Cristina Olaverri-Monreal, Editor

The CASTLab in CASIA

EDITOR'S NOTE

Please send your proposal on profiling research activities of your or other ITS research groups and labs in the ITS Research Lab column to Cristina Olaverri-Monreal at cristina.olaverri-monreal@jku.at

Mission

The Complex Adaptive Systems for Transportation Laboratory (CASTLab) was established by Prof. Fei-Yue Wang in July 1999 for the task of designing and implementing the proposed intelligent traffic system for the city of Xinxiang, Henan, one of the first initiatives in intelligent transportation systems (ITS) in China. At the end of 1999, the CASTLab became a part of the newly created Center for Intelligent Control and Systems in the Institute of Automation, Chinese Academy of Sciences (CASIA), one of the premier and oldest national research organizations in information, automation, and artificial intelligence in China and worldwide.

The initial goal of the CASTLab was to develop a new traffic control system to be used during the 2008 Olympic Games in Beijing. In 2011, the CASTLab became a division of the new national key lab, the State Key Laboratory for Management and Control of Complex Systems, which was officially established by the Ministry of Science and Technology (MOST) of China and hosted by CASIA. Prof. Wang was the CASTLab director during 1999–2019 (Figure 1), and Dr. Yisheng Lv became the new director in 2020. Currently, there are more than 30 faculty and staff members and more than 40 graduate students in the CASTLab. In the last two decades, it has graduated more than 100 Ph.D. and master students.

The CASTLab focuses on the analysis, modeling, optimization, management, and control of transportation systems based on the artificial systems, computational experiments, parallel execution (ACP) theory and thus advances ITS technologies to enhance global safety, mobility, and sustainability. The vision is to become a world-class academic research center for its

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FIGURE 1 CASTLab Director Fei-Yue Wang (front row, sixth from right) and graduate students hiking at the National Olympic Forest Park, Beijing, Summer 2019.

ITSs are evolving rapidly into a class of the most comprehensive cyber-physical-social systems.

unique and promising scientific and technical research in the field.

The CASTLab faculty members have participated in many projects funded by the National Natural Science Foundation of China, MOST, and others. They have published numerous technical papers in high-quality refereed journals and at conferences. They have won domestic and international awards for their research in ITS, including the IEEE ITS Outstanding Research Award, IEEE ITS Outstanding Application Award, IEEE ITS Institutional Lead Award, and IEEE ITSS Best Dissertation Award, among others.

Several faculty members have held key leadership positions in the IEEE Intelligent Transportation Systems Society (ITSS); IEEE Systems, Man, and Cybernetics Society (SMC); IEEE Council on RFID; and IEEE technical committees. They have served as general chair/program chair for many IEEE conferences such as the IEEE International Conference on Intelligent Transportation Systems; IEEE Intelligent Vehicles Symposium; and IEEE International Conference on Service Operations and Logistics, and Informatics, and as editor-in-chief/senior editor/associate editor for journals like *IEEE Transactions on Intelligent Transportation Systems*, *IEEE Transactions on Computational Social Systems*, *IEEE Intelligent Systems*, and more.

Research

The CASTLab focuses on transportation 5.0 and parallel transportation. The research team has expertise across the ITS spectrum of transportation systems modeling and simulation; traffic sensing, data fusion analysis, prediction, and control; vehicular networks; connected and automated vehicles; and intelligent vehicle testing via virtual–real interaction.

Parallel Transportation Systems

With the fast development of artificial intelligence (AI), big data, cloud computing, social computing, and Internet of Things (IoT) technologies, ITSs are evolving rapidly into a class of the most comprehensive cyber-physical-social systems (CPSS), which provide a wide range of challenges and opportunities for traffic management and control. In particular, although AI and R&D in ITS have achieved historic prominence, the long-standing question of "Where is the intelligence in ITS?" has not been satisfactorily addressed yet.

The research team works on how to enable ITS to be truly smart, effective, and efficient, within the framework of Transportation 5.0 and parallel transportation asystems (PTS) based on the ACP approach (Figure 2). The basic ideas of PTS are:

1) modeling and representing physical transportation systems using artificial transportation systems
2) analyzing and evaluating traffic situations by computational experiments
3) controlling and managing transportation systems by parallel execution through interaction of physical and artificial transportation systems.

The ACP-based PTS provides a platform to generate big data from small data and then extract precise intelligence for specific tasks from big data

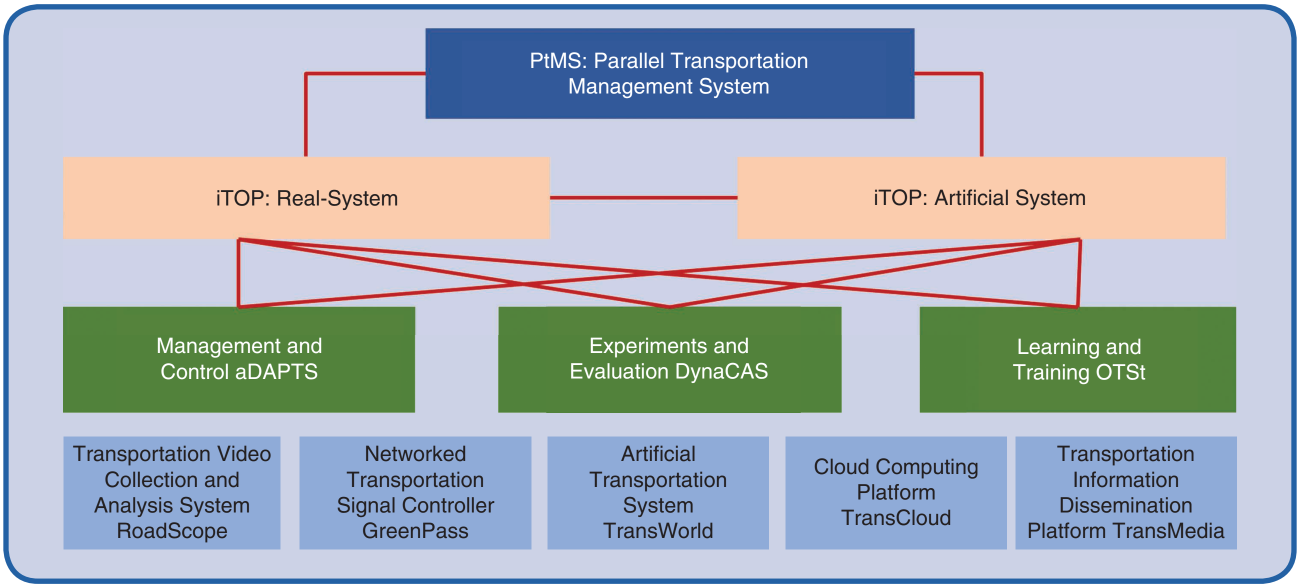

FIGURE 2 The parallel transportation system overview.

via various AI methods, which enables seamless integration of AI techniques into transportation operations. The CASTLab established state-of-the-art research facilities and platforms, including the parallel transportation platform (Figure 3), agent-based networked traffic controllers (Figure 4), and traffic signal control systems testing platform (Figure 5).

Parallel Internet of Vehicles

Vehicles in the Internet of Vehicles (IoV) exchange information about location, environment, infotainment, and social information with other units via vehicular communication networks. This makes the IoV work with key social entities in the human–vehicle–infrastructure–roadside units as part of the integrated intelligent transportation systems. Therefore, by identifying the cyber–physical–social features of the IoV and presenting its complexity issues of both engineering and social dimensions, we proposed the concept, architecture, and applications of the parallel IoV (PIoV). The three main components of the PIoV are:

FIGURE 3 The parallel transportation platforms.

FIGURE 4 Networked traffic signal controllers.

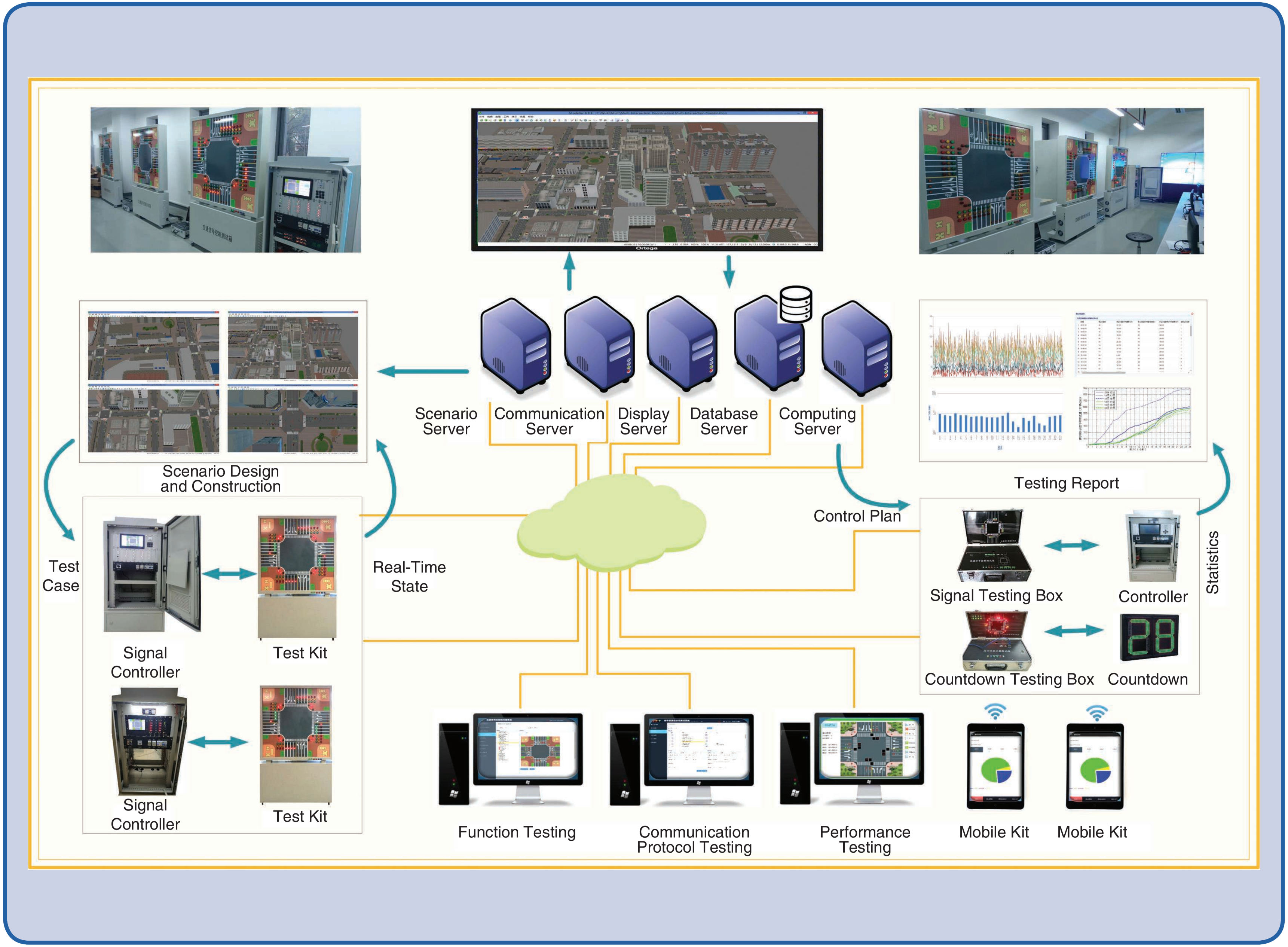

FIGURE 5 Traffic signal control systems testing platform.

1) artificial IoV to learn and describe the physical IoV
2) computation experiments to evaluate and predict the consequences and values of driving strategies
3) parallel execution to prescribe the operation of the physical IoV.

The PIoV makes it possible to achieve safe, smart, effective, and efficient transportation management and control. The objective of the PIoV is to equip the IoV with descriptive, predictive, and prescriptive intelligence based on the parallel intelligence approach.

The PIoV jointly considers in-vehicle networks, intervehicle networks, onboard mobile networks, and social networks as shown in Figure 6. By building a virtual artificial IoV corresponding to the physical IoV and with the help of computational experiments, an IoV management and control experiment can be designed to be repeatable, configurable, computable, and guidable. For effective evaluation, computational experiments forecast and guide the operation state of the physical IoV.

> In the coming two to four decades, the road transportation system will consist of a mix of connected vehicles with different levels of automation.

The computational experiment results become a possible outcome in the running state of the system but are no longer just a simulation of the physical operation status. The physical IoV provides the real data information to the PIoV and furnishes the state parameters for the establishment, adjustment, and optimization of the artificial IoV mode. Computational experiments use the real data for model training, generate a large amount of "artificial data," and increase learning based on the "mixed huge amounts of data" from both real small data and artificial big data. Therefore, the system scenario learning and cognitive ability can be improved and optimized. On the other hand, by parallel execution, computational experiment results are fed back to the physical IoV for real-time and online reference, prediction, and prescription.

Parallel Driving

It can be well foreseen that in the coming two to four decades, the road transportation system will consist of a mix of connected vehicles with different levels of automation, which necessitates a unified approach for future smart and safe driving and motivates the development of CPSS-based parallel driving. For future connected automated driving, physical vehicles, human drivers, and cognitive (e.g.,

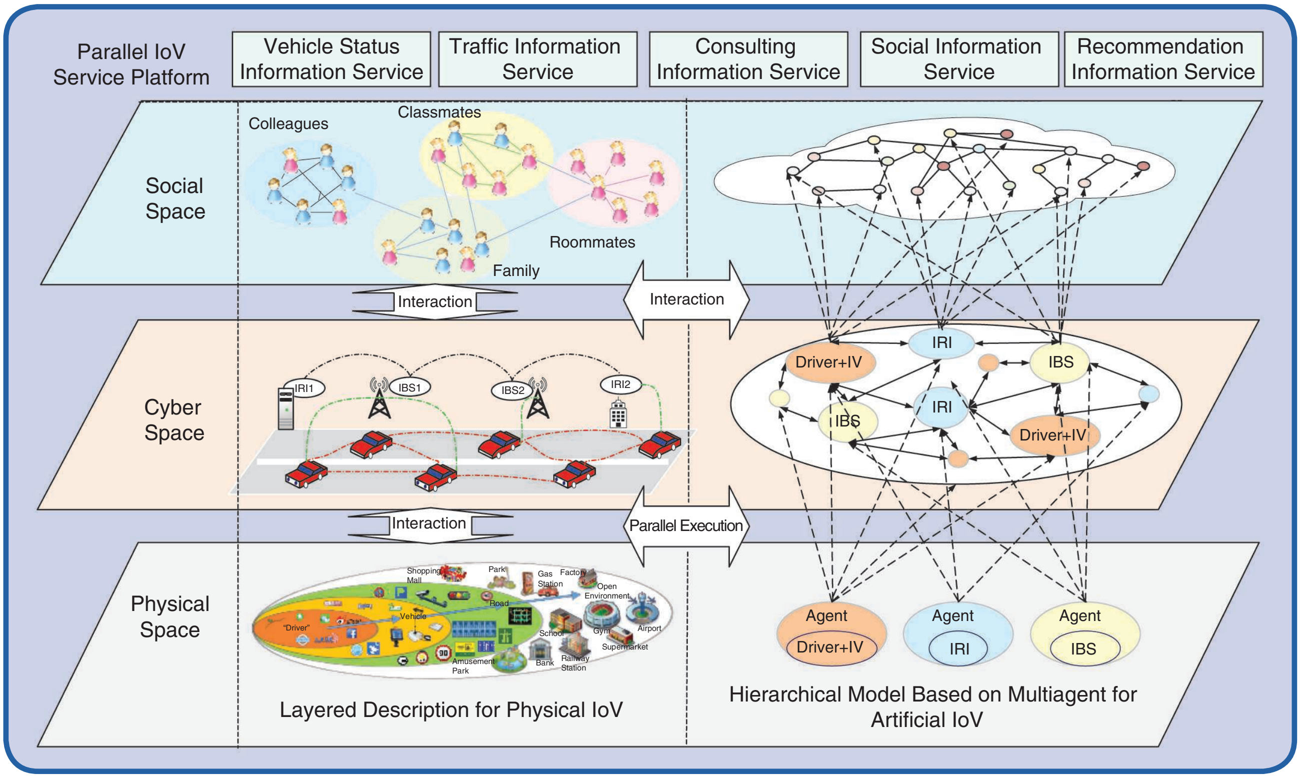

FIGURE 6 The architecture of the PIoV. IRI: intelligent roadside infrastructure; IBS: intelligent base station.

attention, intention) attributes, as well as control and information related to driving (artificial), will co-exist. Based on the ACP approach, these road driving elements can be naturally projected into the three parallel worlds, namely the physical, mental, and artificial worlds, as seen in Figure 7, which presents the CPSS-based parallel driving framework. Parallel driving is a novel paradigm of cloud-based unmanned driving technologies that makes unmanned vehicles and the IoV the two main topics of the current R&D in intelligent vehicles.

The Intel Collaborative Research Institute on Intelligent and Automated Connected Vehicles (ICRI-IACV) has been started to devote synergized efforts to academic research and industrial development of CPSS-based parallel driving (Figure 8). ICRI-IACV was launched by Intel, the Institute of Automation, the Chinese Academy of Sciences, and Tsinghua University. In 2018, the parallel driving technology research and application verification project was funded by the Beijing Municipal Science and Technology Commission as the next-generation artificial intelligence technology cultivation project. It mainly studies the key technologies of parallel driving, including parallel vision,

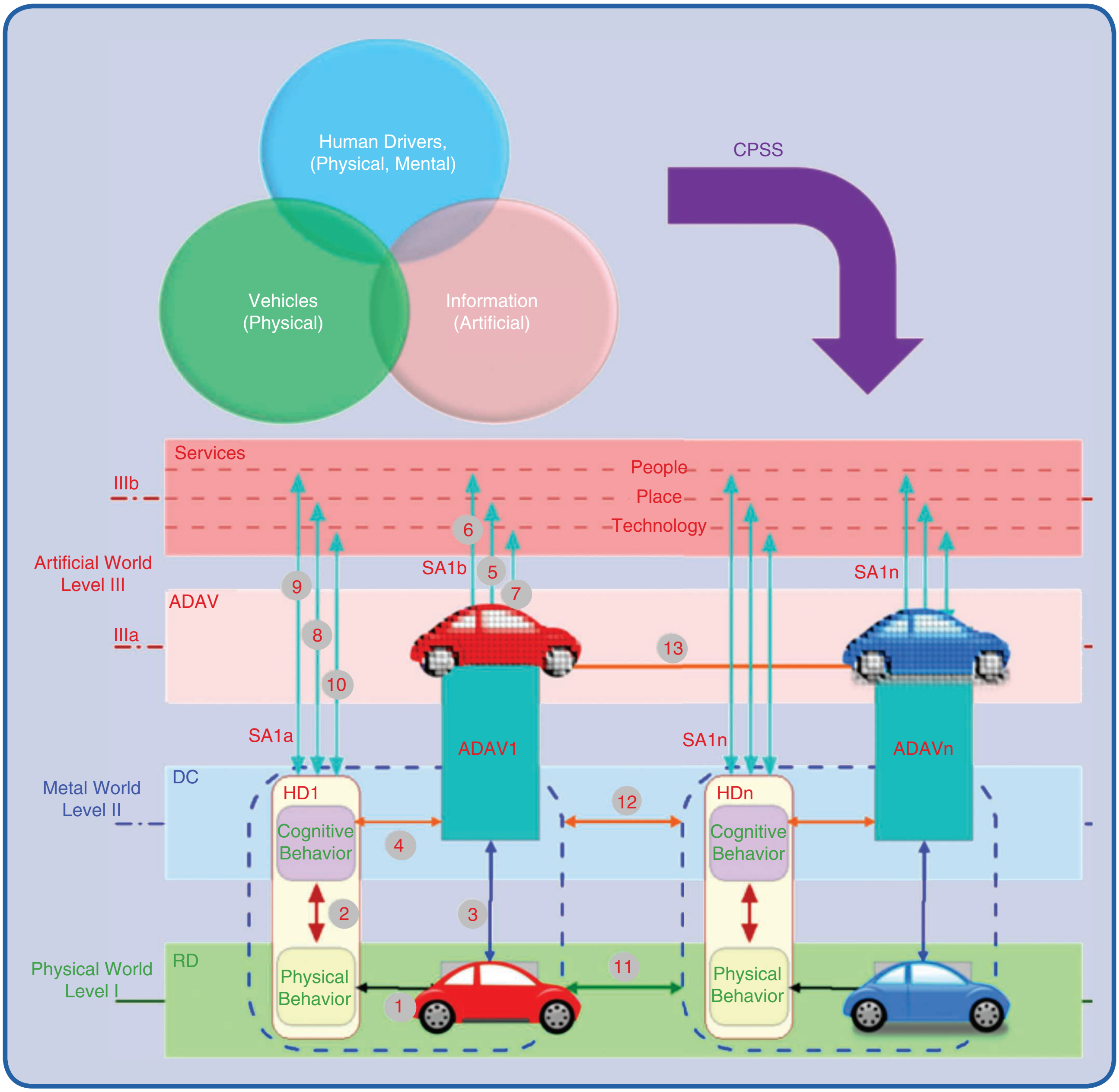

FIGURE 7 The framework of parallel driving. RD: real driving; DC: driver cognition; CPSS services including three components: people (social web), place/location(geo web), and technology (sensors, IoT, etc.); HD: human driver; RV: real vehicle; ADAV: artificial driver and artificial vehicle; SA: situation awareness.

perception, planning, decision, control, and testing of intelligent vehicles. To promote the cooperation and exchange of scholars in the field of parallel driving and to realize safe, stable, fast, and intelligent cooperation among intelligent vehicles with different levels of automation in the future, the International Parallel Driving Alliance was launched in Changshu, Jiangsu Province, China, in June 2018 (Figure 9).

One typical application of parallel driving is parallel mining for unmanned mine fields and intelligent mine transportation (Figures 10 and 11). Parallel mining techniques are widely used by the main construction machinery manufacturers in China.

Parallel Testing of Intelligent Vehicles

Researchers and automobile manufacturers have built proving grounds, simulation-based test systems, and testing data sets dedicated to autonomous driving. However, tests for intelligent vehicles remain challenging. We propose a novel testing paradigm called *parallel testing* to implement more challenging tests to accelerate the building and testing of autonomous vehicles.

For parallel testing of intelligent vehicles, the field and simulation tests for intelligent vehicles are tightly integrated to ensure test safety and accelerate testing speed. Parallel testing consists of three parts, as shown in Figure 12. The first part is for testing task abstraction and generation, where a set of semantic definitions is established

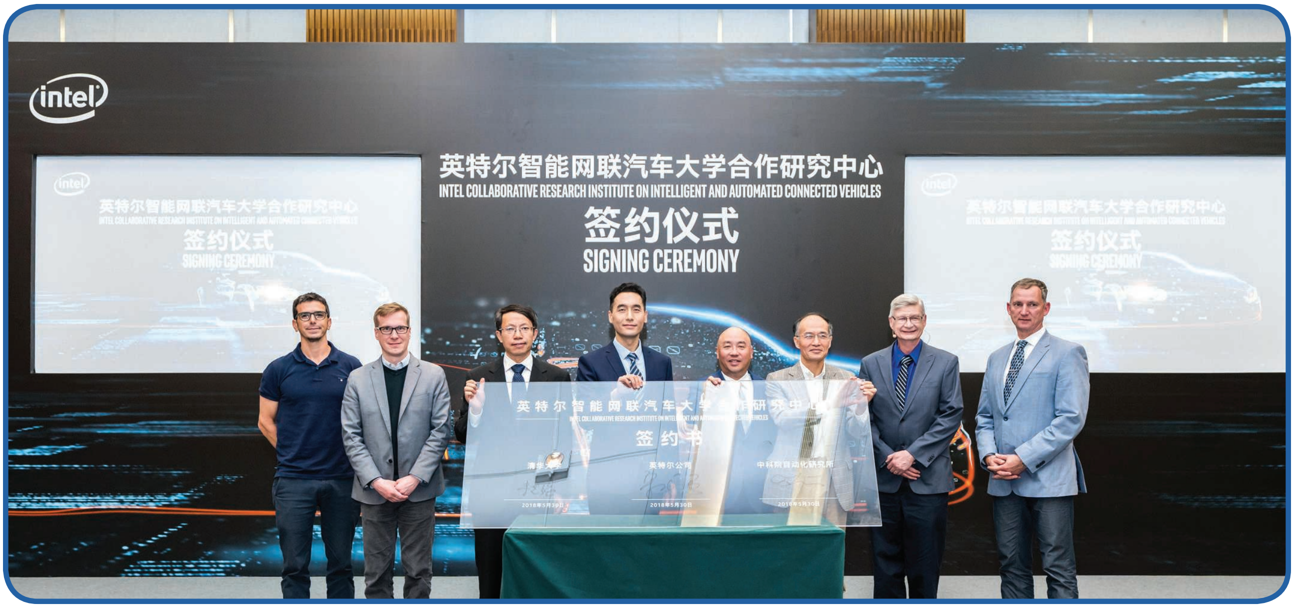

FIGURE 8 The Intel Collaborative Research Institute on Intelligent and Automated Connected Vehicles. (Source: Intel; used with permission.)

FIGURE 9 The International Parallel Driving Alliance, launched in June 2018.

to characterize the tasks that should be finished by autonomous vehicles. The second part is to implement the tests for the specified task instances in which the field test and simulation test are tightly integrated and interacted. The third part evaluates both vehicle performances and task difficulties to seek the most challenging new tasks. To make the test of vehicle intelligence more quantifiable and automatic, the test in our systems is a self-upgrading process occasionally guided by human experts. The parallel testing system has successfully supported the Intelligent Vehicle Future Challenge of China since 2008, which is the longest lasting autonomous driving competition.

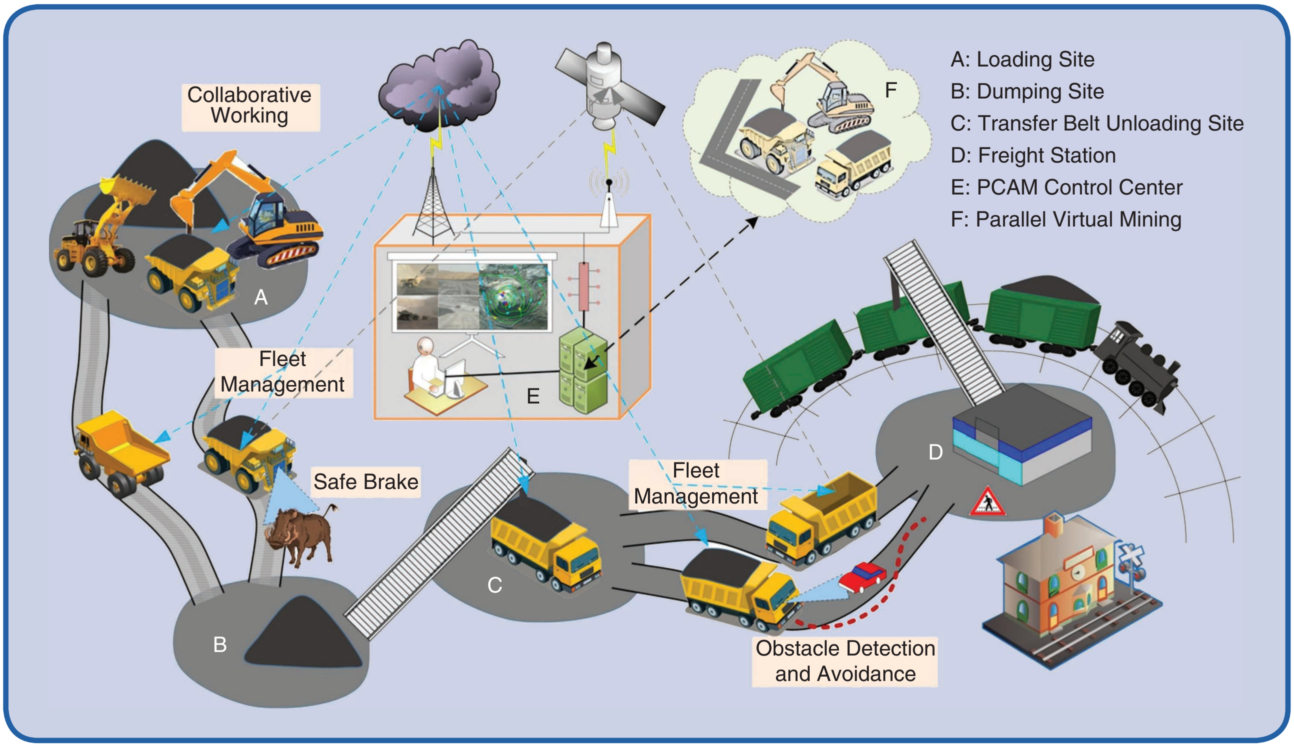

FIGURE 10 The parallel mining architecture. PCAM: parallel control and management.

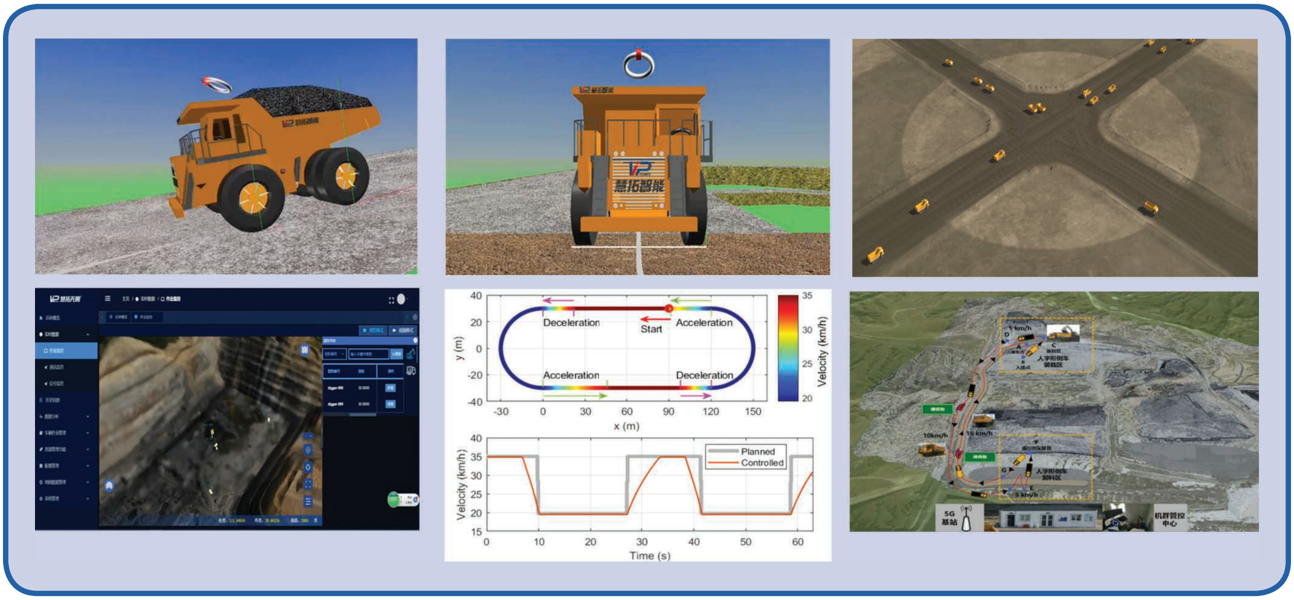

FIGURE 11 The parallel mining snapshots.

Future Directions

In the era of AI, big data, cloud computing, and the IoT, we have entered the age where vehicles, infrastructure, information, and humans are tightly coupled. This is shaping and transforming the field of ITS, in which transportation systems from the physical world and its virtual counterparts in the cyberworld are seamlessly integrated. We must develop new intelligent technologies for ITS, and we need ITS for smart societies and smart living for mankind. The CAST-Lab will continue to advance Transportation 5.0 and parallel transportation based on its previous research success and capabilities.

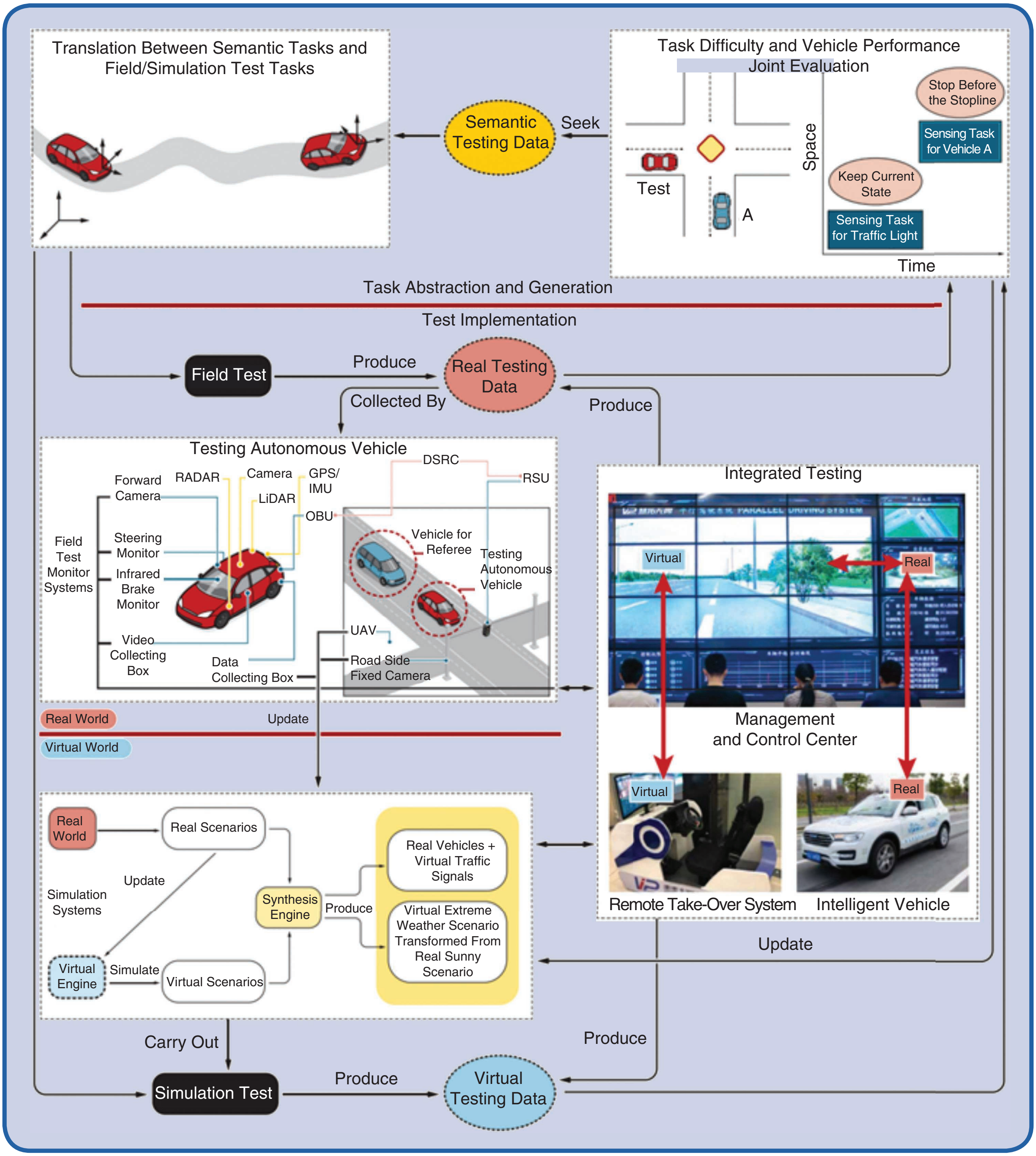

FIGURE 12 A system overview of parallel testing. (Used with permission from [1].)

Founding Director

Fei-Yue Wang is a professor and the founding director of the State Key Laboratory for Management and Control of Complex Systems. He has been elected as a Fellow of the IEEE, International Council on Systems Engineering, International Federation of Automatic Control, American Society of Mechanical Engineers (ASME), and American Association for the Advancement of Science. He received the National Prize in Natural Sciences of China for intelligent control in 2007. He received the IEEE ITS Outstanding Application and Research Awards in 2009, 2011, and 2015, respectively, and the IEEE SMC Norbert Wiener Award in 2014. Since 1997, he has served as the general or program chair of more than 20 IEEE, INFORMS, Association for Computing Machinery (ACM), and ASME conferences. He was the president of the IEEE ITSS 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; the vice president of the ACM China Council from 2010 to 2011; and the vice president and secretary general of the Chinese Association of Automation (CAA) from 2008 to 2018. Since 2019, he has been the president of the Supervision Council of CAA.

He was the founding editor-in-chief (EIC) of the *International Journal of Intelligent Control and Systems* from 1995 to 2000 and the *IEEE Intelligent Transportation Systems* magazine from 2006 to 2007 and the EIC of *IEEE Intelligent Systems* from 2009 to 2012 and the *IEEE Transactions on ITS* from 2009 to 2016. He is currently the EIC of the *IEEE Transactions on Computational Social Systems* and the founding EIC of the *IEEE/CAA Journal of Automatica Sinica* and the Chinese *Journal of Command and Control*.

About the Author

Yisheng Lv is currently an associate professor with the State Key Laboratory for Management and Control of Complex Systems, Institute of Automation, Chinese Academy of Sciences. His research interests include artificial intelligence, intelligent control, intelligent transportation systems, and parallel traffic management and control systems. He is currently an ITS Society Board of Governors member. He is an associate editor of *IEEE Transactions on Intelligent Transportation Systems* and is on the editorial board of *Acta Automatica Sinica*. He received the 2015 IEEE ITS Outstanding Application Award. Contact him at yisheng.lv@ia.ac.cn.

Reference

[1] L. Li et al., "Parallel testing of vehicle intelligence via virtual-real interaction," *Sci. Robot.*, vol. 4, no. 28, Art. no. eaaw4106, 2019. doi: 10.1126/scirobotics.aaw4106.

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