Towards the Synergy of Cognitive Informatics, Neural Informatics, Brain Informatics, and Cognitive Computing

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ABSTRACT

The contemporary wonder of sciences and engineering recently refocused on the starting point: how the brain processes internal and external information autonomously rather than imperatively as those of conventional computers? This paper explores the interplay and synergy of cognitive informatics, neural informatics, abstract intelligence, denotational mathematics, brain informatics, and computational intelligence. A key notion recognized in recent studies in cognitive informatics is that the root and profound objective in natural, abstract, and artificial intelligence, and in cognitive informatics and cognitive computing, is to seek suitable mathematical means for their special needs. A layered reference model of the brain and a set of cognitive processes of the mind are systematically developed towards the exploration of the theoretical framework of cognitive informatics. A wide range of applications of cognitive informatics and denotational mathematics are recognized in the development of highly intelligent systems such as cognitive computers, cognitive knowledge search engines, autonomous learning machines, and cognitive robots.

Keywords: *Abstract Intelligence, Artificial Intelligence, Cognitive Computing, Computational Intelligence, Concept Algebra, Denotational Mathematics, Informatics, Machinable Intelligence, Natural Intelligence*

1. INTRODUCTION

Cognitive informatics studies the natural intelligence and the brain from a theoretical and a computational approach, which rigorously explains the mechanisms of the brain by a fundamental theory known as abstract intelligence, which formally models the brain by contemporary denotational mathematics. The contemporary wonder of sciences and engineering has recently refocused on the starting point of them: how the brain processes internal and external information autonomously and cognitively rather than imperatively as those of conventional computers? The latest advances and engineering applications of CI have led to the emergence of *cognitive*

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computing and the development of *cognitive computers* that perceive, learn, and reason (Wang, 2006, 2009d, 2009f, 2010a, 2011). CI has also fundamentally contributed to autonomous agent systems (Wang, 2009a) and cognitive robots (Wang, 2010a). A wide range of applications of CI are identified such as in the development of cognitive computers, cognitive robots, cognitive agent systems, cognitive search engines, cognitive learning systems, and artificial brains. The work in CI may also lead to a fundamental solution to computational linguistics, Computing with Natural Language (CNL), and Computing with Words (CWW) (Zadeh, 1975, 1999).

Cognitive Informatics is a term coined by Wang in the first IEEE International Conference on Cognitive Informatics (ICCI 2002) (Wang, 2002a). Cognitive informatics (Wang, 2002a, 2003, 2007b; Wang & Wang, 2006; Wang & Kinsner, 2006; Wang, Jonston, & Smith, 2002; Wang, Wang, Patel, & Patel, 2006; Wang, Zhang, Latombe, & Kinsner, 2008; Wang, Kinsner, & Zhang, 2009; Wang, Zhang, & Tsumoto, 2009; Wang et al., 2009, Wang & Chiew, 2010) studies the natural intelligence and the brain from a theoretical and a computational approach, which rigorously explains the mechanisms of the brain by a fundamental theory known as *abstract intelligence*. Cognitive informatics formally models the brain by contemporary *denotational mathematics* such as *concept algebra* (Wang, 2008b), *real-time process algebra* (RTPA) (Wang, 2002b, 2008d), *system algebra* (Wang, 2008c; Wang, Zadeh, & Yao, 2009), and *visual semantic algebra* (VSA) (Wang, 2009e). The latest advances in CI have led to a systematic solution for explaining brain informatics and the future generation of intelligent computers.

A key notion recognized in recent studies in cognitive informatics is that the root and profound objective in natural, abstract, and artificial intelligence in general, and in cognitive informatics and cognitive computing in particular, is to seek suitable mathematical means for their special needs, which were missing in these multidisciplinary areas. This is a general requirement for searching the metamethodology in any discipline particularly those of emerging fields where no suitable mathematics has been developed or of traditional fields where persistent hard problems have been unsolved efficiently or completely (Bender, 1996; Boole, 2003; Russell, 1996; Wang, 2008a, 2010b, 2011).

This paper is an extended summary of the invited keynote lecture presented in the 2010 *International Conference on Brain Informatics* (BI 2010), which covers some of the theoretical foundations of brain informatics developed in cognitive informatics and denotational mathematics. In this paper, cognitive informatics as the science of abstract intelligence and cognitive computing is briefly described in Section 2. Neural informatics is presented to explain how intelligence and knowledge are represented in the brain. The fundamental theories and expressive tools for cognitive informatics, brain Informatics, and computational intelligence, collectively known as denotational mathematics, are introduced in Section 4. Brain informatics as an interdisciplinary field for studying brain mechanisms by computing and medical imaging technologies is introduced in Section 5. Applications of cognitive informatics and denotational mathematics in cognitive computing are elaborated in Sections 6 towards the development of the next generation of cognitive computers.

2. COGNITIVE INFORMATICS: THE SCIENCE OF ABSTRACT INTELLIGENCE AND COMPUTATIONAL INTELLIGENCE

Information is the third essence of the word supplementing energy and matter. A key discovery in information science is the basic unit of information, *bit*, abbreviated from "binary digit", which forms a shared foundation of both computer science and information science.

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