The Cognitive Informatics Theory and Mathematical Models of Visual Information Processing in the Brain

Yingxu Wang, University of Calgary, Canada

ABSTRACT

It is recognized that the internal mechanisms for visual information processing are based on semantic inferences where visual information is represented and processed as visual semantic objects rather than direct images or episode pictures in the long-term memory. This article presents a cognitive informatics theory of visual information and knowledge processing in the brain. A set of cognitive principles of visual perception is reviewed particularly the classic gestalt principles, the cognitive informatics principles, and the hypercolumn theory. A visual frame theory is developed to explain the visual information processing mechanisms of human vision, where the size of a unit visual frame is tested and calibrated based on vision experiments. The framework of human visual information processing is established in order to elaborate mechanisms of visual information processing and the compatibility of internal representations between visual and abstract information and knowledge in the brain. [Article copies are available for purchase from InfoSci-on-Demand.com]

Keywords: AI; The Basic Visual Frame; The Brain; Cognitive Informatics; Cognitive Models; Cognitive Principles; Computational Intelligence; Gestalt Principles; Hierarchical Abstraction Model; Hypercolumns; Visual Frame; Visual Information Processing; Visual Invariance

INTRODUCTION

It is recognized that, although over 90% information receptors of the brain are in the visual form, the internal processing mechanisms for the visual information are based on semantic or symbolic inferences rather than graphical reasoning (Hubel and Wiesel, 1959; Matlin, 1998; Payne and Wenger, 1998; Pinel, 1997; Westen, 1999; Wilson, 2001). In other words, the brain carries out thinking, reasoning, and inference on visual stimuli and image information in an abstract approach, and all visual information is represented and processed as visual semantic objects rather than direct images or episode pictures in long-term memory.

A fundamental question about the mechanisms of the brain is what the form of internal
representations of visual information is in long-term memory (Glickstein, 1988; Goldstein, 1999; Wang, 2009b; Wang and Wang, 2006). Early studies perceived that visual information is stored as pictures and the eyes work as cameras (Gray, 1994; Smith, 1993). Contemporary studies reveal that it may be true only in Sensory Buffer Memory (SBM) and Short-Term Memory (STM), but images retained and recognized in LTM are in the form of abstract visual semantics or symbolic concepts (Coaen et al., 1994; Hubel and Wiesel, 1959; Wang, 2009b). Therefore, the mechanisms of visual knowledge processing are based on abstract semantic analyses and syntheses.

This article presents the cognitive informatics foundations of visual information processing in the brain and their applications in knowledge engineering and computational intelligence. In the remainder of this article, fundamental principles of visual perceptions such as the gestalt principles, the cognitive informatics principles, and the hypercolumn theory, are described. The visual information processing mechanisms are explained by the visual frame theory and the calibration of the size of a unit visual frame. The framework of human visual information processing is developed to elaborate the fundamental mechanisms of visual information processing in the brain for visual knowledge representation and manipulation.

COGNITIVE FOUNDATIONS OF VISUAL INFORMATION PROCESSING

The mechanisms of visual information representation, processing, recognition, and comprehension, as well as their relationships to those of abstract information processing, are a set of fundamental questions in explaining the nature of human vision. This section presents the classic gestalt (holistic) principles and the cognitive informatics principles of visual information processing. Hubel and Wiesel’s hypercolumn theory for visual information processing in the visual cortex is introduced, which reveals the important mechanism of internal image information representation, interpretation, and processing.

The Holistic Principles

The classic gestalt principles of visual perception are developed in Germany based on experiments conducted in the 1920s and 1930s, where the term gestalt means an organized whole that is related to the philosophical doctrine of holism (Gray, 1994; Westen, 1999). The gestalt or holistic philosophy states that the whole is greater than the sum of its parts, which is inherited by modern system science.

In system algebra (Wang, 2008b), Wang creates a mathematical model of the holistic system principle that reveals the mechanism of abstract systems gains known as incremental union.

Definition 1. An incremental union of two sets of relations $R_1$ and $R_2$, denoted by $\Delta$, are a union of $R_1$ and $R_2$, plus a newly generated incremental set of relations $\Delta R_{12}$ i.e.: 

$$R_1 \oplus R_2 \triangleq R_1 \cup R_2 \cup \Delta R_{12} \quad (1)$$

where $\Delta R_{12} \subseteq R_1 \cap \Delta R_{12} \subseteq R_2$ and $\Delta R_{12} = 2(C_1 \bullet C_2) \subseteq R_1 \oplus R_2$.

The incremental union operation on abstract systems is a new denotational mathematical structure, which provides a generic mathematical model for revealing the fusion principle and system gains during system unions and compositions.

Six gestalt principles for visual object and pattern perception are identified (Kanizsa, 1979) such as similarity, proximity, good continuation, simplicity, closure, and background contrast, as summarized in Table 1.