Steps toward Parallel Intelligence

Fei-Yue Wang, *Fellow, IEEE*, Xiao Wang, *Member, IEEE*, Lingxi Li, *Senior Member, IEEE*,
and Li Li, *Senior Member, IEEE*

***Abstract*—The origin of artificial intelligence is investigated, based on which the concepts of hybrid intelligence and parallel intelligence are presented. The paradigm shift in Intelligence indicates the "new normal" of cyber-social-physical systems (CPSS), in which the system behaviors are guided by Merton's Laws. Thus, the ACP-based parallel intelligence consisting of Artificial societies, Computational experiments and Parallel execution are introduced to bridge the big modeling gap in CPSS.**

***Index Terms*—Artificial intelligence, hybrid intelligence, parallel intelligence, cyber-social-physical systems, ACP.**

I. INTRODUCTION

IN "Steps toward artificial intelligence"[1], Marvin Minsky's classical paper, the artificial intelligence (AI) pioneer gave an outstanding summary of work that had been done during his era in AI. Today, about sixty years after that paper was published, AI technologies have evolved drastically, and are reaching a new peak. For instance, the computer Go program AlphaGo by Deepmind won 4:1 in a five game match against one of the world's best Go players, Lee Sedol, in March 2016[2]. This victory stunned many in the AI field and beyond. It marked the beginning of a new era in AI, that is, parallel intelligence: the interaction between the actual and the artificial world, supported by new ITs (intelligent technologies) such as deep neural networks, reinforcement learning, knowledge automation, big data, internet, internet of things (IoT), cloud computing, etc.

This article starts with the definition of AI, and then moves toward the status of human-machine hybrid intelligence (HI), where Cyber-Physical-Social systems (CPSS) must be considered instead of Cyber-Physical systems (CPS) because of the human intelligence involved. However, for CPSS traditional Newton's Laws cannot be directly applied (Small Data, Big Laws); instead, our focus shifts to Merton's Laws (Big Data, Small Laws). Therefore, there exists a modeling gap between the physical world and the artificial world. To overcome this gap, an ACP-based parallel control approach is introduced to achieve the ultimate "parallel intelligence".

II. FROM CYBERNETICS TO ARTIFICIAL INTELLIGENCE

The term AI, was coined by John McCarthy in 1955, where AI was defined as "the science and engineering of making intelligent machines[3]". This definition, however, leads to another ancient debate in *Cybernectics*: "Can machines have intelligence?" Many scientists during that time are optimistic about intelligent machines, while others insist that "machines cannot possess any degree of originality" and "nothing can come out of the machine which has not been put into it[4]". To those views, Norbert Wiener, the father of Cybernetics, made harsh criticism and stated that "It is my thesis that machines can and do transcend some of the limitations of their designers[5]". Now with the milestone winning of AlphaGo, not only the operation of machines has greatly transcended its human designers, but also the computing capabilities of machines have surpassed humans in a competition (the number of games that is theoretically possible is in the order of 10^{700})[6]. How could this happen?

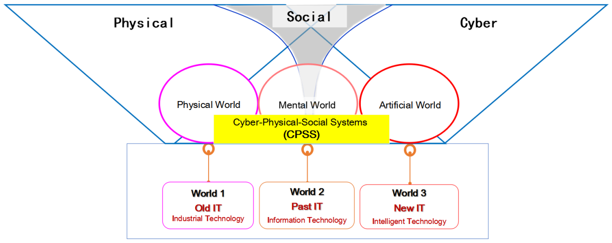

Fig. 1. CPSS: Infrastructure for Human-Machine Hybrid Intelligence and Virtual-Real Interactive Parallel Intelligence.

It is said that before the historical match with Lee, AlphaGo played more than 30,000,000 games with itself, which is more than the number of games a 100-year old human could play in his entire life. The big data, in turn, provided the richest resources for the deep learning approaches behind AlphaGo, thus improved and optimized AlphaGo's game-playing strategies through learning. Considering the immense amount of time the human designers spent on AlphaGo, the decision rules, learning algorithms, and evaluation models built in AlphaGo, Lee was not defeated by a computer program, but by all the humans standing behind the program, combined with the significant cyber-physical information inside it. This also verifies the belief of many AI experts that intelligence must emerge from the process of computing and interacting. As stated by Minsky: "What magical trick makes us intelligent? The trick is that there is no trick. The power of intelligence

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Fei-Yue Wang is with the State Key Laboratory of Management and Control for Complex Systems (SKL-MCCS), Institute of Automation, Chinese Academy of Sciences (CASIA), Beijing 100190, China, and also with Research Center of Computational Experiments and Parallel Systems, the National University of Defense Technology, Changsha 410073, China (e-mail: feiyue.wang@ia.ac.cn).

Xiao Wang is with the Qingdao Academy of Intelligent Industries (QAII), Qingdao, Shandong, China, and SKL-MCCS, CASIA, Beijing 10019, China (e-mail: x.wang@ia.ac.cn).

Lingxi Li is with the Department of Electrical and Computer Engineering, Purdue School of Engineering and Technology, Indiana University-Purdue University Indianapolis, Indiana 46202-5132, USA (e-mail: LL7@iupui.edu).

Li Li is with the Department of Automation, Tsinghua University, Beijing 100084, China, and also with Jiangsu Province Collaborative Innovation Center of Modern Urban Traffic Technologies, Nanjing 210096, China (e-mail: li-li@tsinghua.edu.cn).

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stems from our vast diversity, not from any single perfect principle[7].”

III. FROM CPS TO CPSS

With new technologies such as IoT, cloud computing, robotics, AI, virtual-reality (VR) and the promotion of other emerging social media, we have entered the new era of Hybrid Intelligence (HI), where machines, information, and humans are tightly coupled through pervasive physical and social signals[8]. Therefore, we are now dealing with new types of machines where humans are an integral part[9]. This fact puts forward new requirements for us to think about the problems in complex systems in a CPSS way.

The term CPS, was coined to describe the tight conjoining of and coordination between computational (or cyber) and physical resources, that is, systems that feature a tight integration between computation, communication, and control in their operation and interactions with the task environment in which they are deployed. However, due to the unprecedented sphere and speed of influence experienced in the cyberspace field and its profound impact on the way we behave and interact with each other, we must add and address the presence of human and social dimension in CPS. We have reached the point where social and human dynamics must be considered as an integral part of any effective CPS design and operation, thus inserting the term “social” into CPS is perfectly justified, and CPSS becomes the new paradigm in our current HI Age. This change also has a philosophical implication that brings CPSS in line with Karl Popper’s theory of reality[10]. The theory states that our universe consists of three interacting worlds: World 1, the physical world; World 2, the mental world; and World 3, the artificial world, the home to abstract objects such as theories, stories, myths, tools, social institutions, and works of art. Cyberspace can be a materialization or reflection of Worlds 1, 2, and 3. Traditional human intelligence is the connection between Worlds 1 and 2, AI is the connection between Worlds 2 and 3, whereas HI is the universal connection among Worlds 1, 2, and 3 (shown in Fig. 1).

Using the “old” IT (Industrial Technologies), we exploited World 1 at the surface level; with the help of the “past” IT (Information Technologies), we greatly stimulated human imagination and creativity, and fully developed the underground, surface, and space resources in Worlds 1 and 2; now the human society is entering the era of the “new” IT (Intelligent Technologies) which represented mainly by AI and robotics, thus data and knowledge in cyberspace become the new resources to be mined.

IV. A PARALLEL PARADIGM SHIFT: FROM NEWTON’S LAWS TO MERTON’S LAWS

Under the framework of CPSS, Newton’s Laws, which are applicable to traditional CPS, are no longer adequate for describing, manipulating, and controlling entities in CPSS. Therefore, Merton’s Laws are introduced, such as Merton’s Self-Fulfilling Prophecy, as well as Simon’s Bounded Rationality and Heiner’s Theory of Predictable Behaviors[11].

We call the type of systems where Newton’s Laws govern system behaviors as *Newton’s Systems*. Their main characteristics are: when given the current system state and the control actions, the next system state can be obtained theoretically through the system equations, thus the system behaviors can be accurately computed and predicted (shown in Fig. 2(a)). Therefore, for Newton’s systems, the main task for modeling is to identify Newton’ Laws that control system behavior, and directly design corresponding control functions to achieve the objectives.

Similarly, the types of systems where Merton’s Laws guide system behaviors are called *Merton’s Systems*. Merton’s Laws are named after American sociologist Robert King Merton, and are in general referred as Merton’s Self-Fulfilling Prophecy Law. More specifically, a self-fulfilling prophecy is a prediction that directly or indirectly causes itself to become true, due to feedback between belief and action. The main characteristics are: although the current system state and control conditions are given, the next system state cannot be accurately computed and thus system behaviors cannot be accurately predicted (shown in Fig. 2(b)). Because these types of systems have “free will”, thus cannot be directly controlled in principle, rather, can only be influenced indirectly to promote the appearance of desirable objectives in a probabilistic setting. For Merton’s systems, the main task for modeling is to design Merton’s Laws that can effectively guide the system behaviors based on desirable objectives[12].

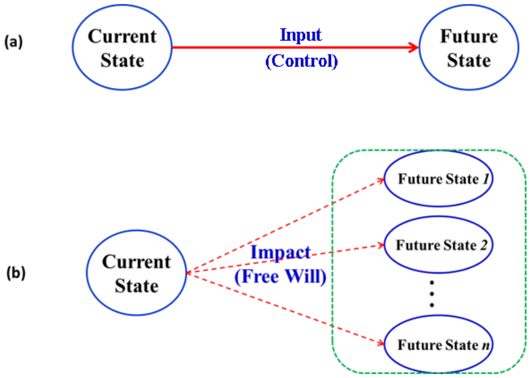

Fig. 2. Newton’s Laws vs. Merton’s Laws. (a) Newton’s system-controlling laws: Target implementation with certainty. (b) Merton’s self-fulfilling prophecy laws: Target implementation with uncertainty.

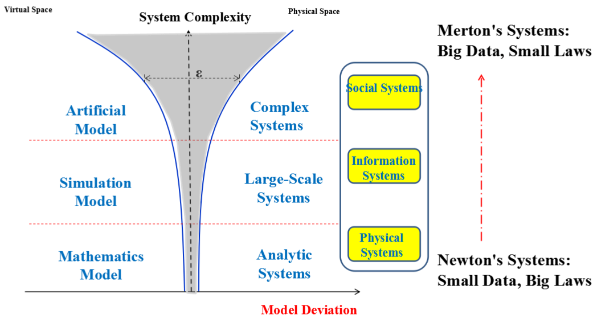

Fig. 3. The modeling gap between physical systems and artificial systems.

The complex characteristics of human and social behaviors with high uncertainty, spatiotemporal dynamics, and variety, etc., create a gap between the physical systems and its model, thus presenting a big challenge for the modeling of Merton's systems (shown in Fig. 3). Because of this gap, the modeling focus will be shifted from Newton's Laws where system behaviors are directly controllable (small data, big laws), to Merton's Laws where system behaviors are only indirectly implied (big data, small laws)[13]. In Newton's systems, causality normally prevails. But in Merton's systems, where only association revealed by data or experience is available, causality is a luxury that is no longer attainable with limited resources for Uncertainty, Diversity, and Complexity (UDC).

V. THE ACP APPROACH: BRIDGING THE MODELING GAP BY PARALLEL INTELLIGENCE

Due to the pervasive use of mobile devices, location-based services, social media Apps, etc., cyberspace has become as real to human beings as physical space. In cyberspace data becomes the most important resource. Using Big Data as input, Software-Defined Objects (SDO), Software-Defined Processes (SDP), Software-Defined Systems (SDS), and Software-Defined Humans (SDH) in parallel with physical objects, processes, systems, and humans can be designed and constructed through learning, based mainly on existing data, knowledge, experience, or even intuition[14]. With Software-Defined everything, computational experiments can be conducted (i.e., self-play, self-run, self-operation, self-evaluation), and a huge amount of "artificial data" can be generated. That data is then used for reinforcement learning to enhance intelligence and decision-making capabilities. Meanwhile, the decisions are evaluated against various conditions. In the end, the physical objects, processes, and systems interact with the SDOs, SDPs, and SDSs, forming a closed-loop feedback decision-making process to control and manage the complex systems (as Fig. 4 shows). This is the core concept of the ACP-based parallel intelligent systems[15-17]. We believe parallel intelligence (PI) will be the successor of HI.

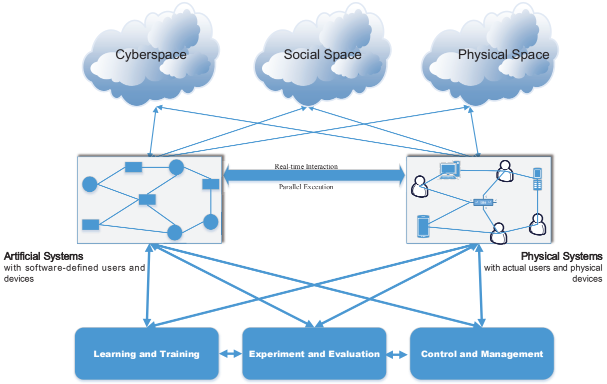

Fig. 4. The CPSS-based parallel execution for control and management for complex systems.

In ACP, "A" stands for "artificial systems", which is the generalized form of software-defined systems; "C" denotes "computational experiments", which aims at accurate analysis and reliable evaluations; and "P" represents "parallel execution", which targets at innovative and prescriptive decision-making. As indicated in Fig. 4, such parallel intelligence can be used in three modes of operations: 1) Learning and training, 2) Experiment and evaluation, and 3) Control and management.

Thus, ACP approach consists of three major steps. 1) Using **A**rtificial systems to model complex systems; 2) Using **C**omputational experiments to train and evaluate complex systems; and 3) Setting the actual physical system to interact with the virtual artificial system, and through the virtual-real system interaction, realizing effective **P**arallel control and management over the complex systems.

Based on the ACP approach, the parallel intelligence can be defined as one form of intelligence that is generated from the interactions and executions between physical and artificial systems. Parallel intelligence is characterized by being data-driven, using SDS-based modeling and computational experiments-based system behavior analytics and evaluation.

The core philosophy of parallel intelligence for a complex system is firstly, constructing a parallel system, which consists of the real physical systems and the virtual artificial systems. Then, through virtual-real interaction, the objective of parallel intelligence is to control, guide, and manage decision-making processes to drive the real system convergence to the virtual system. In this way, the main UDC challenges in complex system problems are simplified utilizing the virtual artificial system, and the AFC (Agility, Focus and Convergence) management and control of the complex systems are achieved (shown in Fig. 5).

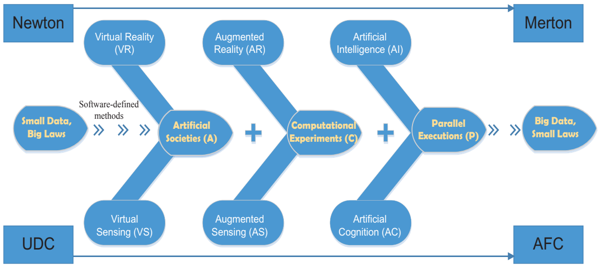

Fig. 5. ACP-based Parallel Intelligence: From UDC to AFC.

It is obvious that we paid more attention to what AI can do than what AI really means. This is because we are trying to figure out the essence of the question that came from *Cybernetics* long long age. AI is not "artificial" any more. Ultimately, it becomes the "real" intelligence that can be embodied into machines, artifacts, and our societies. Under the framework of CPSS, with new technologies in Big Data, social computing, knowledge automation, etc., the ACP-based parallel control and management architecture provides a new paradigm to observe, depict, predict, and prescript the dynamics of the flowing intelligence, thus leading the way to achieve the ultimate goal of parallel intelligence.

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Fei-Yue Wang (S'87-M'89-SM'94-F'03) received his Ph. D. in Computer and Systems Engineering from Rensselaer Polytechnic Institute, Troy, New York in 1990. He joined the University of Arizona in 1990 and became a Professor and Director of the Robotics and Automation Lab (RAL) and Program in Advanced Research for Complex Systems (PARCS). In 1999, he founded the Intelligent Control and Systems Engineering Center at the Institute of Automation, Chinese Academy of Sciences (CAS), Beijing, China, under the support of the Outstanding Oversea Chinese Talents Program from the State Planning Council and "100 Talent Program" from CAS, and in 2002, was appointed as the Director of the Key Lab of Complex Systems and Intelligence Science, CAS. In 2011, he became the State Specially Appointed Expert and the Director of the State Key Laboratory of Management and Control for Complex Systems. Dr. Wang's current research focuses on methods and applications for parallel systems, social computing, and knowledge automation. He was the Founding Editor-in-Chief of the International Journal of Intelligent Control and Systems (1995-2000), Founding EiC of IEEE ITS Magazine (2006-2007), EiC of IEEE Intelligent Systems (2009-2012), and EiC of IEEE Transactions on ITS (2009-2016). Currently he is EiC of China's Journal of Command and Control. Since 1997, he has served as General or Program Chair of more than 20 IEEE, INFORMS, ACM, ASME conferences. He was the President of IEEE ITS Society (2005-2007), Chinese Association for Science and Technology (CAST, USA) in 2005, the American Zhu Kezhen Education Foundation (2007-2008), and the Vice President of the ACM China Council (2010-2011). Since 2008, he is the Vice President and Secretary General of Chinese Association of Automation. Dr. Wang is elected Fellow of IEEE, INCOSE, IFAC, ASME, and AAAS. In 2007, he received the 2nd Class National Prize in Natural Sciences of China and awarded the Outstanding Scientist by ACM for his work in intelligent control and social computing. He received IEEE ITS Outstanding Application and Research Awards in 2009 and 2011, and IEEE SMC Norbert Wiener Award in 2014.

Xiao Wang (M'16) received her Bachelor's degree in network engineering from Dalian University of Technology, in 2011, and the Ph. D. degree in Social Computing from CASIA in 2016. She is currently a research assistant in CASIA with SKL-MCCS. Her research interests are artificial intelligence, social transportation, cyber movement organizations,and social network analysis

Lingxi Li (S'04-M'08-SM'13) received the B. E. degree in Automation from Tsinghua University, Beijing, China, in 2000, the M. S. degree in Control Theory and Control Engineering from the Institute of Automation, Chinese Academy of Sciences, Beijing, China, in 2003, and the Ph. D. degree in Electrical and Computer Engineering from the University of Illinois at Urbana-Champaign, in 2008. Since August 2008, he has been with Indiana University-Purdue University Indianapolis (IUPUI) where he is currently an Associate Professor in Electrical and Computer Engineering. Dr. Li's current research focuses on modeling, analysis, and control of complex systems; fault-tolerant systems; discrete-event systems; intelligent transportation systems; intelligent vehicles; active safety systems; and human factors. Dr. Li received Remarkable Paper Award at ACM ICUIMC in 2011, Indiana University Trustees Teaching Award in 2012, Outstanding Editorial Service Award for IEEE Transactions on Intelligent Transportation Systems in 2012, and IUPUI Prestigious External Awards Recognition (PEAR) in 2013. Dr. Li has served as Program Chair of 2011 and 2013 IEEE International Conference on Vehicular Electronics and Safety (ICVES 2011, ICVES 2013), Program Co-Chair of 2010 IEEE International Conference on Vehicular Electronics and Safety (ICVES 2010), and has been serving as an Associate Editor for IEEE Transactions on Intelligent Transportation Systems since 2009. Dr. Li is a Senior Member of the IEEE.

Li Li (S'05-M'06-SM'10) is currently an associate professor with Department of Automation, Tsinghua University, China. His research interests include complex and networked systems, intelligent control and sensing, intelligent transportation systems and intelligent vehicles. Dr. Li had published over 50 SCI indexed international journal papers and over 50 international conference papers as a first/corresponding author. He serves as an Associate Editor for IEEE Transactions on Intelligent Transportation Systems.