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Assessment of Cognitive Style Preference: A Conceptual Model

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ABSTRACT

Research in adaptive hypermedia educational systems has increased with the growth of the Internet. Currently, all adaptive hypermedia educational systems collect information about cognitive style through completion of a questionnaire based on a psychometric test. This direct measure may be intrusive and annoying to a student and makes an adaptive system aligned to cognitive style unavailable for students that have not completed the questionnaire. It is posited that non-intrusive methods for determining the cognitive style of hypermedia system users are needed to maximize the usability, functionality, and goals of adaptive hypermedia systems.

This paper offers a new approach for the autonomous computer-based assessment of preferred cognitive style that can support studies in user modeling and human-computer interface domains. It further posits a conceptual model that attempts to determine the preferred cognitive style of an online educational hypermedia user through click-stream analysis of their web-based hypermedia choices and browsing patterns.

Keywords

Adaptive hypermedia. Cognitive style. Neural networks. Click-stream analysis.

INTRODUCTION

Research in the use of hypermedia in learning has increased with the expansion of the Internet. Long posited as a promising medium for an educational system (Mullier), questions to whether hypermedia learning environments can be designed to be effective and efficient for different kinds of learning objectives are still unanswered (Chen and Dwyer 2003). Hypermedia environments, characterized as the inclusion of hypertext with additional multimedia artifacts, have three problems when used to support learning: user distraction due to the large amount of information in the hyperspace, spatial disorientation due to the user not knowing where they are in the hyperspace, and cognitive overload when a user is confronted with high memory demands (Chen and Dwyer 2003). The first two problems deal with the information retrieval process and the third problem is related to human information acquisition. To overcome the problems associated with hypermedia environments, adaptive hypermedia technologies have been proposed to provide adaptive course content aligned with a user's knowledge level and need. Adaptability is accomplished by building a "user model of the goals, preferences, and knowledge of the individual user (Brusilovsky 1996)." The model is then used to adapt the hypermedia environment (e.g., page content and links) to the needs of the associated user (Triantafillou, Pomportsis et al. 2003). Most adaptive educational hypermedia systems research has focused on adapting to a particular set of user features including goals/task, knowledge, background, and hyperspace experience (Brusilovsky 2001). To optimally adapt educational material to the student, the cognitive style or learning style of the student must also be considered (Carver, Howard et al. 1999). Research has shown that by matching instructional presentation style with a student's cognitive style, significant effects in terms of learning effectiveness are achieved (Ford 2000).

Cognitive style is described as an individual's preferred mode of organizing stimuli and constructing meaning out of their experiences (Witkin and Goodenough 1981). It is a stable personality characteristic that refers to the way information is cognitively processed by an individual (Mammars and Bernard). Cognitive styles deal with cognitive form (i.e., thinking, perceiving, remembering, etc.) and not with content (Triantafillou, Pomportsis et al. 2003). Different cognitive styles and psychometric tests have been defined and created as different researchers have promulgated different aspects of cognitive styles (Witkin, Moore et al. 1977). Witkin's Group Embedded Figures Test, Kirton's Adaptive-Innovator Inventory, and Ridings Cognitive Style Analysis are examples of psychometric test designed to determine cognitive style (Sadler-Smith and Badger 1998). Currently, all adaptive hypermedia educational systems collect information about a student's cognitive style by having the student complete an evaluation questionnaire based on one of the psychometric test listed above (Lo and Shu 2002; Rumetshofer and Wos 2003). This direct measure may be intrusive and annoying to the student and makes an adaptive

instruction system aligned to cognitive style unavailable for students that have not completed an evaluation questionnaire. It is posited that effective and non-intrusive methods for determining the cognitive style of hypermedia system users are needed to maximize the usability, functionality, and success measures of adaptive hypermedia systems.

Cognitive Styles: Definition, Models, and Relationships

Research on cognitive styles dates back to laboratory studies by Witkin et al. (Witkin, Moore et al. 1977) with their ideas of field dependence-independence becoming one of the most widely studied dimensions of an individual's preferred and habitual approach to accepting, organizing, and representing information (Chen 2002). Witkin et al. (1977) introduced the term cognitive style to describe the concept that "individuals consistently exhibit stylistic preferences for the ways in which they organize stimuli and construct meanings for themselves out of their experiences." Witkin's definition of cognitive style is not singular. Additional definitions of cognitive style do exist with each highlighting several important characteristics: 1) cognitive style is distinct from cognitive abilities and is concerned with form rather than content of information processing; 2) it is bipolar, characterized by a continuum along a dimension; 3) it can be assessed using a psychometric test; 4) it has temporal stability; 5) it may be value differentiated and described as a "different" rather than a "better" thinking process (Sadler-Smith and Badger 1998). For example, Kirton's model of cognitive style states that style is orthogonal to cognitive capacity, cognitive techniques, or coping behavior (Kirton 1976).

Riding and Cheema (Riding and Cheema 1991) in a comprehensive review of the literature dealing with cognitive style concluded that all the various labels and descriptors for cognitive style could be grouped into two orthogonal and bipolar dimensions: information processing and information coding. Common descriptors along the information-processing dimension include Riding's wholist/analytic, Allinson and Haye's intuition-analysis, Kirton's adaptor-innovator, and Witkin's field dependence-independence divisions of cognitive style. Each refers to the preferred way an individual processes information (Sadler-Smith and Badger 1998). The second dimension identified by Riding is the verbal-imager dimension. This dimension reflects how individuals perceive or mentally code information. Both dimensions are mutually exclusive and position on one dimension does not affect position on the other.

Differences between cognitive style types have been seen in users operating in a hypermedia environment. Verbalizers, in contrast to imagers, prefer words or word associations over information structured in pictorial form (Riding and Cheema 1991; Pillay 1998) and perform better in environments where the text to image ratio is high (Ford and Chen 2001; Graff 2003; Graff 2003). Imagers, in comparison, prefer images or descriptive text that can easily be converted to mental images over information structured in textual form (Pillay 1998). Individuals who are wholistic tend to process information globally, thrive in environments where information is highly structured and processed, and prefer to navigate in a hypermedia environment using concept maps (Ford 2000; Ford and Chen 2000; Ford and Chen 2001). Analytic individuals, in comparison, tend to process information into segmented conceptual groups (Pillay 1998; Ford and Chen 2000) with preference given to comprehending the details of each group before combining them into an overall picture (Graff 2003).

Marked differences between the cognitive styles are further seen with use of search engines to support information search strategies. Ford et al. (Graff 2003), in a series of studies that looked at online literature search patterns between wholist and imagers, noted that wholist displayed a tendency to adopt a broad search strategy with use of "OR" Boolean logic and truncation (e.g., wildcard) operators. Analytics, in comparison, adopted a focused search strategy with use of "AND" logic operators to link keywords. Differences between the two cognitive styles were also noted in their awareness of spatial location within a hypermedia environment. Verbalizers were shown to have lower spatial location awareness (Carver, Howard et al. 1999; Graff 2003) and heavily used navigation organizers to support spatial tracking (Graff 2003).

While an individual may consciously use non-preferred cognitive styles, adopting non-habitual styles results in extraneous cognitive load due to the additional effort required in organizing and coding the given information. Matching information presentation to preferred ways of perceiving and processing information frees cognitive resources for more effective learning (Pillay 1998).

Cognitive Style: Match-mismatch in Learning Effectiveness

In the last ten years, a significant number of studies have examined the influence of cognitive styles in hypermedia environments. Ford and Chen (Ford and Chen 2001) investigated the relationship between matching and mismatching instructional presentation with students' cognitive style. Significant differences in performance were noted on a multiple test of conceptual knowledge between matched and mismatched test subjects. Parkinson and Redmond (Parkinson and Redmond 2002) examined the impact of cognitive style on learning performance within three different computer media: text, CD-ROM, and Internet site. They concluded that learning performance was enhanced when cognitive style was considered. Pask (Ford 2000), in a series of experiments conducted in the 1970's, found dramatic effects in terms of learning effectiveness

when complex academic subject matter was presented to individuals aligned with their preferred cognitive style. These studies highlight the importance of accounting for cognitive style in information systems where human-computer interactions will occur.

Hypermedia Navigation and Adaptive Learning Systems

Hypermedia research within the education domain has grown due to the consumer growth of the Internet in the early 1990's. Studies have shown that effective hypermedia learning systems must be adaptable to the goals/tasks, knowledge, background, hyperspace experience, preference, and interest of its users (Brusilovsky 2001). A cognitive and learning style construct must be included in an adaptive hypermedia learning system to optimally adapt instructional materials to the student (Carver, Howard et al. 1999). Identification of cognitive style is primarily done by having students complete evaluation questionnaires (Carver, Howard et al. 1999) prior to usage of the adaptive hypermedia learning system. Identifying user characteristics such as cognitive style and browsing strategies through analysis of online user behavior is a relatively novel area of research. Mullier applied neural networks and fuzzy logic techniques to educational hypermedia systems in order to correlate browsing strategies to task drivers (Mullier 1999). Kiili and Ketamo (Kiili and Ketamo) created methods based on statistics to determine the theoretical browsing strategies of online users from observed user behavior. Currently, the only known study to posit the use of a computer to assess a user's psychological trait was by Lo and Shu in their paper on identifying learning styles through use of embedded support devices and artificial neural networks (Lo and Shu 2002). This unpublished paper is a draft-stage proposal with a model proposed but not tested. Both Lo and Shu and Mullier et al. indicate that the research questions addressed in this proposal are important and are still unanswered. Therefore, additional empirical study is warranted.

RESEARCH QUESTION (S)

This author is currently investigating if preferred cognitive styles of online educational hypermedia users can be deduced with probability greater than chance through computer-based passive observation of hypermedia navigation patterns. Specifically, the followings questions are being investigated:

- *Can an online educational hypermedia user's position on a Wholist-Analytic cognitive style dimension be determined using machine learning (i.e., artificial neural networks) and click-stream analysis of their hypermedia choices and browsing patterns?*
- *Can an online educational hypermedia user's position on a Verbalizer-Imager cognitive style dimension be determined using machine learning (i.e., artificial neural networks) and click-stream analysis of their hypermedia choices and browsing patterns?*
- *Can a comprehensive and complete design framework based on machine learning be developed for determining preferred cognitive styles of online educational hypermedia users?*

The research questions will be answered in a future study and will be based on the use of a computer to autonomously determine the preferred cognitive style of an online educational hypermedia user through click-stream analysis of their web-based hypermedia choices and browsing patterns. Fundamentally, a user will be asked to navigate through a study website to answer questions related to a freshman-level college course. As the user navigates, the study website computer will record their navigation choices. A navigation choice will include buttons, concept maps, text links, illustrations, and search parameters. From the recorded navigation choices, the study website computer will attempt to determine the preferred cognitive style of the user. Each test subject, prior to starting the study, will be given Riding's Cognitive Style Analysis (CSA) psychometric test to determine his or her preferred cognitive style. The CSA test will be given online through the study website.

To support the study, several conceptual models were developed from the collation of research findings in hypermedia and adaptive educational systems (see Introduction section for a summary of the empirical findings). The conceptual models will guide the development of the study artifact and will form a basis for the determination of cognitive style preference. The conceptual models are discussed in the following sections.

RESEARCH MODELS

A conceptual model of the study artifact is shown in Figure 1.

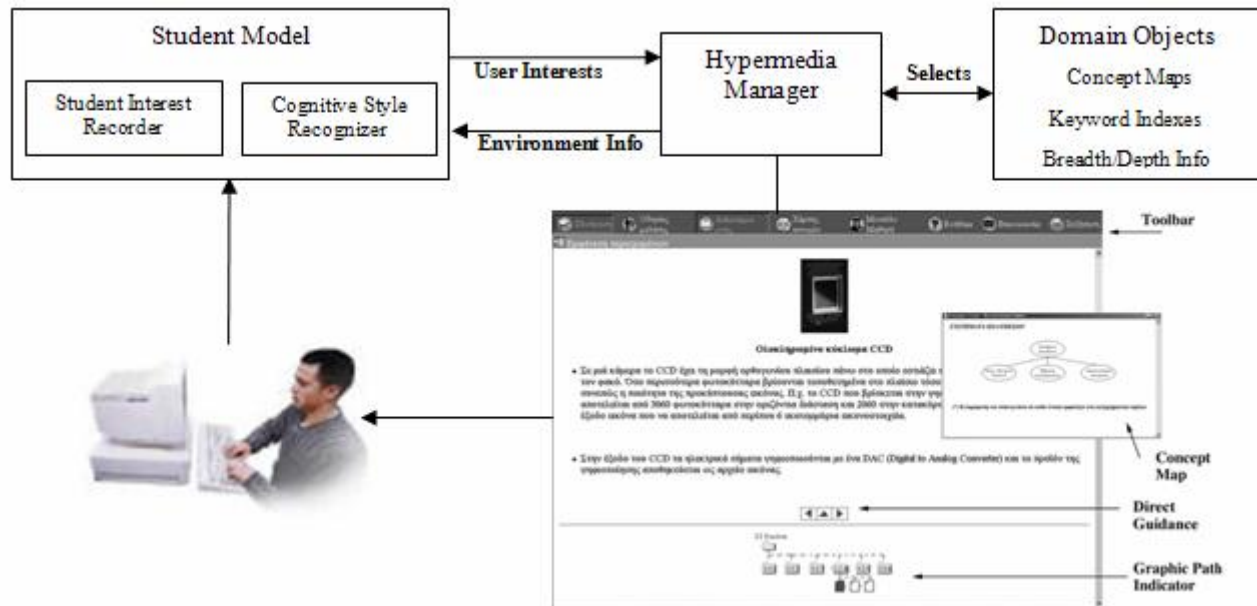


Figure 1. Conceptual Model of Study Artifact

Operation of the system begins with the Hypermedia Manager creating an initial navigation domain based on an assumption about a subject's cognitive style. Figure 1 shows an example of a hypermedia environment adapted for a wholist-imager (Triantafyllou, Pomportsis et al. 2003). Study participants will interface with the Student Model through an Internet link using their workstation as a client. The Student Model will capture all user hypermedia object choices using a Student Interest Recorder (SIR). The SIR module will store all navigation patterns using a relational database and will communicate this information to the Hypermedia Manager, which will adapt the presentation of the hypermedia environment to reflect the interest of the navigating subject. A Cognitive Style Recognizer module that employs a neural network will build a pattern that is hypothesized to represent the preferred cognitive style of a test subject, as the iterations between changing the hypermedia environment and recording of the selected domain objects are done. The anticipated number of iteration cycles and time required by the system to determine cognitive style preference are unknown at this time but will be determined through pre-test simulations of the system.

Two conceptual models have been formulated to structure and support the design and development of the Cognitive Style Recognizer and to support hypermedia environment adaptation by the Hypermedia Manager. The operational measurements within each model form the Domain Objects used by the Hypermedia Manager to create varying web page structures and presentations.

Conceptual Research Models of Cognitive Style Determination

For the verbalizer-imager cognitive style dimension, a model with two constructs for each style is shown in Figure 2.

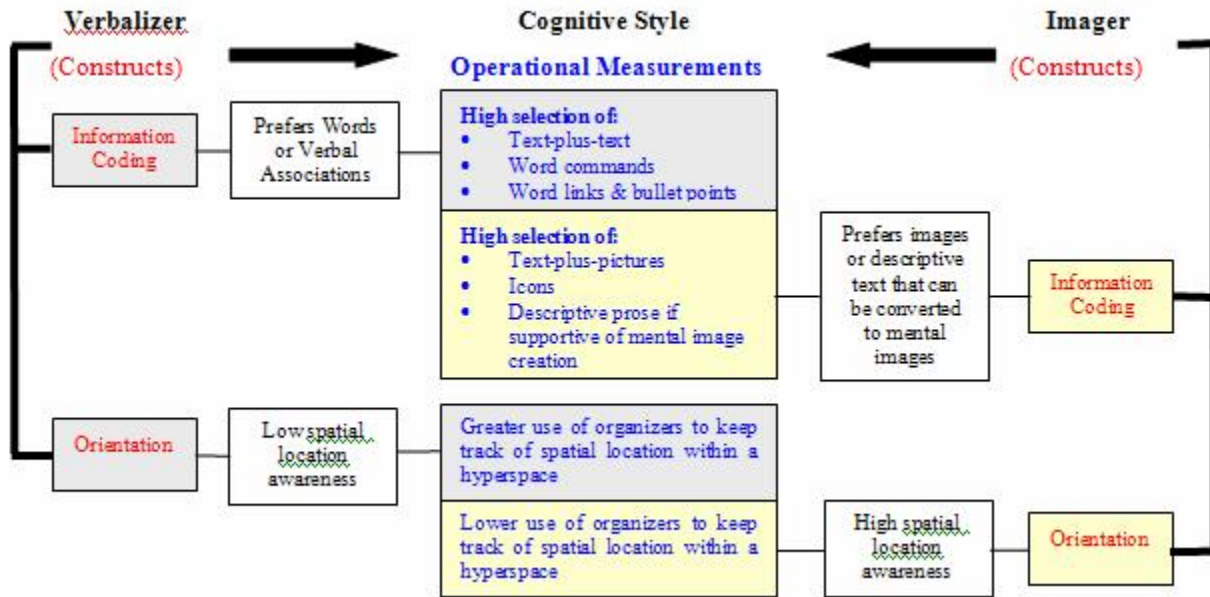


Figure 2. Cognitive Style Model: Imager-Verbalizer Dimension

For the wholist-analytic dimension, three constructs were selected and include information processing, navigation, and knowledge acquisition. Information processing refers to the preferred way an individual processes information. Navigation refers to the preferred way an individual navigates through a hypermedia environment and is divided into three sub-constructs: routing, orientation, and tools. Routing accounts for path and direction dependencies. Orientation addresses how individuals maintain spatial awareness. Tools detail the navigation tools preferred by a user to navigate within a hyperspace. Lastly, a knowledge acquisition construct is used to capture how cognitive style differs between wholist and analytics in terms of information search strategies and learning. Figure 3 shows the conceptual model for the wholist-imager dimension.

Neural Network Model

Details of the artificial neural network algorithms that will support the Cognitive Style Recognizer is beyond the scope of this paper but a general model is discussed. The Cognitive Style Recognizer is an artificial neural network that will be used to analyze the complex and non-discrete browsing patterns of the study participants and to extract a preferred cognitive style preference. A neural network was selected since it can support multiple interacting criteria and imprecise information sets and does not require explicit rule-based instructions to solve tractable problems (Negnevitsky 2002).

While many neural network architectures exist, the Multi-Layer Feed Forward neural network (MLFF) is very popular in practice (Luger 2002). Mathematically, a MLFF neural network can simulate any function provided that it can be trained by providing examples of output responses given an input data set. Figure 4 shows a typical three-layer feed forward neural network (Nawari, Liang et al.). The number of inputs and outputs are selected to match the number of independent and dependent variables. The number of hidden layer elements, which provides the processing power of the system, is selected to balance the learning power versus the computational power of the network. Increasing the number of elements within the hidden layer increases learning functionality but also increases the processing demand of the system (Negnevitsky 2002).

For this study, the output layer is posited to equal four elements, one for each cognitive style (Wholist, Analytic, Imager, and Verbalizer). The number of input elements will be set to match the number of constructs established in the cognitive style models shown in Figures 2 and 3. The number of hidden layer elements will initially be set to six, following work done by Muller (Mullier; Mullier 1999) in his study to use artificial neural networks to determine browsing strategy patterns of users

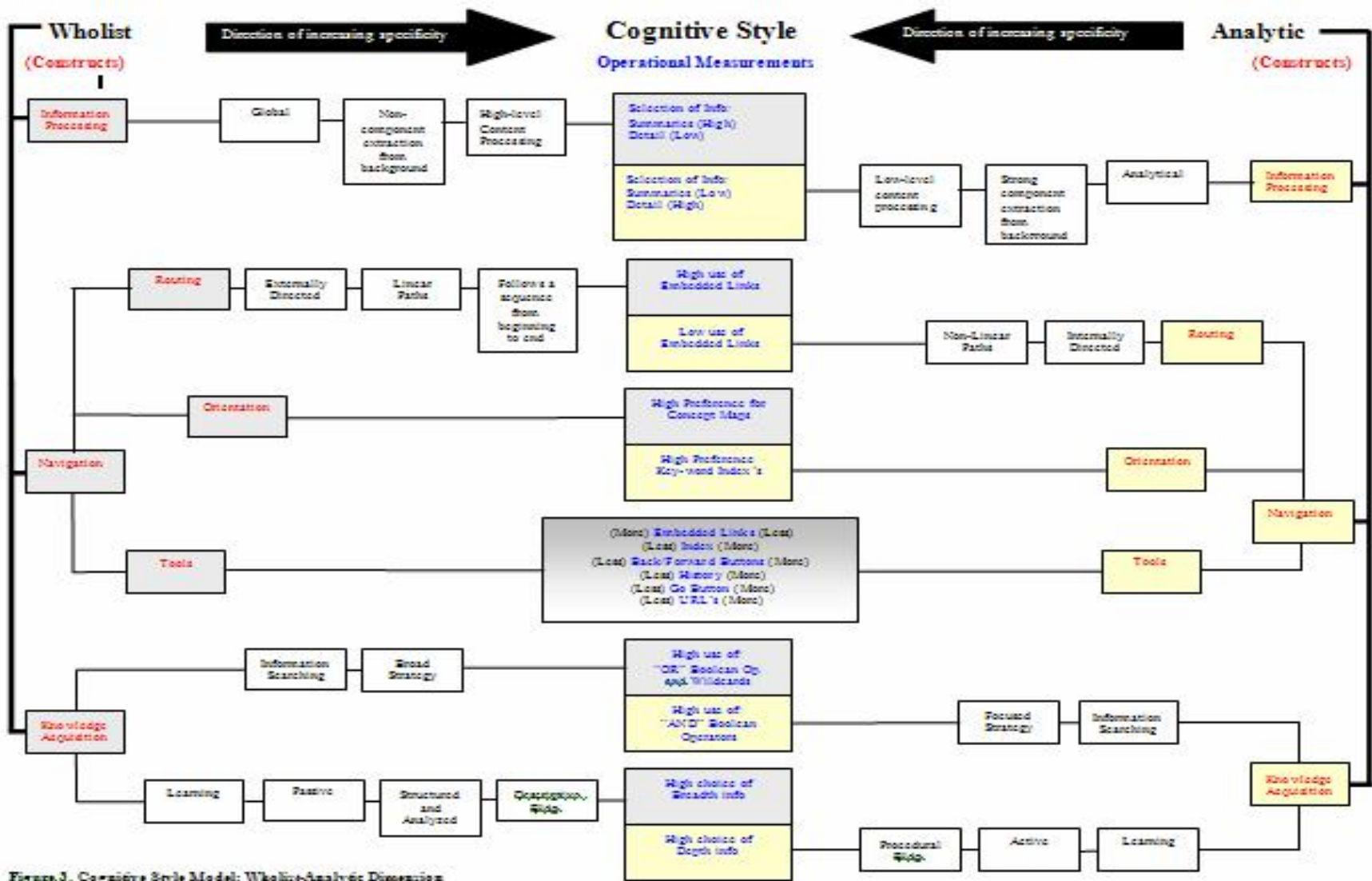


Figure 3. Cognitive Style Model: Wholist-Analytic Dimension

in a hypermedia environment. According to Mullier (Mullier 1999), the required number of hidden layer elements cannot be calculated and must be determined experimentally. A final number of hidden layer elements will be determined experimentally during the development of the design artifact and before the experimental trials begin.

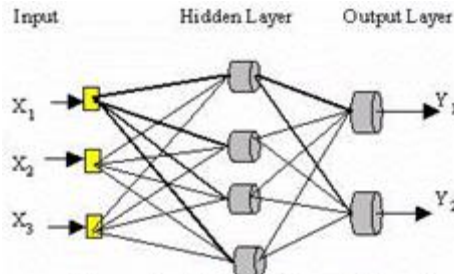


Figure 4. Artificial Neural Network

A conceptual neural network model proposed for this study is shown in Figure 5.

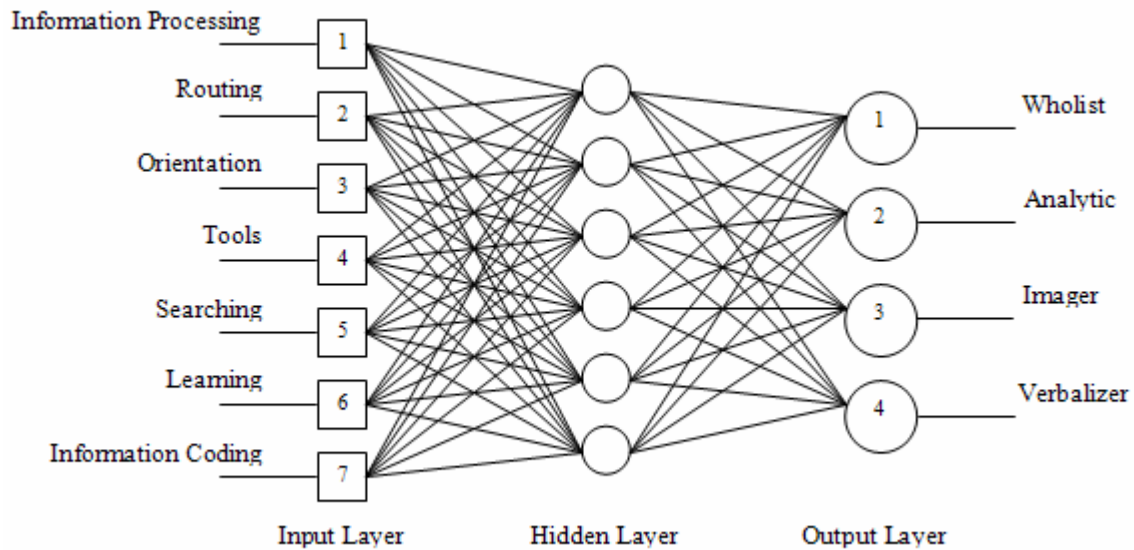


Figure 5. Conceptual Model of Proposed Artificial Neural Network

CONCLUSION

This paper offers a new approach and conceptual model for the autonomous computer-based assessment of a user’s preferred cognitive style. Support for this proposition is based on research that provided evidence that hypermedia-learning systems may not be suitable for all learners due to their inability to easily adapt to different cognitive styles (Chen 2002). Adaptive hypermedia technologies attempt to overcome deficiencies with traditional “one-size-fits-all” hypermedia systems by building a model of the goals, preferences, and knowledge of each user. While adaptive hypermedia systems promise support in application areas where users have different goals and knowledge and hyperspaces are relatively large, adaptive hypermedia systems must rely on obtaining and verifying the veracity of data needed to build a user model. Information acquisition and verification may be difficult if users are neither interested nor willing to provide the required information needed by an adaptive hypermedia system (Kilfoil, Ghorbani et al. 2003).

The models proposed in this paper are untested but provide a starting point for research that bridges work in the fields of computer science, psychology, and information science in order to: make a contribution to the field of computer science by integrating cognitive style theory and adaptive educational hypermedia technologies with practical adoption of machine learning theories; make a contribution to the field of psychology by developing a design framework and prototype for the autonomous computer-based assessment of preferred cognitive style; and, make a contribution to the field of information science by developing a model for the autonomous computer-based assessment of preferred cognitive style that can be used to support studies in user modeling and human-computer interface domains.

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