Spatial cognition in the mind and in the world - the case of hypermedia navigation

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Abstract

We present the results of a study of spatial cognition and its relationship to hypermedia navigation. The results show that a distinction can be made between two kinds of spatial cognition. One that concerns the concomitant acting in the physical world, and on that is a pure internal mental activity. This conclusion is supported by two kinds of data. First, a factor analysis of the subtests used in this study groups them into these two categories, and second, it is shown that only the internal one of these factors is related to the subjects performance in using a hypertext-based on-line help system. In the final section we point to the theoretical connections between this work and work in areas of situated cognition and on different kinds of mental representations, and discuss various possibilities that the results from this study suggest for the development of interface tools that will help users with low spatial abilities to use hypermedia systems.

Introduction

The present study investigates the relation between spatial ability and the ability to navigate in hypermedia. It has one applied and one theoretical foci. On the applied side, it can be seen as an attempt to diagnose the reasons behind differential difficulties in using hypermedia, with the goal of suggesting improvements in the design of these. On the theoretical side it can be seen as a contribution to the clarification of different aspects of spatial and graphical reasoning, and hence to the clarification of the concepts involved.

The paper is structured as follows. First we discuss some applied motivations for the present work. We then report on an experimental study on the relationship between individual differences in spatial cognition and the ability to use a hypertext based on-line manual. In the final section we discuss the implications of the results obtained for the development of user-friendly hypermedia systems and mention some of the theoretical questions which we suggest emerge from this study.

Navigation in the World and in Computer Systems

Navigation in large hypermedia information structures has long been recognized as a difficult task. The expression 'lost in hyperspace' to describe what happens when users loose track of where they are and where to go next in the hypertext, see for example (Nielsen, 1990). Navigation in hypermedia and large information spaces in general, may be compared to navigation in cities and natural surroundings, although it is not obvious that they are comparable situations. Still, we need to find tools and designs that help users to find their way just as maps, signs and other devices have helped navigation in general. In order to do so, we must find out more about when navigation is difficult, to whom and why?

While there are similarities between navigation in the real world and navigation in the virtual world of hypermedia, there is also at least one important difference. In the former case people live in the world and they can move physically in it, whereas in the latter the *groundedness* is more limited, we cannot move with our bodies and physically manipulate objects in the virtual hypermedia world. The question then arises whether the same tools (maps etc.) can be used to help users navigating in hypermedia systems, as well as whether the same cognitive abilities are used in the two kinds of navigation.

Individual Differences

Individual differences appear to have a big impact on human-computer interaction (Egan 1988). When designing tools for navigation in hypermedia, individual differences can be one crucial factor that a system should accommodate to. Vicente and Williges found that spatial ability could be linked with whether users get lost in a hierarchical file system (1988). Benyon and Murray (1993) found that spatial ability determined how well users performed with different interfaces to a database system. Users with low spatial ability performed better with a aided-navigation interface with a constrained dialogue, while users with high ability made better use of a non-aided navigation interface with a flexible command-based dialogue. In one of our

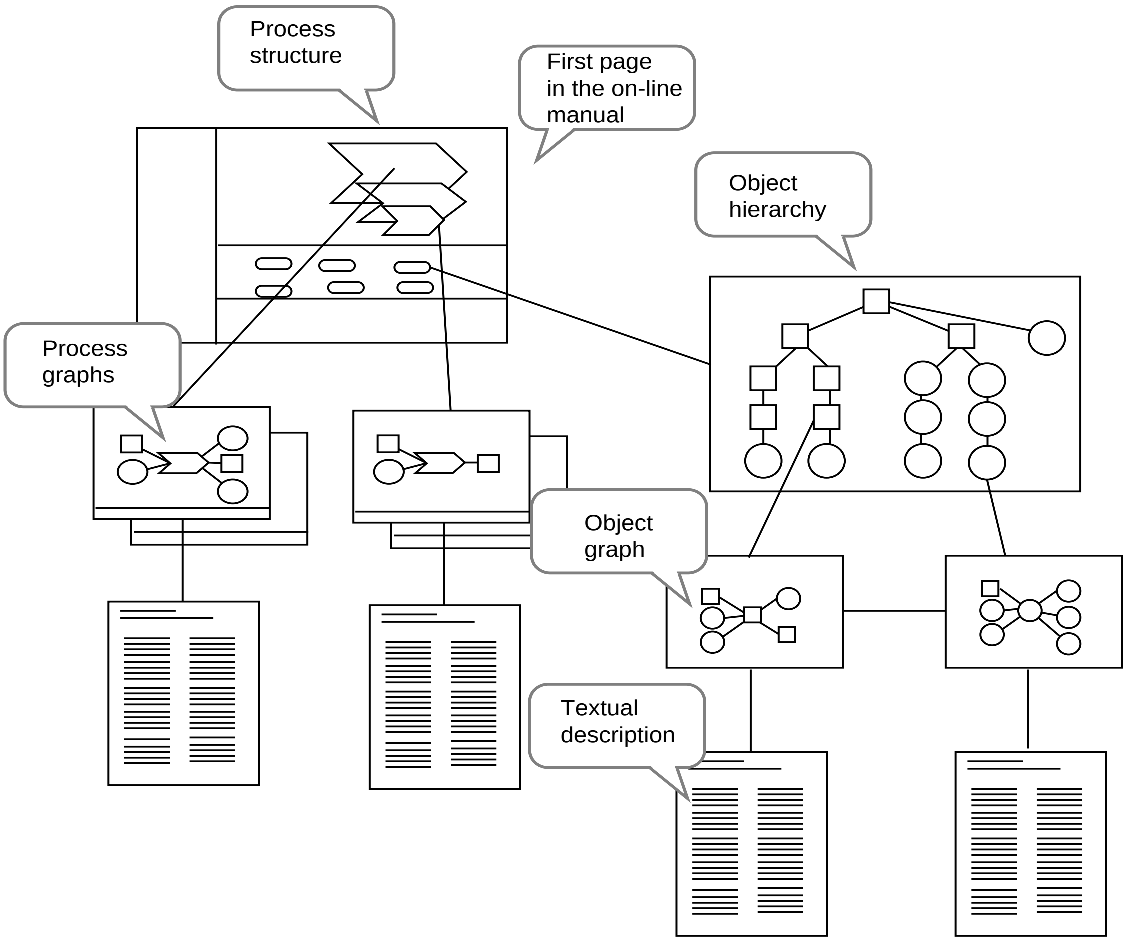

Figure A A schematic picture of the on-line manual. The two overview pictures show the process structure and the object hierarchy. From those, each process and object description can be reached.

previous studies (Bladh and Höök 1995) on a hypermedia documentation system (described in section two), we found that the user group could be divided into two sub-groups. One found the graphs provided by the system helpful as tools for navigating to documents. The other group was annoyed by the graphs, and would have preferred other ways to navigate and search for information. We believe that it is important that these kinds of individual preferential differences are catered for in the design of computer systems and their interfaces. While many users today appreciate and find graphical interfaces easy to use, the current 'one size fits all'-approach to interfaces risk leaving a large subset of the user population behind. And we believe that the more complex the systems' domain spaces become, the more important becomes this issue.

The initial aim of the present study was to investigate whether the observed differences in interface preferences can be related to spatial, visual or other cognitive factors.

Characteristics of the Hypermedia Tool Studied

Before presenting the details of the study, we give in this section a short description of the help system and the domain it is used in. The hypermedia tool used as the target domain in this study contains information about a software development method, SDP. The method consists of *processes* which are activities done during the project phases, and *objects* which are specifications, codes, etc. produced as a result of the method. Processes and objects are related, objects are related to objects and processes to processes.

The user of the on-line documentation of SDP that we studied has no other means of finding a particular document, but through clicking in several graphs until the document is reached. A schematic picture of the structure of the on-line manual can be found in figure 1. The *process structure* and the *object hierarchy* function as maps to the two main structure in the domain: the process structure and the object structure. From the process structure it is possible to reach descriptions of each process, the *process graphs*. From the process graphs in turn, textual descriptions of each process can be reached. From the object hierarchy the *object graphs* can be reached, and from those the textual descriptions of each object .

So, in order to get to a textual description of a process or object, it is necessary to navigate via a set of graphs until the desired process or object graph is reached. From there, and only from there, is it possible to get to the textual description.

Note that there are two aspects of the domain studied which are spatial in their nature. First, the domain itself is an abstract structure with relations between the domain's concepts of processes and objects (see section 1.4 for a description of the domain). Second, the on-line manual is structured in a set of documents with specified relations between the documents[1]. The structure of the on-line manual is only partly based on the structure of the domain. Hence, it is not sufficient to be knowledgeable in the domain to be able to use the on-line manual. Knowledge of both domains is required, as well as being able to map between these, probably making the use of the system a task requiring high levels of spatial competence.

Method

Subjects

There where 23 subjects in the experiment, 19 male and 4 female, all employed at a telecommunications company in Sweden. The subjects where in a range of 20-55 years old (m=34 years). All had some computer training, but not all had gone through higher academic training (18 with higher academic training and 5 with no higher academic training). All had recently gone through a four day course on the method that was described in the information base that we tested them on, but they had received little or no training on how to use the on-line manual.

Materials and Procedure

The experiment consisted of three parts. The first tested different cognitive abilities, the second was a questionnaire on the subjects' previous knowledge in the domain, and the third was a set of navigation tasks in the hypertext-based on-line manual. The subjects were tested in individual sessions which lasted approximately 3 hours.

Cognitive Abilities. We used 6 tests from the Düremann-Sälde test battery (Psykologiförlaget 1971). This is a widely used Swedish standardized test of cognitive abilities. These cognitive tests took approximately 2 hours per subject and the tested abilities as described in the test manual were:

• *verbal ability* which was tested in a synonym test where the subject should choose one of five words that meant the same as the word in the task.

• *logical-inductive ability* which was tested through classification of images where one of five should be chosen on bases of its differences from the others.

• *perceptual analysis ability* which was tested through drawing imitation of images

•*spatial ability* which was tested with three different tests:

  • *rotation of images* where the subject should choose, by turning the images in their head, the images that were identical with the image in the task. The number of correct chosen images differed in each task, but they always came from a group of seven.

  • *left or right hand identification* in pictures of hands that were turned in different ways

  • a *block test* (Kohs' blocks test) where the subject should make a pattern with blocks, witch should be identical with a pattern on a card that the subjects were shown.

The results from the cognitive tests were transformed into stanine-scores based on the standardization of the tests on a sample of 166 persons balanced for age (between 15 and 64) and sex. In some cases standardization data from a group of subjects with higher education were used.

Questionnaire

In nine questions subjects were asked to estimate their own knowledge, on a scale from 0 to 5, of the SDP method and the on-line manual, of computers in general, of other hypermedia systems, of point and click interfaces and of their own judged spatial ability (if they were good using maps, if they had good sense of direction etc.).

Hypermedia Navigation Task

Finally the subjects were asked to complete a set of six information seeking tasks and after each to evaluate their own performance, as whether they thought they had found the answer and whether they found it in the most efficient way. The six tasks to be solved with the on-line manual and the evaluation of the own performance took approximately 1/2 - 1 hour per subject. To ensure the ecological validity and relevance of the tasks used in the study, we only used questions that we had collected in a previous study from users actually working with the method.

The information seeking tasks were designed to have the following properties: 1. They should force the subjects to navigate between the different graphs, that to see if and how the subjects used a mental model of the information space. 2. Some of the questions solutions were in the object-view and some in the process-view, that to see if there were any differences in the way of seeking information in the different views (see figure 1). (A number of other requirements not relevant to the results presented in the present paper were also considered.) The on-line manual was available on Sun workstations.

The performance on the solving of the six tasks was recorded on video and analyzed. Task completion time was calculated from the first "click" to the last written letters in the answer. Number of "clicks" in the graphs was counted for each task, and a map depicting how a particular user has moved in the on-line manual between graphs and texts was drawn. After each task the subjects were asked a number of questions, i.e. how certain they were that they had found the correct answer, if they had found it using the shortest path etc.

[1] 'Spatial' is here used to denote relations between objects in a space that need not necessarily be visually presented or represented.

Cognitive test	Factor 1	Factor 2	Factor 3
Synonym test	-.164	***.843***	-.046
Image classification	.284	***.810***	-.041
Figure drawing	***.958***	.071	-.071
Figure rotation	.227	-.393	***.654***
Hand test	.00001	.067	***.940***
Block test	***.792***	-.001	.376

Figure 2: Results from the factor analysis of the cognitive tests

Results and Discussion

The results will be presented in two steps[2]. First we show the analysis of the pattern of different cognitive abilities. We then illustrate the relationship between these identified factors and the performance when using the on-line manual.

Patterns of Cognitive Abilities

An orthogonal factor analysis of the results of the six cognitive tests revealed three underlying factors, with two tests with high loading in each factor (see fig 2). Factor 1 with high loading on figure drawing test and the block test, factor 2 with high loading on the tests of synonyms and the classification of images, and factor 3 with high loading on the tests on rotation of images and of hand identification.

What is especially noteworthy here is that the pattern obtained seem to put in question the test manual's classification of these tests. We find two factors (1 and 3) which both seem to relate to visual-spatial cognition, but with the factor loadings very differently distributed[3]. What seems to be the critical difference here is that the test that have high loadings on factor 1 both concern the active manipulation of physical objects, whereas the tests with high loadings on factor 3 are require a purely mental effort to obtain the correct answer. This could indicate that from a psychological point of view there is a difference between the manipulation of spatial information in the mind and the acting in the world, even if both from a superficial point of view seem to concern the same kind of information processing.

Having shown that it is possible to group the tests into these groups does not of course entail that the distinction is of any theoretical or practical relevance. Following the path set by recent work by Stenning and Oberlander (1995, Stenning, Cox, and Oberlander, 1995), we will instead try to see whether the suggested theoretical distinction can be related to performance in other tasks, in our case hypermedia navigation. If it can be shown that the subjects different abilities is correlated with differential performance in other tasks, the validity of the distinction is given some further credence, something which seems necessary before discussing connections to other theoretical constructs.

Cognitive Abilities and Task Performance

To get a simple measure of the factors we added the standardized stanine points for the two tests most strongly associated with each factor. The correlation between the different factors and the task performance as measured by the time to complete the 6 tasks was then computed. These tests showed that the only significant correlation was with the internal spatial ability as measured with the two tests in factor 3. ($r = .56$, $p < .005$). No other correlations achieved or even approached significance. (Factor 1 $r = .04$, factor 2 $r = .13$) The same pattern is revealed when looking at the correlations between the dependent variable and the six different tests taken separately. The strongest correlations were with the two tests of internal spatial cognition, whereas the correlation between the completion time and the blocks test was for instance only $r = .04$.

There are two conclusions that can be drawn from this. First, this analysis supports the validity of the distinction being made here between spatial tasks that also involve some external physical manipulation or transformation of the objects, and where therefore visual feedback is available, and tasks where the entire transformation is done in the mind without any external support.

Second, that there is a correlation between users' spatial abilities and their ability to use the hypertext based system. But this is only true for a subset of the different spatial tests used in this study, namely the ones measuring internal spatial cognition. Another illustration of this connection can be made by first dividing the subjects into two groups, one with high scores on the spatial tests and one with low scores, and then compare the time used for solving the tasks for the two groups. This difference between the groups with high and low internal spatial ability is 16.94 minutes vs. 25.47 minutes. This difference is statistically significant ($F(1,21)=5.53$, $p<0.05$). When dividing the groups on how well they performed on the external spatial tasks, the difference between the groups' task completion time is much smaller (20.18 vs. 22.10 minutes) and not statistically significant.

In our questionnaire, we asked the subjects to estimate their own ability to read and use maps and their ”sense of location”. This is of course a very indirect measure of this ability. But it has been shown by Streeter and Vitello (1985)

[2] We will here only present results relevant to the issue of different kinds of spatial cogniton. For a complete description of this study, see Sjölinder (1996) and Höök, Dahlbäck, Sjölinder (1996). For a description of the PUSH project, see Höök, Karlgren, Waern, Dahlbäck, Jansson, Karlgren, and Lrmaire (*forthcoming*)

[3] Note that while the image classification test uses pictorial material, this is primarily a test of logic-inductive ability.

that subjects ability to read and use maps was strongly correlated with their actual map-reading ability. It is also the case that those who tend to like maps will use maps more often and thereby improve their performance. So, our subjects own estimate of the map-reading ability can with some caution be taken as a measure of their actual ability.

We found that the subjects map-reading ability was correlated with factor 1 (the ”external” spatial ability) in our cognitive tests, r=.42, P<.05, while there was no correlation between map-reading ability and factor 3 (the ”internal” spatial ability).

Again, this would indicate that there is a difference between spatial ability for solving problems in the world (where groundedness is possible) and spatial ability for abstract structures in non-grounded domains.

Concluding Remarks

On the theoretical side we have argued that a distinction could, and perhaps should, be made between spatial tasks that are performed as bodily actions in the world and those that take place solely in the mind. The crucial difference between these is probably that in the former but not the latter tasks continuous visual feedback on the results of the transformations (actions) performed is available. Our analysis of the subjects' response pattern on the cognitive abilities test gave some support for that notion. Further support was gained from the fact that the only cognitive abilities tests that correlated with the performance in using the help system was those that seemed to measure internal spatial tasks. We are aware of the fact that it is possible to make connections between the pattern obtained here and recent discussions on situated cognition, and on mental imagery and other aspects of mental representations. A full treatment of the issues involved here would take us beyond the scope (and the space limitations) of the current paper, not the least since both the concepts of 'mental imagery' and 'spatial cognition' for a long time have been subject to intense theoretical discussions. Let us instead just mention one issue which we will consider in our future work in this area; what is the relationship between the 'internal' spatial ability discussed here and the ability to use visual imagery? Do the subjects that perform well on our internal tasks use mental imagery to a larger extent than the low performers? Our current data do not make it possible to answer this question, since we did not ask the subjects how they performed their tasks, nor did we include any test on imaginability.

On the applied side, we found that users differed in their navigation performance, and that this could be related to the ability to perform spatial tasks which did not have any external support, but not to other kinds of spatial or other cognitive abilities. The question then arises whether it is possible to device support for the users who find the navigation tasks difficult. Some work by (Vicente and Williges 1988) suggests that this can be the case. They have shown that users with low spatial ability are helped by system where parts of the previous state of the interface is visible after the user has made an action at the interface. Their explanation for this is by creating what they call a *visual momentum* the interface provides memory support for the users, since it is no longer required that they recall where they are and where they should go next in the hyperspace. Instead they can recognize the structure and the links and basing their decisions on that recognition. An alternative or complementary hypothesis, based on the results from the present study, would be that the visual information on the screen transforms an internal spatial task to an external one.

It could of course be the case that map reading ability is related to the internal spatial ability described here, in which case it would probably be difficult to help the low performing subjects with some kind of map-like tool for navigation support.

We have no data that can give a definite answer to this question. But since we found that subjects' own judgment on their map reading ability correlated only with their results on Factor 1, i.e. external spatial tasks, and since it has been shown by Streeter and Vitello (1986) that people's own judgment of their ability on this is rather accurate, we at least consider it a hypothesis worth exploring further.

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