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Development and evaluation of an ergonomic software package for predicting multiple-task human performance and mental workload in human–machine interface design and evaluation

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ABSTRACT

Predicting human performance and mental workload in multiple task situations at an early stage of system design can save a significant amount of time and cost. However, existing modeling tools either can only predict human performance or require users of tools to learn a new programming language. Queueing Network-Model Human Processor (QN-MHP) is a new cognitive architecture for modeling both human performance and mental workload in multiple tasks. This paper describes the development of a Visual Basic Application in Excel (VBA) software package and an illustrative case study to evaluate its effectiveness. The software package has an easy-to-use user interface for QN-MHP that assists users of the modeling tool to simulate a dual task including definition of the tasks and interfaces by clicking buttons to select options and filling texts in a table, with no need to learn a simulation language. It allows the model user to intuitively observe the information processing state of the model during simulation, and conveniently compare the simulated human performance and mental workload for different designs. The illustrative case study showed that naïve users without prior simulation language programming experience can model human performance and mental workload in a complex multitask situation within 3 min; and this software package can save 71% of modeling time and reduce 30% of modeling errors. Further developments of the VBA software package of QN-MHP are also discussed on how to make it a comprehensive proactive ergonomic design and analysis tool.

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1. Introduction

Performing two tasks concurrently is one of the common activities in human–machine interaction. Operators in control rooms in manufacturing industry may operate a device and monitor several displays at the same time. Pilots need to control the airplane and at the same time communicate with the air traffic controllers. Drivers may operate an instrument panel or use a Global Positional System (GPS) while steering a car simultaneously. Predicting human performance and mental workload in dual task conditions at an early stage of system design can save system development teams (engineers, human–machine interface designers and even managers) a significant amount of time and cost in comparison to revising the systems at a later stage of system development (Gore, 2000; Gore, 2002). The need for models that can predict both performance and mental workload has often been mentioned in the literature on human modeling (Olsen & Olsen, 1990).

Besides several digital modeling tools to predict and assess human physical movement (Kuo & Chu, 2005; Resnick & Zanotti, 1997; Shidar, SAl-Araimi, & Omurtag, 2002; Yoon & Kim, 1996), several cognitive modeling techniques have been recently developed and they are mainly used to predict human performance, including CRITIQUE (Hudson & Stasko, 1995), Micro Saint (Laughery, 1989; Schunk, 2000), APEX (Freed, Matessa, Remington, & Vera, 2003; Freed & Remington, 2000), and QN-MHP (Wu & Liu, 2004a, 2004b, 2004c, 2006a, 2006b, 2006c, 2007, 2008a, 2008b). Hudson et al. (1995), Hudson, John, Knudsen, and Byrne (1999) developed a innovative modeling tool called CRITIQUE (the Convenient Rapid, Interactive Tool for Integration Quick Usability Evaluations), which was able to automatically produce KLM (Keystroke-Level Model) to predict single task performance time. CRITIQUE uses features of the subArctic input model to transparently record detailed logs of user interactions. Micro Saint was developed in 1985, and it is another valuable human performance modeling software package (Laughery, 1989; Schunk, 2000). It uses a task network modeling method to predict performance time: activities of target users of a device or system are represented in a diagram as nodes and arrows between the nodes, which represent the sequences in which the activities are

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performed. Researchers in the NASA Ames Research Center (e.g., Freed & Remington, 2000) developed a useful modeling tool called APEX – a GOMS (Goal-Operator Methods-Selection)-like framework that incorporates mechanisms and methodologies for predicting certain forms of human error.

Queueing network modeling approach has been established both as a psychological theory and a human performance modeling technique in human–computer interaction. In modeling human performance, computational models based on queueing networks have successfully integrated a large number of mathematical models in response time (Liu, 1996) and in multitask performance (Liu, 1997) as special cases of queueing networks. A simulation model of a queueing network mental architecture, called the Queueing Network-Model Human Processor (QN-MHP), has been developed to represent information processing in the mental system as a queueing network on the basis of neuroscience and psychological findings. Ample research evidence has shown that major brain areas with certain information processing functions are localized and connected with each other via neural pathways (Bear, Connors, & Paradiso, 2001; Faw, 2003; Roland, 1993; Smith & Jonides, 1998), which is highly similar to a queueing network of servers that can process entities traveling through the routes serially or/and in parallel depending on specific network arrangements. Therefore, brain regions with similar functions can be regarded as servers and neural pathways connecting them are treated as routes in the queueing network (see Figs. 1 and 2). Information being processed in the network is represented by entities traveling network.

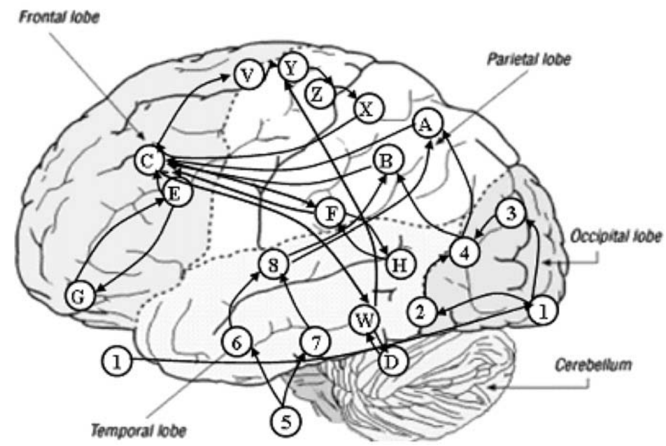
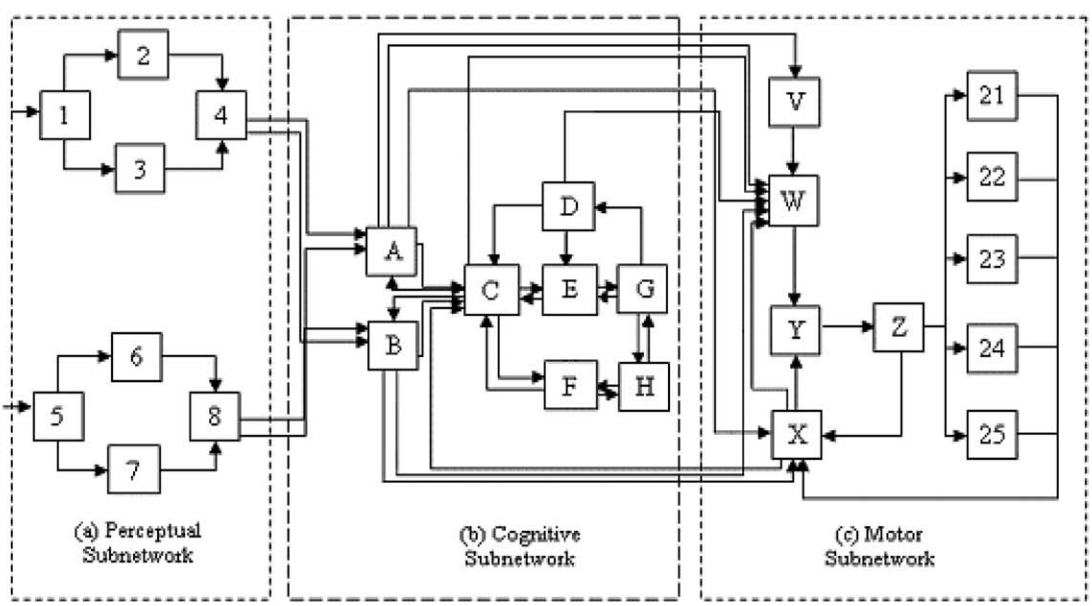


Fig. 2. Approximate mapping of servers in the queueing network model onto human brain (Wu and Liu, 2007).

QN-MHP has been successfully used to generate human behavior in real time, including simple and choice reaction time (Feyen, 2002), transcription typing (Wu & Liu, 2004a, 2004b, 2008a), psychological refractory period (Wu & Liu, 2004c, 2008b), physiological index of mental workload in visual-manual tracking (Wu & Liu, 2006a; Wu, Liu, & Walsh, 2008), subjective index of mental workload in driving (Wu & Liu, 2006b, 2006c, 2007; Wu, Tsimhoni, & Liu, in press), and driver performance (Liu, Feyen, & Tsimhoni,



Perceptual Subnetwork	Cognitive Subnetwork	Motor Subnetwork
1. Common visual processing	A. Visuospatial sketchpad	V. Sensorimotor integration
2. Visual recognition	B. Phonological loop	W. Motor program retrieval
3. Visual location	C. Central executive	X. Feedback information collection
4. Visual recognition and location integration	D. Long-term procedural memory	Y. Motor program assembling and error detecting
5. Common auditory processing	E. Performance monitor	Z. Sending information to body parts
6. Auditory recognition	F. Complex cognitive function	21-25: Body parts: eye, mouth, left hand, right hand, foot
7. Auditory location	G. Goal initiation	
8. Auditory recognition and location integration	H. Long-term declarative & spatial memory	

Fig. 1. The general structure of the queueing network model (Wu and Liu, 2007).