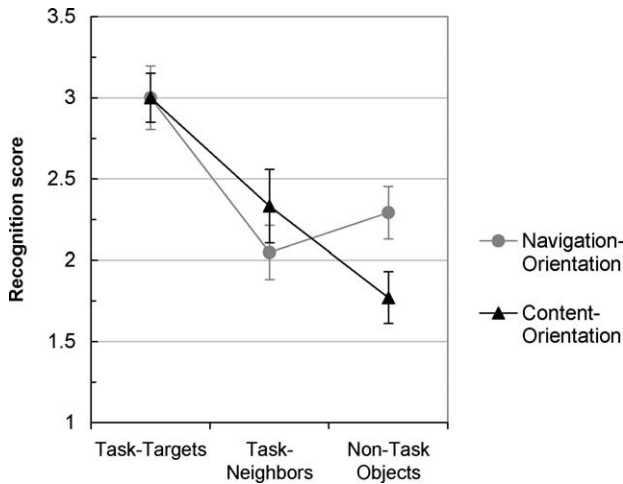


Fig. 2. Overall feature recognition scores for target elements, their task-related neighbors, and non-task elements, separately for content-orientation and navigation-orientation. Maximum score is here 4, minimum 0, and chance level 1. Error bars denote 95% confidence intervals (Tukey HSD).

remembered on both task-orientations. However, content-orientation enhanced feature memory for task-neighbors, whereas navigation-orientation enhanced memory for elements unrelated to the task (content elements in this case). Fig. 2 presents this interaction. The interaction effect Element Location  $\times$  Element Type  $\times$  Feature Type was significant,  $F(1, 23) = 32.92$ . Memory for semantic features of navigation elements was on the same level for targets and neighbors, whereas for surface features it was significantly higher for targets than for neighbors. For the content elements, the situation was the opposite: semantic features of targets were significantly better remembered than those of neighbors, but surface features equally well remembered both for all elements. This interaction is represented in Fig. 3. Other effects were non-significant, all  $F$ s  $< 1.89$ .

*Confidence.* A 3-way (Task  $\times$  Element Type  $\times$  Element Location) RM-ANOVA was run on these scores. In contrast to accuracy scores, the main effect of Element Type on confidence was insignificant,  $F(1, 23) = 2.38$ , ns. However, the trend paralleled to what was found with accuracy: participants were more confident in recognizing content elements ( $M = 10.19$ , 95% CI  $\pm 2.47$ ) than navigation elements ( $M = 9.25$ , 95% CI  $\pm 2.67$ ). All the other effects were both significant and closely matched participants' true accuracy. The main effect of Element Location was significant,  $F(1, 23) = 16.89$ . Participants were more confident for target elements ( $M = 10.81$ , 95% CI  $\pm 2.72$ ) than for neighbor elements ( $M = 8.63$ , 95% CI  $\pm 2.37$ ). The interaction effect Task  $\times$  Element Type was significant,  $F(1, 23) = 28.53$ . In the navigation-oriented task, navigation elements were more confidently remembered than content elements ( $M = 11.38$ , 95% CI  $\pm 3.15$ , and  $M = 7.80$ , 95% CI  $\pm 2.02$ , respectively), and vice versa in the content-oriented task ( $M = 7.13$ , 95% CI  $\pm 2.29$ , and  $M = 12.58$ , 95% CI  $\pm 3.58$ ). The interaction Task  $\times$  Element Location was also significant,  $F(1, 23) = 8.50$ . The more complex interaction Task  $\times$  Element Type  $\times$  Element Location was significant as well,

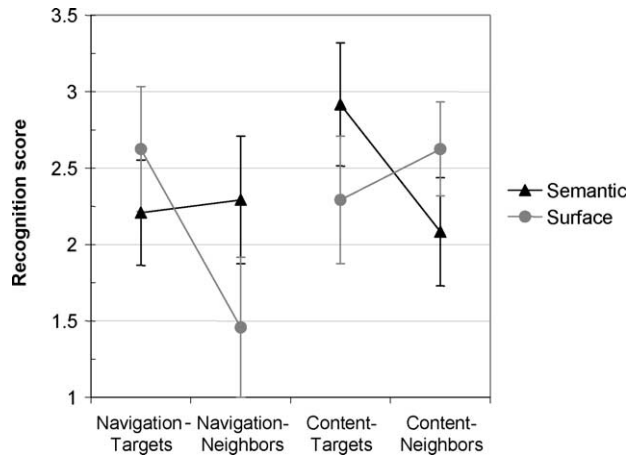


Fig. 3. Semantic and surface feature recognition scores separately for content and navigation targets and neighbors. Maximum score is here 4, minimum 0, and chance level 1. Error bars denote 95% confidence intervals (Tukey HSD).

$F(1, 23) = 8.25$ . Here, in navigation-orientation, confidence was higher for content-targets ( $M = 12.75$ , 95% CI  $\pm 3.37$ ) than for content-neighbors ( $M = 10.00$ , 95% CI  $\pm 3.44$ ), which in turn was higher than confidence for task-irrelevant elements (i.e. navigation elements,  $M = 7.79$ , 95% CI  $\pm 2.02$ ). Similarly, in content-orientation, confidence was higher for content-targets ( $M = 15.42$ , 95% CI  $\pm 4.00$ ) than for content-neighbors ( $M = 9.75$ , 95% CI  $\pm 3.63$ ), which in turn was higher than confidence for task-irrelevant elements ( $M = 7.13$ , 95% CI  $\pm 2.29$ ).

### 3.4. Location memory

*Scoring.* Point-coordinates for participants' responses were measured in millimeters with an error margin of 1 mm. Coordinates were converted to on-screen pixels for calculations and reporting. Two location distortion scores were calculated by comparing the response to the test item to the original location of the item: *Distance Error* (in pixels) and *Angle Error* (in radians). Distance error is the Euclidian distance between the two point coordinates: the thought location and the true location. Angle Error, in radians, ranging from  $-\pi$  to  $+\pi$ , denotes the direction of the assumed location of the test item from its real location, assuming the vertical axis as the point of reference. (Then, for example,  $\frac{1}{2}\pi$  would mean the assumed location being directly to the right from the real location, and  $\pi$  directly below it.)

*Results.* A three-way RM-ANOVA (Task  $\times$  Element Location  $\times$  Element Type) was run separately for Distance Error and Angle Error as DVs. Mean Distance Error was 48.18 pixels (95% CI  $\pm 2.90$ ) and mean Angle Error  $-0.52$  radians (95% CI  $\pm 0.07$ ) indicating a slight bias towards the left edge of the browser window. No main effect of Task on either DV was found, both  $F_s < 1.40$ , *ns*. The main effect of Element Type was significant on Distance Error and Angle Error,  $F(1, 23) = 38.68$ , and  $F(1, 23) = 6.23$ , respectively.

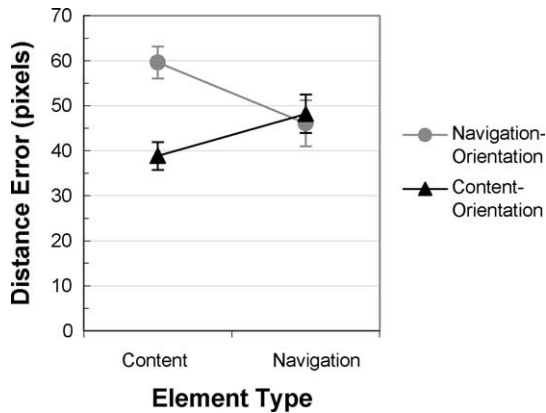


Fig. 4. Distance errors (in pixels) in the location memory test for content and navigation elements, presented separately for navigation- and content-orientation tasks. Error bars denote 95% confidence intervals for the means (Tukey HSD).

Content elements' Distance Error ( $M = 43.50$ , 95% CI  $\pm 2.93$ ) was substantially smaller than navigation elements' ( $M = 52.84$ , 95% CI  $\pm 3.62$ ) and angular position less biased towards left ( $M = -0.38$ , 95% CI  $\pm 0.19$ ;  $M = -0.66$ , 95% CI  $\pm 0.20$ , respectively). The main effect of Element Location was significant on Distance Error and Angle Error,  $F(1, 23) = 6.60$ , and  $F(1, 23) = 39.19$ , respectively. Target elements' locations were slightly better remembered ( $M = 46.71$ , 95% CI  $\pm 3.30$ ) than neighbor elements ( $M = 49.64$ , 95% CI  $\pm 3.16$ ). Concerning Angle Error, target elements were more twisted towards left than neighbor elements ( $M = -0.70$ , 95% CI  $\pm 0.16$ ;  $M = -0.34$ , 95% CI  $\pm 0.17$ , respectively). Most important, a significant interaction effect of Task  $\times$  Element Type was observed both for Distance Error and Angle Error,  $F(1, 23) = 57.12$ ,  $F(1, 23) = 5.98$ , respectively. Distance Errors are depicted in Fig. 4, and Angle Errors in Fig. 5. Interestingly, content elements were less of the target in

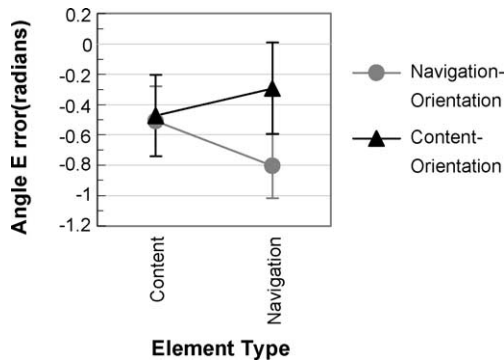


Fig. 5. Angle errors (in radians) in location memory test for content and navigation elements, presented separately for navigation- and content-orientation tasks. Error bars represent 95% confidence intervals for the means (Tukey HSD).

content-orientation than in navigation-orientation, whereas distance error for navigation elements was on the same level across the two task conditions. However, the angle error for navigation elements was significantly larger in navigation condition than what it was in content condition. Navigation-orientation resulted in expecting the navigation elements being more towards the left side of the screen than they really were, whereas content-orientation biased towards the top part of the screen. All other effects were insignificant,  $F_s < 4.23$ .

#### 4. Towards a model of attention and memory in web interaction

##### 4.1. Attention and memory in navigation- and content-orientation: expanding the matching model

The complexity of the results points out that it is necessary to expand the simple matching task model by analyzing how attention is guided in searching a target. Attention is necessary for accurate long-term memory of perceived elements (Hollingworth and Henderson, 2002), and knowing how its guidance is affected by task demands has implications for understanding memory. In the following, the empirical results, summarized in Table 1, are bound together in a broader model of attention and cognition in navigation and content-orientation. The model breaks down the search task to four temporally ordered subtasks, each having distinct processing characteristics and thus different impacts on memory. Two basic assumptions taken from the levels-of-processing framework are that (1) memory trace is a result of those analyses that had been carried out for the purposes of perception and comprehension, and that (2) these processes differ between the two orienting task. The proposed model systematizes a body of research in perception, eye movements, menu selection, and web browsing.

*First saccade.* Users often program, execute, and complete the first saccade before the interface is even visible (Byrne, 2001). This is possible, because over the many years of using the Web, they have incidentally registered frequently occurring configurations of web elements. In a study investigating expectations of element locations (Bernard, 2001), 304 students were asked to place cards representing different web elements on a  $8 \times 7$  grid representing an empty browser window. Expected locations were as follows: web page title: top center of the page, internal links: upper left side, external links: right side, link referring to homepage: upper left side, internal search engine: upper center part, and advertisement banners: top part.<sup>3</sup> This means that in navigation-orientation, attention is likely to be directed to top and left areas of the page first, whereas in content-orientation, it is likely to be directed to the top-center part of the page. Note that vision is suppressed during the saccades and information can be only gathered during fixations. Therefore, the user actually perceives the page for the first time only after the first saccade.

This subtask is *a*perceptual and can be executed on the basis of expectations, which are likely to differ between navigation and content-orientation. Thus, no memory impact is

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<sup>3</sup> A shortcoming of that study was that it tapped only knowledge available for consciousness (i.e. explicit memory), whereas perceptual and implicit memories are not accessible for consciousness.

Table 1  
Summary of findings

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*Feature memory*

Across the two orienting tasks, semantic memory for navigation elements was equally good for targets and neighbors. Surface feature memory was higher for targets than for neighbors

Across the two orienting tasks, surface features of content elements were equally well remembered, whereas semantic features of content-targets were better remembered than those of content-neighbors

Task-related web elements were better remembered than task-irrelevant elements

Content-orientation resulted in better memory for task-relevant neighbor elements than for (irrelevant) navigation elements

Memory for unrelated elements was better in navigation-orientation than in content-orientation

Participants' confidence for their memory performance closely paralleled their true performance

*Location memory*

Across the two task conditions, content elements were less of the target than navigation elements and their angular position was less biased towards left

Target elements' locations were slightly better remembered than neighbor elements

Content elements were less of the target in content- than in navigation-orientation, whereas for navigation elements the distance error was on the same level across the two task conditions

In navigation-orientation, navigation elements were more biased towards the left side and in content-orientation towards the top part of the screen

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expected. Because the region designated to content is most often located in the bottom center of the screen, whereas navigation regions are spread around the screen, and the predictability of the targets location is therefore worse, more errors are likely to be done in navigation orientation. In the present experiment that used paper-based materials, however, the first saccade does not likely have the same role than in computer-controlled experiments.

*Region search.* Unless the target is directly found already with the first fixation—which is unlikely because people can do this with very simple menus only after some 800 practice trials (Card, 1981)—the next task is to pin down the search to a region potentially containing the target. Whereas the first saccade was *a*perceptual, this subtask is perceptual and attentional in nature. After the first fixation, much more information is available for selecting candidate regions. Task-goals, expectations of web element locations, global visual properties of the page, and local visual characteristics of the currently fixated region all contribute to how fixations are placed. Features not present in the fovea can guide saccades from there on and there is usually a plenty of extra-foveal information available for saccade selection: Link regions usually are located in the sides of the central area (e.g. top left corner) and marked by distinct background color. Moreover, links are usually underlined, thus forming uniform regions parallel lines, a useful visual cue. Contents, on the other hand, are usually centrally located blocks of uniformly colored text. These visual and place cues can help finding relevant regions quite directly without a need for exhaustive semantic scan. It is known that in search tasks such as this, saccade is directed mostly using local rather than global strategies (Byrne, 2001). Some computational models of eye movements have been based on Markov models, where the location of the next fixation is determined by the preceding fixation (Hacisalihzade et al., 1992).

From this description, it is clear that region search is dominantly both perceptual and attentional task, involving processing of visual and spatial features of the page. The LOP framework would implicate that this kind of processing does not lead to strong memory trace that would help users later remembering much of the semantic contents of the page. Instead, it can have a role in memory for visual and spatial properties. Indeed, with practice, contextual cues (i.e. spatial organizations of interface elements) are more efficiently used in search. Users that have been exposed to the page several times can better benefit from the extra-foveal spatial context (Chun and Jiang, 1998). This kind of implicit learning of spatial context is robust across noise and biased towards spatially grouped information (Olson and Chun, 2002). In the case of web pages, these spatial groups may consist of link groups, paragraphs of text, etc. that may serve as learned ‘navigation landmarks’ in saccade selection.

The fact that this task is relatively easy and the candidate regions are found quickly, has also some other interesting consequences. In experiments of scene perception, people are more likely to fixate to semantically informative (i.e. task-related) elements after the initial fixations within the scene (Henderson and Hollingworth, 1999). Eyes dwell on regions relevant to the task. This explains, partly, why features of task-relevant elements were better remembered than features of task-irrelevant elements.

The fact that task-relevant subregions are not equally distributed across the display is a factor also worth considering. The possible area for content elements in our materials was restricted to a small rectangle-shaped area in the middle of the page, making it easy to generate an informed guess on their location in the memory test. Content elements are usually lumped together whereas navigation elements reside in groups across the page. Thus, because of better predictability, ‘remembering’ the correct region containing the target is easier for content-orientation than for navigation-orientation, which predicts that if all elements were equally deeply processed, content-elements’ locations were better remembered.

*Subregion scan.* At this point, the user has localized and fixated to a uniform region that has to be scanned to locate subregions potentially containing the target. In navigation-orientation this subregion is usually a group of links and in content-orientation a paragraph of text. Since navigation panels are usually ordered in a top-to-bottom or left-to-right fashion, it is logical to assume that they are scanned in this order (Byrne, 2001). If there is a possibility for scanning to both directions, what will be preferred? Using a matrix of element groups, Goldberg et al. (2002) found that eye-movements were biased towards horizontal search (across columns) instead of vertical (within column). Subregion scan in content-orientation is more straightforward, because content is ordered top-to-bottom, which makes it logical to follow that order. After finding the starting point, search for the target can proceed in a linear manner from one paragraph to the following.

If the category of the group can be easily determined from available cues without exhaustive processing of all individual items in the group, subregion scan can be effective. Concerning content-orientation, appropriate clustering of text to coherent paragraphs, use of headings, captions and leads, concise sentences, unambiguous language, and bullet lists, tables and graphs are all likely to facilitate locating candidate regions. In navigation-orientation, however, people do not seem to use all available cues. Goldberg et al. (2002) found that header bars of link groups are not reliably fixated, implicating that they are not

reliably used as cues for narrowing down the search. If headers are not reliably utilized, first few items of the link group must be scanned to get an idea whether the target is included or not. Indeed, Engelbeck (1986, as cited in Soto, 1999) observed that novice users tended to examine those label groups that share one or more words with the task description provided by the experimenter. Representativeness of the first few links in respect to the whole group is thus crucial. Experimental (e.g. card sorting) and automatic measures (e.g. Latent Semantic Analysis; Soto, 1999) exist for the analysis of semantic similarity. Indeed (Hornof and Kieras, 1999), items top in the subregion have special status, because they are selected faster than other items, even after extensive practice (Perlman, 1984), perhaps because they function as ‘gating’ items indicating contents of the rest of the subregion.

The extent to which subregion scan enhances semantic memory is thus largely determined by the design. In contrast, visuo-spatial features are most likely incidentally registered in both content- and navigation-orientation. Learned locations and visual features can function as *indirect* indicators of group’s semantic content. The use of visuo-spatial versus semantic cues in subregion scan is an important question for further research.

*Matching of individual elements.* From the point of view of memory, matching of individual elements is the most crucial phase in search. Within each subregion, attended items are to be matched to the internal description of the target. It is known that search through perceptually similar items cannot take advantage of ‘pop-out’ but has to be serial in nature (Treisman and Gelade, 1980). Similarity of distractors to the target slows down search (Anderson et al., 1998). Matching in both navigation- and content-orientation is therefore likely to in most cases proceed more or less exhaustively, processing all elements in the subregion scan one-by-one, unless some items clearly hint that the scanned subregion cannot contain the target. Furthermore, as in the ACT-R/PM model, search does not need to be totally exhaustive but can skip items that do not share surface features with the target (Byrne, 2001). For example, it is known that listing items in alphabetical or numerical order significantly reduces search times within a menu, most likely because it helps to skip irrelevant items. Thus, good organization of link regions and content regions may facilitate this task.

As argued earlier, navigation-orientation is mainly perceptual or lexical matching. Link texts are usually short in length and therefore quickly processed. Eye-movements through columns of links are therefore quick and jittery, and directed top-to-bottom (Oulasvirta, Kärkkäinen, and Laarni, submitted). In the process of picking between web links, short-term memory may not need to be overloaded (Larson and Czerwinski, 1998). Instead, this kind of search appears to be perceptual-attentional task, where good labeling and visual categorization helps in finding the target (Dumais et al., 2001). In content-orientation, sentences are processed top-to-bottom. Web elements that are perceptually dissimilar to target, such as graphical elements or links, are likely to be skipped. Sentence’s meaning is extracted and compared to the description of the target residing in working memory. The extraction of meaning involves building and maintaining representations of surface features, prepositional structure, and situational models (Perrig and Kintsch, 1982). In comparison to link matching, comprehension of sentences thus draws on working memory (Baddeley, 1986; Daneman and Carpenter, 1980; Kintsch and van Dijk, 1978; Kintsch, 1986).

This distinction between lexical matching in navigation and semantic matching in content-orientation explains why content targets' semantic features were better remembered than navigation targets'. A more complicated result from the experimental study was that scores for content and navigation targets' *surface* features were on the same level, but surface feature memory for neighbor elements was substantially better for content than for navigation elements. This may reflect the fact that content elements are often less varied in their surface features than navigation elements. Remembering, even vaguely, the overall 'flavor' of content elements visual appearance may thus suffice, whereas navigation elements are more varied and therefore require more distinctive memories. It was also found that feature memory was markedly better for targets than their neighbors. This is in line with the LOP framework. Numerous experiments have shown that a positive response to the orienting question results in better memory (Roediger and Gallo, 2001; Rouet et al., 2001). Targets are more important for task-goals and thus more deeply processed. Remembering their meaning and location is beneficial for adaptive behavior. Moreover, they are probably also processed longer than non-targets.

How about location memory? It was hypothesized that navigation-orientation would lead to more accurate location memory, both because link processing is more surface-oriented and because remembering locations of links would be facilitate navigation. Contrary to this, content elements were less of the target in content-orientation than in navigation-orientation, but navigation elements' locations equally well remembered in the two task condition. It seems that locations of elements are incidentally picked up in both task orientations, but the fact that navigation elements are more varied in their location and appearance makes guessing their location accurately difficult. Navigation-orientation also resulted in remembering navigation elements being located more towards the left side of the screen and content-orientation in a bias towards the top. At this point we have no explanation for the angle distortion in terms of the current model. One possibility is that content-oriented users use content regions as their frame of reference when recalling positions of web elements, causing a slight bias towards the top center region, whereas navigation-orientation leads to referencing towards the left side. Another possibility is suggested by results from a study by Farivar et al. (2000), who showed that when participants asked to recall presented words, words on larger font were remembered more often as being presented on top, while small targets were incorrectly remembered as being presented on bottom. Authors suggest that larger items are normally presented on top (i.e. headers in newspapers) and that memory uses this knowledge in 'compressing' the location and size information to only one description, 'header'. It might be that the two orienting tasks differ in the amount and quality of this kind of chunking. Further studies are needed, however, to replicate this effect.

#### 4.2. *Limitations to the model*

*Exploratory viewing.* The four-step model of attention guidance may be too straightforward because, if the web page is unfamiliar, users are likely to engage in exploratory viewing. In natural scene viewing, however, it is known that gaze duration is longer for elements that are less likely to be found in a particular scene (Friedman, 1979). Most of the studies studying web page viewing have been administered in contrived task

conditions using simple, unrepresentative stimuli (e.g. menus consisting of numbers or letters in a column; e.g. Nilsen, 1991) and speeded response tasks. Consequently, this aspect of web page viewing has been largely ignored. During exploration, a coherent perception consisting of background elements and multiple discrete elements arranged spatially is constructed. This representation is constructed in co-operation of information gathered across fixations and pre-existing knowledge about the scene genre (web page) in general (Henderson and Hollingworth, 1999). The few relevant HCI studies are contradictory. For example, Josephson and Holmes (2002) found some support for the notion that with repeated viewings of web pages, users' scanpaths become to follow a habitually preferred path, whereas Goldberg et al. (2002) found no evidence of scan becoming more directed as screen sequence increased. More work is clearly needed to understand exploration, because it is most likely to affect representations. In line with this, Altmann's (2001) SOAR-based model of near-term memory in programming assumes that storage of event chunks in memory is a by-product of attending to that item. According to Altmann, mere 'browsing' may result in memory for locations and meanings of elements. It would be interesting to know if navigation- and content-orientation lead to different exploration strategies in terms of how attention is guided.

*Matching model.* The lexical-matching model of navigation-orientation might also be too simplistic. First, user's goal is not always easily translated into a target description. This might lead to adopting a strategy of going through all links exhaustively and then deciding which one is the closest match. This strategy would require comparing options to the match and ranking them, something that could be considered as deep processing. Second, sometimes none of the available links on the page match to the target description. In this situation, user has to either decide the closest matching link, or simply navigate back in the hierarchy to find another branch to try. The first of these could be considered deep processing of the link elements. Third, many available links can weakly match to the target description. For example, if user's goal is to find a software upgrade, links 'products', 'support', and 'downloads' would all match goal. In this situation, again, user is required to find similarities and differences between options and target, which is semantic orientation. Moreover, in experiments, people put much more effort in finding the correct solution than they do when they have no experiment-induced social pressures. These considerations suggest that the absolute level of semantic memory in navigation-orientation should be moderately close to that of content-orientation. The results support this supposition.

Analogous criticism extends to our description of content processing. As noted already in the first paragraph of this paper, there are many simultaneous operations carried out when reading and comprehending content (Kintsch, 1974; Kintsch and van Dijk, 1978). The key question in future studies is to focus selectively on those orientation styles in reading that are important in the use of hypertext systems. These could include reading more information on a topic, summarizing a text, monitoring a set of variables, explaining text, sharing information with colleagues, re-finding a previously seen piece of information on a page, etc. (Byrne et al., 1999; O'Day and Jeffries, 1993). Moreover, the material itself has also a prominent role in guiding levels of processing. For example, Baccino and Thierry's (1998) participants were faster and more accurate at locating text areas where perspective shifts occurred. They proposed that spatial encoding is a strategic

process optimizing potentials by backtracking to important parts of a text in order to solve referential difficulties occurring later in the text. Similarly, Rouet et al. (2001) conclude that “text processing can be successfully guided toward deeper levels of comprehension by means of appropriate task settings and presentation formats” (p. 163). This notion is interesting since it implies that quality of content is important: the way the material engages levels of processing affects subsequent ability to remember semantic and spatial aspects of that material.

## 5. Implications to human–computer interaction

Memory for user interfaces and information content is unarguably crucial in the information age. The way information is encoded, stored, and later on retrieved determines our success in many information tasks. In this paper, we have studied the role of memory in the tasks of finding information from the user interface (here: navigation-orientation) and mentally analysing it (here: content-orientation). As shown in the experiment, and summarized in Table 1, task characteristics radically affect what elements on the page are remembered, and how they are remembered.

Particularly, it was found that navigation-orientation leads to better feature memory for navigation elements than for content elements, and to a better overall feature memory for the page than content-orientation. However, non-target navigation elements are as poorly remembered as content elements. Concerning location memory, memory is equally poor for navigation and content elements, and navigation elements are biased towards the left side of the screen in memory. In content-orientation, content elements’ features are better remembered than navigation elements’. Here, location memory is more accurate for content elements than for navigation elements, and is biased towards the top of the screen.

In what follows, the role of these results in web interaction is examined. Then, practical implications are drawn.

### 5.1. Role of memory in guiding interaction behavior

The model proposed above makes predictions on the stage in search where memory traces are formed, and on the quality of these traces. Two important aspects of this memory are discussed below: their role in guiding search and their context-dependence.

*Explicit vs. implicit memories.* Some 20 years after the birth of the levels of processing approach, psychological and neuroscientific evidence begun to accumulate showing that memory is not unitary but there are many subsystems, and, importantly, each serve different function and have their own characteristic properties (Schacter and Tulving, 1994; Schacter et al., 2000; Squire, 1992). The most relevant division of memory systems here is the distinction between *explicit* and *implicit* memory (Graf and Schacter, 1985; Schacter, 1987). Explicit memory consists of episodic (i.e. events) and semantic knowledge (i.e. facts) that are accessible to consciousness, whereas implicit memory can be defined as past events influence on cognition and behavior—in the absence of awareness of that influence. It is modality-specific and independent of explicit memory. This division is important, because the present memory tests required conscious retrieval

and thus tap explicit memory. That participants' confidence on their answers closely paralleled their true performance supports this notion (Yonelinas, 2001).

Assuming that our memory tests really tapped mainly explicit memory, what, then, is explicit memory worth in interaction? Melcher and Kowler (2001) showed that even when people have to use very fast saccadic eye-movements to scan a scene shown on a computer, scene memory is relatively good and persistent. However, a careful analysis of the recalled elements and related eye-movements showed that this visual memory was not utilized in planning the eye-movements in the scanning task. It was speculated that the use of this kind of explicit recollection is too slow to help in rapid on-line decision of oculomotor acts. Similarly, Chun and Jiang (2003) showed that representations of spatial context that control visual search are not accessible to consciousness but effect response times even after one week of delay period between tests. It therefore seems likely that explicit memory does *not* have a prominent role in controlling eye-movements in web browsing. Lauwereyns and d'Ydewalle (1996) made an analogous conclusion from their more HCI-related study of expert's eye-movements and verbal protocols.

Instead of on-line control of eye-movements, explicit memory of web elements may be called for in two cases: (1) when there is a need to remember information about the web page when it is not visible, or (2) when the automatic processes relying on implicit memories fail and users must relapse into voluntary control of action. The first case may occur, for example, when planning retrieval strategies or verbalizing information about a web site to other people. The second case may occur, for example, if the user fails to find a target or makes an error and notices that. In both cases, voluntary control is needed in considering different alternative strategies in approaching the problem. This decision-making obviously draws on consciously recollected memories on how information is organized in the user interface. These hypotheses, however, should be empirically tested.

*Cue-dependency.* In the domain of explicit memory, retrieval often depends on the availability of contextual cues. The classic example of cue-dependency is the distinction between *recognition* and *recall*. This distinction is important here, because it is known that different levels of processing can have separable effects on them (Greene, 1987). It is likely that navigation leads to encoding that is more accessible in situations cued by directly observable information. This could lead to a situation where it was more difficult for navigation-oriented users to verbalize and recollect contents of their memory, whereas their recognition accuracy could be on the same level or even better than in content-orientation. Therefore, it may not be surprising that we found that navigation-orientation led to poor ability in recalling locations of elements. In like manner, Christie and Just (1976) who showed that readers' ability to retain and make use of locative information for both organized and disorganized passages is better if the passage is in view at the time they are answering the questions. They concluded: "Apparently the locative information provides an index to the spatial distribution of sentences in the passage." (p. 702). Similarly, Altmann's (2001) SOAR-based model of programmer's memory predicts that forgetting of information is cue-dependent, meaning that the item may be well recalled in some contexts for longer time whereas its accessibility could rapidly decrease in other contexts. Yet another example is a study by Ehret (2002) who showed that in situations where users continuously have to rely on their memory in finding interface elements, they, as a by-product of this effort, incidentally learn their locations. When memory was not

needed, but targets ‘popped-out’, memory trace for the location of targets was poor. The conclusion is that different orientations lead to benefits in different cuing conditions as noted by theories of memory retrieval that emphasize the match between the encoding and retrieval conditions, such as the transfer-appropriate processing hypothesis (Morris et al., 1977) and later elaborations of the LOP framework (Craik, 2002; Lockhart, 2002). Future research should not simply measure memory performance, but also discuss and show their functions in real-world tasks (de Vries and de Jong, 1997).

## 5.2. Practical design issues

In the following, practical design issues are discussed. Apart from the basic usability and user interface design implications proposed first, memory and memorability is an important issue in more specific research questions in web interaction, notifications and adaptation.

*Designing memorable web interfaces.* Memory is highly selective, and the selection processes are determined by the interplay between task processing demands and the user interface design. The model proposed in Section 4 extends the empirical findings by proposing a more detailed account of how task characteristics guide attention, which in turn determines the quality of resulting memory traces. As shown along the way, a variety of design choices can affect this process, directly or indirectly, for good or for worse. For example, the following design factors can be elicited from the model:

- Positioning navigation regions to their expected locations supports predictability and memorability.
- Positioning task-relevant regions together makes their location more predictable and memorable. Placing these regions according to conventions further facilitates these goals.
- Conforming to visual conventions helps directing attention quickly to task-relevant regions of the interface and remember their surface features correctly.
- Visual distinctiveness of task-relevant regions helps directing attention to them and promotes their memorability.
- Consistent use of landmarks (e.g. navigation panels, logos, figures) helps directing attention quickly to task-relevant regions and promotes memorability.
- Organization of elements within the group (e.g. links within a link group) should adhere to their expected scanning order. First items in the group are more likely to be scanned and thus later remembered.
- Labels (e.g. link titles and content headers) should match closely to target descriptions. Short and descriptive labels promote quick finding of targets and memorability.

Considering these design factors may help designers in designing memorable and easily learnable web pages.

*Adaptive hypertext.* Knowing what the user knows is essential for designing adaptive interfaces to WWW. As shown in the experiment, solely by knowing the task-orientation, one can make broad predictions on what is remembered of the page and how. Information about the representations the user possesses can be used for several intelligent purposes.

First, adaptive presentation of content could better organize content according to what the user needs to know or what most likely has been forgotten. Second, adaptive navigation support could give a more prominent presentation format for links that the user could be interested about, but is unlikely to remember or know. Or, sitemaps could be designed with those contents preferred that the user is unlikely to remember. Third, adaptive help could better suggest solutions that are more likely not to be already known by the user. In summary, we can bring more relevant information to user's focus of attention, given that we know what he/she has learned and remembers.

*Notifications.* One central HCI issue in notifications and other interruptions is their deleterious effects on memory. By hampering our memories of task-relevant information, interruptions do not only cause slowing down of task performance, but they also cause frustration. The main point in the levels of processing framework is that what we remember is a corollary of task processing characteristics. By modeling user's tasks, one can thus make inferences on his/her knowledge of the user interface and its information contents. In designing notifications, this model can be used to minimize the negative effects of interruptions on memory by at least two ways. Firstly, one can adaptively trigger notifications at a time when the user is likely to remember the content robustly enough to not be vulnerable to an interruption; that is, at a time the material is semantically processed and thus deeply encoded. This could markedly facilitate task resumption after the interrupting task that would normally require reading and rehearsing the content studied before the interruption. Secondly, one can facilitate task resumption more directly by providing adaptive memory cues about the interrupted task. Consider, for example, providing short summaries of previously read material to help bring in mind the information content, or highlighting a navigation history to facilitate resuming interrupted navigation.

## 6. Conclusions

How information content and user interfaces are remembered is an important, but underresearched topic in human–computer interaction. The present study has proposed a simple yet powerful heuristic adopted from the levels of processing research in cognitive psychology. It entails making predictions of memory performance by looking at task demands. Predictions of the framework were tested in an empirical study utilizing ecological materials and task demands. It was shown that memory for features and locations of web elements can be radically different between navigation- and content-orientation. A model was proposed that integrated the levels of processing framework to an emerging body of research in eye-movements and attention in scene perception, menu selection, and web browsing. The model describes four stages in information tasks that have different perceptual, attentional, and cognitive characteristics—and thus different memory impacts as well. The kind of explicit (i.e. consciously accessible) memory tested in the experiment was suggested to play a role when the more automatic and implicit processes fail, and in novel problem solving situations. Design of memorable user interfaces, adaptive hypertext, and notifications can draw concrete implications from the results of this work.

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