

Chapter 5

On Visual Semantic Algebra (VSA): A Denotational Mathematical Structure for Modeling and Manipulating Visual Objects and Patterns

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ABSTRACT

A new form of denotational mathematics known as Visual Semantic Algebra (VSA) is presented for abstract visual object and architecture manipulations. A set of cognitive theories for pattern recognition is explored such as cognitive principles of visual perception and basic mechanisms of object and pattern recognition. The cognitive process of pattern recognition is rigorously modeled using VSA and Real-Time Process Algebra (RTPA), which reveals the fundamental mechanisms of natural pattern recognition by the brain. Case studies on VSA in pattern recognition are presented to demonstrate VSA's expressive power for algebraic manipulations of visual objects. VSA can be applied not only in machinable visual and spatial reasoning, but also in computational intelligence as a powerful man-machine language for representing and manipulating visual objects and patterns. On the basis of VSA, computational intelligent systems such as robots and cognitive computers may process and inference visual and image objects rigorously and efficiently.

INTRODUCTION¹

Pattern recognition is a fundamental cognitive process of the brain at the higher-cognition layer according to the Layered Reference Model of the Brain (LRMB) (Wang et al., 2006). The human

natural intelligence on visual object recognition, comprehension, and processing is highly dependent on the mechanisms of pattern recognition (Biedeman, 1987; Coen et al., 1994; Gray, 1994; Kanizsa, 1979; Marr, 1982; Payne and Wenger, 1998; Western, 1999; Wilson and Keil, 2001; Wang, 2009a). However, there is a lack of studies on the cognitive mechanisms of pattern recogni-

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tion, particularly how the natural intelligence processes visual objects and patterns (Wang, 2008d), as well as their *denotational mathematical models* (Wang, 2008a, 2008b).

The *gestalt (holistic) principles* of visual perception were developed in Germany based on experiments conducted in the 1920s and 1930s (Gray, 1994; Westen, 1999). Five gestalt principles for object and pattern perception were elicited (Kanizsa, 1979), such as *similarity, proximity, good continuation, simplicity, closure, and background contrast*. The gestalt principles reveal a set of important natural tendencies of human visual perception. Another set of seven cognitive informatics principles of visual object perception is identified in (Wang, 2009c) known as *association, symmetry, perfection, abstraction, categorization, analysis, and appreciation*, which are used in perception and identification of human figures, physical objects, abstract structure, mathematics entities, and nature.

A variety of theories and approaches are proposed for visual object and pattern recognition. Marr proposed a method for object recognition in the algorithmic approach known as the *computational method* (Marr, 1982). Biederman developed a method for object recognition in the analytic approach called *recognition by components* (Biederman, 1987). Various methods and technologies are developed for pattern recognition in the fields of cognitive psychology (payne and Wenger, 1998; Reed, 1972; Wilson and Keil, 2001), computer science (Bender, 2000; bow, 1992; Miclet, 1986; Storer, 2002), and robotics (Horn, 1986; Murry et al., 1993). Wang presents a cognitive theory of visual information processing as well as the unified framework of human visual processing systems (Wang, 2009c) in the development of cognitive informatics – a formal theory for explaining the natural and computational intelligence (Wang, 2002a, 2003, 2007b; Wang and Kinsner, 2006; Wang et al., 2002, 2008b, 2009a, 2009b). A set of denotational mathematics (Wang, 2006, 2008a), such as concept algebra (Wang, 2008c),

system algebra (Wang, 2008d), Real-Time Process Algebra (RTPA) (Wang, 2002b, 2007a, 2008b), and granular algebra (Wang, 2009d), are created in order to rigorously manipulate complex mental processes and computational intelligence.

This paper presents the cognitive process of pattern recognition and the denotational mathematical means known as Visual Semantic Algebra (VSA). The cognitive informatics theories for pattern recognition are explored such as cognitive principles of visual perception and basic mechanisms of object and pattern recognition. A generic denotational mathematical means, VSA, is developed to manipulate basic geometric shapes and figures, as well as their compositions by a set of algebraic operations. A number of case studies are provided to explain the expressive power of VSA and its applications.

COGNITIVE INFORMATICS THEORIES FOR PATTERN RECOGNITION

It is recognized that the brain tends to perform inference and reasoning using abstract semantic objects rather than direct visual (diagram-based) objects (Coen et al., 1994; Wang, 2009c). This is evidenced by that the brain cannot carry out concrete image inference in Short-Term Memory (STM) without looking at them in external media such as figures or pictures on paper, because this cognitive process requires too large memory beyond the capacity of STM in the brain

Basic Mechanisms of Object Recognition

Definition 1. *Object recognition is a special type of pattern recognition where the patterns are frequently used 2-D shapes, 3-D solid figures, and their compositions.*

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