
Yingxu Wang*

Visiting Professor, Dept. of Computer Science
Stanford University, Stanford, CA 94305-9010, USA
yingxuw@stanford.edu; yingxu@ucalgary.ca

Du Zhang

Dept. of Computer Science, California State University
Sacramento, CA 95819-6021, USA
zhangd@ecs.csus.edu

Shusaku Tsumoto

Dept. of Medical Informatics, School of Medicine, Shimane University
Enya-cho Izumo City, Shimane 693-8501, Japan
tsumoto@computer.org

Abstract. Cognitive Informatics is a cutting-edge and multidisciplinary research area that tackles the fundamental problems shared by modern informatics, computing, software engineering, AI, cybernetics, cognitive science, neuropsychology, medical science, systems science, philosophy, linguistics, economics, management science, and life sciences. This editorial introduces the emerging field of cognitive informatics and its applications in cognitive computing, abstract intelligence, computational mathematics, and computational intelligence. The themes and structure of this special issue on cognitive informatics are described, and then, focuses of the selected papers in Part II of this special issue are highlighted.

*Address for correspondence: Visiting Professor, Dept. of Comp. Sc., Stanford University, Stanford, CA 94305-9010, USA
Also works: Theoretical and Empirical Software Engineering, Research Centre (TESERC), International Center for Cognitive Informatics (ICICI), Dept. of Electrical and Computer Engineering, Schulich School of Engineering, University of Calgary, Calgary, Alberta, Canada T2N 1N4
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The theories of informatics and their perceptions on information as an abstract object have evolved from the classic information theory, modern informatics, to cognitive informatics in the past half century. Classic informatics [1, 5], particularly Shannon's information theory [5] known as the first-generation informatics, studies signals and channel behaviors based on statistics and probability theories. Modern informatics studies information as properties or attributes of the natural world that can be generally abstracted, quantitatively represented, and mentally processed. The first- and second-generation informatics put emphases on external information processing, which overlook the fundamental fact that human brains are both the original sources and final destinations of information. Therefore, any information must be cognized by human beings before it is understood and utilized in the society. This observation leads to the establishment of the third-generation informatics, a term coined by Wang in 2002 as Cognitive Informatics in [6, 8, 9, 10, 12, 13, 20].

Definition 1. Cognitive informatics (CI) is the transdisciplinary enquiry of cognitive and information sciences that investigates into the internal information processing mechanisms and processes of the brain and natural intelligence, and their engineering applications via an interdisciplinary approach.

A series of IEEE International Conferences on Cognitive Informatics (ICCI) have been annually organized. The inaugural ICCI event in 2002 was held in Calgary, Canada (ICCI'02) [21], followed by the events in London, UK (ICCI'03) [4], Victoria, Canada (ICCI'04) [2], Irvine, USA (ICCI'05) [3], Beijing, China (ICCI'06) [24], Lake Tahoe, USA (ICCI'07) [25], and Stanford University, USA (ICCI'08) [22]. The development and the cross fertilization between the aforementioned science and engineering disciplines have led to a whole range of extremely interesting new research topics in CI. The special issue on Cognitive Informatics in Fundamenta Informaticae (FI) covers selected papers on topics that transcend disciplinary boundaries of computing, cognitive science, and mathematics, which investigate the cognitive mechanisms and processes of human information processing, and their applications in computing and software engineering. This special issue has its focuses on the latest development in cognitive computing, neural informatics, abstract intelligence, denotational mathematics, and computational intelligence. The main themes of cognitive informatics encompass three categories of topics, i.e., cognitive computing, computational intelligence, and neural informatics, as shown in Table 1.

Across the three themes of cognitive informatics, their denotational and expressive needs lead to new forms of mathematics collectively known as denotational mathematics [11, 14, 19].

Definition 2. Denotational mathematics is a category of expressive mathematical structures that deals with high-level mathematical entities beyond numbers and sets, such as abstract objects, complex relations, behavioral information, concepts, knowledge, processes, and systems.

Typical forms of denotational mathematics are such as concept algebra [15], system algebra [16, 23], Real-Time Process Algebra (RTPA) [7, 11, 17, 19], and Visual Semantic Algebra (VSA) [18]. The paradigms of denotational mathematics provide a rigorous methodology and means for dealing with complex abstract entities in an extremely wide range of application areas such as cognitive computing,
abstract intelligence, computational intelligence, software science, software engineering, and knowledge engineering.

Table 1. The Theoretical Framework of Cognitive Informatics

<table>
<thead>
<tr>
<th>Cognitive Computing</th>
<th>Computational Intelligence</th>
<th>Neural Informatics</th>
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<tbody>
<tr>
<td>• Informatics models of the brain</td>
<td>• Imperative vs. autonomous Computing</td>
<td>• Neuroscience foundations of information processing</td>
</tr>
<tr>
<td>• Cognitive processes of the brain</td>
<td>• Reasoning and inferences</td>
<td>• Cognitive models of the brain</td>
</tr>
<tr>
<td>• Internal information processing</td>
<td>• Cognitive informatics foundations</td>
<td>• Functional modes of the brain</td>
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<td>Mechanisms</td>
<td></td>
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<tr>
<td>• Theories of natural intelligence</td>
<td>• Robotics</td>
<td>• Neural models of memory</td>
</tr>
<tr>
<td>• Intelligent foundations of computing</td>
<td>• Informatics foundations of software engineering</td>
<td>• Neural networks</td>
</tr>
<tr>
<td>• Denotational mathematics</td>
<td>• Fuzzy/rough sets/logic</td>
<td>• Neural computation</td>
</tr>
<tr>
<td>• Abstraction and means</td>
<td>• Knowledge engineering</td>
<td>• Cognitive linguistics</td>
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<tr>
<td>• Ergonomics</td>
<td>• Pattern and signal recognitions</td>
<td>• Neuropsychology</td>
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<tr>
<td>• Informatics laws of software</td>
<td>• Autonomic agent technologies</td>
<td>• Bioinformatics</td>
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<td>• Knowledge representation</td>
<td>• Memory models</td>
<td>• Biosignal processing</td>
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<tr>
<td>• Models of knowledge and skills</td>
<td>• Software agent systems</td>
<td>• Cognitive signal processing</td>
</tr>
<tr>
<td>• Formal linguistics</td>
<td>• Decision theories</td>
<td>• Gene analysis and expression</td>
</tr>
<tr>
<td>• Cognitive complexity &amp; metrics</td>
<td>• Problem solving theories</td>
<td>• Cognitive metrics</td>
</tr>
<tr>
<td>• Distributed intelligence</td>
<td>• Machine learning systems</td>
<td>• Neural signal interpretation</td>
</tr>
<tr>
<td>• Semantic computing</td>
<td>• Distributed objects/granules</td>
<td>• Visual information representation</td>
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<tr>
<td>• Emotions/motivations/attitudes</td>
<td>• Web contents cognition</td>
<td>• Visual semantics</td>
</tr>
<tr>
<td>• Perception and consciousness</td>
<td>• Nature of software</td>
<td>• Sensational cognitive processes</td>
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<tr>
<td>• Hybrid (AI/NI) intelligence</td>
<td>• Granular computing</td>
<td>• Human factors in systems</td>
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</table>

The key application areas of CI can be divided into two categories. The first category of applications uses informatics and computing techniques to investigate cognitive science problems, such as memory, learning, and reasoning. The second category including the areas that use cognitive theories to investigate problems in informatics, computing, software engineering, knowledge engineering, and computational intelligence. CI focuses on the nature of information processing in the brain, such as information acquisition, representation, memory, retrieve, generation, and communication. Through the interdisciplinary approach and with the support of modern information and neuroscience technologies, mechanisms of the brain and the mind may be systematically explored within the framework of CI.

2. Highlights of This Special Issue, Part II

This special issue on *Cognitive Informatics* in EATCS’ *Fundamenta Informaticae* presents the latest advances in cognitive informatics and cognitive computing. The volume includes selected and refined papers from the 7th IEEE International Conference on Cognitive Informatics (ICCI 2008) at Stanford University, USA, held in August 2008 [22] and the 6th IEEE International Conference on Cognitive Informatics (ICCI 2007) at Lake Tahoe, USA, in August 2007 [25], as well as additional new contributions. This special issue is published in two parts. The second part of this special issue encompasses six papers as highlighted below.
Yingxu Wang creates “A Formal Syntax of Natural Languages and the Deductive Grammar.” This paper presents a formal syntax framework of natural languages for computational linguistics. The abstract syntax of natural languages, particularly English, and their formal manipulations are described. On the basis of the abstract syntax, a universal language processing model and the deductive grammar of English are developed toward the formalization of Chomsky’s universal grammar in linguistics. Comparative analyses of natural and programming languages, as well as the linguistic perception on software engineering, are discussed. A wide range of applications of the deductive grammar of English have been explored in language acquisition, comprehension, generation, and processing in cognitive informatics, computational intelligence, and cognitive computing.

Hidenao Abe and Shusaku Tsumoto present “Investigating Accuracies of Classifications for Randomized Imbalanced Class Distributions.” In data mining post-processing, rule selection with objective rule evaluation indices is one of useful methods for extracting valuable knowledge from mined patterns. However, the relationship between an index value and experts’ criteria has never been clarified. In order to determine the relationship, authors have developed a method to obtain learning models from a dataset consisting of objective rule evaluation indices and evaluation labels for rules. In this study, authors have compared accuracies of classification learning algorithms for datasets with randomized class labels. Then, the result shows that accuracies of classification learning algorithms without any criterion of a human expert cannot outperform each percentage of majority class on both the balanced and imbalanced class distribution datasets. With regard to this result, one can determine whether or not a labelled rule set contains some criteria based on the dataset consisting of the objective rule evaluation indices.

Bogdan Kwolek presents “Object Segmentation in Video via Graph Cut Built on Superpixels.” This paper proposes a real-time scheme for object segmentation in video. In the first stage a segmentation based on pairwise region comparison is utilized to oversegment image through extracting superpixels. Next, the algorithm applies the graph cut built on such superpixels instead of image pixels. Owing to the optimization being performed on a simpler graph, the object segmentation consequently runs in shorter time. Tracking of object features over time contributes toward improved segmenting of an object from one image to another. The segmentation information supports following the entire object instead of just a few features on it. The objects are segmented correctly as complete entities, despite the high variability of the object shape and cluttered background. Experimental results illustrate the efficiency and effectiveness of the algorithm.

Guoyin Wang and Yan Wang present “3DM: Domain-Oriented Data-Driven Data Mining.” Recent developments make it possible to gather and store incredible volume of data. It creates unprecedented opportunities for knowledge discovery in large-scale databases. Data mining technology is an emerging area of computational intelligence that offers new theories, techniques, and tools for processing large volume data in data analysis and decision making. Despite empirical studies on data mining techniques, methods, and algorithms, there are still questions on the basic research on data mining, such as: What is data mining? What is the product of data mining? What is the nature of a data mining process? What are the applicable rules in data mining? And what is the relationship between the prior knowledge of domain experts and the knowledge mined from data? This paper addresses the aforementioned basic issues of data mining from the viewpoint of cognitive informatics. Data is taken as a manmade format for encoding knowledge about the natural world, and data mining is modeled as a process of knowledge transformation. A domain-oriented data-driven data mining (3DM) model based on a conceptual data mining model is proposed. Some data-driven mining algorithms are proposed to show the validity of
this method, e.g., the data-driven default rule generation algorithm, data-driven decision tree pre-pruning algorithm, and data-driven knowledge acquisition from concept lattice.

Shusaku Tsumoto and Shoji Hirano present “Contingency Matrix Theory II: Degree of Dependence as Granularity.” The degree of granularity of a contingency table is closely related with that of dependence of contingency tables. Authors investigate these relations from the viewpoints of determinantal devisors and determinants. From the results of determinantal devisors, it seems that the devisors provide information on the degree of dependencies between the matrix of the whole elements and its submatrices and the increase of the degree of granularity may lead to that of dependence. However, the other approach shows that a constraint on the sample size of a contingency table is very strong, which leads to the evaluation formula where the increase of degree of granularity gives the decrease of dependency.

Yingxu Wang presents “Toward Formal Models of the Theoretical Framework of Fundamental Economics.” Many fundamental theories and doctrines of micro- and macro-economics are not formally studied in economics. This paper presents a rigorous treatment and explanation of a set of fundamental empirical theories of economics. It is recognized that the adaptive equilibrium of market systems is rooted in the negative feedback mechanisms of demands and supplies. A mathematical model of economic equilibrium developed in this paper provides a formal proof of Adam Smith's hypothesis of the invisible hand. An economic equilibrium theorem is derived to deal with more complicated multivariable equilibrium problems that could not be handled in conventional economic theories. Then, a set of mathematical models is developed for dynamic cost analyses and the estimation of economical outcomes of engineering projects.

The editors expect that the readers of the journal of Fundamenta Informaticae will benefit from the papers presented in this special issue on the latest advances in theories and applications of cognitive informatics, natural intelligence, abstract intelligence, denotational mathematics, cognitive computing, and computational intelligence.

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