Exploring Hypermedia-Based Information Spaces on Small Screen Devices

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March 15, 2004

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1. Introduction

The proliferation of the World Wide Web has resulted in widespread exposure to hypermedia[1]-based information spaces, and has made online information-gathering a common activity for millions of North Americans (Howard et al., 2001). With wireless access to the Internet becoming more prevalent, there has been an observed trend towards mobile connectivity via compact and handheld devices, such as net-enabled personal digital assistants (PDAs) (Chapman, 1998). Some have suggested that handheld technology will overtake the traditional workstation paradigm as ubiquitous computing becomes more dominant (Chen, 1999; Weiser, 1998).

Handheld computing varies greatly in form and function, and the industry is certain to evolve with greater rapidity as major technological hurdles are overcome, and users are introduced to (and discover on their own) novel applications within the new mobile/hand-held paradigm. Throughout this paper, the term *small screen devices* will be used to collectively refer to a relatively broad range of commercial products that are currently available, such as Research In Motion's Blackberry™ wireless communication devices (www.blackberry.com), Hewlett-Packard's IPAQ PDAs (www.hp.com), and Ericsson's web-enabled line of mobile phones (www.sonyericsson.com/ca/). Although these products range in terms of their respective hardware and software specifications, target users, and envisaged functional applications, they are nevertheless convergent in that they all support navigation of hypermedia-based information spaces—namely, the World Wide Web—within a unique set of constraining parameters: small screen size, proximal physical relationship to the user, non-conventional input modalities, and speed, battery, and bandwidth limitations, to name a few. Some of these constraints (such as speed and bandwidth) will no doubt become less pronounced as the technology evolves, while others (screen size and other ergonomic factors) are likely to remain relatively stable over time.

Gaining insight into the how hypermedia-based information spaces are navigated—that is, how they are conceptualized and traversed—on small screen devices will be useful for a number of reasons. Designing navigable content is important to companies and organizations that want to utilize (that is, *make usable*) their online content for small screen devices. Also, innovation in the area of browser interfaces for small screen devices will allow users to better take advantage of

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[1] In the present discussion, the term hypermedia is used to describe hypertext-based information systems that include additional media forms (e.g. graphics, audio, and video).

web-based information services in a mobile context. Beyond these industry-oriented motivators, understanding how users interact with hypermedia-based information spaces on small screen devices sheds light on the nature, and possibly the future, of our society's relationship to information.

This document outlines prior research and scholarly work that is topically relevant, and proposes measures for further investigating how information spaces are perceived and traversed when they are accessed through small-screen devices. In particular, the ensuing sections present conceptual and methodological groundwork that is intended to address the following research question: *How, if at all, do the physical and interactional parameters of an information device, such as screen size and input mode, affect one's conceptual model of a hypermedia-based information space?* This question is a special case of the larger question: is an ecological approach to information spaces warranted? That is, do individuals' conceptions of an information space change as the means through which they accesses this space varies?

2. Previous Work

While there is a large body of relevant previous work, this has not been assembled under a single heading that would be directly applicable to the proposed study. Prior research is therefore presented in three parts. Kim and Albers (2001) lament the current state of affairs in small screen device interface guidelines, arguing that these "reflect the interface design of current web pages and computer systems in general. However, this view considers the PDA as simply a miniature computer monitor, a view that is problematic" (p. 194). The ecological approach to information spaces, proposed in Section 2.1, is intended to address this problem by facilitating a suitably flexible and productive conceptual framework. There is furthermore the issue of how best to discover and analyze users' underlying mental models of a given information space. Section 2.2 considers three possible approaches in this respect. Finally, it will be necessary (Section 2.3) to consider findings that specifically address how information spaces are engaged and perceived through small screen displays.

2.1 Ecological view of information spaces as a conceptual frame

The informational dimension of texts, hypertexts, and other forms of knowledge media (KM) has traditionally been conceived of as a spatial one (Boechler, 2001[2]). Terms like “navigation” and “environment,” and neologisms such as “hyperspace” have come to be associated with the World Wide Web. Rijken (1999) considers how media design relates to architecture by examining “a number of possible relationships between their central phenomena…information and space” (p. 45). He lists nine conceptual configurations for the terms “information” and “space,” including the following three: (1) information *as* space, real world metaphors; (2) space *in* information, virtual reality; and (4) *information space*, information environments. On this latter configuration, he makes the following observation:

> I think architecture can feed the discourse on these kinds of information spaces. The user creates an “experience” while acting within an information environment. There is no single route or purpose; instead there is a potentially endless set of paths or actions. It reminds me of how a building or a town doesn’t force a single specific route or function, but offers a number of connected spaces and possibilities. However, design decisions do ultimately determine the possible experiences. The space then works as a process facilitator. Experience is the dynamic end result of design in media as well as architecture. (p. 49)

A similar emphasis on the user’s experience in his encounter with a particular information space is found in the literature on information needs analysis/information seeking behaviour. For example, Dervin (1986) profiles the emerging “alternative” paradigm in this domain, pointing out that “[i]t focuses on understanding information use in particular situations and is concerned with what leads up to and what follows intersections with systems…it examines the [information] system only as seen by the user” (p. 16).

Yet to substitute one theoretical disposition, whose analytical focus is decidedly information-centric, with another that solely attends to the user’s constructed experience is merely to replace one deterministic frame with another. The apparent stalemate can be avoided by moving to an affordances-based model, where the information space is viewed as one that is populated with—and, to an extent, constituted by—actual or perceived properties, called affordances. Gibson (1979) comments on the nature of affordances in his ecological model of perception: “an

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[2] It should be noted that Boechler challenges the notion that spatiality is the optimal metaphor for describing hypertext environments. In particular, she proposes that this convention may impede the development of a more accurate navigational model.

affordance is neither an objective property nor a subjective property; or it is both if you like…An affordance points both ways, to the environment and to the observer" (p. 129). In light of this model, an ecological approach to navigation of hypermedia-based information spaces on small screen devices is possible. Here, properties of the information space (e.g. textual affordances; see Toms, 2000), the technology by which it is mediated (e.g. Boechler and Dawson, 2002; Gaver, 1992), and aspects of a user's situation may all be taken into account.

Put in other words, if perceiving hypermedia-based information is like peering through a window into a physical space, then the ecological approach suggests that as the properties of the window (its size and opacity, the function and décor of the room in which it is situated, etc.) is varied, the world beyond the window changes as well. The present study sets out to understand how the user's perceptions of an informational landscape change when it is accessed through a small screen device.

2.2 Discovering the user's mental model of a hypermedia-based information space

There is an intuitive logic to the assertion that conventional hypermedia-based information space conceptualizations should first be understood before one can discover how these concepts change when the same space is alternatively accessed through a small screen device. It will be argued, however, that the question 'What does a hypermedia-based information space look like?' may be at least partially answered with respect to how it changes in the proposed context. Previous research has characterized the World Wide Web according to various conceptual schemes. For example, it has been viewed as a vast hyperlinked document database (Mayhew, 1998), a graph-like structure (Kleinberg *et al*., 1999; Kumar *et al*. 2000); and an object-oriented framework (Schwabe and Rossi, 2000; Song and Salvendy, 2003). From a systems design perspective, these models are useful in their descriptive power; but it is not necessarily the case that these reflect the kinds of models and conceptual schemas that users have in mind when they browse the Web.

According to Beard and Walker II (1990), a mental model of an information system "is an individual's internal set of interconnected ideas that incorporate what the system contains, the rules by which a system is governed, and possibly an explanation of a system's behaviour" (p. 452). Clearly, different technological and interactional properties will afford various kinds of behaviours with respect to a given hypermedia-based information space, but are these behaviours necessarily indicative of a user's underlying mental model?

One approach has been to assume that user behaviours are so indicative, and to develop interpretive schemes for translating behavioural patterns into underlying mental phenomena. For example, McEneaney (2001) used a set of graphical and numerical measures to directly represent and assess navigational behaviour. These tools include methods for visually tracing paths taken within a given hypertext, as well as descriptive metrics such as *path compactness* and *path stratum* (pp. 772-3). In his discussion of the study, McEneaney asserts that “navigational patterns and their associated metrics may be useful as indirect measures of user strategy and perhaps even of users’ success in cognitively modeling the domain represented by a hypertext” (p. 781). Results of his study suggest that there is an empirically significant relationship between these measures and performance in a hypertext search task. Boechler and Dawson (2002) applied multidimensional scaling (MDS) analysis to navigational path data—in particular, page transition frequencies, or the number of times users moved between two given hypertext ‘pages’ in an information space—to show how navigation tools affect navigation behaviour. They comment that, perceived through their proposed MDS interpretive scheme, dimensions of behavioural performance “may be abstract such as the conceptual relatedness between pages or concrete such as the physical distances between page labels on the navigational tool” (p. 99). Ward and Marsden (2003) have suggested that physiological measurements may be used to report on underlying mental events—such as changes in emotional valence, attention, and workload—that are respondent to web-related tasks. In each of these studies, behavioural data—typically in the form of some measure of navigational performance (although, in the case of Ward and Marsden’s study, the data gathered was physiological in nature)—is used to generate some understanding of how a given hypermedia-based information space is perceived by the user.

An alternative approach involves multiple subjective measures that are collectively applied in order to elicit a more qualitatively rich description of users’ mental models of hypermedia-based information spaces. Gray (1990) has been influential in her application of protocol analyses and users’ drawings of the information space to determine how mental models are constructed during hypertext navigation. She used a think-aloud protocol, wherein users verbally articulated their felt level of orientation within a hypertext-based system, along with expectations and reactions concerning the kinds of informational content they were associating with links that they clicked on. Users were also asked to produce hand-drawn sketches of their progress through the information space and comment on how large the space was likely to be, in terms of estimated number of pages, at different stages throughout the interaction. Through this methodological protocol, Gray' discovered, among other things, that users tended to 'get lost' in the information space when routine expectations concerning linear sequencing of content were violated. In other words, users tended to conceive of the hypermedia-based information space in terms of a book (whose content is typically arranged in ordered sequence) rather than a more complex and dynamic, network-like entity. Nielsen (1995) used a card-sorting technique to discover users' models of the information space as part of his usability testing protocol for Sun's public website. Participants were given cards representing conceptual tokens corresponding to content in the information space and asked to arrange these into piles based on their perceived similarity. Subjective measures such as these are useful for gaining a qualitative sense of what users' underlying mental models for a given information space are like.

A final methodological approach, which represents a relatively natural extension of the two discussed above, is to obtain both behavioural (quantitative) and subjective (qualitative) measures concurrently, noting any patterns or commonalities that emerge from the two corpuses of data. This approach is often undertaken in the hope that quantitative and qualitative observations will complement one another and ultimately lead to a more comprehensive understanding of user's mental model with respect to a given hypermedia-based information space. Data analysis for this approach tends to be on a higher order of complexity than in the previous approaches, since it requires a relatively robust translation between qualitative and quantitative frames. To the extent that Gray (1990) analyzed navigational path behaviour, her study (discussed above) was also a mixed protocol analysis. Cockburn (1996) used a symbolic notation to represent the users' navigational paths as they performed a series of hypertext tasks. He also employed a usability study to show that there were systematic discrepancies between the users' mental models of the browsing software they were using, and the actual functionality of that software. Song and Salvendy (2003) proposed an object-oriented model that simultaneously takes into account recorded navigational behaviour and elicited user experiences of an information space. Their model was used to develop an explanatory framework for how prior Web browsing experience is reused. Calisir and Gurel (2003) took both quantitative reading comprehension data and subjective measurements of perceived user control (elicited through post-task questionnaires) to determine how text structure and prior knowledge interact with one another to affect the hypertext browsing experience. Mixed measures protocols have become prevalent in human-centred interaction design (e.g. Preece *et al*. 2001; Rosson and Carrol 2001), and are particularly well suited for the present study, which is interested in measuring how the physical parameters of small screen devices effect navigational behaviour inasmuch as this reflects the user's underlying subjective experience of a given hypermedia-based information space.

2.3 Experiential and performance differences between typical and small screen devices

Having situated the present study within an ecological conceptual framework, and considered three methodological approaches for ascertaining and analyzing users' mental models of hypermedia-based information spaces, it is profitable to reflect upon prior work that specifically addresses how information spaces are used and experienced on small screen devices.

Jones *et al*. (1999, which paper contains a comprehensive summary of prior work concerning screen size effects on information comprehension, efficiency, and interaction) carried out a study on the usability impact of small displays for web-based information retrieval tasks. Their findings included a general tendency for users with "small screens" (conventional monitors with the browser display capacity limited to 640x480 pixels) to follow links less frequently than those accessing the information space with large displays. Moreover, users in the small screen group were 50% less effective in completing assigned information retrieval tasks than those in the large screen group. The study articulates a growing need for improvements in the design of navigational facilities for small screen displays.

Kim and Albers (2001) conducted a study that compared performance in strategic information searches on web pages that were displayed on either a standard desktop monitor or a Palm-based small-screen device. Users in the latter condition took more time to perform the tasks, although accuracy scores in these tasks were not significantly different between the two conditions. Apropos to the proposed research topic presented in this document, the authors comment that "we must examine more closely how the PDA interface supports or erodes users' efforts—how information is presented to and perceived by the user in a handheld environment and how the user manipulates it" (p. 193); they call for further research in this area.

Waycott and Kukulska-Hume (2003) evaluated the use of PDAs for the reading of course materials by Masters students in a study that took place over the span of several months. Results were obtained through a series of pre- and post-study questionnaires and revealed that students found navigating through large amounts of text on these devices to be difficult overall. A frequently reported experience was that of 'lostness,' and this effect was often attributed to a lack of in-display contextual clues such as page numbers. This finding corresponds to Dillon's (1994) observation that small screen devices tend to isolate displayed text from its context, which also makes it difficult to scan-read back and forth multiple lines of text. Further, results showed that "using the PDA for reading changed the way students interacted with the learning materials," (p. 38)—in particular, the ways in which students interacted with the text (highlighting and note taking, etc.) were altered. In general, the study validates the present ecological approach in the sense that possibilities and constraints imposed by the PDA undoubtedly redefined the task of reading. However, as in Jones *et al.*'s and Kim and Albers' studies, the authors did not speculate on how the observed effects might reflect users' underlying conceptions of the information space.

2.4 Summary

The ecological approach, based on an affordances model, suggests itself as a particularly suitable conceptual framework in which to situate the present research topic. Three major methodological bases for studying users' mental models of hypermedia-based information spaces appear in the literature. These are: (1) quantitative measures, based on performance or behavioural data, transposed into a psychological frame; (2) qualitative measures that aim to elicit user experiences and perceptions through subjective techniques; and (3) models in which methods from the former two are jointly applied. This third basis is perhaps best suited for the present study, which is interested in both perfomative and conceptual issues. Finally, there are a number of studies that show how small screen devices have an apparently marked effect on informational processes. The authors have called for further research to be undertaken in this domain, particularly such as that would provide a clearer view of how particular attributes and affordances in small screen devices affect users' performance and experience within an information space. Given this body of research, it is argued that the question proposed earlier in this document becomes all the more salient: What effect does accessing a given hypermedia-based information space through a small screen device have on a user's underlying conceptual model of that space?

3. Methodology

3.1 Study design and procedures

The proposed study has been conceived of in two discrete phases, corresponding to lab-based and user-defined situational environments, respectively. Both quantitative and qualitative data will be gathered and analyzed independently for each phase, and later examined in the larger context of the entire study. The following outlines each of these phases in some detail.

3.1.1 Phase 1

In this phase, a more traditional experimental plan that is intended to extract performative data will be executed. This experiment will serve as a basis for obtaining qualitative measures in order to elicit experiential parameters that are also relevant. The proposed experiment is largely a replication of Kim and Albers' (2001) plan, although their protocol has been modified to better suit the purposes of the present research question. It is a 3 x 3 x 3 x 2 factorial design with the following variables: access device (PC, Tablet, PDA), size of website (small, medium, large), depth of target solution (shallow, medium, deep), and information density (high vs. low density). The access device will be between-subjects whereas the rest of the variables will be within-subjects.

	Size of website					
Depth of solution	**Small**		**Medium**		**Large**	
Shallow	H	L	H	L	H	L
Medium	H	L	H	L	H	L
Deep	H	L	H	L	H	L

Table 1: Condition levels for within-subject factors

Descriptive statistics for two dependent variables—accuracy (correct/incorrect) and efficiency (mean number of page transitions to find solution), based on an information search task—will be obtained. Experimental variables are operationalized according to the following scheme. *Access device*: users are assigned to one of three conditions, which include a typical workstation PC running at 1024x820 display resolution, a tablet PC at 1024x820, or an IPAQ PDA at 240x320. All monitors will be set to display colours at a 16bit depth; browser windows will be maximized to fill the entire screen in each condition. *Size of website*: websites will have to be custom-built, presumably from pre-existing online content to conform to the requirements of the experiment as specified herein. Size is determined by the number of content pages, mean link depth, and mean link breadth (number of links that appear on a given page); some experimental tuning will be required in order to properly set these values. *Depth of target solution*: the level of depth is defined as the minimum number of page transitions (links activated) required in order to access the target solution, which is an informational element. *Information density*: two versions of the experimental web space vary in their density of content (mean number of images, links, and length of textual content per page); these parameters will need to be manually tuned.

Qualitative measures are to be obtained through a range of complementary procedures. A number of these have been adapted from Gray's (1990) protocol. Throughout the experiment, participants will be encouraged to think-aloud by verbally articulating as many facets of their interactional experience as they can identify. At the end of each task, participants will be asked to briefly sketch a map view of the pages they've visited, and how they perceive that these are linked together. They will also be invited to give a rough estimate of the amount of content featured on the site that is relevant to the most recently completed task and asked to comment on whether the site featured too much, not enough, or the right amount of information with respect to their retrieval task. Once all of the tasks have been completed, participants will respond to a brief questionnaire that gauges their overall experience in terms of navigational difficulties, perceived reliability and relevancy of content, and how aesthetically pleasing they found the sites to be. Notes will be taken on how participants tend to physically orient themselves with respect to the various devices.

3.1.2 Phase 2

A week-long situational study will be conducted as a follow-up study, in which a subset of participants from Phase 1 will be asked to spend roughly 20mins each day browsing a regularly updated commercial news site. One group will use their own personal computers for this task, and another group will use PDAs from the experimental phase. In both conditions, software will be used to monitor the amount of time spent in the target website as well as to keep track of users' navigational behaviour. This software will be pre-installed onto the PDAs, and function as a server-side application for participants in the PC condition (who will be asked to log into a proxy server while they are browsing for this study). Participants will be advised that there will be several content-related questions that test their recall performance on content that appeared online throughout the week. This aspect of the study only serves in a motivational capacity—the questions will be very easy, and will not be factored into the analysis. There will be post-task questionnaires for each condition (the PDA questionnaire will have more questions regarding situational factors related to their use of the device) intended to elicit experiential data.

3.2 Participants

Because most of the experimental factors under analysis are within-subject, thirty-to-forty subjects are expected to be sufficient for the first phase study. Ten of these will be asked to participate in Phase 2. Participants should be English-speaking, and are expected to be generally proficient web-users in a Windows™-based environment. There will not be an elaborate sampling protocol for this study; participants will self-select from a population of students at UT, and most of these students are likely to be enrolled in the Faculty of Information Studies. Due to security constraints associated with the loaning out expensive technology, only those individuals who have a established personal rapport with study handlers (e.g. student colleagues at FIS) will be candidates for the PDA condition in Phase 2. Furthermore, these individuals must be privy to environments that support wireless networking on a daily basis. Those who have been selected for the PC condition in Phase 2 must have personal access to a PC with a connection to the internet, preferably high-speed, for at least 20 minutes in each day of the week during which this component of the study takes place.

3.3 Materials

3.3.1 Physical devices

The proposed study will require at least one PC, running Windows 2000 or later, that has been furnished with a high-speed connection to the Internet. (Connectivity to the Net may not be an absolute requirement if the a copy of the experimental web content is stored locally. The PC monitor should be at least seventeen inches in diameter, and the screen resolution will be set to display 16bit colour at a resolution of 1024x820. There should also be a left-handed mouse on hand. The protocol also calls for the use of a tablet-style PC. The tablet PC offers the same screen size and resolution as the desktop workstation, but is typically held, and uses a stylus as its primary input mechanism in a similar fashion to the PDA. Some models—for example, Hewlett Packard's Tablet PC tc1100 (http://h18000.www1.hp.com/products/tabletpc/) are dockable, which would allow the device to be used in both workstation and tablet conditions. Native resolution for tablet PCs like the tc1100 is 1024x820. The tc1100 ships with integrated 802.11b wireless LAN capabilities. Finally, several small screen devices (at least five) will need to be secured for this study. Optimal configurations would be in line with specifications for HP's IPAQ Palmtop (e.g. H5555), which displays 16bit colour at 240x320, and also includes wireless 802.11b networking. Estimated costs for these items are listed in Appendix B.

3.3.2 Website content

Special websites will be crafted in order to accommodate factorial requirements outlined in Section 3.1.1. Content for these sites will be “borrowed” from commercial websites that address relatively plain topics that do not require a high degree of domain experience in order to be understood, such as travel information. Altogether, six such websites will need to be constructed that conform to two levels of information density at each of the three levels of overall size.

3.3.4 Experimental facilities and recording apparatus

Lab-time will be secured in an environment where the experiments may be undertaken with a minimum of external disturbances. These environments will need to offer fairly stable wireless access to the Internet. Digital video will be used to capture the user performance. Navigational monitoring software will be loaded onto the proxy server and PDAs.

3.4 Data analysis

Data gathered on the two dependant variables in the experimental component of Phase 1 will be tested for significance via ANOVA, and (if a significant difference is found) post-hoc tests will be run to determine where the difference lies. Descriptive statistics (means and standard deviations) for some of the qualitative measures, such as numerical items on questionnaires, will also be generated. Since the proposed study is an explanatory-exploratory hybrid, the object in much of the qualitative data analysis will be to identify any emergent patterns within each performance, commonalities between performances, or correspondences with experimental findings. Accordingly, it is difficult to predict in detail how this will play out.

Performative data associated with navigational behaviour collected during Phase 2 will be analyzed through McEneaney’s (2001) matrix models for path analysis (discussed in Section 2.2). Comparisons between PC and PDA groups will be based on a variety of metrics that relate to navigational dispositions such as network saturation. (Such measurements should be divided over time-spent, so that overly enthusiastic browsers do not scew the results.) As in Phase 1, qualitative data obtained through the post-task questionnaires, etc. will also be taken into account.

3.5 Ethical issues

Given the ethically sensitive nature of tracking users’ online behaviour outside of a lab environment (Phase 2), special measures should be taken to ensure that a) participants understand which aspects of their activity are being kept track of, and b) why this monitoring is necessary. The former should be explained to participants before the study takes place, while the latter will be communicated to them after they have completed the study.

4. Conclusion

Coming to a better understanding of how web-enabled small screen information and communication devices influence the user's subjective experience of a given hypermedia-based information space will be useful as ubiquitous and mobile computing paradigms become more and more popular. With respect to the proposed study's speculative findings, primary stakeholders include hardware and software designers in the small screen device industry, as well as content producers and information architects who are interested in making their online material more useful, and usable, in a mobile context. The present research question is also interesting from an academic perspective, insofar as it provides a means for evaluating the proposed ecological approach to information spaces. Learning about how users' mental models of information spaces change as the form of electronic media through which these spaces are accessed varies may also reveal more about how these conceptual schemas are constructed in the first place.

Future researchers might consider extending the ecological model outlined in this paper to include additional aspects of the relationship between user and technology. Situational factors that are relevant to mobile usage in distractive environments (for example, a crowded bus) are one possible direction. If there appear to be significant differences between tablet PC and traditional workstation PC conditions in the experimental component of this study (where screen size is not likely to have been an influential factor), then this would suggest new research opportunities for investigating how ergonomic and physical orientations to information devices affect the subjective nature of delivered information. For example, does the act of 'holding information' in one's hand (on a PDA) engender this information with more of a propriety feel? Does accessing information at a stationary computer terminal (the user *goes* to the information) vs. via a handheld wireless device (the information *comes* to the user) affect one's perception of how authoritative, or familiar, or relevant that information is?

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