

Cognitive Computing and Machinable Thought

Yingxu Wang

International Center for Cognitive Informatics (ICfCI)
Theoretical and Empirical Software Engineering Research Centre (TESERC)
Dept. of Electrical and Computer Engineering
Schulich School of Engineering, University of Calgary
2500 University Drive, NW, Calgary, Alberta, Canada T2N 1N4
Tel: (403) 220 6141, Fax: (403) 282 6855
Email: yingxu@ucalgary.ca

ABSTRACT

Cognitive Computing (CC) is an emerging paradigm of intelligent computing methodologies and systems that implements computational intelligence by autonomous inferences and perceptions mimicking the mechanisms of the brain [12]. CC is emerged and developed based on the transdisciplinary research in cognitive informatics and abstract intelligence. *Cognitive Informatics* (CI) is a transdisciplinary enquiry of computer science, information sciences, cognitive science, and cybernetics that investigates into the internal information processing mechanisms and processes of the brain and natural intelligence, as well as their engineering applications [2, 3, 16, 18]. The theoretical framework of cognitive informatics [5] covers the Information-Matter-Energy (IME) model [4], the Layered Reference Model of the Brain (LRMB) [15], the Object-Attribute-Relation (OAR) model of information representation in the brain [6], the cognitive informatics model of the brain [14], Natural Intelligence (NI) [5], and neuroinformatics [5]. Recent studies on LRMB in cognitive informatics reveal an entire set of cognitive functions of the brain and their cognitive process models, which explain the functional mechanisms and cognitive processes of the natural intelligence with 43 cognitive processes at seven layers known as the sensation, memory, perception, action, meta-cognitive, meta-inference, and higher cognitive layers [15].

Abstract Intelligence (αI) is the mathematical form of intelligence that transfers information into knowledge and behaviors [11]. The studies on αI form a human enquiry of both natural and artificial intelligence at the reductive levels of neural, cognitive, functional, and logical from the bottom up. The paradigms of αI are such as natural, artificial, machinable, and computational intelligence. The studies in CI and αI lay a theoretical foundation toward revealing the basic mechanisms of different forms of intelligence. As a result, cognitive computers may be developed, which are characterized as

knowledge processors beyond those of data processors in conventional computing.

Denotational Mathematics (DM) is a category of expressive mathematical structures that deals with high-level mathematical entities beyond numbers and sets, such as abstract objects, complex relations, perceptual information, abstract concepts, knowledge, intelligent behaviors, behavioral processes, and systems [7]. It is recognized that the maturity of a scientific discipline is characterized by the maturity of its mathematical (meta-methodological) means. The paradigms of DM are such as concept algebra [8], system algebra [9], real-time process algebra [1, 10], granular algebra [17], visual semantic algebra [13], fuzzy quantification/qualification, fuzzy inferences, and fuzzy causality analyses. DM provides a coherent set of contemporary mathematical means and explicit expressive power for CI, αI , CC, AI, and computational intelligence.

The latest advances in CI, αI , CC, and DM lead to a systematic solution for future generation intelligent computers known as *cognitive computers* that think and feel [12], which will enable the simulation of *machinable thought* such as computational inferences, reasoning, and causality analyses. A wide range of applications of CI, αI , CC, and DM is expected toward the implementation of highly intelligent machinable thought such as formal inference, symbolic reasoning, problem solving, decision making, cognitive knowledge representation, semantic searching, and autonomous learning.

Keywords: Cognitive informatics, abstract intelligence, cognitive computing, natural intelligence, artificial intelligence, machinable intelligence, computational intelligence, denotational mathematics, concept algebra, system algebra, RTPA, visual semantic algebra, granular algebra, autonomic knowledge processing, machinable thought, computational inferences, formal reasoning, and symbolic causality analyses.

REFERENCES

- [1] Wang, Y. (2002a), The Real-Time Process Algebra (RTPA), *Annals of Software Engineering*, 14, 235-274.
- [2] Wang, Y. (2002b), Keynote: On Cognitive Informatics, *Proc. 1st IEEE International Conference on Cognitive Informatics (ICCI'02)*, Calgary, Canada, IEEE CS Press, August, 34-42.
- [3] Wang, Y. (2003a), On Cognitive Informatics, *Brain and Mind: A Transdisciplinary Journal of Neuroscience and Neurophilosophy*, USA, August, 4(3), 151-167.
- [4] Wang, Y. (2007a), *Software Engineering Foundations: A Software Science Perspective*, CRC Series in Software Engineering, Vol. II, Auerbach Publications, NY, USA, July.
- [5] Wang, Y. (2007b), The Theoretical Framework of Cognitive Informatics, *International Journal of Cognitive Informatics and Natural Intelligence*, 1(1), 1-27.
- [6] Wang, Y. (2007c), The OAR Model of Neural Informatics for Internal Knowledge Representation in the Brain, *International Journal of Cognitive Informatics and Natural Intelligence*, 1(3), 64-75.
- [7] Wang, Y. (2008a), On Contemporary Denotational Mathematics for Computational Intelligence, *Transactions of Computational Science*, 2, Springer, June, 6-29.
- [8] Wang, Y. (2008b), On Concept Algebra: A Denotational Mathematical Structure for Knowledge and Software Modeling, *International Journal of Cognitive Informatics and Natural Intelligence*, 2(2), 1-19.
- [9] Wang, Y. (2008c), On System Algebra: A Denotational Mathematical Structure for Abstract System Modeling, *International Journal of Cognitive Informatics and Natural Intelligence*, 2(2), 20-42.
- [10] Wang, Y. (2008d), RTPA: A Denotational Mathematics for Manipulating Intelligent and Computational Behaviors, *International Journal of Cognitive Informatics and Natural Intelligence*, 2(2), 44-62.
- [11] Wang, Y. (2009a), On Abstract Intelligence: Toward a Unified Theory of Natural, Artificial, Machinable, and Computational Intelligence, *International Journal of Software Science and Computational Intelligence*, 1(1), 1-18.
- [12] Wang, Y. (2009b), On Cognitive Computing, *International Journal of Software Science and Computational Intelligence*, 1(3), 1-15.
- [13] Wang, Y. (2009c), On Visual Semantic Algebra (VSA): A Denotational Mathematical Structure for Modeling and Manipulating Visual Objects and Patterns, *International Journal of Software Science and Computational Intelligence*, 1(4), 1-15.
- [14] Wang, Y. and Y. Wang (2006), Cognitive Informatics Models of the Brain, *IEEE Trans. on Systems, Man, and Cybernetics (C)*, 36(2), 203-207.
- [15] Wang, Y., Y. Wang, S. Patel, and D. Patel (2006), A Layered Reference Model of the Brain (LRMB), *IEEE Trans. on Systems, Man, and Cybernetics (C)*, 36(2), 124-133.
- [16] Wang, Y., W. Kinsner, and D. Zhang (2009a), Contemporary Cybernetics and its Faces of Cognitive Informatics and Computational Intelligence, *IEEE Trans. on System, Man, and Cybernetics (B)*, 39(4), 1-11.
- [17] Y. Wang, L.A. Zadeh, and Y. Yao (2009b), On the System Algebra Foundations for Granular Computing, *International Journal of Software Science and Computational Intelligence*, IGI, USA, Jan., 1(1), 1-17.
- [18] Wang, Y., W. Kinsner, J.A. Anderson, D. Zhang, Y. Yao, P. Sheu, J. Tsai, W. Pedrycz, J.-C. Latombe, L.A. Zadeh, D. Patel, and C. Chan (2009c), A Doctrine of Cognitive Informatics, *Fundamenta Informaticae*, 90(3), 1-26.

About the Keynote Speaker



Yingxu Wang is professor of cognitive informatics and software engineering, Director of International Center for Cognitive Informatics (ICfCI), and Director of Theoretical and Empirical Software Engineering Research Center (TESERC) at the University of Calgary. He is a Fellow of WIF, a

P.Eng of Canada, a Senior Member of IEEE and ACM, and a member of ISO/IEC JTC1 and the Canadian Advisory Committee (CAC) for ISO. He received a PhD in Software Engineering from the Nottingham Trent University, UK, in 1997, and a BSc in Electrical Engineering from Shanghai Tiedao University in 1983.

He has industrial experience since 1972 and has been a full professor since 1994. He was a visiting professor in the Computing Laboratory at Oxford University in 1995, Dept. of Computer Science at Stanford University in 2008, and the Berkeley Initiative in Soft Computing (BISC) Lab at University of California, Berkeley in 2008, respectively. He is the founder and steering committee chair of the annual IEEE International Conference on Cognitive Informatics (ICCI). He is founding Editor-in-Chief of *International Journal of Cognitive Informatics and Natural Intelligence* (IJCINI), founding Editor-in-Chief of *International Journal of Software Science and Computational Intelligence* (IJSSCI), Associate Editor of IEEE Trans on System, Man, and Cybernetics (A), and Editor-in-Chief of *CRC Book Series in Software Engineering*.

Prof. Wang is the initiator of a number of cutting-edge research fields or subject areas such as cognitive informatics, abstract intelligence, denotational

mathematics (i.e., concept algebra, system algebra, real-time process algebra, granular algebra, visual semantic algebra, fuzzy quantification/qualification, fuzzy inferences, and fuzzy causality analyses), cognitive computing, software science (i.e., theoretical software engineering and mathematical laws of software engineering), coordinative work organization theory, deductive semantics, the layered reference model of the brain (LRMB), the mathematical model of consciousness, the reference model of autonomous agent systems, cognitive complexity of software, and built-in tests (BITs). He has published over 105 peer reviewed journal papers, 190 peer reviewed full conference papers, and 12 books in cognitive informatics, software engineering, and computational intelligence. He is the recipient of dozens international awards on academic leadership, outstanding contributions, research achievement, best paper, and teaching in the last 30 years.