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EXTENDED ABSTRACT

Inference as a fundamental mechanism of thought is one of the gifted abilities of human beings. Inference can be described as a cognitive process that creates rational causations between a pair of cause and effect based on empirical arguments, formal reasoning, and/or statistical regulations [2, 15, 24, 26]. Conventional logic inferences may be classified as logical arguments, deductive, inductive, abductive, and analogical inferences [4, 9, 10, 11, 15].

Studies on mechanisms and laws of inferences can be traced back to the very beginning of human civilization, which formed part of the foundations of various disciplines such as philosophy, logic, mathematics, cognitive science, artificial intelligence, computational intelligence, abstract intelligence, knowledge science, computational linguistics, and psychology [2, 5, 25, 26, 28]. Aristotle (384BC – 322BC) established syllogism that formalized inferences as logical arguments on propositions in which a conclusion is deductively inferred from two premises [1]. Sylogism was treated as the fundamental methodology for inferences by Bertrand Russell in The Principles of Mathematics [8]. In his classic work, Principia: Mathematical Principles of Natural Philosophy [7], Isaac Newton described a set of rules for inferences about nature known as the experimental philosophy of causality. In A System of Logic, John S. Mill identified a rich set of five forms of causal connections between events in philosophy known as the methods of agreement, difference, joint agreement and difference, residues, and concomitant variation [6]. George Boole in The Laws of Thought studied the mathematical and logical laws of human thinking mechanisms and processes, where he perceived inference as operations of the mind based on logical and probability laws [3]. Lotfi A. Zedeck created the fuzzy set theory and fuzzy logic since 1960s [25, 26, 27, 28, 29], which become one of the most applied theory for fuzzy inferences and building fuzzy reasoning models in modern sciences and engineering. Fuzzy inferences are a powerful denotational mathematical means for rigorously dealing with degrees of matters, uncertainties, and vague semantics of linguistic variables, as well as for precisely reasoning the semantics of fuzzy causations.

In the above classic work, it is recognized that abstraction is not only a powerful means of philosophy and mathematics, but also a preeminent trait of the brain as identified in cognitive informatics [12, 13, 14, 16, 17, 18, 19, 20, 21, 22, 23]. All formal inferences can be better conducted on the basis of abstract properties shared by a given set of objects under study. For seeking generality and universal truth, either the objects or the relations may only be symbolically described and rigorously inferred by abstract models rather than real world details.

Although there are various inference schemes and methods developed in a wide range of disciplines and applications, the framework of formal inferences can be described in five categories known as the relational, rule-based, logical, fuzzy logical, and causal inferences as shown in Fig. 1. With an extended expressive power, causal inferences are a set of advanced inference methodologies building upon the other fundamental layers. The coherent framework of formal inferences reveals how human reasoning may be formalized and how machines may rigorously mimic the human inference mechanisms.

Fig. 1 The hierarchical framework of formal inferences

This keynote lecture presents a theory of formal inferences and a framework of causal inferences based on the denotational mathematical structure known as Inference Algebra (IA). The taxonomy and framework of formal causal inferences are explored in three categories: a) Logical inferences on Boolean and fuzzy causations; b) Analytic inferences on general functional, correlative, linear regressive,
and nonlinear regressive causations; and c) Hybrid inferences on qualitative and quantitative causations. As that of Boolean algebra for explicit logical reasoning and fuzzy logic for approximate and uncertainty reasoning, IA is introduced as a denotational mathematical structure with a set of algebraic operators on a set of formal causations (\(\mathcal{E}\)) for logical, analytic, and hybrid inferences. In IA, the general forms of causations are rigorously modeled as the Boolean, fuzzy, functional, correlative, linear-regression, nonlinear-regression, qualitative and quantitative causations. Eight algebraic inference operators (\(K\)) of IA are created for manipulating the formal causations. IA elicits and formalizes the common and empirical reasoning processes of humans in a rigorous form, which enable AI and computational intelligent systems to mimic and implement similar inference abilities of the brain by cognitive computing. A wide range of applications of IA are identified and demonstrated in cognitive informatics and computational intelligence towards novel theories and technologies for machine-enabled inferences and reasoning.

**Keywords:** Cognitive informatics, cognitive computing, abstract intelligence, denotational mathematics, inference algebra, formal causations, cognitive computers, computational intelligence, applications

**REFERENCES**


About the Keynote Speaker

**Yingxu Wang** is professor of cognitive informatics and software engineering, President of International Institute of Cognitive Informatics and Cognitive Computing (IICICC), 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, and a BSc in Electrical Engineering from Shanghai Tiedao University. 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* (Part A), associate Editor-in-Chief of *Journal of Advanced Mathematics and Applications*, 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, cognitive computing, cognitive computers, denotational mathematics (i.e., concept algebra, inference algebra, system algebra, real-time process algebra, granular algebra, and visual semantic algebra), software science (i.e., theoretical software engineering, and unified mathematical models and laws of software), coordinative work organization theory, deductive semantics, the layered reference model of the brain (LRMB), the mathematical model of consciousness, the reference model of cognitive robots and autonomous agent systems, cognitive complexity of software, and built-in tests (BITs). He has published over 110 peer reviewed journal papers, 200+ peer reviewed full conference papers, and 16 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 papers, and teaching in the last three decades.