Parallel Ecology for Intelligent and Smart Cyber–Physical–Social Systems

Fei-Yue Wang, *Fellow, IEEE*, and Yanfen Wang

WELCOME to the last issue of IEEE TRANSACTIONS ON COMPUTATIONAL SOCIAL SYSTEMS (TCSS) this year. This is also the last time I am serving as the Editor-in-Chief of this great journal, and I would like to take this opportunity to thank you all for your great help and support during the last three and half years. A special thank must go to my "Executive Editorial Task Force": Professor Yong Yuan of People's University of China; Drs. Rui Qin, Xiao Wang, and Xueliang Zhao of The State Key Laboratory for Management and Control of Complex Systems, Institute of Automation, Chinese Academy of Sciences; and Dr. Juanjuan Li of Beijing Institute of Technology, for their hardworking and dedication within my term as EiC. We have rejuvenated TCSS in a very short period and maintained its state of healthy growth, and this is a great team I must remember and will be proud of.

Next, I am grateful to report that, as of November 8, 2020, the *Citescore* of TCSS has leapfrogged back to 5.4, another new high. Consecutive new highs in the citation are a clear indication of our quality and relevance in social computing and computational social systems research.

In my last editorial and final note on parallel science and technology, I would like to discuss the topic of parallel intelligence for ecological systems, not only natural ecological systems but also social-ecological systems, as well as artificial or cyber or digital or knowledge ecological systems, along the line and light of Karl Popper's three-world philosophy of reality. I am extremely grateful to have Professor Yanfen Wang, a renowned scientist with rich field experiences in ecological and environmental studies and research from the University of Chinese Academy of Sciences in Beijing, to join me on the discussion and investigation here.

I. SCANNING THE ISSUE

1. "Analysis of the Impact of High-Frequency Trading on Artificial Market Liquidity"
Isao Yagi, Yuji Masuda, and Takanobu Mizuta

This article uses agent-based simulations to compare the major liquidity indicators in an artificial market, where a high-frequency trader (HFT) participated is compared to one where no HFT participated. The results show that all liquidity indicators in the market where an HFT participated improve more than those in the market where no HFT participated. Furthermore, as a result of investigating the correlations between the major liquidity indicators in our simulations and the extant empirical literature, they find that market liquidity can be measured not only by the major liquidity indicators but also by execution rate. Therefore, it is suggested that it could be appropriate to employ execution rate as a novel liquidity indicator in future studies.

2. "Modeling and Analysis of Mood Dynamics in the Bipolar Spectrum"
Hugo Gonzalez Villasanti and Kevin M. Passino

This article introduces a nonlinear ordinary differential equation model of mood dynamics for disorders on the bipolar spectrum. The model characterizes mood as a 2-D state corresponding to manic and depressive features, enabling the representation of most diagnoses of bipolar and depressive disorders. They perform a mathematical analysis of conditions for the mood to stabilize to euthymia and discuss its psychotherapeutic implications. Furthermore, a computational analysis applied to pharmacotherapy depicts a mechanism that results in a switch from depression to mania when the bipolar disorder is misdiagnosed as major depressive disorder, and an antidepressant is administered without a mood stabilizer. This work innovates by offering a concise representation of most features of mood disorders in existing mathematical models and providing a framework for studying dynamics in the bipolar spectrum.

3. "Computational Social Simulation With E-CARGO: Comparison Between Collectivism and Individualism"
Haibin Zhu

This article establishes the fundamental requirements for social simulation and demonstrates that the Environments-Classes, Agents, Roles, Groups, and Objects (E-CARGO) model for role-based collaboration (RBC) and the subsequent group role assignment (GRA) optimization model are highly qualified to meet these requirements. Based on E-CARGO and GRA, they propose an approach to social simulation and conduct a case study to verify it. The case study involves a comparison between collectivism and individualism. The contribution of this work is a novel approach to social simulation using E-CARGO and GRA. This approach reveals the exciting results that explain social phenomena, e.g., collectivism is better than individualism if the team manager is perfect in the evaluation process, and individualism can beat collectivism without much difficulty if the team manager is not perfect.

4. "Aspect-Based Sentiment Analysis: A Survey of Deep Learning Methods"
Haoyue Liu, Ishani Chatterjee, MengChu Zhou, Xiaoyu Sean Lu, and Abdullah Abusorrah

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This article summarizes the recently proposed methods to solve an aspect-based sentiment analysis problem. For three mainstream methods: lexicon-based, traditional machine learning, and deep learning methods, they provide a comparative review of state-of-the-art deep learning methods. Several commonly used benchmark data sets, evaluation metrics, and the performance of the existing deep learning methods are introduced. Finally, existing problems and some future research directions are presented and discussed.

5. "Identifying the Real Influentials at Nonexplicit-Relationship Online Platforms"

Xiao Wang, Ke Zeng, Lifang Li, and Lingxi Li

This article proposes three new criteria, which are explicit conversion rate, frequency of promotion, and average participation density, and design a novel algorithm to effectively calculate and evaluate users' influence on nonexplicit-relationship platforms. The stability and sustainability of user influence are evaluated to distinguish the real influentials from the disguised ones, while the latter usually appears for temporary commercial advertisement purposes. The experiments proved the effectiveness of the proposed criteria and algorithm in determining influentials' influence as well as the corresponding stability and sustainability.

6. "Two-Path Deep Semisupervised Learning for Timely Fake News Detection"

Xishuang Dong, Uboho Victor, and Lijun Qian

This article proposes a novel framework of two-path deep semisupervised learning (SSL) for timely detection of fake news in social media, where one path is for supervised learning and the other is for unsupervised learning. The supervised learning path learns on the limited amount of labeled data, while the unsupervised learning path is able to learn on a huge amount of unlabeled data. Furthermore, these two paths implemented with convolutional neural networks (CNNs) are jointly optimized to complete SSL. In addition, they build a shared CNN to extract the low-level features on both labeled data and unlabeled data to feed them into these two paths. To verify this framework, they implement a Word CNN-based SSL model and test it on two data sets: LIAR and PHEME. Experimental results demonstrate that the model built on the proposed framework can recognize fake news effectively with very few labeled data.

7. "Differentiate the Game Maker in Any Soccer Match Based on Social Network Approach"

Samya Muhuri, Susanta Chakraborty, and Sanjit K. Setua

This article represents the players and their ball passing using a dynamic social network structure. They analyze some random games of Fédération Internationale de Football Association (FIFA) men's world cup 2018, to distinguish the game makers from the matches where the performance of any individual player is not directly involved with the cumulative effect of the scoring mechanism. They also investigate the games and identified the tactical position of the influential passes in different time frames. The accuracy of the proposed method is tested over the real-life benchmark data set.

8. "Blockchain and IoT for Insurance: A Case Study and Cyberinfrastructure Solution on Fine-Grained Transportation Insurance"

Zhe Xiao, Zengxiang Li, Yechao Yang, Piao Chen, Ryan Wen Liu, Wei Jing, Yauheni Pyrloh, Ekanut Sotthiwat, and Rick Siow Mong Goh

This article initiates a cyberinfrastructure solution by synergizing both the blockchain and Internet of Things (IoT) technologies for transportation insurance. A hybrid scheme coordinating both the permissioned (Hyperledger) and public (Ethereum) blockchains is proposed to exploit their respective capabilities in terms of high transaction throughput and built-in cryptocurrency. A working prototype platform is implemented with a basic premium calculation model. The prototype system is deployed across Amazon Web Services cloud in a real-world Internet environment. A comprehensive performance study from the aspects of throughput, latency, and resource usage under different configurations is presented to show the solution's feasibility.

9. "Understanding Shifting Triadic Relationships in the Al-Qaeda/ISIS Faction Ecosystem"

Daniele Bellutta, Youdinghuan Chen, Daveed Gartenstein-Ross, Chiara Pulice, Anja Subasic, and V. S. Subrahmanian

This article proposes and investigates 14 hypotheses linking changes in the intensity of relationships between two factions in the Al-Qaeda/ISIS (AQ/ISIS) ecosystem to future changes in other relationships involving one of those two factions. Using a novel 28-year data set of relationships between factions of Al-Qaeda and the Islamic State encoded as a time series of 267 signed weighted networks, they identify triangles of any set of connected factions and develop hypotheses capturing how the intensity of relationships between two factions changes. They investigate how the strength of these relationships changes in the short term, medium term, and long term, and show that AQ/ISIS triangles that are not in balance are unlikely to move toward balance, but those that are in balance will likely stay balanced. These findings provide better insight into the inner workings and complex dynamics that shape the AQ/ISIS competition worldwide.

10. "Batch Processing for Truss Maintenance in Large Dynamic Graphs"

Qi Luo, Dongxiao Yu, Xiuzhen Cheng, Zhipeng Cai, Jiguo Yu, and Weifeng Lv

This article studies the batch processing of truss maintenance in large graphs, and proposes batch processing algorithms for truss maintenance with multiedge insertions/deletions. By presenting an edge structure called triangle disjoint set, they tackle the difficulty in quantifying the trussness changes of the edges in batch processing. More specifically, they propose two indices, namely sustain support and pivotal support, to help measure whether the edges have the potential to change their trussness, such that the search range of the potential edges is greatly reduced. The experiments on real-world graphs illustrate that compared with the single-edge processing approach, the proposed algorithms can significantly improve the processing efficiency, and the improvement becomes more obvious when more edges are inserted/deleted.

11. "Quantifying Nonrandomness in Evolving Networks"

Pradumn Kumar Pandey and Mayank Singh

This article proposes a novel spectrum-based methodology that leverages configuration models as a reference network to quantify the nonrandomness in a given candidate network. Besides, we derive mathematical formulations for demonstrating the dependence of nonrandomness on three structural properties: modularity, clustering, and the highest degree node's growth rate. They also introduce a novel graph signature to visualize the nonrandomness in the network, and discuss the relationship between the proposed nonrandomness measure and the diffusion affinity of networks. They also extensively discuss observations emerging from these signatures for both real-world and simulated networks.

12. "The Family of Assortativity Coefficients in Signed Social Networks"

Ai-Wen Li, Jing Xiao, and Xiao-Ke Xu

This article proposes four new mixing patterns for signed social networks and defines a set of six signed assortativity measures based on traditional assortativity coefficients, to form a complete family of assortativity coefficients. The statistical significance of the family of assortativity coefficients is confirmed by comparing with null models, showing the assortativity significance profile of different empirical signed networks. Besides, the relationship and distinction between the family of assortativity coefficients and network indexes are analyzed, revealing the endogenous complexity of signed social networks and the diversity of their assortativities. The proposed method is beneficial to measure and analyze complex structure, function, and evolution of social networks.

13. "Dynamic Distributed Secure Storage Against Ransomware"

Jason Castiglione and Dusko Pavlovic

This article puts forward the idea that ransomware is a symptom of a broader problem of architectural imbalance in social computation, while the processes are dynamic and nonlocal, the storage is static and local. They study and discuss some paths toward dynamic, nonlocal, and secure storage. Furthermore, they provide a toy method for locally encrypting the data that can provide a balance of high security and encryption speed.

II. Parallel Ecology for Complex Ecological Systems in CPSS

"What is ecology?" is a question that has been asked in almost every decade since the new ecology became a prominent science during the second half of the 20th century. Good or bad, this is an accurate indication and reflection of the complex nature and interdisciplinary characteristics of ecological studies. From James Lovelock's Gaia hypothesis to its evil twin, Peter Ward's Medea hypothesis; from Boris Kozo-Polyansky's symbiogenesis, Roy Clapham and Arthur Tansley's ecosystems, to Lynn Margulis' endosymbiotic theory and Symbiotic Planet that defined Gaia as an emergent property of interaction among organisms through the series of interacting ecosystems that compose a single huge ecosystem at the earth's surface, to the Earth System Science today; and from Charles Elton's ecological niche, Robert Whittaker's gradient analysis for classification and ordination, Peter Greig-Smith's quantitative plant ecology, to G. Evelyn Hutchinson's Circular Causual Systems and Mathematical or Theoretical Biology with Robert MacArthur, as well as Systems Ecology with Odum brothers, and afterward the Island Biogeography, the United Neutral Theory of Biodiversity, the Modern Ecosystem Science [item 1) in the Appendix], we see so many ecological theories in parallel. Now, with deep learning for artificial intelligence that revolutionizes intelligent technology, we need new and deep thinking with deep techniques for deep analysis of Arne Naess' deep ecology, an environmental philosophy that "promotes the inherent worth of all living beings regardless of their instrumental utility to human needs, plus the restructuring of modern human societies in accordance with such ideas." This is our motivation for moving from many ecological theories in parallel into a theory of parallel ecology for integrated natural, social, and cyber ecological systems.

III. Scientific and Smart Methods for Ecological Research

The gap between the Hutchinson–Odum–MacArthur Approach pioneered in theoretical ecology and systems ecology of the 1950s and the Scientific Methods for ecological research summarized in E. D. Ford's outstanding book [item 2) in the Appendix] of the 2000s has clearly demonstrated the urgent need for intelligent technology and smart solutions for ecological and environmental studies.

To achieve the original goal of holistic view and treatment of ecological systems with formal conceptual models, mathematical analysis, computer simulations, and data analytics, as outlined in theoretical and systems ecology, especially their "dream" of the general application of ecosystem principles to all ecological systems at any scale, with Energy Systems Language for modeling and constructing circular feedback and adaptive control of Energetic Dynamics for complex ecologic systems as cybernetics for general systems [items 3)–5) in the Appendix], to solve the current complex ecological tasks to be dealt with in ecology today, with organization levels from individuals, populations, communities, to ecosystems, in domains of natural, social, and cyber environments, we need not only new methods and new techniques but also new thinking and new philosophy. Particularly, along the lines discussed in our previous editorials [items 6)–9) in the Appendix], we need to take major initiatives in the following three directions.

1) *Deep Model for Ecologic Systems:* Data-driven and model-based approaches, from digital twins, software-defined processes, or software twins, to artificial models or virtual twins, along with knowledge graphs, knowledge categories, complex networks, graphical neural networks, and many other AI techniques, should be widely used for ecological systems. Similar to IBM's Watson project for medical sciences, we need to convert systematically the ecologic knowledge in our textbooks into computational models and executable processes. Automatic model construction, verification, and deployment should be key and the use of the related state-of-the-art algorithms and approaches in AI should be investigated.

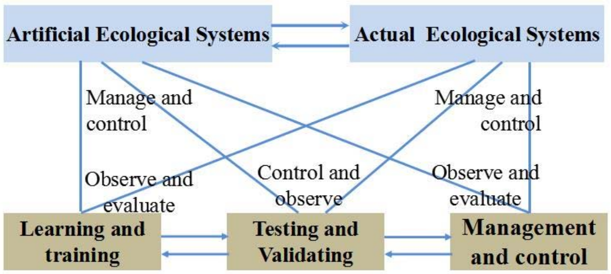

Fig. 1. Deep control and management for parallel ecological systems.

2) *Deep Analytics for Ecologic Systems:* We need to change our traditional use of models for analysis to that of models for data generation, and the traditional thinking of computer simulations to that of computational experiments, much more beyond traditional "hypothesis testing." We should treat models as machines for making ecological data, producing big and deep data from small and shallow data collected from natural, social and cyber systems, and use AI algorithms such as machine learning and parallel intelligence to refine and distill those data into precise and deep intelligence for specific ecologic tasks. The current ecological analysis is mainly on the stage of descriptive analytics and is struggling on moving toward predictive analytics, but the complex ecological tasks today require it to go quickly to prescriptive analytics and produce various Merton's laws of "big data, small laws" to help people and societies to understand and support ecological and environmental issues, missions, and projects.

3) *Deep Management for Ecologic Systems:* Cyber or virtual resources must be utilized fast and in a full scale for control and management of complex ecologic systems. Circular causality and feedback mechanism were the key in the origination of modern ecological thinking, and we need to move much further and deep into virtual-real circulation and feedback by parallel thinking of actual and artificial resources in parallel, and transfer the conventional utopian thinking of Being, Becoming, and Believing in trusted organizations of ecological engineering systems with computable and executable piecemeal decisions and actions. Fig. 1 outlines a basic procedure of deep control and management for ecologic systems. For every implementation step of an ecological or environmental policy, it should be learned and trained in the corresponding artificial system or digital twin, tested and evaluated by the related ecologic computational experiments, and finally actually applied in both the artificial and actual ecologic systems simultaneously. The difference between artificial and actual steps constitutes the feedback between the real and virtual systems and forms a closed loop between them, therefore, the deep feedback and double closed loop among the real and virtual spaces, which would lead to a mechanism of deep control and management of ecologic systems. Considering the economic cost and timespan of ecologic management, the proposed parallel mechanism should be an effective and efficient solution to many urgent and current global ecological and environmental concerns.

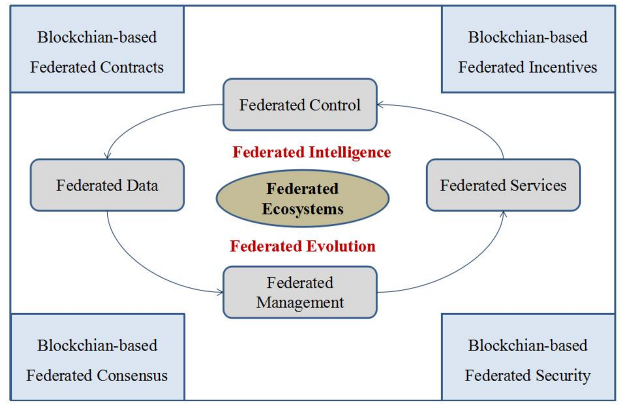

Fig. 2. Framework of federated ecosystems for parallel ecological systems.

IV. Intelligent Ecology for Cyber-Physical-Social Systems

According to Karl Popper's reality model of three interacting worlds: 1) world one, the physical world of objects and events, including biological entities; 2) world two, the mental world of individual and collective mental processes, including cognitive and intellectual functions; and 3) world three, the artificial world of knowledge and abstraction that emerge from and have an effect on world two through their representations in world one [item 10) in the Appendix], [item 11) in the Appendix], we need a Generalized Gaia Hypothesis that extends the natural or physical Earth to include both mental Earth and artificial Earth, and a new thinking and a new theory of ecology for three earths or three worlds correspondingly. In AI or intelligent science technology, the concept of cyber–physical–social systems (CPSS) has been introduced to integrate three worlds through the interaction of physical space and cyberspace [item 12) in the Appendix] as the basic infrastructures for constructing intelligent systems, accordingly, a new theory of ecology, i.e., intelligent ecology or Karl Popper's ecology, could be developed by investigating CPSS-based interacting ecosystems and studying their corresponding ecological issues through virtual-real interaction.

For this purpose, we need deep systems rethinking for ecology. Historically, the pioneering ecological thinking and studies had played an important role in the original conceptual formation of modern general systems theory, systems science, and systems engineering. For example, the International Council of Systems Engineering (INCOSE) has identified the historical link between E. P. Odum's Energy Systems Language or Generic Systems Symbols for systems ecology and various Systems Modeling Languages for engineering systems. However, ecological studies today must go back to systems engineering to learn their new concepts and techniques, such as model-based systems processes (MBSP), model-based systems engineering (MBSE) systems of systems (SoS), parallel systems, embedded cosimulation and coevolution, parallel learning, and corresponding engineering tools and standards, and apply them into related ecological research and projects.

The future smart ecological systems must deal with and integrate "Big 5G" into their development, i.e., transportation grids, energy grids, information grids, Internet of Things (IoT) grids, and Internet of Minds (IoM) grids, systems sciences, and engineering would be essential for their success.

The method of systems federation is recently emerging as an effective and efficient mechanism for organizing distributed and autonomous intelligent systems, and it could be extremely useful for parallel ecology. Fig. 2 presents a framework for constructing federated or co-federated ecosystems with federated control and management of parallel ecological systems based on blockchain and federated intelligence techniques with the goal of implementing and achieving federated ecological intelligence and learning from artificial ecological systems, through federated data and service. This should enable us to move from law enforcement legally to ecological enforcement ethically for environmental protection via ecological knowledge automation [item 13) in the Appendix].

Of course, there might be a long way to a full-scale parallel ecology. Modern ecology had received two quick and giant boosts for its development, the Manhattan Project for Atomic Bombs and Rachel Carson's Silent Spring. We must not expect such tragic boosts any more. To us, the development of parallel ecology for intelligent and smart ecological systems simply needs the smooth but deep nurturing of two readings: John Donne's poem "No Man Is An Island" and Alfred North Whitehead's book *Process and Reality*.

Gaia, not Medea, for our worlds, all three of them.

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APPENDIX
RELATED WORKS

1) R. P. Mclntosh, *The Background of Ecology*. Cambridge, U.K.: Cambridge Univ. Press, 1985.
2) E. D. Ford, *Scientific Method for Ecological Research*. Cambridge, U.K.: Cambridge Univ. Press, 2000.
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10) K. Popper, "Epistemology without a knowing subject," in *Proc. 3rd Int. Congr. Log., Methodology Philosophy Sci.*, Amsterdam, Holland, 1967.
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Fei-Yue Wang (Fellow, IEEE) received the Ph.D. degree in computer and systems engineering from the Rensselaer Polytechnic Institute, Troy, NY, USA, in 1990.

He joined The University of Arizona, Tucson, AZ, USA, in 1990, where he 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 the Vice President for Research, Education, and Academic Exchanges at the Institute of Automation from 2006 to 2010. In 2011, he was named 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 was elected Fellow of the International Council on Systems Engineering (INCOSE), the International Federation of Automatic Control (IFAC), the American Society of Mechanical Engineers (ASME), and the American Association for the Advancement of Science (AAAS). He received best paper awards for his work from IEEE ITSS in 2012 and the Computational Intelligence Society in 2017, and the Franklin V. Taylor Memorial Award and the Andrew P. Sage Award from IEEE SMCS in 2002 and 2019. 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 Intelligent Transportation Systems (ITS) Outstanding Application and Research Awards in 2009, 2011, and 2015 and the IEEE SMC Norbert Wiener Award in 2014. He has been the General or Program Chair of more than 50 IEEE, INFORMS, IFAC, INCOSE, ACM, ASME, and other professional conferences. He was the President of the IEEE ITS Society from 2005 to 2007; the Chinese Association for Science and Technology, USA, in 2005; and the American Zhu Kezhen Education Foundation from 2007 to 2008. He was the Vice President of the ACM China Council from 2010 to 2011 and the Chair of the IFAC TC on Economic and Social Systems from 2008 to 2014 and 2017 to 2023. He was the Vice President and the Secretary-General of the Chinese Association of Automation from 2008 to 2018, where he has been the President of the Supervision Council since 2018. He is currently the President of the IEEE Council on RFID and the Vice President of the IEEE Systems, Man, and Cybernetics Society. He was the Founding Editor-in-Chief of the *International Journal of Intelligent Control and Systems* from 1995 to 2000, *IEEE Intelligent Transportation Systems Magazine* from 2006 to 2007, and IEEE/CAA JOURNAL OF AUTOMATICA SINICA from 2014 to 2017. He was the Editor-in-Chief of IEEE INTELLIGENT SYSTEMS from 2009 to 2012 and IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS from 2009 to 2016. He is also the Editor-in-Chief of IEEE TRANSACTIONS ON COMPUTATIONAL SOCIAL SYSTEMS and the Founding Editor-in-Chief of the *Chinese Journal of Command and Control* and *Chinese Journal of Intelligent Science and Technology*.

Yanfen Wang received the Ph.D. degree in ecology from the Institute of Botany, Chinese Academy of Sciences, Beijing, China, in 2001.

She joined the University of Chinese Academy of Sciences (UCSA), Beijing, in 2003, where she later became a Professor in ecology in 2005 and the Vice President in 2008. In 2014, she founded the Yanshan Earth Critical Zone and Surface Fluxes Research Station (previously named Huairou Ecosystem Observation and Research Station). In 2018, she was named the Executive Vice President of UCAS. Her current research interests include the structure and function of the Eurasian grassland ecosystem and its response and adaption to human activities and climate change. She has also an independent board member of the International Center for Integrated Mountain Development (ICIMOD) since 2014. She is particularly interested in the biotic processes of carbon and nitrogen cycling. She has spent over 30 years on the carbon and nitrogen turnovers across hierarchical scales and identified Chinese temperate grassland as a weak carbon sink. In addition, her research has uncovered the microbial mechanism, spatial–temporal distribution, and limitation of methane emission at Alpine wetland, including the discovery of novel methanogens. Another distinguished work of hers is the overall assessment of methane oxidation by wetland, forest, and grassland in China, which clarified the contribution of methane emission from Chinese wetland to global scale methane emission. She has published more than 200 articles in major scientific journals such as *Proceedings of the National Academy of Sciences*, *National Science Review*, *Global Change Biology*, and *Journal of Ecology*.

Dr. Wang has served as the Vice Chairman of the China Ecological Society and the China Natural Resources Society since 2018 and 2019, respectively. She received the First Prize of Science and Technology Award of Tibet and the Second Prize of Science and Technology Progress Award of Qinghai province for her long-standing efforts in grassland research of Tibetan Plateau in 2018.