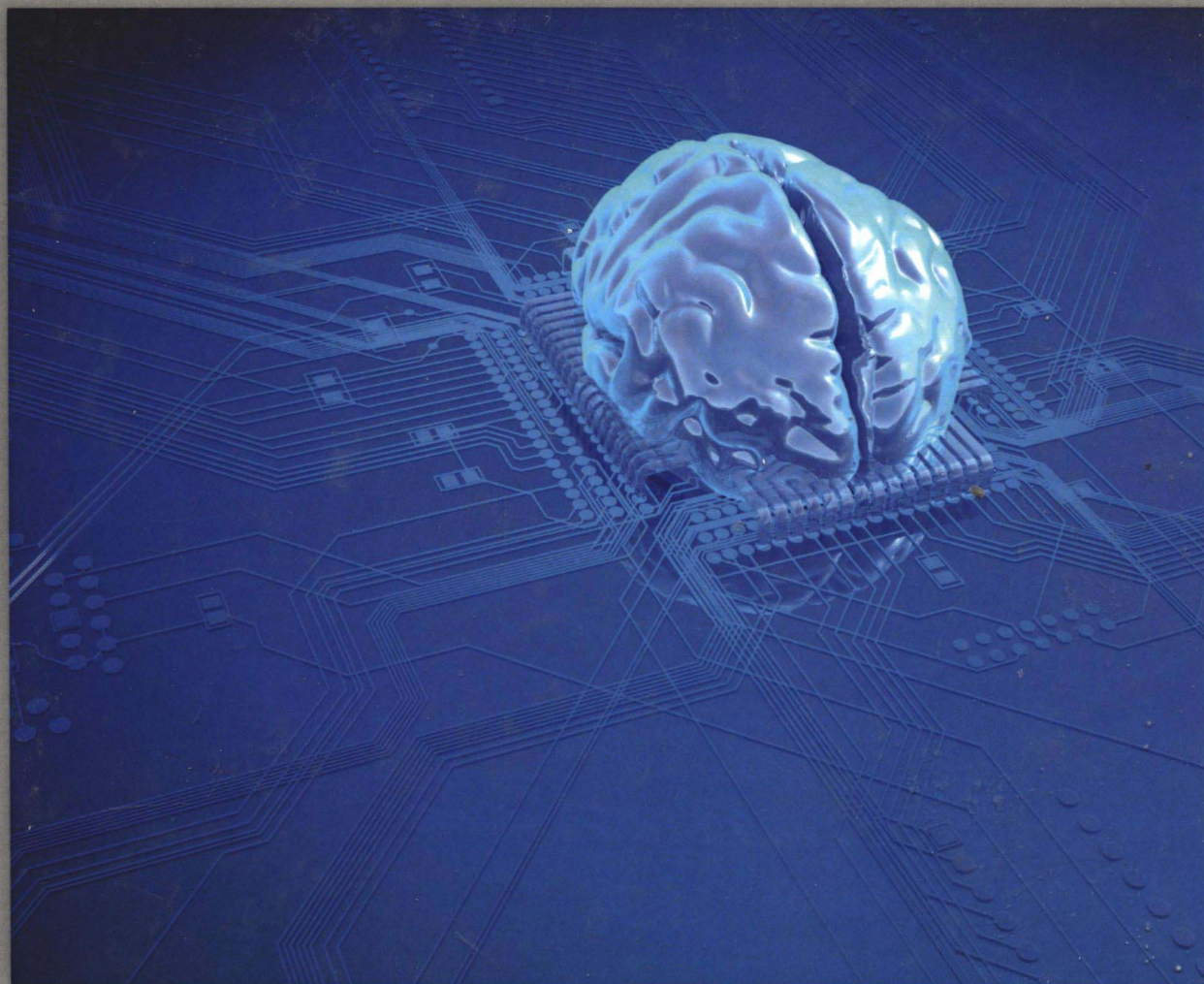# Cognitive Informatics for Revealing Human Cognition

Knowledge Manipulations in Natural Intelligence

Yingxu Wang
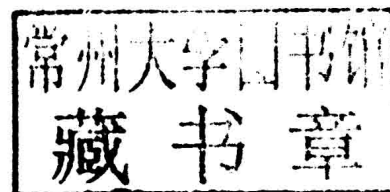
Cognitive Informatics for Revealing Human Cognition:

Knowledge Manipulations in Natural Intelligence

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The views expressed in this book are those of the authors, but not necessarily of the publisher.

Preface

Cognitive informatics (CI) is a new discipline that studies the natural intelligence and internal information processing mechanisms of the brain, as well as the processes involved in perception and cognition. CI was initiated by Yingxu Wang and his colleagues in 2002. The development and the cross fertilization among computer science, information science, cognitive science, brain science, and intelligence science have led to a whole range of extremely interesting new research fields known as CI, which investigates the internal information processing mechanisms and processes of the natural intelligence – human brains and minds – and their engineering applications in computational intelligence.

The theories of informatics and their perceptions on the object of information have evolved from the classic information theory, modern informatics, to cognitive informatics in the last six decades. The *classic information theories*, particularly Shannon's information theory, are the first-generation informatics that study signals and channel behaviors based on statistics and probability theory. The *modern informatics* studies information as properties or attributes of the natural world that can be distinctly elicited, generally abstracted, quantitatively represented, and mentally processed. The first- and second-generation informatics put emphases on external information processing, which are yet to be extended to observe the fundamental fact that human brains are the original sources and final destinations of information. Any information must be cognized by human beings before it is understood, comprehended, and consumed. The aforementioned observations have led to the establishment of the third-generation informatics, *cognitive informatics*, a term coined by Yingxu Wang in a keynote to the First IEEE International Conference on Cognitive Informatics in 2002. It is recognized in CI that *information* is the third essence of the natural world supplementing to matter and energy, which is any property or attribute of the natural world that can be distinctly elicited, generally abstracted, quantitatively represented, and mentally processed. On the basis of the evolvement of intension and extension of the term information, *informatics* is the science of information that studies the nature of information, its processing, and ways of transformation between information, matter and energy.

In many disciplines of human knowledge, almost all of the hard problems yet to be solved share a common root in the understanding of the mechanisms of natural intelligence and the cognitive processes of the brain. Therefore, CI is a discipline that forges links between a number of natural science and life science disciplines with informatics and computing science. CI provides a coherent set of fundamental theories, and contemporary mathematics, which form the foundation for most information and knowledge based science and engineering disciplines.

This book, entitled *Cognitive Informatics for Revealing Human Cognition: Knowledge Manipulations in Natural Intelligence*, is the fifth volume in the IGI series of Advances in Cognitive Informatics and Natural Intelligence. The book encompasses 24 chapters of expert contributions selected from the International Journal of Cognitive Informatics and Natural Intelligence during 2011. The book is organized in five sections on: (1) Cognitive informatics; (2) Cognitive computing; (3) Denotational mathematics; (4) Computational intelligence; and (5) Applications in cognitive informatics and cognitive computing.

SECTION 1: COGNITIVE INFORMATICS

Cognitive Informatics (CI) is a transdisciplinary enquiry of computer science, information science, cognitive science, and intelligence science that investigates into the internal information processing mechanisms and processes of the brain and natural intelligence, as well as their engineering applications in cognitive computing. Fundamental theories developed in CI covers the Information-Matter-Energy-Intelligence (IME-I) model, the Layered Reference Model of the Brain (LRMB), the Object-Attribute-Relation (OAR) model of internal information representation in the brain, the cognitive informatics model of the brain, natural intelligence (NI), abstract intelligence (αI), neuroinformatics (NeI), denotational mathematics (DM), and cognitive systems. 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.

According to CI, natural intelligence, in the narrow sense, is a human or a system ability that transforms information into behaviors; while in the broad sense, it is any human or system ability that autonomously transfers the forms of abstract information between data, information, knowledge, and behaviors in the brain. The history of human quest to understand the brain and natural intelligence is certainly as long as human history itself. It is recognized that artificial intelligence is a subset of natural intelligence. Therefore, the understanding of natural intelligence is a foundation for investigating into artificial, machinable, and computational intelligence.

The section on cognitive informatics encompasses the following five chapters:

- **Chapter 1:** Towards the Synergy of Cognitive Informatics, Neural Informatics, Brain Informatics, and Cognitive Computing
- **Chapter 2:** Perspectives on the Field of Cognitive Informatics and Its Future Development
- **Chapter 3:** Role-Based Human-Computer Interaction
- **Chapter 4:** Main Retina Information Processing Pathways Modeling
- **Chapter 5:** Songs to Syntax: Cognition, Combinatorial Computation, and the Origin of Language

Chapter 1, *Towards the Synergy of Cognitive Informatics, Neural Informatics, Brain Informatics, and Cognitive Computing*, by Yingxu Wang, recognizes that 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 rather than imperatively as those of conventional computers? The interplay and synergy of cognitive informatics, neural informatics, abstract intelligence, denotational mathematics, brain informatics, and computational intelligence are explored in this chapter. 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 that were missing. 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.

Chapter 2, *Perspectives on the Field of Cognitive Informatics and its Future Development*, by Yingxu Wang, Bernard Widrow, Bo Zhang, Witold Kinsner, Kenji Sugawara, Fuchun Sun, Jianhua Lu, Thomas Weise, and Du Zhang, presents Cognitive Informatics (CI) as a transdisciplinary enquiry of computer science, information sciences, cognitive science, and intelligence science that investigates into the internal information processing mechanisms and processes of the brain and natural intelligence, as well as their engineering applications in cognitive computing. This chapter reports a set of eight position statements presented in the plenary panel of IEEE ICCI'10 on *Cognitive Informatics and its Future Development* contributed from invited panelists who are part of the world's renowned researchers and scholars in the field of cognitive informatics and cognitive computing.

Chapter 3, *Role-Based Human-Computer Interaction*, by Haibin Zhu and Min Hou, presents that with the increased understanding of cognitive informatics and the advance of computer technologies, it is becoming clear that human-computer interaction (HCI) is an interaction between two kinds of intelligences, i.e., natural intelligence and artificial intelligence. This chapter attempts to clarify interaction-related terminologies through step-by-step definitions, and discusses the nature of HCI, arguing that shared models are the most important aspect of HCI. This chapter also proposes that a role-based interaction can be taken as an appropriate shared model for HCI, i.e., role-based HCI.

Chapter 4, *Main Retina Information Processing Pathways Modeling*, by Hui Wei, Qingsong Zuo, and Xudong Guan, identifies there always confront a balance issue among real-time, accuracy, computing load, power consumption and other factors in digital image processing and artificial retina design. It is difficult to achieve an optimal balance among these conflicting requirements. However, human retina can balance these conflicting requirements very well. It can efficiently and economically accomplish almost all the visual tasks. This chapter presents a bio-inspired model of the retina, not only to simulate various types of retina cells but also to simulate complex structure of retina. The model covers main information processing pathways of retina so that it is much closer to the real retina. In this chapter, the authors researched various characteristics of retina via large-scale statistical experiments, and further analyzed the relationship between retina's structure and functions. The model can be used in bionic chip design, physiological assumptions verification, image processing, and computer vision.

Chapter 5, *Songs to Syntax: Cognition, Combinatorial Computation, and the Origin of Language*, by Robert C. Berwick, reveals that language comprises a central component of what the co-founder of modern evolutionary theory, Alfred Russell Wallace, called "man's intellectual and moral nature" – the human cognitive capacities for creative imagination, language and symbolism generally, a complex that is sometimes simply called "the human capacity." This complex seems to have crystallized fairly recently among a small group in East Africa of whom we are all descendants, distinguishing contemporary humans sharply from all other animals, with enormous consequences for the whole of the biological world, as well as for the study of computational cognition. How can we explain this evolutionary leap? On the one hand, common descent has been important in the evolution of the brain, such that avian and mam-

malian brains may be largely homologous, particularly in the case of brain regions involved in auditory perception, vocalization and auditory memory. On the other hand, there has been convergent evolution of the capacity for auditory-vocal learning, and possibly for structuring of external vocalizations, such that apes lack the abilities that are shared between songbirds and humans. Language's recent evolutionary origin suggests that the computational machinery underlying syntax arose via the introduction of a single, simple, combinatorial operation. Further, the relation of a simple combinatorial syntax to the sensory-motor and thought systems reveals language to be asymmetric in design: while it precisely matches the representations required for inner mental thought, acting as the "glue" that binds together other internal cognitive and sensory modalities, at the same time it poses computational difficulties for externalization, that is, parsing and speech or signed production. Despite this mismatch, language syntax leads directly to the rich cognitive array that marks us as a symbolic species, including mathematics, music, and much more.

SECTION 2: COGNITIVE COMPUTING

Computing systems and technologies can be classified into the categories of *imperative, autonomic,* and *cognitive* computing from the bottom up. The imperative computers are a passive system based on stored-program controlled behaviors for data processing. The autonomic computers are goal-driven and self-decision-driven machines that do not rely on instructive and procedural information. Cognitive computers are more intelligent computers beyond the imperative and autonomic computers, which embody major natural intelligence behaviors of the brain such as thinking, inference, and learning.

Cognitive Computing (CC) is a novel paradigm of intelligent computing methodologies and systems based on CI that implements computational intelligence by autonomous inferences and perceptions mimicking the mechanisms of the brain. CC is emerged and developed based on the multidisciplinary research in CI. The latest advances in CI and CC, as well as denotational mathematics, enable a systematic solution for the future generation of intelligent computers known as *cognitive computers* (CogCs) that think, perceive, learn, and reason. A CogC is an intelligent computer for knowledge processing as that of a conventional von Neumann computer for data processing. CogCs are designed to embody *machinable intelligence* such as computational inferences, causal analyses, knowledge manipulation, machine learning, and autonomous problem solving.

The section on cognitive computing encompasses the following five chapters:

- **Chapter 6:** Cognitive Memory for Semantic Agents Architecture in Robotic Interaction
- **Chapter 7:** Interactive Feature Visualization and Detection for 3D Face Classification
- **Chapter 8:** A Computational Simulation of the Cognitive Process of Children Knowledge Acquisition and Memory Development
- **Chapter 9:** A Novel Emotion Recognition Method Based on Ensemble Learning and Rough Set Theory
- **Chapter 10:** Cognitive Informatics and Cognitive Computing in Year 10 and Beyond

Chapter 6, *Cognitive Memory for Semantic Agents Architecture in Robotic Interaction*, by Sébastien Dourlens and Amar Ramdane-Cherif, presents that since 1960, lots of AI researchers work on intelligent and reactive architectures able to manage multiple events and act in the environment. This issue is also part of robotics domain. An extraction of meaning at different levels of abstraction and the decision

process must be implemented in the robot brain to accomplish the multimodal interaction with human in human environment. In this chapter, the authors present a semantic agents architecture giving the robot the ability to well understand what is happening and thus provide more robust responses. They describe their agent component. Intelligence and knowledge about objects like behaviours in the environment are stored in two ontologies linked to an inference engine. To store and exchange information, an event knowledge representation language is used by semantic agents. This architecture brings other advantages: pervasive, cooperating, redundant, automatically adaptable and interoperable. It is independent of platforms.

Chapter 7, *Interactive Feature Visualization and Detection for 3D Face Classification*, by Jason Mclaughlin, Shiaofen Fang, Luther Robinson, Sandra Jacobson, Tatiana Foroud, and H Eugene Hoyme, presents a new visual approach to the surface shape analysis and classification of 3D facial images. It aims to allow the users to visually explore the natural patterns and geometric features of 3D facial scans to provide decision-making information for face classification which can be used for the diagnosis of diseases that exhibit facial characteristics. Using surface feature analysis under a digital geometry analysis framework, the authors employ an interactive feature visualization technique that allows interactive definition, modification and exploration of facial features to provide the best discriminatory power for a given classification problem. OpenGL based surface shading and interactive lighting are employed to generate visual maps of discriminatory features to visually represent the salient differences between labeled classes. This technique will be applied to a medical diagnosis application for Fetal Alcohol Syndrome (FAS) which is known to exhibit certain facial patterns.

Chapter 8, *A Computational Simulation of the Cognitive Process of Children Knowledge Acquisition and Memory Development*, by Jeff Bancroft and Yingxu Wang, identifies that the cognitive mechanisms of knowledge representation, memory establishment, and learning are fundamental issues in understanding the brain. A basic approach to study these mental processes is to observe and simulate how knowledge is memorized by little children. This chapter presents a simulation tool for knowledge acquisition and memory development for young children of 2 to 5 year-old. The cognitive mechanisms of memory, the mathematical model of concepts and knowledge, and the fundamental elements of internal knowledge representation are explored. The cognitive processes of children memory and knowledge development are described based on concept algebra and the object-attribute-relation (OAR) model. The design of the simulation tool for children knowledge acquisition and memory development is presented with the graphical representor of memory and the dynamic concept network of knowledge. Applications of the simulation tool are described by case studies on children knowledge acquisition about family members, relatives, and transportation. This work is a part of the development of cognitive computers that mimic human knowledge processing and autonomous learning.

Chapter 9, *A Novel Emotion Recognition Method Based on Ensemble Learning and Rough Set Theory*, by Yong Yang and Guoyin Wang, presents an emotion recognition technology related to computer science, psychology, and artificial intelligence. It is always performed on facial or audio information with classical method such as ANN, fuzzy set, SVM, HMM, et cetera. Ensemble learning theory is a novelty in machine learning and ensemble method is proved an effective pattern recognition method. In this chapter, a novel ensemble learning method is proposed, which is based on selective ensemble feature selection and rough set theory. This method can meet the tradeoff between accuracy and diversity of base classifiers. Moreover, the proposed method is taken as an emotion recognition method and proved to be effective according to the simulation experiments.

Chapter 10, *Cognitive Informatics and Cognitive Computing in Year 10 and Beyond*, by Yingxu Wang, Robert C. Berwick, Simon Haykin, Witold Pedrycz, Witold Kinsner, George Baciu, Du Zhang, Virendrakumar C. Bhavsar, and Marina Gavrilova, presents Cognitive Informatics (CI) as a transdisciplinary enquiry of computer science, information sciences, cognitive science, and intelligence science that investigates into the internal information processing mechanisms and processes of the brain and natural intelligence, as well as their engineering applications in cognitive computing. The latest advances in CI leads to the establishment of cognitive computing theories and methodologies, as well as the development of Cognitive Computers (CogC) that perceive, infer, and learn. This chapter reports a set of nine position statements presented in the plenary panel of IEEE ICCI*CC'11 on *Cognitive Informatics in Year 10 and Beyond* contributed from invited panelists who are part of the world's renowned researchers and scholars in the field of cognitive informatics and cognitive computing.

SECTION 3: DENOTATIONAL MATHEMATICS

The needs for complex and long-series of causal inferences in cognitive computing, αI, computational intelligence, software engineering, and knowledge engineering have led to new forms of mathematics collectively known as denotational mathematics. *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.

It is recognized that the maturity of any scientific discipline is characterized by the maturity of its mathematical means, because the nature of mathematics is a generic meta-methodological science. In recognizing mathematics as the *metamethodology* for all sciences and engineering disciplines, a set of DMs has been created and applied in CI, αI, AI, CC, CogC, soft computing, computational intelligence, and computational linguistics. Typical paradigms of DM are such as *concept algebra* (Wang, 2008), *system algebra* (Wang, 2008), *real-time process algebra* (Wang, 2002), *granular algebra* (Wang, 2009), *visual semantic algebra* (Wang, 2009), and *inference algebra* (Wang, 2011). DM provides a coherent set of contemporary mathematical means and explicit expressive power for cognitive informatics, cognitive computing, artificial intelligence, and computational intelligence.

The section on denotational mathematics encompasses the following five chapters:

- **Chapter 11:** Inference Algebra (IA): A Denotational Mathematics for Cognitive Computing and Machine Reasoning (I)
- **Chapter 12:** Human Centricity and Perception-Based Perspective and Their Centrality to the Agenda of Granular Computing
- **Chapter 13:** Semantic Manipulations and Formal Ontology for Machine Learning Based on Concept Algebra
- **Chapter 14:** Text Semantic Mining Model Based on the Algebra of Human Concept Learning
- **Chapter 15:** In Search of Effective Granulization with DTRS for Ternary Classification

Chapter 11, *Inference Algebra (IA): A Denotational Mathematics for Cognitive Computing and Machine Reasoning (I)*, by Yingxu Wang, presents that inference as the basic mechanism of thought is one of the gifted abilities of human beings, which is a cognitive process that creates rational causations between a pair of cause and effect based on empirical arguments, formal reasoning, and/or statistical norms. It

is recognized that a coherent theory and mathematical means are needed for dealing with formal causal inferences. This chapter presents a novel denotational mathematical means for formal inferences known as *Inference Algebra* (IA). IA is structured as a set of algebraic operators on a set of formal causations. The taxonomy and framework of formal causal inferences of IA are explored in three categories: a) *Logical inferences* on Boolean, fuzzy, and general logic causations; b) *Analytic inferences* on general functional, correlative, linear regression, and nonlinear regression causations; and c) *Hybrid inferences* on qualification and quantification causations. IA introduces a calculus of *discrete causal differential* and formal models of causations, based on them nine algebraic inference operators of IA are created for manipulating the formal causations. IA elicits and formalizes the common and empirical reasoning processes in a rigorous form, which enable artificial intelligence and computational intelligent systems to mimic human inference abilities by cognitive computing. IA is one of the basic studies towards the next generation of intelligent computers known as *cognitive computers*. 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. This work is presented in two parts due to its excessive length. The structure of formal inference, the framework of IA, and the mathematical models of formal causations are described in this chapter; while the inference operators of IA as well as their extensions and applications are elaborated in *IJCINI, 6*(1).

Chapter 12, *Human Centricity and Perception-Based Perspective and Their Centrality to the Agenda of Granular Computing*, by Witold Pedrycz, presents that in spite of their striking diversity, numerous tasks and architectures of intelligent systems such as those permeating multivariable data analysis (e.g., time series, spatio-temporal, and spatial dependencies), decision-making processes along with their underlying models, recommender systems and others exhibit two evident commonalities. They promote (a) human centricity and (b) vigorously engage perceptions (rather than plain numeric entities) in the realization of the systems and their further usage. Information granules play a pivotal role in such settings. Granular Computing delivers a cohesive framework supporting a formation of information granules and facilitating their processing. The chapter exploits two essential concepts of Granular Computing. The first one, formed with the aid of a principle of justifiable granularity, deals with the construction of information granules. The second one, based on an idea of an optimal allocation of information granularity, helps endow constructs of intelligent systems with a much needed conceptual and modeling flexibility. The study elaborates in detail on the three representative studies. In the first study being focused on the Analytic Hierarchy Process (AHP) used in decision-making, the author shows how an optimal allocation of granularity helps improve the quality of the solution and facilitate collaborative activities (e.g., consensus building) in models of group decision-making. The second study is concerned with a granular interpretation of temporal data where the role of information granularity is profoundly visible when effectively supporting human centric description of relationships existing in data. The third study concerns a formation of granular logic descriptors on a basis of a family of logic descriptors.

Chapter 13, *Semantic Manipulations and Formal Ontology for Machine Learning Based on Concept Algebra*, by Yingxu Wang, Yousheng Tian, and Kendall Hu, presents a new form of denotational mathematics known as concept algebra towards the formalization of ontological methodologies for dynamic machine learning and semantic analyses. *Concept Algebra* (CA) is a denotational mathematical structure for formal knowledge representation and manipulation in machine learning and cognitive computing. CA provides a rigorous knowledge modeling and processing tool, which extends the informal, static, and application-specific ontological technologies to a formal, dynamic, and general mathematical means. An operational semantics for the calculus of CA is formally elaborated using a set of computational processes

in real-time process algebra (RTPA). A case study is presented on how machines, cognitive robots, and software agents may mimic the key ability of human beings to autonomously manipulate knowledge in generic learning using CA. This work demonstrates the expressive power and a wide range of applications of CA for both humans and machines in cognitive computing, semantic computing, machine learning, and computational intelligence.

Chapter 14, *Text Semantic Mining Model Based on the Algebra of Human Concept Learning*, by Jun Zhang, Xiangfeng Luo, Xiang He, and Chuanliang Cai, presents that dealing with the large-scale text knowledge on the Web has become increasingly important with the development of the Web, yet it confronts with several challenges, one of which is to find out as much semantics as possible to represent text knowledge. As the text semantic mining process is also the knowledge representation process of text, this chapter proposes a text knowledge representation model called text semantic mining model (TSMM) based on the algebra of human concept learning, which both carries rich semantics and is constructed automatically with a lower complexity. Herein, the algebra of human concept learning is introduced, which enables TSMM containing rich semantics. Then the formalization and construction processes of TSMM are discussed. Moreover, three types of reasoning rules based on TSMM are proposed. Lastly, experiments and the comparison with current text representation models show that our model performs better than others.

Chapter 15, *In Search of Effective Granulization with DTRS for Ternary Classification*, by Bin Zhou and Yiyu Yao, presents a decision-Theoretic Rough Set (DTRS) model. DTRS provides a three-way decision approach to classification problems, which allows a classifier to make a deferment decision on suspicious examples, rather than being forced to make an immediate determination. The deferred cases must be reexamined by collecting further information. Although the formulation of DTRS is intuitively appealing, a fundamental question that remains is how to determine the class of the deferment examples. In this chapter, we introduce an adaptive learning method that automatically deals with the deferred examples by searching for effective granulization. A decision tree is constructed for classification. At each level, we sequentially choose the attributes that provide the most effective granulization. A subtree is added recursively if the conditional probability lies in between of the two given thresholds. A branch reaches its leaf node when the conditional probability is above or equal to the first threshold, or is below or equal to the second threshold, or the granule meets certain conditions. This learning process is illustrated by an example.

SECTION 4: COMPUTATIONAL INTELLIGENCE

Intelligence science studies theories and models of the brain at all levels, and the relationship between the concrete physiological brain and the abstract soft mind. Intelligence science is a new frontier with the fertilization of biology, psychology, neuroscience, cognitive science, cognitive informatics, philosophy, information science, computer science, anthropology, and linguistics. A fundamental view developed in software and intelligence sciences is known as *abstract intelligence* (αI), which provides a unified foundation for the studies of all forms and paradigms of intelligence such as natural, artificial, machinable, and computational intelligence. αI is an enquiry of both natural and artificial intelligence at the neural, cognitive, functional, and logical levels from the bottom up. In the narrow sense, αI is a human or a system ability that transforms information into behaviors. However, in the broad sense, αI is any human or system ability that autonomously transfers the forms of abstract information between data, information, knowledge, and behaviors in the brain or intelligent systems.

Computational intelligence (CoI) is an embodying form of abstract intelligence (αI) that implements intelligent mechanisms and behaviors by computational methodologies and software systems, such as expert systems, fuzzy systems, cognitive computers, cognitive robots, software agent systems, genetic/ evolutionary systems, and autonomous learning systems. The theoretical foundations of computational intelligence root in cognitive informatics, software science, and denotational mathematics.

The section on computational intelligence encompasses the following five chapters:

- **Chapter 16:** Cognitive Dynamic Systems
- **Chapter 17:** A Modular Dynamical Cryptosystem Based On Continuous Cellular Automata
- **Chapter 18:** Time and Frequency Analysis of Particle Swarm Trajectories for Cognitive Machines
- **Chapter 19:** On Machine Symbol Grounding and Optimization
- **Chapter 20:** Image Dimensionality Reduction Based on the Intrinsic Dimension and Parallel Genetic Algorithm

Chapter 16, *Cognitive Dynamic Systems*, by Simon Haykin, address the following four issues: a) Distinction between how adaptation and cognition are viewed with respect to each other; b) With human cognition viewed as the framework for cognition, the following cognitive processes are identified: the perception-action cycle, memory, attention, intelligence, and language. With language being outside the scope of the chapter, detailed accounts of the other four cognitive processes are discussed; c) Cognitive radar is singled out as an example application of cognitive dynamic systems that "mimics" the visual brain; experimental results on tracking are presented using simulations, which clearly demonstrate the information-processing power of cognition; and d) Two other example applications of cognitive dynamic systems, namely, cognitive radio and cognitive control, are briefly described.

Chapter 17, *A Modular Dynamical Cryptosystem Based on Continuous Cellular Automata*, by Jesus D.T. Gonzalez and Witold Kinsner, presents a new cryptosystem based on chaotic continuous-interval cellular automata (CCA) to increase data protection as demonstrated by their flexibility to encrypt and decrypt information from distinct sources. Enhancements to cryptosystems are also presented including (i) a model based on a new chaotic CCA attractor, (ii) the dynamical integration of modules containing dynamical systems to generate complex sequences, and (iii) an enhancement for symmetric cryptosystems by allowing them to generate an unlimited number of keys. This chapter also presents a process of mixing chaotic sequences obtained from cellular automata, instead of using differential equations, as a basis to achieve higher security and higher speed for the encryption and decryption processes, as compared to other recent approaches. The complexity of the mixed sequences is measured using the variance fractal dimension trajectory to compare them to the unmixed chaotic sequences to verify that the former are more complex. This type of polyscale measure and evaluation has never been done in the past outside this research group.

Chapter 18, *Time and Frequency Analysis of Particle Swarm Trajectories for Cognitive Machines*, by Dario Schor and Witold Kinsner, examines the inherited persistent behavior of particle swarm optimization and its implications to cognitive machines. The performance of the algorithm is studied through an average particle's trajectory through the parameter space of the Sphere and Rastrigin function. The trajectories are decomposed into position and velocity along each dimension being optimized. Then, a threshold is defined to separate the transient period, where the particle is moving towards a solution using information about the position of its best neighbors, from the steady state reached when the particles explore the local area surrounding the solution to the system. Using a combination of time

and frequency domain techniques, the inherited long-term dependencies that drive the algorithm are discerned. Experimental results show the particles balance exploration of the parameter space with the correlated goal oriented trajectory driven by their social interactions. The information learned from this analysis can be used further to extract complexity measures in order to classify the behavior and control of particle swarm optimization, and make proper quick decisions on what to do next. Thus, this novel analysis of a particle trajectory in the time and frequency domains presents clear advantages of particle swarm optimization and inherent properties that make this optimization algorithm a suitable choice for use in cognitive machines.

Chapter 19, *On Machine Symbol Grounding and Optimization*, by Oliver Kramer, perceives that the world consists of high-dimensional dynamic sensorimotor data from the point of view of an autonomous agent. Interface algorithms translate this data into symbols that are easier to handle for cognitive processes. Symbol grounding is about whether these systems can, based on this data, construct symbols that serve as a vehicle for higher symbol-oriented cognitive processes. Machine learning and data mining techniques are geared towards finding structures and input-output relations in this data by providing appropriate interface algorithms that translate raw data into symbols. This work formulates the interface design as global optimization problem with the objective to maximize the success of the overlying symbolic algorithm. For its implementation various known algorithms from data mining and machine learning turn out to be adequate methods that do not only exploit the intrinsic structure of the subsymbolic data, but that also allow to flexibly adapt to the objectives of the symbolic process. Furthermore, this work discusses the optimization formulation as a functional perspective on symbol grounding that does not hurt the zero semantical commitment condition. A case study illustrates technical details of the machine symbol grounding approach.

Chapter 20, *Image Dimensionality Reduction Based on the Intrinsic Dimension and Parallel Genetic Algorithm*, by Liang Lei, TongQing Wang, Jun Peng, and Bo Yang, presents that without losing the main features of the image, how to reduce more of the image dimensions is highlighted in the research of web content-based image retrieval. Many features of dimensional reduction schemes are determined by the breaking of higher dimensional general covariance associated with the selection of a particular subset of coordinates. This chapter started by analysis of commonly used methods for the dimension reduction of Web images, followed a new algorithm for nonlinear dimensionality reduction based on the HSV image features. The approach obtains intrinsic dimension estimation by similarity calculation of two images. Finally, some improvements were made on the Parallel Genetic Algorithm (APGA) by use of the image similarity function as the self-adaptive judgment function to improve the genetic operators, thus achieving a Web image dimensionality reduction and similarity retrieval. Experimental results illustrate the validity of the authors' algorithm.

SECTION 5: APPLICATIONS OF COGNITIVE INFORMATICS AND COGNITIVE COMPUTING

A series of fundamental breakthroughs have been recognized and a wide range of applications has been developed in cognitive informatics and cognitive computing in the last decade. This section reviews applications of theories, models, methodologies, mathematical means, and techniques of CI and CC toward the exploration of the natural intelligence and the brain, as well novel cognitive computers. 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 adopts cognitive theories to investigate problems in informatics, computing, and software/knowledge engineering. 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.

The section on applications of cognitive informatics and cognitive computing encompasses the following four chapters:

- **Chapter 21:** Equivalence between LDA/QR and Direct LDA
- **Chapter 22:** A Novel Algorithm for Block Encryption of Digital Image Based on Chaos
- **Chapter 23:** Cognitive MIMO Radio: Performance Analysis and Precoding Strategy
- **Chapter 24:** Fuzzy Neural Network Control for Robot Manipulator Directly Driven by Switched Reluctance Motor

Chapter 21, *Equivalence between LDA/QR and Direct LDA*, by Rong-Hua Li, Shuang Liang, George Baciu, and Eddie Chan, presents the singularity problem of scatter matrices in Linear Discriminant Analysis (LDA), which is very challenging and has obtained a lot of attentions during the last decade. Linear Discriminant Analysis via QR decomposition (LDA/QR) and Direct Linear Discriminant analysis (DLDA) are two popular algorithms to solve the singularity problem. In this chapter, we establish the equivalent relationship between LDA/QR and DLDA. We show that they can be regarded as special cases of pseudo-inverse LDA. Similar to LDA/QR algorithm, DLDA can also be considered as a two-stage LDA method. Interestingly, we find out that the first stage of DLDA can act as a dimension reduction algorithm. In our experiment, we compare LDA/QR and DLDA algorithms in terms of classification accuracy, computational complexity on several benchmark datasets. We also conduct experiments to compare their first stages on these datasets. Our results confirm the established equivalent relationship and verify their capabilities in dimension reduction.

Chapter 22, *A Novel Algorithm for Block Encryption of Digital Image Based on Chaos*, by Jun Peng, Du Zhang, and Xiaofeng Liao, presents a novel image block encryption algorithm based on three-dimensional chaotic dynamical system. The algorithm works on 32-bit image blocks with a 192-bit secret key. The main idea is that the key is employed to drive the Chen's system to generate a chaotic sequence that is inputted to a specially designed function G, in which we use new 8x8 S-boxes generated by chaotic maps in (Tang, 2005). In order to improve the robustness against difference cryptanalysis and produce desirable avalanche effect, the function G is iteratively performed several times and its last outputs serve as the keystreams to encrypt the original image block. The design of the encryption algorithm is described in detail, along with security analyses. The results from key space analysis, differential attack analysis, information entropy analysis, correlation analysis of two adjacent pixels have proven that the proposed algorithm can resist cryptanalytic, statistical and brute force attacks, and achieve higher level of security. Moreover, the algorithm can also be easily employed to realize the security cryptosystems over the Internet.

Chapter 23, *Cognitive MIMO Radio: Performance Analysis and Precoding Strategy*, by Mingming Li, Jiaru Lin, Fazhong Liu, Dongxu Wang, and Li Guo, presents a cognitive radio network in which a set of cognitive users make opportunistic spectrum access to one primary channel by time-division multiplexing technologies. Multiple Input Multiple Output techniques (MIMO) are similarly considered

to enhance the stable throughput for cognitive links while they should guarantee co-channel interference constraints to the primary link. Here, we consider two different cases: one is that cognitive radio network is distributed; the other is centrally-controlled that cognitive radio network has a cognitive base station. In the first case, how to choose one fixed cognitive user and power control for each transmission antenna at the cognitive base station are considered to maximize the cognitive link's stable throughput. In the second case, a scheme how to choose a group of cognitive users and a Zero-Forcing method how to pre-white co-channel interference to the primary user are also proposed in order to maximize cognitive base station's sum-rate. The algorithm can be employed to realize opportunistic spectrum transmission over the wireless fading channels.

Chapter 24, *Fuzzy Neural Network Control for Robot Manipulator Directly Driven by Switched Reluctance Motor*, by Baoming Ge and Aníbal T. de Almeida, finds that applications of switched reluctance motor (SRM) to direct drive robot are increasingly popular because of its valuable advantages. However, a greatest potential defect is its torque ripple owing to the significant nonlinearities. In this chapter, a fuzzy neural network (FNN) is applied to control the SRM torque at the goal of the torque-ripple minimization. The desired current provided by FNN model compensates the nonlinearities and uncertainties of SRM. On the basis of FNN-based current closed-loop system, the trajectory tracking controller is designed by using the dynamic model of the manipulator, where the torque control method cancels the nonlinearities and cross-coupling terms. A single link robot manipulator directly driven by a four-phase 8/6-pole SRM operates in a sinusoidal trajectory tracking rotation. The simulated results verify the proposed control method and a fast convergence that the robot manipulator follows the desired trajectory in a 0.9-s time interval.

This book is intended to the readership of researchers, engineers, graduate students, senior-level undergraduate students, and instructors as an informative reference book in the cutting-edge fields of cognitive informatics, natural intelligence, abstract intelligence, and cognitive computing. The editor expects that readers of *Developments in Natural Intelligence Research and Knowledge Engineering* will benefit from the 24 selected chapters of this book, which represent the latest advances in research in cognitive informatics, cognitive computing, and computational intelligence as well as their engineering applications.

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