Guest Editorial
Special Issue on Cybernetics and Cognitive Informatics

***Abstract*—The three greatest theories in science and engineering developed in the 1940s are cybernetics, information theory, and systems theory. *Cybernetics* is the science of communication and control in humans, machines, organizations, and societies across the reductive hierarchy of neural, cognitive, functional, and logical levels. A contemporary form of cybernetics, known as cognitive informatics (CI), is a transdisciplinary inquiry 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. This special issue on cybernetics and CI focuses on the theme of "*convergence of CI* and *cybernetics*," which investigates the shared foundations of cybernetics and CI and their impacts on cybernetic and cognitive systems. This editorial demonstrates that the investigation into CI and cybernetics may encouragingly result in fundamental discoveries toward the development of next-generation intelligent systems and cognitive computing technologies.**

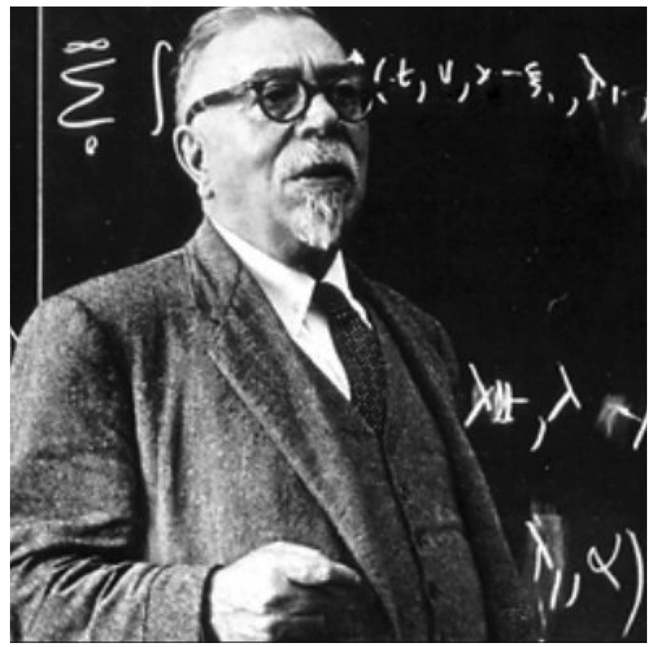
***Index Terms*—Abstract intelligence, cognitive computing, cognitive informatics (CI), computational intelligence, cybernetics, denotational mathematics, natural intelligence.**

I. Contemporary Cybernetics

CYBERNETICS, delineated by Wiener in 1948, is the science of communication and autonomous control in both machines and living things. In his seminal work entitled *Cybernetics or Control and Communication in the Animal and the Machine* [43], Wiener initiated the field of cybernetics to provide a mathematical means for studying adaptive and autonomous systems. Cybernetics mimics information communicated in machines with that of the brain and nervous systems. It also attempts to elaborate human behavior by cybernetic engineering concepts [2], [3], [7]–[11], [14], [16], [18], [20], [42], [44], [48]. Cybernetics constitutes one of the roots of modern cognitive science and computational intelligence.

Definition 1: Cybernetics is the science of communication and control in humans, machines, organizations, and societies across the reductive hierarchy of neural, cognitive, functional, and logical levels.

Studies in cybernetics cover biologically, cognitively, and intelligently motivated computational paradigms such as vision, neural networks, genetic algorithms, fuzzy systems, autonomic systems, cognitive systems, computational intelligence, and robotics. The domain and architecture of contemporary cybernetics encompass a wide range of coherent fields from the machine, natural, and organizational intelligence to social



Norbert Wiener (1894–1964)

intelligence in the horizontal scopes and from the logical, functional, and cognitive models to neural (biological) models in the vertical reductive hierarchy. Therefore, cybernetics in nature is a multidisciplinary and transdisciplinary inquiry of cognitive information processing and autonomic systems.

The scope of contemporary cybernetics has been extended from mainly machine intelligence to natural, organizational, and societal intelligence. Its reductive framework has been enriched from logical and functional models to cognitive and neural models. A number of emerging fields have developed in cybernetics and closely related areas such as cognitive informatics (CI) [13], [24], [26], [29], [41], abstract intelligence [35], natural intelligence [27], computational intelligence [1], [12], [17], [22], [23], [30], [38], [40], autonomous agent systems [15], [36], and denotational mathematics for cybernetics [30].

II. CI

The theories of informatics and their perceptions on information as the object under study have evolved from the classic information theory to modern informatics and then to CI in the last six decades. *Classic information theories* [5], [21], particularly Shannon's information theory [21], known

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as the first-generation informatics, study signals and channel behaviors based on statistics and probability theory. *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 emphasis on external information processing, which overlooks the fundamental fact that human brains are the original sources and final destinations of information and that any information must be cognized by human beings before it is understood. This observation leads to the establishment of the third-generation informatics, known as *CI*, a term coined by Wang in 2002 [24].

Definition 2: CI is the transdisciplinary inquiry 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.

An intensive review on the *theoretical framework of CI* was presented in [29], which provides a coherent summary of the latest advances in the transdisciplinary field of CI and an insightful perspective on its future development. The latest advances of CI not only encompass a coherent set of theories for explaining the logical and cognitive mechanisms of abstract intelligence and computational intelligence but also result in plenty of engineering applications such as cognitive computers, machine learning systems, autonomous agent systems, and intelligent search engines. The theories and applications of CI are rigorously supported by new forms of mathematics, collectively known as denotational mathematics [30].

Definition 3: 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.

The emergence of denotational mathematics is driven by the practical needs in cybernetics, CI, computational intelligence, cognitive computing, software science, and knowledge engineering, because all these modern disciplines study complex human and machine behaviors and their rigorous treatments. These phenomena stem from the fact that new problems require new forms of mathematics [6], [19], [30], [45], [46] and the maturity of a scientific discipline is characterized by the maturity of its mathematical underpinnings [28], [30].

Typical forms of denotational mathematics are *concept algebra* [31], *system algebra* [32], [39], *real-time process algebra* (RTPA) [25], [33], [34], and *visual semantic algebra* (VSA) [37]. Among the four forms of denotational mathematics, *concept algebra* is designed to deal with the new abstract mathematical structure of concepts and their representation and manipulation in knowledge engineering. *System algebra* is created for the rigorous treatment of abstract systems and their algebraic relations and operations. RTPA is developed for algebraically denoting and manipulating system behavioral processes and their attributes. In addition, VSA is developed for the formal modeling and manipulation of abstract visual objects and patterns.

The key application areas of CI can be divided into two categories. The first category of applications uses informatics and computing techniques to investigate cybernetics and cognitive science problems such as abstract intelligence, memory, learning, and reasoning. The second category includes the areas that use cybernetic and cognitive theories to investigate problems in informatics, computing, software engineering, knowledge engineering, and computational intelligence. CI focuses on the nature of information processes in the brain, such as information acquisition, representation, memory, retrieval, creation, 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.

III. Convergent Framework of Cybenetics and CI

Among the three abstract scientific disciplines that emerged in the 1940s—cybernetics, information science, and system science—it was conventionally perceived that cybernetics is closer to system science than to information science. However, the descriptions provided in Sections I and II, particularly the emergence of CI, reveal that cybernetics is actually closer to information science supplement to system science. This notion leads to an interesting convergence between contemporary cybernetics and CI, as well as system science and intelligence science, in a systematic and transdisciplinary context.

The theme of this special issue in IEEE Transactions on Systems, Man, and Cybernetics (Part B) is on the "*convergence of CI* and *cybernetics*," which investigates the shared foundations of cybernetics and CI and their impacts on cybernetic and cognitive systems. This special issue focuses on the cognitive, functional, and logical levels of cybernetics that explain what the cognitive mechanisms of the brain are and how it processes cognitive information in cybernetic systems.

The convergent framework of the transdisciplinary field of CI and cybernetics mainly encompasses the following topic areas:

(A) **Fundamental Theories of Cybernetics and CI**

- Cybernetics in CI.
- CI for cybernetics.
- Denotational mathematics for CI/cybernetics.
- System algebra for modeling cybernetic system architectures.
- Process algebra for modeling cybernetic system behaviors.
- Cybernetics versus intelligence science.
- Abstract system theories.
- Cybernetic mechanisms shared by natural and machine intelligence.
- Neural models of knowledge.
- Neural models of intelligence.

(B) **Systems Shared in Cybernetics and CI**

- Cybernetic models of the brain.
- CI models of the brain.
- Hybrid man–machine systems.
- Distributed intelligent systems.
- Long-life-span systems.
- Knowledge systems.
- System models of memory.

- Cognitive agent systems.
- Autonomic learning systems.
- Cognition systems of web contents.
- Soft and granular computing.
- Autonomous agent systems.
- Machine learning systems.

IV. Structure of This Special Issue

This special issue on *CI* and *cybernetics* presents the latest advances in cybernetics, CI, and computational intelligence [47]. This special issue includes nine papers on the following key areas of cybernetics and CI:

- The contemporary framework of cybernetics.
- The advances in CI and cognitive computing.
- The CI aspect of cybernetics.
- The computational intelligence aspect of cybernetics.
- Collaborative intelligent systems.
- Denotational mathematics for cybernetics.
- Software engineering and cybernetics.
- Granular computing and cybernetics.
- Multimodal biometric systems.
- Formal unification verification.
- Autonomous agent systems.
- Generalized competitive learning.
- Absorbing Markov chains.

The guest editors expect that readers of the IEEE Transactions on Systems, Man, and Cybernetics will benefit from the papers presented in this special issue on theories, models, algorithms, and applications of contemporary cybernetics in general and CI, natural intelligence, and computational intelligence in particular.

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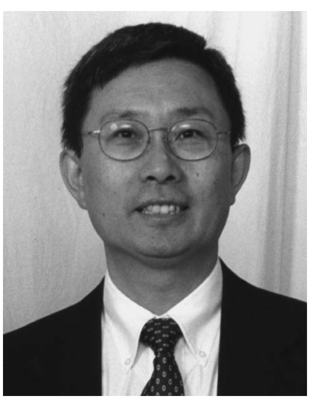

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