

## **Chapter 6. Conclusion and discussion**

This chapter starts with a summary of the main contributions of this thesis, then shortly concludes on the extent to which the objectives of this research stated in Chapter 1 have been attained, and ends with discussing some restrictions, limitations and opportunities encountered throughout this project.

### **6.1. Summary of contributions**

Throughout this project, attention was paid simultaneously to theory, method and real-world applicability. Web navigation was grounded in the theories of Cognitive Science, in particular Text Comprehension, and Information Science, in particular Human-Computer Interaction. Methodological paradigms of experimentation, statistics and modeling have been applied. The whole research was placed as much as possible in realistic settings and practical needs of Web engineering and design has always guided research decisions.

This section presents a summary of the main contributions of our research. The first subsection presents contributions to Information Science and Human-Computer Interaction, and the second subsection presents contributions to Cognitive Science and Hypertext Comprehension. Arguably, this distinction is somewhat artificial since each contribution is part of all these fields; however, presenting our findings in this way emphasizes both the theoretical and the applied value of our research.

#### **6.1.1. Contributions to the fields of Information Science and Human-Computer Interaction**

There are three main contributions of our research to these fields: facts regarding the use of Web applications, methods to gather and interpret information about user behavior, and ways to conceive and deliver effective Web navigation support. Each of these contributions will be briefly summarized here. The interested reader is pointed back to sections of this thesis where more detail can be found, and we also cite here our own publications in which these aspects are treated.

##### **6.1.1.1. Facts regarding the use of Web applications**

We have documented how real Web applications are used. A large number of users have been invited to our Usability Lab, where they have performed Web tasks of various sorts from several domains (Juvina & Van Oostendorp 2003). Their behavior was recorded by various means: Web-logging, screen capture, video, audio, paper-and-

pencil, etc. A large amount of data has been analyzed and interpreted in order to discover the regularities that can inform scientists and practitioners. The most important findings in this category are:

- Using the Web can be seen as a dialogue: users inform Web applications about their choices and Web applications “reply” with content. Thus, interaction paradigms such as reading/writing and talking/listening can be applied in understanding Web navigation behavior. In addition, involving spatial features (syntax) in processing contents (semantics) is a distinguishing characteristic of Web navigation.
- In order to adequately characterize Web navigation behavior, a complete set of criteria is needed, including objective (performance), subjective (satisfaction) and undesirable aspects of task execution (disorientation).
- Users re-visit pages not only because they forget what they have seen before, but mostly to get acquainted with the structure of the information space, which in turn helps them in preventing disorientation (see Section 4.1.2.2 where navigation styles are discussed).
- Using the Web via a screen reader is more taxing from a cognitive point of view, and users are more vulnerable to dissatisfaction and disorientation if they have to visit a large number of pages to reach their goal (see Section 5.1).

Observational and empirical research has allowed us to discover what are the most important user-related factors that determine performance in Web assisted tasks. Evidence from various studies (see Section 4.2) converged toward a combination of two factors: a structure related factor (spatial ability and average connected distance) and a content related factor (domain expertise and reading time).

Studying a large number of factors in relation to a comprehensive range of outcomes of Web navigation tasks was useful in several respects. A limited number of significant predictors were identified, and their relative contribution to the accuracy of predictions was estimated. Since factors were studied together and the stepwise method of regression analysis was employed, it was possible to rule out factors that were only marginally significant or confounded with one another. This is an important contribution of this research in comparison with other work of this type. Most of the studies addressing individual differences in Web navigation (including those referenced here) are restricted to a limited number of user characteristics, and for this reason they can easily overlook other (more important) characteristics. For example, the influence of working memory on hypertext navigation as reported by Tucker and Warr (1996) might have not appeared as significant if spatial ability was included as a predictor in their model (Tucker & Warr

1996). Our results show that *spatial ability* is more important for Web navigation performance than *working memory capacity*. These findings have been well received by the research community (Juvina & Van Oostendorp, 2005) and confirmed by more recent studies (Gugerty, Treadaway et al., 2006).

#### **6.1.1.2. Methods to gather and interpret information about user behavior**

Factors such as spatial ability can be measured only with specialized tests, which cannot be implemented in realistic Web applications. For this reason, we have proposed using Web-logging data to calculate metrics of Web navigation behavior (Section 4.1).

By summarizing raw Web-logging data such as use of navigation actions, page visits and re-visits, links followed and duration of visits, *first-order metrics* have been computed, such as:

- Path length
- Amount of re-visits
- Back button usage
- View time per page
- Fan degree
- Number of cycles
- Net density
- Average connected distance

*Second-order metrics* were computed as linear combinations of the first-order metrics by the aid of principal component analysis. They were completely specified (numerically) by first-order metrics. However, interpreting their meaning and labeling them was based on their correlations with user characteristics and task outcomes. The interpreted second-order metrics were labeled *navigation styles*. Two of these navigation styles are described below:

- **Flimsy Navigation** is a parsimonious navigation style. The navigation path was not very elaborate, most of the navigation taking place around the homepage. Time was spent more with processing content than with figuring out the hyperstructure that showed where the relevant information was. A high score on the flimsy navigation style was associated with low Internet expertise ( $r=-0.5$ ), low working memory capacity ( $r=-0.38$ ), and high perceived disorientation ( $r=0.46$ ).
- **Laborious Navigation** involves intensive use of navigational infrastructure provided by the site. Users seemed to employ a trial and error strategy. They followed links just to see if they were useful or not. They figured out quite fast when paths were not leading towards their goal and returned. Re-visits were quite numerous but they were not redundant: once a page was re-

visited a different link was followed, it was just another trial. This navigation style was associated with high episodic memory ( $r=0.49$ ) and low spatial ability ( $r=-0.40$ ). This style indicates the type of re-visitation that does not relate to disorientation. The user needed to look around for a while until she/he had a good representation of the site structure, because she/he had a weak spatial ability. Yet, her/his memory prevented her/him from making redundant re-visits. This component shows how people compensate for the lack of spatial ability by effort and memory, and do not necessarily decrease performance (no correlation with task performance was found). It also shows why re-visitation is not always associated with disorientation. The term "laborious" should not suggest a correlation with effectiveness (task success). This style is effective in compensating (to some extent) for lack of spatial ability and avoiding a major decrease in performance and increase of perceived disorientation. But the style itself is not necessarily effective, it is not employed by highly effective users.

A *semantic metric*, called *Path adequacy*, was calculated based on navigation data and the task description that subjects were provided with at the beginning of a task. A navigation path was considered to be a concatenation of semantic objects that the user has encountered in her/his way. As semantic objects we have used page titles and link labels. Link labels were better than page titles in characterizing user's navigation path and computing semantic metrics, because they convey specific information. A navigation path was used in simulations of Web navigation as an indicator of contextual information involved in selecting specific navigation actions. *Path adequacy* was determined as a coefficient of semantic similarity between a navigation path and a task description. Semantic similarity was calculated with Latent Semantic Analysis (LSA). *Path adequacy* calculated at the end of a particular task was significantly correlated with *spatial ability* ( $r=0.36$ ), and *task performance* ( $r=0.47$ ). *Path adequacy* calculated at each step of a navigation session was used in simulations of Web navigation as a coherence criterion involved in selecting specific navigation actions.

Thus, we have shown that different types of knowledge about users can be inferred based on the kind of information that is extracted from Web-logging data: *syntactic* (structural) information indicated mainly users' navigation styles, for example, if they rather re-visit pages than viewing new pages, if they return using the back button or just by following links, etc. (first- and second-order metrics); and *semantic* information indicated if users were effective in pursuing their goals (path adequacy) independent of their navigation styles. We have argued for using

navigation metrics in building adaptive Web applications, such as recommender systems (Juvina & Van Oostendorp, 2004).

### **6.1.1.3. Ways to conceive and deliver effective Web navigation support**

We have suggested that a cognitive model of Web navigation can be used as generator of Web navigation support, particularly when the model is specified in computational terms and can be run as a computer program (Juvina & Van Oostendorp, 2005). In a series of empirical studies, several ways to deliver model-based navigation support have been tested.

Suggestions of goal-relevant links via voice (Section 4.4) have been shown to increase task performance. In addition, users with low spatial abilities had a higher performance increase than users with high spatial abilities. It seems that the offered navigation support prevented users from spending time and cognitive resources with those navigating actions that are not directly effective but are usually employed in order to accurately represent the information structure. Users engage in apparently useless navigation actions in order to get acquainted with the context of a particular piece of information, which is eventually useful in judging the value of that particular information. It follows that users with low spatial abilities are probably less able to represent the information space and this is why they benefit considerably when the cognitive model is doing this job for them. However, suggestions via voice were not well received from a subjective point of view, users found them annoying and manipulative.

Graphical suggestions in the form of small red arrows pointing at the relevant link (Juvina & Herder, 2005) were not only effective but also well received from a subjective point of view (Section 4.5). Men receiving support showed a decreased level of perceived disorientation as compared with men in the control condition, whereas such a difference was not found in women. Navigation support in the form of graphical link suggestions changed the structure of users' navigation behavior. In the support condition, participants used the back button less and the average connected distance in the navigation path was higher than in the control group. Thus, link suggestions caused the subjects to navigate in a more linear manner and reduced the amount of backtracking. High performers tend to take fewer suggestions than average and low performers. However, within each performance level, taking more suggestions is associated with increased task performance.

In the case of using the Web via screen readers, we tried to implement suggestions by changing the order of items on Web pages, in the sense

that relevant items were placed upper so that they are read sooner in a sequence. This manipulation was not successful, most probably because changing the order of items on Web pages breaks the coherence established by the content authors (Section 5.1).

### **6.1.2. Contributions to the fields of Cognitive Science and Hypertext Comprehension**

There are two main contributions of our research to these fields: amendments to existing models of Web navigation and applying well-established theories in new settings.

#### **6.1.2.1. Amendments to existing models of Web navigation**

CoLiDeS+, our proposed augmented version of CoLiDeS, has been shown to account for important aspects of user navigation behavior such as: considering contextual information when judging goal-relevance and employing navigation strategies (Section 4.3). This was done by including the user's navigation path in the model and allowing the model to backtrack and reconsider past selections (e.g., next-best strategy). The model has been empirically tested for how well it simulates the actual user behavior and whether it is useful in generating Web navigation support. Although it does not simulate the user behavior particularly well, CoLiDeS+ was shown to perform better than its previous version (CoLiDeS). CoLiDeS+ was used to generate navigation support and this support had a positive impact on user behavior and task outcomes. A number of limitations of CoLiDeS+ have been identified, such as: low accuracy in simulating the users' behavior, caused mainly by its reliance on LSA to compute semantic similarities, and a high amount of hand-coding required for running simulations.

An ACT-R model of Web navigation has been presented in order to demonstrate the possibility of overcoming some of the CoLiDeS+ limitations. This model offered computational solutions to implement key features of Web navigation behavior as reported in the literature and found in our empirical research. Some of these features were shared with previous models – selections based on goal relevance (information scent) (SNIF-ACT and CoLiDeS); backtracking, threshold and opportunistic strategies (MESA); back coherence (CoLiDeS+) – others were implemented here for the first time – intertwining between conservative and explorative strategies, and post-valued recall.

#### **6.1.2.2. Well-established theories applied in new settings**

Well-established theories of text comprehension (Kintsch, 1998), memory and cognition (Anderson, 1983), and working memory

(Baddeley, 1986) have been used in our experimentation and model development processes. While using these theories to explain Web navigation behavior, specific aspects have been noticed. For example, coherence of the memory representation plays an essential role in reading comprehension (Van den Broek, Young et al., 1999) whereas in Web navigation goal relevancy is essential and coherence is secondary (Section 4.3).

In addition, in Web navigation a spatial representation of the information space is much more important than in the case of reading plain text. The fact that spatial ability was the most important determinant of Web navigation performance was an unexpected and non-intuitive result. Why would performance on a semantically void mental rotation task predict performance on a semantically intensive Web navigation task? We have shown that the correlation between spatial ability and Web task performance is a robust result:

- It was found in three successive studies.
- Possible confounders for this correlation – working memory capacity, episodic memory, Internet expertise, reading comprehension, reading speed, and cognitive style – have been checked for and proven to have no influence.
- The correlation between spatial ability and another type of computer task performance has been found non-significant.

Correlations between spatial ability and navigation metrics have helped us understand the behavioral mediators between spatial ability and Web task performance. Spatial ability is negatively correlated with metrics involving re-visitation (re-visits, back button, and fan degree). It seems that spatial ability helps users in figuring out the information space structure so less re-visitation is needed. Supposedly common cognitive processes are used to represent and operate on an information space and to mentally rotate objects in a three-dimensional space. Even in the case of VIPs' reading or Web use, spatial aspects are essential (Section 5.1). Presumably both sighted and VIPs represent information in terms of *what* (content) and *where* (location). For sighted users, information of the type *where* could literally mean visual location. For VIPs *where* information could refer to: temporal position of a particular information element in a sequence, category membership, etc.

Our findings showing the importance of spatial cognition in Web navigation (Chapters 4 and 5) can be added to the body of evidence of established theories of text comprehension, memory and cognition.

## 6.2. Conclusions

This section provides conclusive answers to the research questions stated in Chapter 1.

### 6.2.1. What are the most important factors determining success in Web-assisted tasks? How can one measure or estimate these factors in an automatic way?

Success in Web assisted tasks depends essentially on a combination of spatial cognition and domain knowledge. Spatial cognition is involved in representing the structure of the information space while domain knowledge is necessary for understanding and selecting relevant content. These factors are expressed in the user's behavior. We have shown that users' behavior can be automatically logged and various navigation metrics can be computed based on these logs. Metrics referring to the structure of user navigation were called syntactic metrics, whereas metrics referring to the visited content were called semantic metrics.

### 6.2.2. What are the explanatory cognitive mechanisms for the identified factors? How can one implement these mechanisms in a (computational) cognitive model?

Users build and update a mental representation of the information space being navigated. This representation has a spatial character (in the sense that positions and distances are relevant, but not in the sense that it is visual or three-dimensional), and it is relatively independent of the contents (semantics) being represented. Users make assessments of relevance and decisions to select particular contents based on:

- prior knowledge they have about those contents, and
- knowledge they gain from the local context of those particular contents (i.e., what contents they link to).

We have proposed a cognitive model (CoLiDeS+) in which assessments of relevance are made based on both

- prior knowledge, modeled by an LSA semantic space, and
- contextual information, modeled by users' past selections.

We have also shown in an ACT-R demonstrative model how a developing memory representation can be used to mentally traverse (backward or forward) an information space.

### **6.2.3. What kind of Web navigation support can be conceived based on the knowledge gained from the previous questions? What impact has this support on users?**

Navigation support should aim at preserving the information space structure and helping users traverse it in an efficient way. We do not favor extracting the relevant information from its original context as in the case of search engines. Instead, we have shown that emphasizing the relevant information in its original context helps users to discern between relevant and irrelevant information, and compensates for their deficient spatial abilities (when this is the case).

Providing contextual aids for the link-following behavior is not a new idea (Hardman, Bulterman, & Rossum, 1993). We have investigated it in the context of common use of the Internet under the assumption that the structure and contents of the information space are not known in advance but defined dynamically based on the user-system interaction. For instance, keeping the information in its original context is also used in the ScentTrails agent (Olston & Chi, 2003). ScentTrails starts by performing a search based on keywords entered by the user. Pages returned by the search engine are not immediately displayed to the user; instead, paths to these pages are suggested by means of highlighting. Thus, the user gets the chance to see the context and to collect additional information along the path. This approach assumes that the supporting agent knows the information space (e.g., a website's content and structure), so that a path can be identified from the search results to the user current position and relevancies of items to search results can be computed. In contrast, our approach assumes that the supporting agent is exploring the information space in the same manner as the user. Suggestions are made based on the goal relevance of links on the current page and their consistence with the user's past selections. It only needs to know the user's goal and to track the path followed by the user. These features allow the supporting agent to behave in an adaptive way. Our solution is less accurate than solutions based on an *a priori* knowledge of the system; however, it has less implementation constraints, a lower computational complexity and it is more realistic: users do switch websites in searching for their targets (Nielsen, 2006) and most information spaces are changing environments.

### **6.3. Discussion and future developments**

It was one of our most important desiderata to do ecologically valid research; we have used real websites and realistic tasks as much as possible. While this impetus is not to be regretted, it must be admitted that this was the cause for results that were not always very compelling,

at least in terms of statistical significance and magnitude of effects. Limitations of our studies in terms of sample size and accuracy of measurement prevented us from applying powerful statistical techniques such as Structural Equation Modeling. In addition, it is a matter of discussion how accurate and complete a cognitive model of Web navigation can be. We have opted for a trade-off between accuracy and practical relevance. CoLiDeS+ was conceived with the aim of building model-based navigation support. For this reason, some of the methodological criteria of cognitive modeling were relaxed. The simulation of user behavior was not complete. For example, the model did not have a mechanism to identify target content pages. Such a mechanism would have been extremely difficult to build and it was not really necessary for our intended use of the model. The model was meant to work alongside the user and suggest links that are relevant to a given user goal. The user was assumed to take those suggestions or not and stop when the target page was reached. Performance of cognitive models in the field of Web navigation depends on progress made in other fields such as machine learning and natural language processing. For cognitive modeling, a task domain as weakly structured and knowledge-intensive as the one proposed here is a great challenge. A cognitive model of Web navigation needs to handle natural language, large knowledge networks, and a great deal of sub-symbolic computations. These aspects are not part of the traditional work in cognitive modeling research (Gluck & Pew, 2005) but are becoming increasingly prominent in the cognitive modeling community (Pirolli, 2005). A foreseeable problem will be to handle the computational complexity required by up-scaling cognitive models to be included in adaptive Web applications as generators of navigation support.

The research presented here has not dealt with domain-specific applications such as intranets and specialized knowledge repositories. The target population was that of the common Web users performing everyday Web tasks, such as online shopping, requiring no or little domain knowledge. For this reason, the Semantic Web technology (Bocconi, Nack, & Hardman, 2005) was not applicable. Instead of particular ontologies corresponding to particular application domains, we have used semantic spaces corresponding to particular user populations. A semantic space contains all the concepts that a particular user population is assumed to have encountered, and it can be used to compute associations between concepts based on co-occurrence and dimensionality reduction. The advantage of semantic spaces over ontologies is a lower amount of hand-coding needed (they are just bags of words); the drawback is lower accuracy.

CoLiDeS+ (as well as other cognitive models) relies on the users' goals to be known. It was not our concern in this research how user goals are

entered in an adaptive Web application or how such an application could infer them. In a previous paper (Juvina & Van Oostendorp, 2004) we suggest a way to infer pragmatic information (including users' goals) based on users' navigation history. This would be an interesting direction for future research. Another point to be addressed in future research is the dynamic characteristic of the user's memory representation (including the goal representation); so far in our models the goal remains unchanged during a navigation session, and this is a questionable assumption.

