Fei-Yue Wang, Editor

Forward to the Past: CASTLab's Cyber-Social-Physical Approach for ITS in 1999

EDITOR'S NOTE

Please send your submissions for the "History and Perspectives" column to Fei-Yue Wang at feiyue.wang@ia.ac.cn.

Many thanks to our new EIC, Prof. Yisheng Lv, for inviting me to launch this new Department of History and Perspective for *ITSM*.

First of all, I would like to congratulate Prof. Ljubo Vlacic and all previous EICs for a job well done. Clearly, *IEEE Intelligent Transportation Systems Magazine* (*ITSM*) is becoming the flagship publication for communicating news and activities for our IEEE Intelligent Transportation Systems Society (ITSS) and intelligent transportation system (ITS) professional communities around the world. Next, many thanks to our new EIC, Prof. Yisheng Lv, for inviting me to launch this new Department of History and Perspective for *ITSM*. It is the right time to reflect on our history and look forward into our future at the ITSS.

I will start with my personal research and teaching experiences in ITSs, a journey of almost four decades in my academic life. My major research had been concentrated on artificial intelligence (AI) and intelligent control for robotics and intelligent systems during the first two decades; ITSs were a minor interest until the turn of the new century. I hope my effort and experience are valuable and help our young generation of ITS professionals.

"CASTLab: A Cyber-Social-Physical Approach for Traffic Control and Transportation Management" is my original report for the creation of CASTLab, the Complex Adaptive Systems for Transportation Laboratory, to the Intelligent Control and Systems Engineering Center (ICSEC) I had founded in 1999 with support from both China and the United States, currently the State Key Laboratory for Management and Control of Complex Systems, hosted by the CAS and supported by the Ministry of Science and Technology of China. Although it is kind of embarrassing to read your direct and arrogant style of expression when you were young, many ideas in this report remain valid and useful today, and it should help others to understand my works in parallel driving and parallel transportation, and more generally, in parallel intelligence and Industry 5.0.

A recent report and its current focus on CASTLab can be found in [1], [2], along with other related publications in *ITSM* and other IEEE publications [3], [4], [5], [6], [7], [8], [9]. CASTLab's work was expanded at Qingdao Academy of Intelligent Industries in 2014, as presented at the IEEE International Conference on Intelligent Transportation Systems (ITSC 2014) in Qingdao, China. Starting from 2023, CASTLab will be in the process of transforming itself into a new decentralized autonomous organization with decentralized autonomous operations (DAOs) for both smart urban and ecological systems, open to all, and based on blockchains and smart contracts, conducting decentralized science (DeSci), decentralized economics (DeEco), and decentralized society (DeSoc) [10], [11] research and development to achieve "6S" ITSs for future logistics and mobility as follows:

1) safety in the physical world
2) security in the cyberspace or metaverse

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Forward to the Past: CASTLab's CSP Approach for ITS in 1999

CASTLab: A Cyber-Social-Physical Approach for Traffic Control and Transportation Management

Fei-Yue Wang
October 15, 1999

Executive Summary

This report summaries the critical issues and key points raised and addressed in workshops on Intelligent Transportation Systems (ITS) during the last two years conducted at the University of Arizona (mainly at its PARCS and ATLAS centers, Tucson, AZ), Zhejiang University (Hangzhou, China), Northern Jiaotong University (Beijing, China), Xi'an Jiaotong University (Xian, China), Shanghai Jiaotong University (Shanghai, China), and Chinese Academy of Sciences (mainly its CASIA and Graduate School, Beijing, China).

Based on those discussions, it is clear that we need a dramatic transformation and paradigm change for ITS research and development, as well as application and implementation. Our conclusion is simple: ITS are special complex systems of both and equally distributed engineering complexity and social complexity, human factors and social relationships must play a central role at a critical stage in their design, analysis, verification, construction, validation, and deployment. The most of current approaches adapted by ITS research communities have largely ignored human and social aspects of transportation complexity. Considering the situation, it is decided that the first research laboratory to be established by CASIA's Intelligent Control and Systems Engineer Center (ICSEC) will be ***CASTLab***: The Complex Adaptive Systems for Transportation Laboratory. Our second laboratory will be on intelligent houses and smart home systems, in collaboration with major household appliance companies in China. These two labs will be our research platforms for mobile and stationary intelligent spaces, an emerging and important field for artificial intelligence and intelligent systems.

The ***CASTLab*** will be the first ITS Institute in the world that would adapt Karl Popper's Three Worlds Philosophy of Reality as its fundamental belief in all aspects of research and development. It will be a major part of our main initiative on building cyber social physical systems for knowledge automation.

Based on the experience and lesson learned from ATLAS's RHODES and MILOS, and PARCS's TransWorld and DynaChina, our first step will be constructing various artificial transportation systems or transportation shadows that could enable us to move away from computer traffic simulations to computational traffic experiments, and eventually achieving the goal of real-time feedback and closed-loop control between artificial and actual transportation systems, including both road traffic control and vehicular driving systems. Our mission is to provide the ITS field a new direction that uses a cyber-social-physical approach for traffic control and transportation management which would prescribe, in additional to describe and predict, complex and smart transportation behaviors for ITS. As a by-product, we hope our research will provide an academic foundation and support the deployment of a new generation urban traffic control and management systems in the near future, especially in the Beijing metropolitan area for its effort to host future Olympic Games.

1. Introduction

In this report, I would like to share my thoughts on our plan for R&D activities at ***CASTLab***, The Complex Adaptive Systems for Transportation Laboratory in both Beijing and Tucson, Arizona, over the next decade, including mainly: 1) Our new thinking for both science and technology in the new century, 2) Our new framework for intelligent and complex systems, especially for so-called complexity science, 3) Our new approach for current intelligent transportation systems and future smart logistics, smart mobility, smart city, smart economy, smart society, and smart ecology.

As you know, our ***CASTLab*** was motivated by our first major ITS project under the request of Xinxiang Metropolitan Government (through its Public Safety Bureau), Henan Province, and Chinese Academy of Sciences (through its Executive Administration Bureau) in the last summer. Frankly speaking, I doubt about the success of winning this project, since many desired and designed functions for this system are far reach of both hardware and software currently available in China, and the cost of advanced oversea systems and technology is simply beyond the budget provided. Most importantly, the easy and quick promises from related parties might indicate potential troubles for their actual deliveries. I still remember vividly the facial expressions when they saw the colorful cover of our 100+ pages project proposal and appendices for equipment details (the result of whole week's sleepless hard work), it was not a good omen to me.

However, regardless the possible outcome of this project, there is no doubt that the creation of our ***CASTLab*** is the right move for us, which would not only carry on the pioneering effort in China on traffic control, vehicular electronics and automation, smart systems for public and organizational safety, security, and surveillance at CAS' Institute of Automation in earlier 1980s and 1990s, but also continue and integrate my own research on autonomous driving and ITS at Rensselaer Polytechnic Institute in 1980s and the University of Arizona in 1990s.

Above all, ITS will the foundational infrastructure for any modern societies in the future, especially that China is now in the process of winning the right for hosting Olympic Games in Beijing, transportation in the modern sense will definitely a big issue if we would organize the Games in 2008. Therefore, we must work in this area since I see no emerging strong forces in ITS in China at this point. It is my determination and sincere hope that our effort will make ***CASTLab*** a global center of excellence in ITS R&D as well as a symbol for successful Sino-US academic collaboration in the coming new century.

To make ***CASTLab*** a success, we need to think big, and think out of the box, and this is the reason for this report, which has been driven by a series of workshops and presentations on ITS and complex systems in China and USA during the last two years.

2. New Thinking and New Philosophy

Over the last few years, I have been reading Karl Popper's works intensively, especially his analysis on utopian social engineering and piecemeal social engineering, and his thought on world model, i.e., three world model of reality consisting of the physical world as world 1, the mental world as world 2, and the artificial world as world 3. In the conventional two-world model, the top-down utopian social engineering and bottom-up piecemeal social engineering are contradictory and would never converge to the same direction, how about in Popper's three-world model? Can we bridge the gap between utopian and piecemeal social engineering by introducing the artificial world? Along with its artificial societies, artificial people, artificial systems, artificial resources, and artificial intelligence? Can artificial be actual and actual be artificial, or real be virtual and virtual be real? To be clear, this is not philosophical, it is very technical now.

Then back in China, I learned H. S. Tsien's idea of sixth scientifical and technological revolution, i.e., revolution mainly through new bio science, bio technology, and bio engineering. I believe that Popper's philosophical thinking and Tsien's technological vision would lead to the

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same logical conclusion: artificial is actual and real is virtual, vice versa. However, to me, Tsien's bio approach is logical but not feasible, even might not be ethical in the near future, and the best approach should be computational or digital, not biological yet. Computational approach should provide us the means to create possible bridges between various kinds of utopian and piecemeal engineering, social or technical.

Theories and methods in artificial life and artificial societies have demonstrated the feasibility of this "computational biological" approach, I am particularly impressed by the book of Epstein and Axtell, *Growing Artificial Societies: Social Science from the Bottom Up* (MIT, 1996, we are in the process of translating this book into Chinese). Complex and intelligent individual behaviors as well as collective patterns could emerge from various agent-based artificial societies through adaptive interactions, and what we need to do is to use intelligent control or generalized control to find appropriate mechanisms that could guide or prescribe the convergence of those emergent processes to our desired, designed or adapted missions or goals. This is our new thinking for modeling, analysis, control and management of future intelligent transportation systems, this is why we have initiated our research on TransWorld and DynaChina with traffic shadows and transportation agents at PARCS.

For this we need a new philosophy, it will be something based on Popper's three worlds and Whitehead's process philosophy where real and virtual go in parallel and interact with each other beyond Plato's theory of Forms or Ideas, we need new thinking and new technology to make people firstly believe in, and secondly live and work with "Being Entities" of artificial worlds and "Becoming Processes" of artificial societies, so the actual and artificial or virtual and real form closed-loops with real-time feedback in both physical and mental worlds.

For example, our computing power should be enough in the future to build an Artificial Beijing for the purpose of managing our capital's transportation: enough agents or artificial citizens to model our needs for and behaviors of logistics and mobility, accurate simulations to analyze the impacts of various policies and events on traffic before their actually taking place, and eventually forecasting daily traffic better than reporting daily weather, etc.

Our thinking is much broader than what has been proposed and implemented so far in cellular automata based TranSims project. We should go beyond transportation and go after all industries and all operations by building artificial organizations with artificial agents for modeling, analysis, control and management of complex social systems, i.e., generalized intelligent control systems with world models (of course, more than the primitive world model proposed by Meystel and Albus a few years ago), where both physical robots and human-like agents "live" and serve our mankind in harmony.

3. New Framework and New Science

We are from control engineering, so we will start from the three basic steps in control theory: modeling, analysis, and control, but with much big and abstract goals and functions, i.e., description, prediction, and prescription, and without equations, differential or difference. Specifically, my vision for a new framework of complexity science with application to transportation is to

1) Describe behaviors of complex systems by artificial societies or artificial organizations,
2) Predict behaviors of complex systems by computer or computational simulations, and
3) Prescribe or guide behaviors of complex systems by artificial-actual interactions

I am not sure about use of computer simulation, or emulation, or imitation, maybe all of them, not sure about the use of prescribe, or guide, or control, or manage, or govern, maybe all of them. Personally, I prefer prescribing or prescription, from the perspective of the doctor-patient relationship. This will be our discussion and investigation in the next few months in both PARCS and our new ICSEC.

This might be controversial to many, especially to our control people that have deeply immersed in theory proving mathematically for stability and convergence for too long. We do have many beautiful and elegant mathematical tools for complex systems, such as chaos, bifurcation theory, cellular automata, but I do believe computational methods are the key to any useful method for complexity analysis and control.

We need a new science beyond new thinking for complexity research, a science that must accommodate humans in the loop in real-time, not by getting into the loop through conventional means or systems after reading related philosophical books, social books, or scientifical books. This might sound like a technological issue, but actually not, since without changing our thinking and our understanding of science, i.e., a new philosophy of science, there would be no such kind of technologies possible, and Popper's artificial world would be no world at all.

I believe that computational knowledge, or knowledge which is available for use in real-time at needs or demands, should be key to this. In a sense, we should move our attention from physical automation in control engineering to knowledge automation for management sciences, in the whole lifecycle of knowledge management from its generation, dissemination, verification and validation, and utilization and modification, but how? This is the big question for all, and transportation should be a good field to investigate for a possible solution since where social complexity and engineering complexity are almost equally involved.

Let's start with exploring a new science with our proposed new framework.

4. The Cyber-Social-Physical Approach for ITS and Beyond

For me, Popper's three worlds have provided us an ideal setting for implementing Wiener's circular causality, i.e., spatially and procedurally from top-down to bottom-up and vice versa, temporally and logically from past, present, future to future, past, present and vice versa. For example, we could prescribe a future in the artificial world, that would define a past in the physical world, which eventually will lead to a present in the mental world, through complex iterations and interactions of emergences and convergences among those worlds, top-down or bottom-up, and hopefully, engineered pathways between utopian and piecemeal social engineering, for Popper's circular consequences with Wiener's circular causality.

Simply, we need a Cyber-Social-Physical (CSP) approach for our new science, new engineering, and new social studies, and particularly, for our new transportation research. For modeling and analysis, we would conduct the process of emergence in the artificial world without "physical" consequences as often feared, while for control and management, we should execute the process of convergence in the physical world with "artificial" precision as always desired. Our CSP is from Popper three worlds, but we should also remember Hoare's CSP theory in theoretic computer science: communicating sequential processes, its generalization is what we need for emergence and convergence in complex adaptive systems or complexity science.

Specifically, I will do my best to provide the support for R&D in A) intelligent traffic control and management, and B) autonomous driving

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and mobile intelligent spaces. We have extremely solid backgrounds in both directions.

For traffic control, we will deep our current participation in RHODES and MILOS at ATLAS, and find ways to extend and integrate functions of TransSIMS, DynaMIT, and DynaSMART, and make them more practical and useful for real-world problems, particular for Beijing's Olympic Games. To this end, we will have our own CSP-based TransWorld for TransSIMS, OTS for Transportation as OTS for DCS in Petro-Chemical industry, DynaChina and DynaCAS (Yes, CAS for Chinese Academy of Sciences) for DynaSMART and DynaMIT, one opens to all for research and education, and one just for our own use in constructing and testing traffic products and field systems.

For intelligent vehicles, this is my current focus in Arizona, our VISTA Project. VISTA stands for Vehicles with Intelligent Systems for Transport Automation, its goal is to develop autonomous vehicles for automated driving between Tucson International Airport and Phoenix Sky Harbor, a ride over 100 miles. With a small research budget of USD $100K from ADOT, we have made huge progress over the last year, and will extend this research and my previous works with NASA and NIST on shadow systems and Luna/Martian robotic vehicles into five areas at ***CASTLab***: 1) embedded real-time systems and application-specific operating systems (ASOS), 2) sensing, planning and control for autonomous systems, 3) complex and cognitive dynamics and mechatronic design, 4) simulation experiments and virtual testing for verification and validation, and 5) intelligent tires and their related internet-based operations and maintenance, all from our CSP perspective.

While I am extremely confident about our ability in research and software development, I do have some concern on our capacity in hardware and sensing systems. I would like to set up concrete targets for you in this regard, developing a web-based new intersection traffic light controller better than the one we have initiated for GTS and building a web-based new traffic camera system for both roadways and highways better than AutoScope in USA. As for intelligent vehicles, let's still focus on simulation, virtual design and testing, and building toy-type physical vehicles only for educational and entertaining purposes, such as for Formula 1 like autonomous car racing to attract more students getting into this area.

Once we have succeeded in ITS, we will be able to apply our CSP approach in almost any other industrial and social fields, since it would imply a disruptive new way for achieving higher performance with lower cost.

5. Concluding Remarks

What kind of projects and goals would deserve my effort and dedication for the next decade. This has been the question in my head for the last few years, and I need an answer before the end of this century. I think I have the answer now, and it should the central mission and tasks for my involvement in both US and China starting from now.

When I came back from Beijing to Tucson before my Fall Semester starting in UA, I told myself that I need to make a formal resolution for my new endeavor in the coming decade. Number 8 has a special meaning to many Chinese in Hong Kong, Taiwan, and Guangdong, since it reads as "developed" or "getting rich" in Chinese, and this is the reason that many of my Chinese American friends from those regions found their companies on the day of August 8, 1988 (a day of four 8s). But to me, number 9 is much more meaningful, since it reads as "forever" or "long time" in Chinese, so on the morning of September 9, 1999, around the 9th second of the 9th minute of the 9th hour (a moment of eight 9s), facing the Tucson Mountain in the west at the wood balcony on the second floor of Old Main, the oldest building that established UA in 1885, I made myself a resolution: Building Educational Institutions for and with Decentralized Agent-based Organizations, at least for the first decade of 21st century. Why educational? We might be failed in research, but never in education.

Actually, I started this effort almost 10 years ago with shadow systems, behavioral programming and artificial agents for day trading, robotic vehicles, and autonomous Lunar/Martian plants, and more recently for web-based online control experiments in our WAVES (Web-based Audio and Video Educational Systems) Lab with the support of my NSF CRCD grant. I am glad that both Peter Fu and Yuetong Lin are making progress in their PhD research on educational agents for online teaching assistance system. I am sure that their work would provide valuable experience for the development of ***CASTLab***.

Our next lab will be ***DreamSpaces*** for intelligent houses and smart home systems, jointly with a few major household appliance companies in China. We are still in the process of discussion and negotiation, and I hope that this new lab for stationary or fixed smart spaces, and ***CASTLab*** for mobile or cyber intelligent spaces will start a revolution and redefine our way of "Yi (Clothes/Medicare), Shi (Food), Zhu (House/Home), Xing (Logistics/Mobility)" in the 21st century. For example, we can envision a smart lifestyle that would eliminate traffic congestion to a large degree since mobile shops, mobile restaurants, mobile theaters, mobile fitness rooms, mobile hospitals, even mobile hotels for your guests, could come to your home or any place you have ordered, autonomously and without traffic conflicts.

I don't have a grand vision like H.S. Tsien's sixth scientifical and technological revolution, but I do have a technical roadmap for technological and industrial evolution: 1) steamer-driven, the mechanical era, 2) motor-driven, the electrical era, 3) computer-driven, the information era, 4) internet-driven, the network era, and 5) agent-driven, the intelligent era or the age of knowledge automation. We are still in the middle of the network times, and will start the knowledge automation very soon, from hardware, to software, and to "knowware" (hope it would lead us to knowledge ware, not nowhere).

Let's build a first class ITS research team with ***CASTLab***, let's lead the world with CSP for knowledge automation.

Acknowledgement

I would like to express my sincere thanks to my team members in Tucson and Beijing, especially Linda Cramer, Ling Li, Hong Hao for their assistance during my shuttling back and forth between US-China in the past few months.

3) sustainability in the ecological system of systems
4) sensitivity or sovereignty for individual rights and interests
5) service for all
6) smartness of all.

How has this happened?

Back to the Future: From CSP to CPSS

In 2010, I changed the term *CSP* to *CPSS* (cyber-social-physical systems)—reluctantly, since *CPS* (cyber-physical systems) has been becoming a widely accepted term [12], but I still used CSP in some of my writings. I am excited to see that CPS (for knowledge discovery and digital twins) and CPSS (for knowledge automation and parallel intelligence) as well as AlphaGo, Metaverse, ChatGPT, and many other AI generated content or artificial general intelligence systems to come have been

widening the existing ITS field and will continue to open up new directions for effective ways of logistics and mobility in the future [13], [14], [15].

Please submit your articles to this Department of History and Perspective and help me make it our new forum for sharing your unique wisdom and valuable experience.

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Acknowledgment

I would like to end my first article with special thanks to my MUSTDAO team and the Macau Special Administrative Region (SAR) for their support in my proposed research on blockchain and smart contracts (The Science and Technology Development Fund, Macau SAR under Grant 0050/2020/A1), a proposal that had been rejected by the expert panel of the National Natural Science Foundation of China (NSFC) previously and laid the solid foundation for the new CASTLab in the coming decades.

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ITS

ITS RESEARCH LAB *(continued from page 170)*

Innovative Approaches for Improving Automated Road Systems

To understand the limitations of risk perceptions by the current AV systems, we develop VR-enabled simulation approaches and investigate AV operations under various conditions. We focus on AV's operational mechanisms and decision-making principles and systematically study the differences in perceptions and decision making between human drivers and AVs. The objective is to increase the intelligence and the human-centricness of the AVs. Based on extensive human-in-the-loop experiments (Figure 4), using self-developed and commercial simulation platforms, our research measures, compares, and analyzes the differences in driving maneuvers between AVs and human drivers. Utilizing this knowledge, we aim to build up a library of "critical scenarios" from structured experiments to enhance the quality of the training set for AVs. Furthermore, we investigate the impact of AVs under different levels of mixed flow. For example, the environmental impact of vehicular platooning and user acceptance was studied, and eco-driving strategies were tested. The ultimate goal of this stream is to offer alternatives to data-generating, analyzing, and managing approaches for automated road systems.

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