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Individual Differences in Virtual Environments ¾ Introduction and overview

Chaomei Chen
Department of Information Systems and Computing, Brunel University, Uxbridge UB8 3PH, UK. Email: chaomei.chen@brunel.ac.uk

Mary Czerwinski
Microsoft Research, Richmond, USA. Email: marycz@microsoft.com

Robert Macredie
Department of Information Systems and Computing, Brunel University, Uxbridge UB8 3PH, UK. Email: robert.macredie@brunel.ac.uk

The practical significance of identifying and accommodating individual differences has been established across a number of fields of research. There is a renewed interest in individual differences due to the advances in virtual environments, especially through far-reaching technologies such as information visualization and the World-Wide Web. The effects of individual differences on the use of these new technologies are yet to be found out. More fundamentally, theories and methods developed for the earlier generations of information systems are subject to a close examination of their applicability, efficiency, and effectiveness. In this paper, we present a brief historical overview of research in individual differences in the context of virtual environments. In particular, we highlight the notion of structure in the perception of individual users of an information system and the role of individuals' abilities to recognize and use such structures to perform various information-intensive tasks. We introduce the themes shared among articles in the special topical issue. © 2000 Wiley.

INTRODUCTION

The increasingly widespread use of virtual reality, visualization and simulation modeling techniques has highlighted the need for a better understanding of a number of fundamental issues concerning human users in a virtual environment. Individual users now have a much wider range of options to interact with an information system. Users also have an increasing number of channels to receive input from their working environments. On the one hand, individual differences are likely to be widened by the availability of a wider spectrum of user interfaces because modern user interfaces demand more and more abilities from users that vary very much from individual to individual. On the other hand, the majority of these user interfaces are designed with only a generic, ideal user in mind.

Individual differences in human-computer interaction have been a long-standing subject of research. The consensus has been that information systems should and can be designed to accommodate individual differences. Theories and methodologies have been developed over the last decade to tackle various issues concerning individual differences in human-computer interaction.

Theories and methods developed for the earlier generations of information systems are subject to a close examination of their applicability, efficiency, and effectiveness. In this paper, we present a brief historical overview of research in individual differences in the context of virtual environments. In particular, we highlight the notion of structure in the perception of individual users of an information system and the role of individuals' abilities to recognize and use such structures to perform various information-intensive tasks. We introduce the themes shared among articles in the special topical issue.

INDIVIDUAL DIFFERENCES

The topic of individual differences has a diverse range of aspects, including personality, cognitive abilities, cognitive style, gender, age, and domain knowledge. Pioneering and landmark works particularly concerning individual differences in human-computer interaction include (Borgman, 1989; Carroll, 1993; Egan, 1988; Vicente & Williges, 1988).

Dillon and Watson (1996) present an in-depth review of a century of individual differences work in psychology. They suggest that the current over-reliance on experience or job-based criteria in user classifications can be reduced by attending to the existing literature on individual differences to make empirical findings across human-computer interaction applications more comparable and more generally applicable.

More recent work includes (Benyon & Höök, 1997; Chen & Czerwinski, 1997; Chen & Rada, 1996; Curl, Olfman, & Satzinger, 1998; Dillon & Watson, 1996; Höök, Dahlbäck, & Sjölinder, 1996; Robertson et al., 1998; Stanney & Salvendy, 1995). The new generation of studies in individual differences introduce new design features and even new metaphors and paradigms of interaction. On the other hand, the influence of pioneering works is evident.

Accommodating Individual Differences

A number of empirical studies of individual differences in navigation related areas have led to a generic framework for accommodating individual differences through design and training. Egan and Gomez (1985) introduced one of the earliest methodologies for accommodating individual differences in human-computer interaction. One of the most influential models is adapted from instructional research to accommodate the individual characteristics of students (Messick, 1976). Three strategies have been proposed to match individual differences: the challenge match, capitalization match, and compensatory match.

- The challenge match uses a deliberate mismatch between task demands and user capabilities in order to force a user to change and become more flexible. The success of this method largely depends on whether the user processes the cognitive abilities needed.
- The capitalization match aims to tailor task demands to match the strengths of users. This method emphasizes that not only should task demands remain within the capabilities of users, but also task design should exploit what a user already knows. A major drawback of this approach is that it may place unrealistic constrains on the design of the task.
- The compensatory match aims to offset users' deficiencies through training or online assistance. The compensatory match accommodates users by providing mediators, modalities, or organizing structures that users cannot readily provide for themselves (Messick, 1976).

Before one can apply any of these matching techniques successfully, it is necessary to pinpoint which user characteristics to challenge, exploit, or mediate. Egan and Gomez (1985) suggested a three stage approach to accommodate individual differences, including isolation, assaying, and accommodation.

The first stage, isolation, aims to identify the individual differences which significantly influence task performance. For example, spatial ability is an influential source of individual differences in human-computer interaction.

The second stage, assaying, is to decompose a task so that one can identify the key task components that account for performance variability. For example, Vicente and Williges (1988) suggest that constructing spatial mental models of embedded information is such a key task component in dealing with multi-level hierarchies. This suggestion is particularly related to the concept of field dependence.

The third stage of the Egan and Gomez (1985) methodology is the accommodation stage. The key task components identified in the second stage are either modified or eliminated with maximum possible efforts made to the completion of the report. For example, Stanney and Salvendy (1995) identified that the construction of a spatial mental model of embedded information is precisely the key task component to account for performance variability between high and low spatial individuals. From a compensatory point of view, if the need to structure embedded information can be removed, then a compensatory match is likely to help low spatial individuals. In fact, Stanney and Salvendy focused on the effects of 2D visual mediators on the information search performance of low spatial individuals. They found their compensatory match successful — no significant differences were found between high and low spatial individuals.

Earlier studies found individuals who scored low on spatial memory tests had longer completion time and more errors in first attempts. The difficulties experienced by low spatial individuals were particularly related to navigation through abstract information structures, such as hierarchical menu systems, during information search. These hierarchical structures usually have several levels in depth. According to (Egan, 1988; Stanney & Salvendy, 1995; Vicente & Williges, 1988), it was the embedded levels that cause particular difficulties for low spatial individuals in their search. A natural compensatory approach is therefore to eliminate such high spatial ability demanding sources from user interfaces.

Vicente and Williges (1988) attempted to accommodate low spatial individuals by drawing upon the theory of momentum, which is a measure of how easily one can integrate and extract information across different displays. In their study, they used a visual hierarchy to improve visual momentum in file selection. However, the graphical interface was not significantly superior to a verbal interface, although the results were in the predicted direction. From a compensatory point of view, the key question is whether the visual hierarchy successfully reduced the demand for spatial ability.

Stanney and Salvendy (1995) extended Vicente and Williges' study by precisely focusing on this issue. In their study, two user interfaces were designed to compensate for the inability of low spatial individuals to readily construct visual mental models of the structure of a menu system. The two compensatory interfaces included a 2D visual hierarchy and a linear structure. Their interfaces successfully compensated low spatial individuals — no significant performance differences were found between the high and low spatial groups on the two interfaces. High spatial individuals only performed better when information search tasks required mentally constructing a model of the organization and structure of embedded task information, which obviously demanded the use of spatial ability. By eliminating the need to mentally visualize the structure of embedded task information, low spatial individuals were able to perform as good as high spatial individuals. They concluded that visualization techniques can be used to enhance information search performance of low spatial individuals.

Instead of compensating cognitive abilities of individuals, it is possible to capitalize on other abilities which low spatial individuals may possess, such as social-interpersonal skills. From an educational point of view, peer-to-peer collaborative learning also points to a promising route of accommodating individual differences. Furthermore, collaborative virtual environments become increasingly powerful and popular. Searching for new ways of accommodating individual differences in multi-user virtual environments is one of the most challenging and exciting research directions. A few studies have already taken the first step in exploiting small group behavior in collaborative virtual environments (Chen, Thomas, Cole, & Chennawasin, 1999; Tromp et al., 1998).

Individual Differences in Information Retrieval

Information retrieval is by far the most intensively studied topic in relation to individual differences. This is largely attributed to the long-established experimental information retrieval community.

The relationship between technical aptitudes, personality characteristics, and academic orientation has been examined in the context of information retrieval, notably (Borgman, 1989). Borgman examined correlations between more than a dozen of characteristics which contribute to individual differences in information retrieval performance.

Tests:

- Remote Associates Test (RAT)
- Symbolic Reasoning Test (SRT)
- Number of college-level math courses
- Number of high school math courses
- Number of college-level science courses
- Number of high school science courses
- High school grade point average (GPA)
- College GPA
- Number of college-level programming courses
- Number of high school programming courses

Learning Styles:

- Scholastic Aptitude Test (SAT) – Mathematics
- Scholastic Aptitude Test (SAT) – verbal

Courses:

- Learning Style Inventory
- Myers-Briggs Type Indicator

Borgman's study had led to a number of far-reaching findings for research in individual differences. For example, people with high spatial skills tend to perform better in graphic or spatially oriented interfaces; therefore, a system may provide interfaces tailored to specific user groups or multiple interfaces to a single system that can be adapted to user characteristics.

The most general finding of Borgman's research is the consistency of patterns among factors related to computing task performance — performance differences are sufficiently predictable and we can begin to control them through both design and training. Design mechanisms can anticipate where errors are most likely to occur and to design around them, whereas training mechanisms focus on most problem-prone components of the system. She suggested further research in individual differences should try to isolate human characteristics that lead to performance differences and to isolate the interface factors with which they interact.

Individual Differences in Navigation

Individuals have demonstrated considerable differences in their ability to acquire spatial knowledge from maps (Thorndyke & Hayes-Roth, 1982). An increasingly strengthened trend in individual differences research is on navigation tasks, ranging from hypermedia applications to the World-Wide Web (WWW). As a predominant design feature, direct manipulation has become necessary mechanisms chosen for almost all aspects of user interface design. Graphical and spatial user interfaces are introducing more and more types of tasks that demand users to master the skill of navigation in cyberspaces. A special issue of *Presence* has addressed spatial orientation and wayfinding in large-scale virtual spaces (Darken, Allard, & Achille, 1998). Individual differences in spatial orientation in virtual spaces have stimulated considerable interests.

Chen and Rada (1996) developed a generic framework for synthesizing contemporary empirical findings of hypertext systems. The framework includes three interrelated components: users, tasks, and systems. A meta-analysis of 22 experimental studies was conducted. In particular, the meta-analysis on users focused on a range of individual differences such as spatial ability, field-dependence, and learning styles. Behavior patterns began to emerge to account for individual differences. For example, high spatial individuals may not need to access a table of content as often as low spatial individuals, suggesting that high spatial individuals can probably build their mental model of the structure of underlying information more easily than their low spatial counterparts. One of the conclusions from the meta-analysis is that we need to make experimental studies more comparable to each other in terms of individual uses, tasks to be performed, and system functionality.

Spatial ability is often cited as being a good predictor of human-computer interaction performance (Egan, 1988; Egan & Gomez, 1985; Vicente & Williges, 1988). Early studies often found that individuals with lower spatial memory scores had longer completion times and made more errors. The difficulties experienced by low spatial individuals have been regarded particularly related to system navigation issues during information search. In a more recent study (Stanney & Salvendy, 1995), the differences between high- and low-spatial ability users became virtually vanished when a 2D visualization of a hierarchical structure was presented. It was argued because it is the need of mentally constructing a model that slows down low-spatial ability users, the removal of such needs would therefore compensate the ability of users with low spatial ability.

An increasing number of empirical studies have focused on cognitive abilities, especially spatial ability, on navigation in information systems with a strong visual representation. For example, one of the earliest studies was reported by Vicente and Willges (1988), in which they examined the performance of accessing a hierarchy of computer files. Chen and Czerwinski (1997) analyzed the interrelationship between spatial ability and visual navigation, and found a strong correlation between spatial ability and post-test sketches of an abstract semantic structure. Swan and Allan (1998) investigated the use of 3D visualizations in information retrieval. They found that prior experience with computer graphics seemed to be a more reliable predictor. In a more recent study, Robertson and his colleagues examined the use of spatial memory in a document management system called a Data Mountain (Robertson et al., 1998).

More recently, Curl et al. (Curl et al., 1998) studied the roles of individual differences and user interface on database usability. They used recent graphical user interface design techniques to manipulate the level of spatial visualization support provided by the interface. A laboratory experiment was conducted to explore the influence of interface style and the spatial visualization ability of the user on the performance of the query development process. Spatial visualization ability was assessed using a paper-folding test. The results indicate that both spatial visualization support of the system and spatial visualization ability of the user are important components of database usability.

Individual Differences in Virtual Environments

The notion of structure is commonly found across studies in information visualization and virtual environments. The potential of virtual environments largely lies in their role in mediating interaction (Erickson, 1993). The concept of structure is fundamentally associative with a wide spectrum of virtual environments, ranging from abstract, implicit, and complex to concrete, explicit, and simple ones, for example, VR-VIBE (Benford et al., 1995), SPIRE (Wise Jr. et al., 1995). In many cases, it is such a concept of structure that plays a unifying role in users' understanding the meaning of a virtual environment.

The notion of spatial hypertext was originated in order to help users in finding and using implicit structure in human-organized spatial layouts of information (Marshall & Shipman, 1995). It is crucial for us to understand the benefits and difficulties users may encounter when they interact with such structures, communicate through such structures, and extend and adapt such structures in the context of designing, using, and studying virtual environments. Lokuge, Gilbert, & Richards (1996) have demonstrated the differences in individuals as they structure information with mental models. The mental model of Boston area was clearly affected by individuals' general preferences, how familiar to the area, the means of transportation in mind.

The development in information visualization technology has traditionally focused on facilitating information organization and access. Recent research suggests that the key to a more effective approach to advancing information visualization systems lies in the development of a deeper understanding of cognitive demand associative with tasks entailed by interacting with an information visualization system.

The Landmark-Route-Survey (LRS) model (Tversky, 1993) has drawn much attention in a number of recent studies of visual navigation behavior in virtual environments or in abstract information spaces, e.g., (Chen, 1998; Darken et al., 1998; Darken & Sibert, 1996).

After people study a geographic map, they remember more information from a subsequently studied text that is related to the map. In order to find empirical evidence that thematic maps improve memory for facts and inferences, Rittschof et al. (1994) investigated the effects of studying thematic maps before reading factual text. In their study, subjects studied a thematic map of a colonial Ceylon and an expository text containing related facts. The conditions of map-text and text-map were varied between subjects. Subjects in the map-first condition recalled more theme-related and unrelated text facts and made more correct inferences involving the theme displayed on the map.

Rittschof et al. explained their results within the dual coding framework. According to this theory, visuo-spatial attributes of maps and verbal information in text have different representations in long-term memory. The representational units of these two encoding systems are images and verbal propositions. The theory also has a second premise that associative links are created between images in one code and propositions in the other, if the learner is able to relate the two representations in some meaningful manner (Rewey, Dansereau, & Peel, 1991). As a result, when information represented by one code is active in working memory, it may be used to quickly activate related information in the other code.

Based on the dual coding theory, a map is encoded as an image that contains both structural and feature information depicted on the map. While the question “Where is it?” is addressed by structural information, the “What is it?” question is addressed by feature information.

Structural information, including spatial properties like distance and borders, forms a spatial frame of reference for locating individual map landmarks and spatial relations among these landmarks in the map space. Feature information, including detail, shape, size, and color, is used to depict discrete entities on a map. Feature information enables a map viewer to distinguish landmarks from one another without relying on the structural relations that exist among these landmarks. Both structural and feature information facilitates the acquisition of information from related text. According to Rewey et al. (1991), when people study the map, they first construct a representation of the map’s general spatial framework in working memory and subsequently use it to encode the landmarks.

In this special issue, we are particularly interested in the development of such structures associated with a virtual environment. It is the model that a virtual environment intends to convey to its users. It is this model that we expect to provide people a common ground to communicate and interact.

THE THEME OF THE SPECIAL ISSUE

In this special issue, we are interested in exploring issues related to individual differences, especially in terms of how individuals differ in their abilities to capture, recognize, and make effective use of abstract, implicit, and changing structures found in common across many large information systems and virtual environments. In particular, we hope articles in this special issue will help us to understand better how to accommodate these differences. We highlight questions that are likely to make significant contribution to the field. Articles in this special issue address some of these questions in depth. On the other hand, many questions can only be adequately addressed until a critical mass of users of virtual environments emerge and virtual environments with substantial content materials becomes available. The four broad questions are:

1. What are the predominant human factors concerning the design of a virtual environment?
2. What is the role of individual differences in the use of a virtual environment?
3. How do we assess the effectiveness and usability of a virtual reality application?
4. How do we account for users' cognitive and behavioral experiences in a virtual world?

More specific questions include:

- individual differences in virtual environments, including spatial ability and cognitive styles;
- learning in virtual environments, including cognitive models, spatial memory, incidental learning, categorization and abilities;
- usability and evaluation methodologies;

- user preferences and satisfaction;
- multi-user virtual environments, 3D interactive systems, spatial hypermedia;
- visualization and simulation in virtual environments;
- analysis and modeling of user behavior, search strategies and navigation heuristics;
- automated virtual environment generation and transformation;
- semantic structures and spatial structures in virtual environments.

We provide a brief introduction here to the articles in this special issue.

Allen - Optimizing User-System Match

Allen (1999) focuses on the theme of how to optimize the match between users and system configurations in order to optimize their search performance. A key user interface feature in Allen's experiments is a word map. It is a multidimensional scaling model of 100 most frequently occurring words in a collection of bibliographic references. In this case, the intrinsic structure is reflected through the interrelationships in this bibliographic collection. The word map and a multi-window display are referred to collectively as *design features* in his article.

In terms of individual differences, he focuses on spatial scanning and perceptual speed. These cognitive abilities are measured with pencil-and-paper tests described in (Eckstrom, French, Harman, & Derman, 1976), namely, the Maze tracing speed test and the map planning test for spatial scanning, and was also tested based on the number comparison test and the identical pictures test for perceptual speed.

Two experiments are presented in his article. In the first experiment, he explores two matching strategies, namely the capitalization match and the compensatory match. He suggests that a compensatory match is probably a more fruitful route to pursue in information retrieval systems. In the second experiment, he focuses on user selection of system configurations. He concludes that additional matching mechanisms such as user models are needed to help users to find an optimal match between their individual characteristics and system configurations.

An interesting pattern of findings seems to emerge. We tend to presume that individuals with a strong spatial ability are likely to perform better with visual mediators. As found in Allen's experiments, while individuals with low perceptual speed performed the best with the word map, high perceptual speed performed best without the word map. Similarly, high spatial scanning individuals with higher levels of spatial scanning performed the best without the word map, but the worst with the word map. Allen interprets these findings as the evidence that supports the compensatory model. He concludes that the word map compensated low spatial individuals because the word map helped low spatial users to visualize the information space. Similar results were found in our own study (Chen, 1999). High spatial individuals performed better in a simple textual user interface than in a spatial user interface designed with semantic mapping.

According to the framework mentioned earlier (Stanney & Salvendy, 1995), one can probably offer an alternative explanation. That is, the use of the word map has eliminated some key task components that would hinder the performance of low spatial scanning individuals, whereas the remaining key task components did not offer much for high spatial scanning individuals to capitalize on.

Allen's article is thought provoking. It demonstrates the power of theories and methodologies developed in (Egan & Gomez, 1985; Stanney & Salvendy, 1995; Vicente & Williges, 1988). More importantly, it shows how one can adapt and apply these theories and methods to the new generation of systems with greater emphasis on individual differences in virtual environments. Further work is necessary to clarify why high spatial individuals were found to perform better without the word map, as in Allen's experiments, and without the spatial-semantic virtual world, as in Chen's experiments.

Dillon - Combining Spatial and Semantic Cues

The ability to perceive structure in abstract information spaces is crucial to navigation and search performance. Dillon's article distinguishes the role of spatial and semantic cues and explains why this conceptualization may lead to new insights into existing and emerging data. Dillon also introduces the concept of shape as the structural components of the working model of an information space. This is most apparent in Geographical Information Systems (GIS) but is less obvious or conceptualized in abstract information environments.

Dillon suggests that research in the field has largely focused on visual navigational aids that might support users' bottom-up processing of the spatial display. He presents an emerging alternative and particularly emphasizes the top-down application of semantic knowledge by the user gathered from the ecological context of information processing and management.

Dillon's theoretical framework echoes the semantic distance model (SDM) proposed by Brooks (1995). The SDM is a model of relevance assessment. Brooks has shown that relevance assessments declined systematically with an increase in semantic distance. Subjects gave the highest relevance assessments to the topical subject descriptor semantically closest to the bibliographic record, and then incrementally smaller relevance assessments to descriptors more distant. The SDM provides some important input to information visualization, especially when we deal with a heterogeneous network of documents, topical descriptors, subject headings, and search queries. Dillon's article delineates the argument between top-down versus bottom-up approaches with a range of empirical evidence found in the literature.

Chen - Navigating in Spatial-Semantic Worlds

The central theme of the special issue is how individuals differ in their performance in a virtual environment which requires an in-depth understanding of its underlying structure.

Chen's article presents two studies of individual differences in searching through a spatial-semantic virtual environment. In the first study, he focuses on correlations between two memory abilities and search performance scores. The two memory abilities — associative memory and visual memory — are measured with pencil-and-paper tests drawn from (Eckstrom et al., 1976). The spatial-semantic virtual world is based on an adaptation of Pathfinder associative networks. A strong positive correlation was found between associative memory and search performance, but no significant correlation was found between visual memory and search performance.

In the second study, the same spatial user interface and a simple textual user interface were compared. The effects of spatial ability, associative memory, and online experience were examined on a set of interrelated search performance scores. A main effect of online experience was found. In particular, online experience has a significant effect on the recall scores with the textual interface. Individuals experienced in online search are more likely to have a higher recall score with the textual interface than less experienced individuals. No significant main effects were found for spatial ability and associative memory. Subjects' comments suggest a potentially complex interplay between individuals' mental models and the high-dimensional semantic model. Qualitative and process-oriented studies are therefore called for to reveal the complex interaction between individuals' cognitive abilities, domain knowledge, and direct manipulation skills.

The call of an investigation of deeper knowledge structures is made based on previous studies of similar knowledge-intensive displays, e.g., (Rewey et al., 1991; Stanney & Salvendy, 1995).

Ford - Self-Organized Models of Holists and Serialists

The next article included in this special issue is by Ford. His article focuses on the distinction between holists and serialists in learning, and its implications for supporting individual users through user interface design.

A holist tends to concentrate on a broad conceptual overview and subsequently fit details into such a overview. In contrast, a serialist tends to concentrate on local details at early stages. An overall picture tends to be developed relatively late in the learning process. In a wider context, this distinction is related to various implications of cognitive styles on the design of virtual environments.

Of particularly interest to the theme of this special issue, Ford addresses some interesting behavioral patterns of holists and serialists. While holists like to use concept maps, serialists prefer keyword indices. A concept map, or the overview of an underlying structure, is designed for global orientation regarding the overall structure of the subject matter.

Having recognized the fuzzy nature of identifying individuals' cognitive styles and learning strategies, Ford introduces a modeling approach based on Kohonen self-organizing feature maps, an artificial neural-network based classification technique. This self-organized approach has its potential — it is pointing to a possible route for further research and development of adaptive virtual environments. Virtual environments provide a wider framework for integrating and directly manipulating global and analytic aspects of an information space.

Ford's article also draws our attention to the connection between field-dependence and cognitive styles in terms of individuals' behavioral patterns in navigation of hyperspace. Like holists, field-dependent individuals use overview maps more often than field-independent individuals. In the next article, Palmquist and Kim examine the effects of field-dependence in Web search.

Palmquist and Kim - Field-Dependence and Web Search

The Web has captured the imagination of millions of users all over the world. It is crucial for Web designers and indeed for all of us to understand how individuals with different cognitive style, different cognitive abilities, and different background in information systems interact with the vast amount of information presented on the Web. At the heart of the organization of information on the Web, it is the notion of association, as manifested through hyperlinks connecting information that is associated in one way or another. Once again, the ability to understand an abstract structure of information, or derive a coherent structure by articulating fragmented documents becomes a challenge to individuals' ability to find and make the best use of the information available. The significance of accommodating individual differences on Web search is clear.

Palmquist and Kim examine the effects of cognitive style, namely field-dependent and field-independent, and online database search experience on Web search. An interesting finding of their study is that online search experience can greatly reduce the effect of field-dependence on Web search performance.

STRIKING THE BALANCE

The practical significance of individual differences in many areas has led to the development and continuous pursuing of strategic approaches aiming to strike the balance across a range of individual groups. Cognitive abilities have been found as one of the single most influential sources of individual differences.

This special issue includes articles addressing theoretical as well as empirical aspects of individual differences in virtual environments. A number of promising theoretical frameworks are emerging. It is encouraging to see the revival of some pioneering methodologies for accommodating individual differences in the new context of virtual environments, at the new scale of the Web, and in harmony with various design philosophies and principles.

Several articles in this special issue and many more studies published in the contemporary literature have made substantial use of psychometric tests, notably the factor-referenced test kit (Eckstrom et al., 1976). In particular, the Interactive Track at TREC-7 conference started to include verbal fluency as a measure of individual users (Over, 1999) in order to reveal more complex factors involved in information retrieval. The greatest advantage of using standard and widely available tests is that researchers may establish and accumulate empirical studies with comparable findings.

Research in individual differences is interdisciplinary in nature. It involves a number of areas of research, including information retrieval, information visualization, and human-computer interaction. Typical tasks examined in empirical studies include information retrieval as measured in terms of recall and precision, visual navigation as measured in terms of spatial memory of the layout of a virtual environment, and content comprehension as measured in terms of free recall and cued recalls.

Perhaps the single most significant conclusion from the results of articles in this special issue is that maintaining an overall balance of individual differences in task performance is complex and challenging. As we have seen, the gap between high- and low-spatial individuals may vanish when a compensatory interface is introduced. In addition, the gap between field-dependent and field-independent individuals may be considerably reduced if individuals are highly experienced in related task domains.

Articles in this special issue have extensively examined individual differences, especially cognitive abilities and cognitive styles. The role of a virtual environment has been exploited to a less extensive extent in this issue. We hope that these articles on individual differences in virtual environments will stimulate and foster a wider variety of theoretical, engineering, and empirical studies in this interdisciplinary field. We hope the experience shared by these articles and lessons learned from these studies will be invaluable for all of us to explore effective and flexible ways of accommodating individual differences in new generations of information systems. Accommodating individual differences will remain as a challenging issue as more sophisticated technologies emerge, such as multi-modal user interfaces, 3D information landscape, collaborative virtual environments, ubiquitous computing.

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