Parallel Intelligence: Belief and Prescription for Edge Emergence and Cloud Convergence in CPSS

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WELCOME to the new issue of IEEE TRANSACTIONS ON COMPUTATIONAL SOCIAL SYSTEMS (TCSS). First of all, on behalf of the Board of Governors and Prof. Enrique Herrera Viedma, Vice President for Publication, of the IEEE SMCS, I would like to announce and introduce the new Editor-in-Chief of the IEEE TCSS, Prof. Bin Hu, our Associate Editor since 2017 and a member of BoG since 2018. Currently, Bin Hu is the Director of the Gansu Provincial Key Laboratory of Wearable Computing, Lanzhou University, Lanzhou, China, and an Adjunct Professor with the Computing Department, The Open University, Milton Keynes, U.K. He is the Chair of the IEEE SMC Technical Committee on Computational Psychophysiology at IEEE SMC and the Vice-Chair of the China Committee of the International Society for Social Neuroscience. He is also serving as an Associate Editor for IEEE TRANSACTION ON AFFECTIVE COMPUTING. I am sure that IEEE TCSS will march to a new level of excellence under Prof. Bin Hu's leadership. Congratulations to him and TCSS for the beginning of a new chapter!

I am grateful to report that, as of September 7, 2020, the Citescore of TCSS has leapfrogged back to 5.0, a new high. Many thanks to all of you for your great effort and support.

After scanning the issue, I will present a brief history of my involvement in parallel intelligence and complete the recounting of my personal journey of getting into computational social systems research and applications. Thanks for the interesting messages and encouraging words I have received after my editorials on parallel emergency, parallel healthcare, and parallel economics. Hope they are useful for young researchers who are interested in multidisciplinary and interdisciplinary research.

Scanning the Issue

1. Capturing Edge Attributes via Network Embedding Efficient Extraction of Target Users for Package Promotion in Big Social Networks

Lo-Yao Yeh and Hsien-Chu Wu

This article formulates a new research problem, named package-oriented group identification (PGI), which can obtain a set of socially tight users who have the maximum preference for a package of items. They prove that the proposed PGI problem is NP-hard and develop a polynomial-time algorithm named incremental solution construction with redundancy and infeasibility avoidance for PGI (ISCP) that can effectively and efficiently obtain a good solution to the PGI problem. They compare the performance of ISCP with four other baselines on a large-scale product copurchasing data set. The results show that their proposed ISCP algorithm outperforms other baselines in terms of solution quality and efficiency.

2. Prediction of Solar Activity Using Hybrid Artificial Bee Colony With Neighborhood Rough Sets

Abdel-Fattah Attia, Mohamed Abd Elaziz, Aboul Ella Hassanien, and Ragab A. El-Sehiemy

This article introduces a new hybrid technique for predicting solar activity. The proposed hybrid technique consists of four phases. The first phase is feature selection, where the most relevant features (variables) are selected based on an artificial bee colony using a neighborhood rough set as the fitness function. The second phase employs the training support vector regression using a part of the solar activity data set based on the selected features. The third phase tests the regression model based on the second part of the data set. The fourth phase is the process of predicting solar activity. The solution quality is assessed using three indices called average absolute percent relative error, root-mean-square error, and coefficient of determination. These indices prove the high quality of the forecast sunspot number value and the actual ones. In addition, it can be concluded that the proposed system is significantly improved by predicting solar activity performance at acceptable assessment indices.

3. Integrating Social Practice Theory in Agent-Based Models: A Review of Theories and Agents

Rijk Mercuur, Virginia Dignum, and Catholijn M. Jonker

This article provides a set of requirements for integrating social practice theory in agent models and an evaluation of 11 current agent models with respect to these requirements. They find that current agent models do not fully capture habituality, sociality, or interconnectivity, nor is there a model that aims to integrate all three aspects. Their evaluation allows researchers to pick one of the current agent models depending on their needs regarding habituality, sociality, and interconnectivity. Furthermore, this article shows the usefulness of an agent model that integrates SPT and provides the requirements that help modelers to achieve this model.

4. Serverless Blockchain-Enabled Architecture for IoT Societal Applications

Shajulin Benedict

This article proposes to set forth a serverless blockchain-enabled Internet-of-Things (IoT) architecture for societal applications. It explores the existing IoT architectures and pinpoints the advantages of applying serverless blockchains on

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IoT architectures. In addition, the proposed IoT architecture is illustrated with a specific use case of IoT societal applications, namely, air quality monitoring for smart cities (AQMS). This article discloses how air quality sensor data from defective industries were securely transacted to blockchain networks surpassing the three levels of computing, namely, edge, fog, and cloud while utilizing serverless and server-oriented functions. In addition, this article exposes a list of the most potent serverless functions that assist AQMS IoT societal applications in detail. The IoT architecture, discussed in this article, will enable innovations and research works for IoT developers and researchers.

5. Defensive Modeling of Fake News Through Online Social Networks

Gulshan Shrivastava, Prabhat Kumar, Rudra Pratap Ojha, Pramod Kumar Srivastava, Senthilkumar Mohan, and Gautam Srivastava

This article proposes a model to investigate the propagation of fake news. The proposed model describes how misinformation gets disseminated among groups with the influence of different misinformation refuting measures. They aim to develop a model that will be able to detect and eliminate fake news from online social networks (OSNs) and help ease some OSN users' stress regarding the pandemic. A system of differential equations is used to formulate the model. Its stability and equilibrium are also thoroughly analyzed. The basic reproduction number is obtained, which is a significant parameter for the analysis of message spreading in the OSNs. Real-world trends of misinformation spreading in OSNs are discussed. In addition, the model discusses the controlling mechanism for untrusted message propagation. The proposed model has also been validated through extensive simulation and experimentation.

6. BERT-Caps: A Transformer-Based Capsule Network for Tweet Act Classification

Tulika Saha, Srivatsa Ramesh Jayashree, Sriparna Saha, and Pushpak Bhattacharyya

This article presents a novel tweet act classifier (speech act for Twitter) for assessing the content and intent of tweets, thereby exploring the valuable communication among the tweeters. With the recent success of bidirectional encoder representations from transformers (BERT), a newly introduced language representation model that provides pretrained deep bidirectional representations of vast unlabeled data, they introduce BERT-Caps that are built on top of BERT. The proposed model tends to learn traits and attributes by leveraging from the joint optimization of features from the BERT and capsule layer to develop a robust classifier for the task. Some Twitter-specific symbols are also included in the model to observe its influence and importance. The proposed model outperforms several strong baselines and state-of-the-art approaches.

7.Blockchain-Based Knowledge Automation for CPSS-Oriented Parallel Management

Rui Qin, Yong Yuan, and Fei-Yue Wang

In the new era of intelligent technologies, knowledge automation is required to meet the urgent demand for rapid acquisition and application of knowledge. With the rapidly deepened integration of the real world and the virtual society, CPSS-oriented parallel management proves to be an effective and efficient way of solving these problems. This article utilizes the blockchain technology and smart contracts in knowledge automation and investigates blockchain-based knowledge automation, which can be used for CPSS-oriented parallel management. They also propose a management framework based on the smart contract and discuss a case study.

8. Detecting Group Shilling Attacks in Online Recommender Systems Based on Bisecting K-Means Clustering

Fuzhi Zhang and Shilei Wang

This article proposes a group shilling attack detection method based on the bisecting K-means clustering algorithm. The proposed detection model can overcome the problem that the performance is poor when attackers have a few corated items. First, they extract the rating track of each item and divide the rating tracks to generate candidate groups according to a fixed time interval. Second, they propose item attention degree and user activity to calculate the suspicious degrees of candidate groups. Finally, they employ the bisecting K-means algorithm to cluster the candidate groups according to their suspicious degrees and obtain the attack groups. The results of experiments on the Netflix and Amazon data sets indicate that the proposed method outperforms the baseline methods.

9. Effector Detection Problem in Social Networks

Yapu Zhang, Wenguo Yang, Weili Wu, and Yi Li

This article discusses the effector detection problem, which aims to cause a similar activation state as the observed one. Based on the influence spread, the unconstrained and constrained effector detection problems are proposed. They design two approximation algorithms since the problem is NP-hard, and the objective function is nonsubmodular. For the unconstrained case, their objective function can be best provided with the difference of two submodular functions. Thus, they address this problem through the modular–modular algorithm. For the constrained case, they devise the solutions for the original function, submodular upper bound, and lower bound according to an idea of reverse influence sampling. The data-dependent approximate solution is using the sandwich approximation algorithm. Finally, they show the correctness and superiority of the methods through massive experiments in three real-world networks.

10. Feature-Level Rating System Using Customer Reviews and Review Votes

Koteswar Rao Jerripothula, Ankit Rai, Kanu Garg, and Yashvardhan Singh Rautela

This article studies how to obtain feature-level ratings of the mobile products from the customer reviews and review votes to influence decision-making, both for new customers and manufacturers. The rating system gives a more comprehensive picture of the product than what a product-level rating system offers. Feature-level ratings can make buying decisions personalized. They analyze the customer reviews collected on an online shopping site (Amazon) about various mobile products and the review votes. Explicitly, they carry out a feature-focused sentiment analysis for this purpose. It helps in decision making on how to improve the product (from the manufacturer's perspective) and in making the personalized buying decisions (from the buyer's perspective) a possibility.

11. Sparse Nonnegative Matrix Factorization for Multiple-Local-Community Detection

Dany Kamuhanda, Meng Wang, and Kun He

This article presents a novel method for detecting multiple local communities to which a single-seed member belongs. The proposed method consists of three key steps: 1) local sampling with Personalized PageRank (PPR); 2) using the sparseness generated by a sparse nonnegative matrix factorization (SNMF) to estimate the number of communities in the sampled subgraph; and 3) using SNMF soft community membership vectors to assign nodes to communities. The proposed method shows favorable accuracy performance and a good conductance compared with state-of-the-art community detection methods by experiments using a combination of artificial and real-world networks.

12. Agent Categorization With Group Role Assignment With Constraints and Simulated Annealing

Haibin Zhu

This article formalizes the problem of agent categorization (AC) by using the environments–classes, agents, roles, groups, and objects (E-CARGO) model. An innovative solution is proposed using the Group Role Assignment with Constraints (GRA+) algorithm and the simulated annealing (SA) algorithm. The proposed solution is verified by a real-world case study. Its practicability is confirmed through simulations using SA and the IBM ILOG CPLEX Optimization Platform (CPLEX). The contributions of this article include a novel formalization of the ac problem and an innovative and practical solution established by combining the GRA+ and SA algorithms. The generalized form of this solution provides a solid foundation for decision making over a broad range of applications.

13. Resource Allocation Scheme for Community-Based Fog Computing Based on Reputation Mechanism

Ke Gu, Member, IEEE, Linyu Tang, Jiafu Jiang, and WeiJia Jia

This article proposes a resource allocation scheme for community-based fog computing based on a reputation mechanism. When fog network provides computing services for users, they use a reputation mechanism to enable users to obtain reliable resources in fog computing. In the proposed scheme, a user first submits his/her task request to the community-based fog network, and then, the fog server makes a reliable resource allocation process based on multiple-layer communities and reputation calculation. It can be seen from the experiments that the proposed scheme can effectively resist the attacks of malicious nodes and collusion nodes. The scheme enables users to obtain reliable resources and improves the service quality of computing resources in fog computing.

14. Invisible Stories That Drive Online Social Cognition

Raksha Pavagada Subbanarasimha, Srinath Srinivasa, and Sridhar Mandyam

This article mainly studies the detection of online subversive activities. They look at the entire discourse around a trending topic and ask whether the discourse looks "healthy" or is it showing signs of getting hijacked or dominated by one particular perspective. To do this, they break down a social discourse into its constituent narratives. Narratives are in turn modeled as latent stories or worldviews, whose visible characterizations are in the form of specific distributions over different opinions expressed in the discourse. Once the discourse is broken down into narratives, the "health" of the discourse can be addressed using various measures. They also validate their approach with several well-known trending topics on Twitter.

15. Social Group Recommendation With TrAdaBoost

Zhenhua Huang, Juan Ni, Juanjuan Yao, Xin Xu, Bo Zhang, Yunwen Chen, Naiyu Tan, and Chao Xue

This article introduces a social group recommendation model with TrAdaBoost (SGRTAB) to raise the performance of group recommendation in online social networks. The SGRTAB model includes two stages: data preprocessing (DP) and model optimization (MO). In DP, SGRTAB produces the inputs for MO and implements three related tasks, whereas, in MO, SGRTAB implements group preference learning with the assistance of user preference learning based on the TrAdaBoost algorithm. Specifically, SGRTAB can effectively absorb the knowledge of user preferences into the process of group preference learning through the idea of transferring-ensemble learning. Extensive experiments on four real-world data sets indicate that the proposed SGRTAB model significantly outperforms the state-of-the-art baselines for social group recommendation.

16. Automatic Bug Triage in Software Systems Using Graph Neighborhood Relations for Feature Augmentation

Iyad Alazzam, Ahmed Aleroud, Zainab Al Latifah, and George Karabatis

This article introduces a graph-based feature augmentation approach for enhancing bug triaging systems using machine learning. A new feature augmentation approach that utilizes graph partitioning based on neighborhood overlap is proposed. They utilized frequency, correlation, and neighborhood overlap techniques to create another feature augmentation approach that enriches the feature vectors of bug summaries to use them for bug triaging. The new modified vectors are used to classify bug reports into different priorities. Bug triage in this context is to correctly recognize the priority of new bugs. Several classification algorithms are tested using the proposed methods. Experimental results on a data set with eclipse bug reports extracted from the Bugzilla tracking system have shown that the proposed approach outperformed the existing bug triaging systems, including modern techniques that utilize deep learning.

17. Improved TrAdaBoost and Its Application to Transaction Fraud Detection

Lutao Zheng, Guanjun Liu, Chungang Yan, Changjun Jiang, Mengchu Zhou, and Maozhen Li

This article proposes Transfer AdaBoost (TrAdaBoost), which can effectively transfer knowledge from one domain to another. TrAdaBoost decreases the weights of those instances that belong to the source domain but are wrongly classified in a training process. They find that the distribution of credit card transaction data can change with the changes in the transaction behaviors of users; however, the changes are slow most of the time. These changes are yet important for detecting transaction fraud since they result in a so-called concept drift problem. As such, they propose an improved TrAdaBoost (ITrAdaBoost), which updates the weight of a wrongly classified instance in a source domain according to the distribution distance from the

instance to a target domain, and the calculation of distance is based on the theory of reproducing kernel Hilbert space. They do a series of experiments over five data sets, and the results illustrate the advantage of ITrAdaBoost.

Parallel Intelligence: Belief and Prescription for Edge Emergence and Cloud Convergence in CPSS

A few days ago (September 19 and 20, 2020), Parallel Intelligence Conference (PIC) 2020 was held at Qingdao, China, by Chinese Association of Automation (CAA), an annual event started in 2009 as three workshops on parallel control, parallel management, and social computing, respectively. A distributed hybrid conference (DHC) format was adopted by PIC 2020 due to the COVID-19: more that 200 people took part in person at the main symposium on parallel intelligence, over 2200 online viewers participated in six satellite workshops on theoretical foundations, algorithms, and applications of parallel systems. As a pioneer and researcher in this field, I did not expect parallel intelligence would develop so fast and be applied so widely in so many different areas. Twenty years ago, I thought this method would be useful only for complex social systems, it should be a long time before traditional engineering or technological fields finding parallel intelligence attractive and effective.

1. The Seed

The idea of making virtual and real or artificial and actual interactive started in the middle of 1982, when I learnt that I have to conduct micro-crack-propagation testing with various metal samples for my Master of Engineering degree in Fracture Mechanics or Fatigue Mechanics at Zhejiang University, Hangzhou, China. I had to make a 2-mm crack in a metal plate about 6–8 cm wide, 25–30 cm long, and 2–3 cm thick, then put slabs on a compressing-stretching machine and record the crack propagation until it broken. Normally, each testing took 1–6 months to complete, and students before me were able to graduate after 6–18 tests with only two machines. However, in 1982, my advisor Professor Rendong Wang invited to our department a professor from Ghent University of Belgium with a nickname "Professor 1000 Plates," since he was famous in the world of Fracture Mechanics for breaking over 1000 sample plates in his crack propagation investigation, and I was told to follow his steps and do more tests by my advisor after the lecture by "Professor 1000 Plates." This was a mission impossible to me then: no funding for making samples and no time for completing tests since one machine was down, for just ten test samples, let alone 1000! In my desperation, I wrote a long report [1] with solid findings to show that many testing works have flaws, along with a short proposal [2] to suggest that virtual testing via Monte Carlo simulation might be helpful for evaluating micro-crack-propagation, especially investigating interaction of multiple micro-cracks since such samples are difficult to make and tests are hard to design. As expected, my advisor accepted my long report and rejected my short proposal, but asked for more information. Unfortunately, he died in a medical accident a few months late, and I had to change my thesis topic and research from Fracture Mechanics to Computational Mechanics, then to Plates, Shells, Elasticity, Micro-Elasticity, and finally to Theoretical and Rational Mechanics, but the seed of using virtual fighting real, especially the idea of moving or transforming computer simulations into computational experiments for data production and knowledge generation, was rooted in my mind.

2. The Shadow

A decade late, this seed grown into the concept of "shadow systems" after six years working at two NASA centers for designing and analyzing unmanned systems for space exploring and mining operations in Lunar/Martian environments. Around 1994, I wrote two papers, one with my colleagues Bernie Ziegler and Francois Cellier, two pioneers of computer simulation in both U.S. and Europe, on our work in space engineering for Lunar/Martian applications [3], one just by myself on "shadow systems" for nested and embedded cosimulations [4], originated from my own idea in 1982 and inspired by Christopher Langton's artificial life, but actually motivated mainly by the lack of data and experiences in modeling and analyzing Lunar/Martian processes and systems as well as in my day trade adventure. I still remembered the joke on my idea by my colleague Sid Yakowitz or Ferenc Szidarovszky: "Shadow systems? What happens without the Sun?". In 1995 or 1996, I submitted a research preproposal to EPRI with Sid, Szidar, and Terry Bahill for modeling complex power grids with shadow systems without success. A few years later in Beijing, when I met my former roommate and schoolmate Dr. Le Tang for the first time after our graduation from RPI, who were in charge of ABB's research in North America then, he still remembered my proposal of shadow systems, and in 2002 offered me an opportunity to try this approach with augmentation of agent technology for remote power grid fault diagnosis.

3. The Parallel

About another decade after shadow systems, I started to collaborate with Chinese Academy of Sciences (CAS) and was asked to lead the effort of reorganizing its Key Laboratory of Complex Systems and Intelligence Science (KL-CSIS), a research group with about 50 staffs in control, robotics, and artificial intelligence. I needed a theme for the refocusing and reorganizing, and decided to use digital agents, computational experiments and parallel systems as the building blocks for constructing organizational intelligence or systems intelligence, so the concept of parallel intelligence. Actually, this was the theme of my research in intelligent transportation systems, for both traffic control and autonomous driving, in late 1990s and early 2000s, as summarized in my keynote presentation to the Next Generation Traffic Simulation Workshop organized by US Federal Department of Transportation at Sedona, AZ, in 2003, and later again in my lunch presentation at 2006 IEEE International Intelligent Transportation Systems Conference in Toronto, Canada. In 2004, I published the first journal paper on parallel systems and parallel intelligence based on ACP [5], i.e., Artificial Societies, Computational Experiments, and Parallel Execution through virtual-real interaction or feedback and closed loop control between physical space and cyberspace. In 2011, on the basis of KL-CSIS, the State Key Laboratory for Management and Control of Complex Systems (SKL-MCCS) was established and funded officially by China's Ministry of Science and Technology with the aim of developing new intelligent technology with parallel intelligence. Today, SKL-MCCS has over 500 researchers and

graduate students, become a leading research organization in the world in artificial intelligence and parallel intelligence, especially in parallel control and parallel management, parallel robotics and parallel manufacturing, parallel medicine and parallel healthcare, parallel society and parallel ecology, with over a dozen successful startups and many regional R&D centers in China. I am extremely pleased to see the publication of our recent works on parallel control and parallel sensing for both linear and nonlinear dynamic systems where digital twins can be constructed [6]–[8], those papers provide a mathematical foundation to reshape and reformulate automatic control and automation industries with parallel intelligence and intelligent technology.

4. The Multiverse

Many people, including my own graduate students and close colleagues, have thought that my idea of parallel intelligence was originated from the theory of parallel universes or multiverses in quantum mechanics. This is not true since I have no idea about this theory at that time. However, right after the publication of [5], I had a lunch meeting at the Student Union with my colleague Lizhi Fang, a well-known physicist and professor at the University of Arizona. After I described to him my work on parallel intelligence and parallel systems in [5], Prof. Fang told me that I should check with the parallel universe theory in quantum physics and recommended an article in *Scientific American* [9], but claimed he was not an expert and had no research on this topic. This was the first time I learnt about parallel universe and believed that my parallel intelligence had nothing to do with parallel universe, but Max Tegmark's article intrigued and inspired me, and made me a fan of Hugh Everett III and John Wheeler [10]. Now I believe that, as our technology advances, the fourth level of parallelism, i.e., the mathematical parallel universes, can be constructed by human effort at least for limited functionalities in bounded spaces. Yes, such mathematical parallel universes can or should be built and operated by parallel intelligence via parallel control, parallel management, and parallel services.

5. The Belief and Prescription

The cloud-edge computing provides an ideal platform for implementing parallel intelligence: from edge emergence of everything to cloud convergence to all objectives, from small data at edges, to big data in clouds, and deep intelligence for our goals anywhere. Therefore, under the framework of the current technology, parallel intelligence (PI) is the product of edge emergence (E^2) and cloud convergence (C^2), i.e.,

$$\mathrm{PI} = E^2 \cdot C^2.$$

In general, it is my belief that parallel intelligence acts like the pure imaginary number for complex numbers, or mathematically,

$$\mathrm{CI} = \mathrm{HI} + i_{\mathrm{PI}} \cdot \mathrm{AI}.$$

In other words, complex intelligence or complete intelligence (CI) must be an intrinsic integration of human intelligence (HI) and artificial intelligence (AI) via parallel intelligence, and this can only be prescribed in cyber-physical-social systems or artificial-mental-physical (AMP) spaces.

Technology alone is not enough for such change, we need new philosophy for such development, as I have discussed in my previous editorials [11]–[13], computational social systems with parallel intelligence will be the key to those changes and developments, leading us to a great new era.

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Fei-Yue Wang (Fellow, IEEE) received the Ph.D. degree in computer and systems engineering from Rensselaer Polytechnic Institute, Troy, NY, USA, in 1990. He joined the University of Arizona, Tucson, AZ, USA, in 1990, and became a Professor and the Director of the Robotics and Automation Laboratory and the Program in Advanced Research for Complex Systems. In 1999, he founded the Intelligent Control and Systems Engineering Center, Institute of Automation, Chinese Academy of Sciences (CAS), Beijing, China. In 2002, he participated in the development of the Key Laboratory of Complex Systems and Intelligence Science, CAS, as the Director, where he was also the Vice President for Research, Education, and Academic Exchanges at the Institute of Automation from 2006 to 2010. In 2011, he was named as the Director of the State Key Laboratory for Management and Control of Complex Systems, Beijing. His current research interests include methods and applications for intelligent and parallel systems, social computing, parallel intelligence, and knowledge automation.

Dr. Wang has been General or Program chairs of more than 50 IEEE, INFORMS, IFAC, INCOSE, ACM, ASME, and other professional conferences. He was the President of the IEEE Intelligent Transportation Systems (ITS) Society during 2005–2007, the Chinese Association for Science and Technology, USA, in 2005, and the American Zhu Kezhen Education Foundation during 2007–2008. He was the Vice President of the ACM China Council during 2010–2011, and chair of IFAC TC on Economic and Social Systems from 2008 to 2014 and 2017 to 2023. Currently, he is the President of IEEE Council on RFID and Vice President of IEEE SMC Society. He was the Vice President and the Secretary General of the Chinese Association of Automation 2008–2018, and its President of Supervision Council since 2018. He was the Founding Editor-in-Chief of the *International Journal of Intelligent Control and Systems* during 1995–2000, the *IEEE ITS Magazine* during 2006–2007, and the IEEE/CAA JOURNAL OF AUTOMATICA SINICA during 2014–2017. He was the EiC of the IEEE INTELLIGENT SYSTEMS during 2009–2012 and the IEEE TRANSACTIONS ON ITS during 2009–2016. He is currently the EiC of the IEEE TRANSACTIONS ON COMPUTATIONAL SOCIAL SYSTEMS, and the Founding EiC of the *Chinese Journal of Command and Control* as well as *Chinese Journal of Intelligent Science and Technology*. He was elected as a Fellow of INCOSE, IFAC, ASME, and AAAS. He received best paper awards for his work from IEEE ITSS in 2012, Computational Intelligence Society in 2017, as well as Franklin V. Taylor Memorial Award and Andrew P. Sage Award from IEEE SMCS in 2002 and 2019, respectively. In 2007, he was a recipient of the National Prize in Natural Sciences of China and was awarded the Outstanding Scientist by ACM for his research contributions in intelligent control and social computing. He was a recipient of the IEEE ITS Outstanding Application and Research Awards in 2009, 2011, and 2015, and the IEEE SMC Norbert Wiener Award in 2014.