Intelligent Economics: An Explainable AI Approach

Lecture of Undergraduate Studies

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Parallel Economics: From Artificial Intelligence to Intelligent and Smart Economy

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Outline

New Age: From New IT to Big 5G

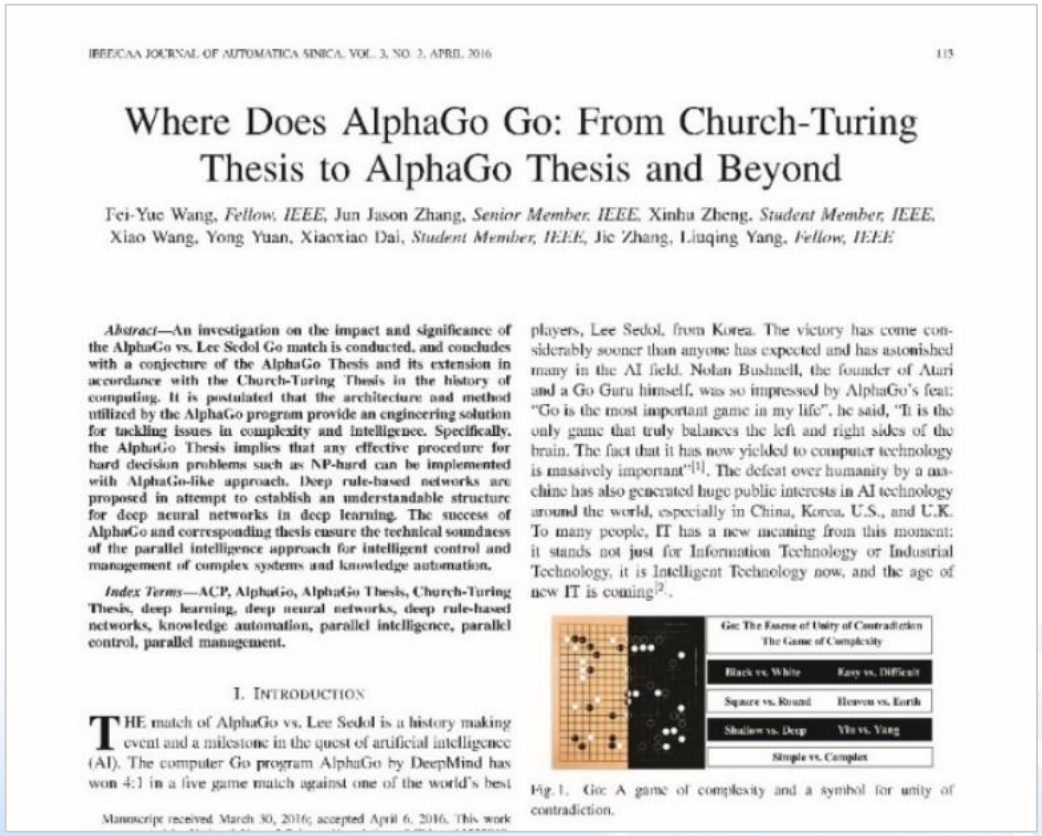
New Theory: From CPSS to ACP Approach

New Economy: From Artificial Intelligence to Intelligent and Smart Economy

New Practice: Applications in China

New Future: An Outlook

Future of AI: Where Does AlphaGo Go?



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Where Does AlphaGo Go: From Church-Turing Thesis to AlphaGo Thesis and Beyond

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***Abstract*—An investigation on the impact and significance of the AlphaGo vs. Lee Sedol Go match is conducted, and concludes with a conjecture of the AlphaGo Thesis and its extension in accordance with the Church-Turing Thesis in the history of computing. It is postulated that the architecture and method utilized by the AlphaGo program provide an engineering solution for tackling issues in complexity and intelligence. Specifically, the AlphaGo Thesis implies that any effective procedure for hard decision problems such as NP-hard can be implemented with AlphaGo-like approach. Deep rule-based networks are proposed in attempt to establish an understandable structure for deep neural networks in deep learning. The success of AlphaGo and corresponding thesis ensure the technical soundness of the parallel intelligence approach for intelligent control and management of complex systems and knowledge automation.**

***Index Terms*—ACP, AlphaGo, AlphaGo Thesis, Church-Turing Thesis, deep learning, deep neural networks, deep rule-based networks, knowledge automation, parallel intelligence, parallel control, parallel management.**

I. Introduction

THE match of AlphaGo vs. Lee Sedol is a history making event and a milestone in the quest of artificial intelligence (AI). The computer Go program AlphaGo by DeepMind has won 4:1 in a five game match against one of the world's best players, Lee Sedol, from Korea. The victory has come considerably sooner than anyone has expected and has astonished many in the AI field. Nolan Bushnell, the founder of Atari and a Go Guru himself, was so impressed by AlphaGo's feat: "Go is the most important game in my life", he said, "It is the only game that truly balances the left and right sides of the brain. The fact that it has now yielded to computer technology is massively important"[1]. The defeat over humanity by a machine has also generated huge public interests in AI technology around the world, especially in China, Korea, U.S., and U.K. To many people, IT has a new meaning from this moment: it stands not just for Information Technology or Industrial Technology, it is Intelligent Technology now, and the age of new IT is coming[2].

Fig. 1. Go: A game of complexity and a symbol for unity of contradiction.

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From:

Church-Turing Thesis

To:

AlphaGo Thesis

Fei-Yue Wang, Jun Jason Zhang, *et al.*, **Where Does AlphaGo Go: From Church-Turing Thesis to AlphaGo Thesis and Beyond**, *IEEE/CAA Journal of Automatica Sinica*, 2016, 3(2): 113-120.

Three Patterns of The AlphaGo Thesis

1) Parallel:

Actual vs Artificial

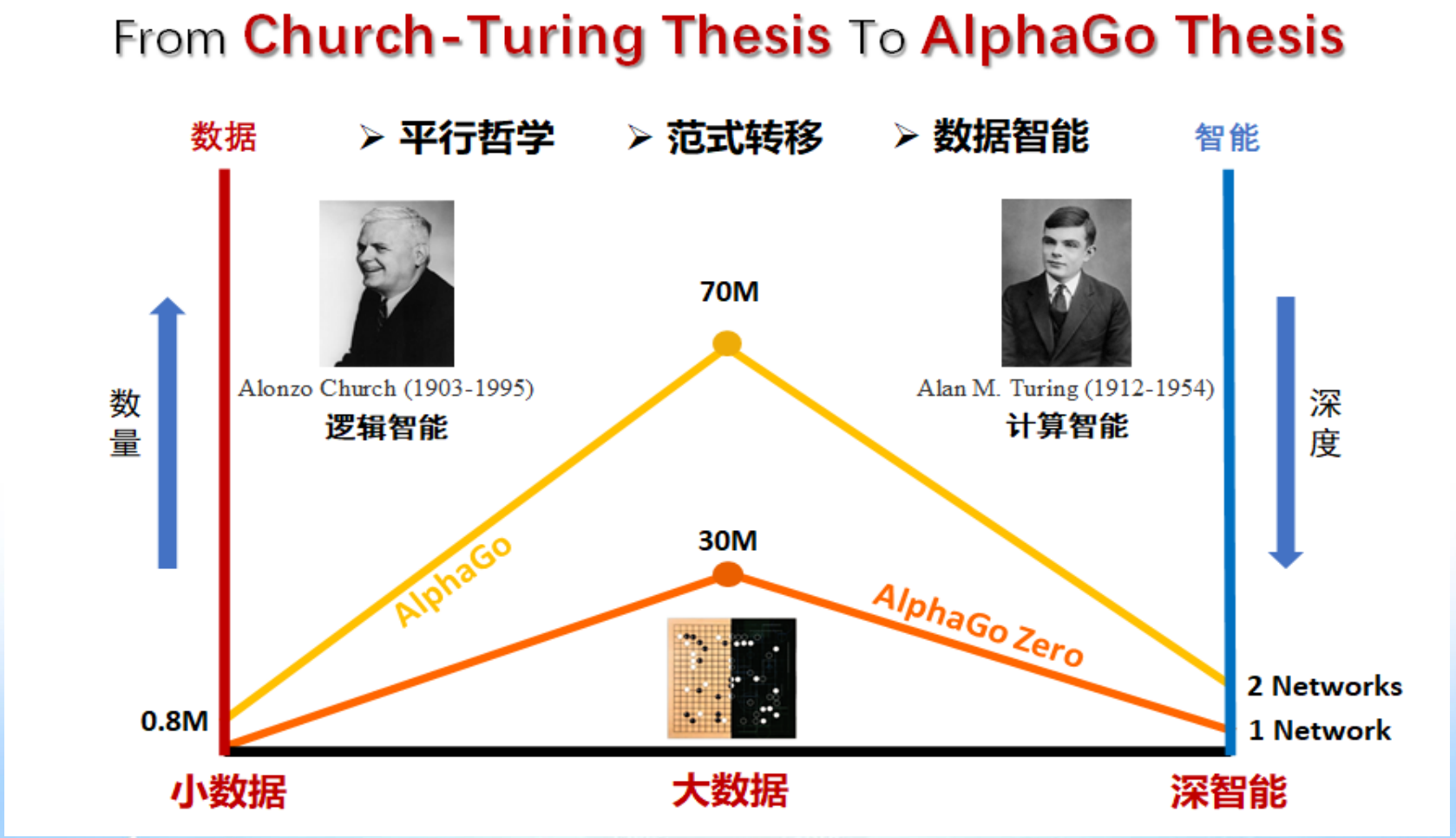
2) Newton to Merton:

From "Big Laws, Small Data" to "Big Data, Small Laws"

3) Three Steps:

Small Data ➡ Big Data ➡ Deep Intelligence

From Small Data to Big Data to Deep Intelligence



The Mega Trend of Artificial Intelligence

New Logic, New Development, New Philosophy

Three ITs

The **Church-Turing Thesis** has opened an era of computer and information technology.

The **AlphaGo Thesis** will open an era of intelligent technology and intelligent industry.

Parallel IT = "Old" IT + "Past" IT + "New" IT

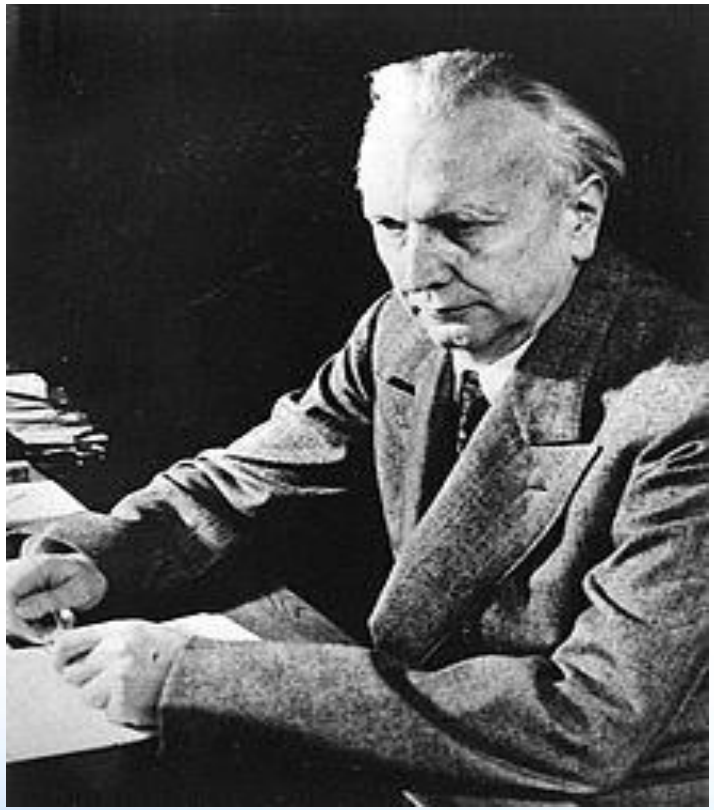
Industrial Technology	**Information** Technology	**Intelligent** Technology

IT is no longer just **Information Technology**, which is **Past IT;**
IT will represent **Intelligent Technology**, which is **New IT**!

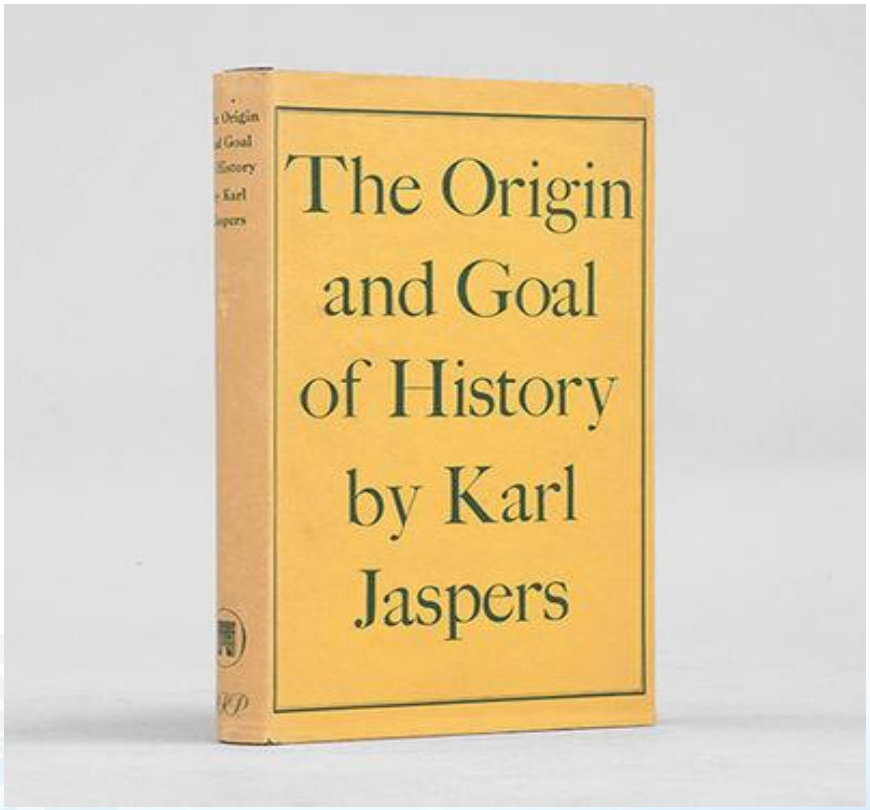
Three ITs and Karl Popper's Three Worlds Theory

	World 1 : **Physical World**		World 2 : **Mental World**		World 3 : **Artificial World**
					
	Resource Asymmetry		Information Asymmetry		Intellectual Asymmetry
	"Old" IT **Industrial Technology**		"Past" IT **Information Technology**		"New" IT **Intelligent Technology**
Parallel Technologies	= **"Old" IT** Industrial Technologies	+	**"Past" IT** Information Technologies	+	**"New" IT** Intelligent Technologies
Parallel Times	= **"Old" IT** Industrial Times	+	**"Past" IT** Information Times	+	**"New" IT** Intelligent Times

Karl Jaspers' Axial Age



Axial Age : Karl Jaspers
(1883.2.23 – 1969.2.20)



***The Origin and Goal of History*, 1949**

Fei-Yue Wang, **Intelligence and Time: Historical Mission and Future**, Strategic Report, 2009.

Beyond Karl Jaspers' Axial Age: Three Worlds and Three Axial Ages

Axial Age I

Humanity Awakening

Physical world

Spring and Autumn
(800s – 200s BC)

Breakthrough of

Philosophy

First Globalization:

***Negative* Sum**

Axial Age II

Rationality Awakening

Mental World

Renaissance
(1300s – 1900s)

Breakthrough of

Science

Second Globalization:

***Zero* Sum**

Axial Age III

Intelligence Awakening

Artificial World

Godel Theorem
(1900s –)

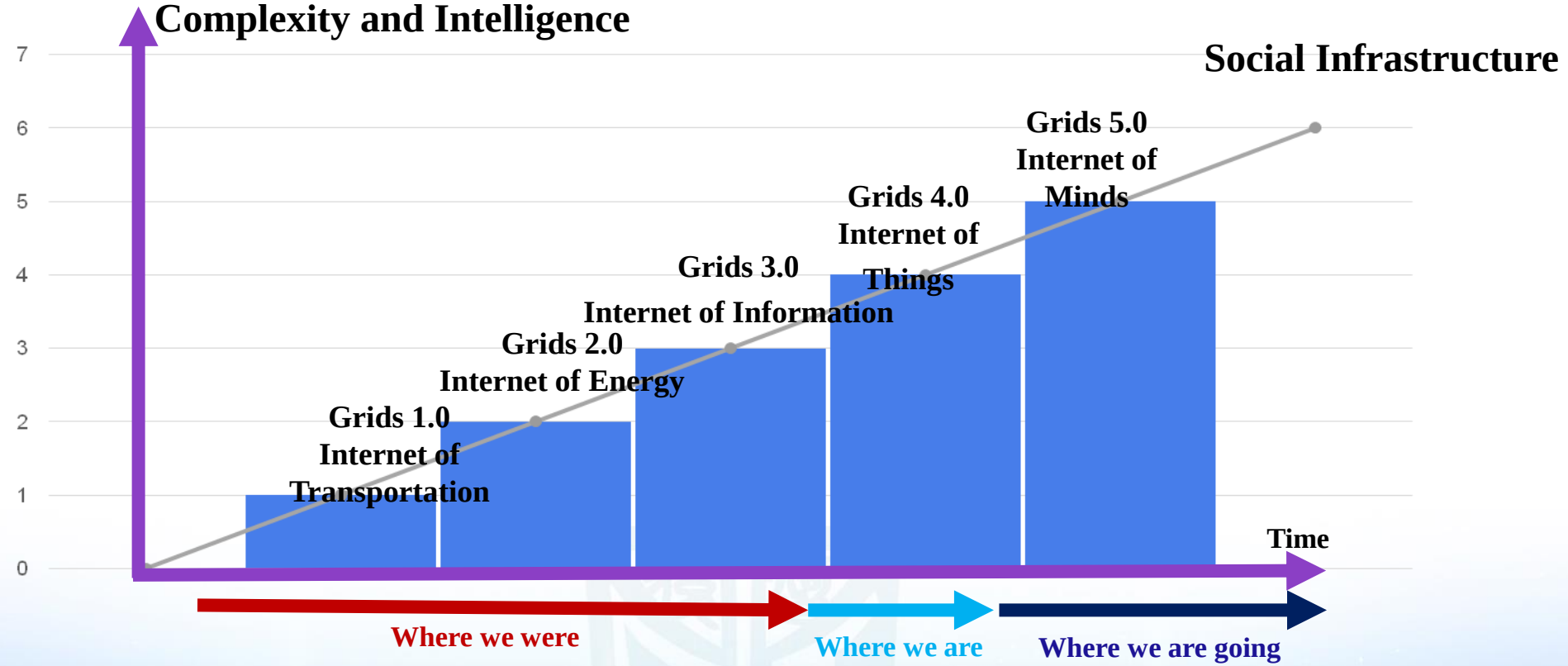
Breakthrough of

Technology

Third Globalization:

***Positive* Sum**

Big 5G：From Grid 1.0 to Grid 5.0



Social Transportation	Social Energy	Social Computing	Social Manufacturing	Social Intelligence

Social Operations + Shared Economy = Smart Society

Big 5G and The Connectivity of Karl Popper's Three Worlds

Grids 1.0

World I :
Physical World

Energy
Old IT

Grids 2.0

Grids 3.0

World II :
Mental World

Entropy
Past IT

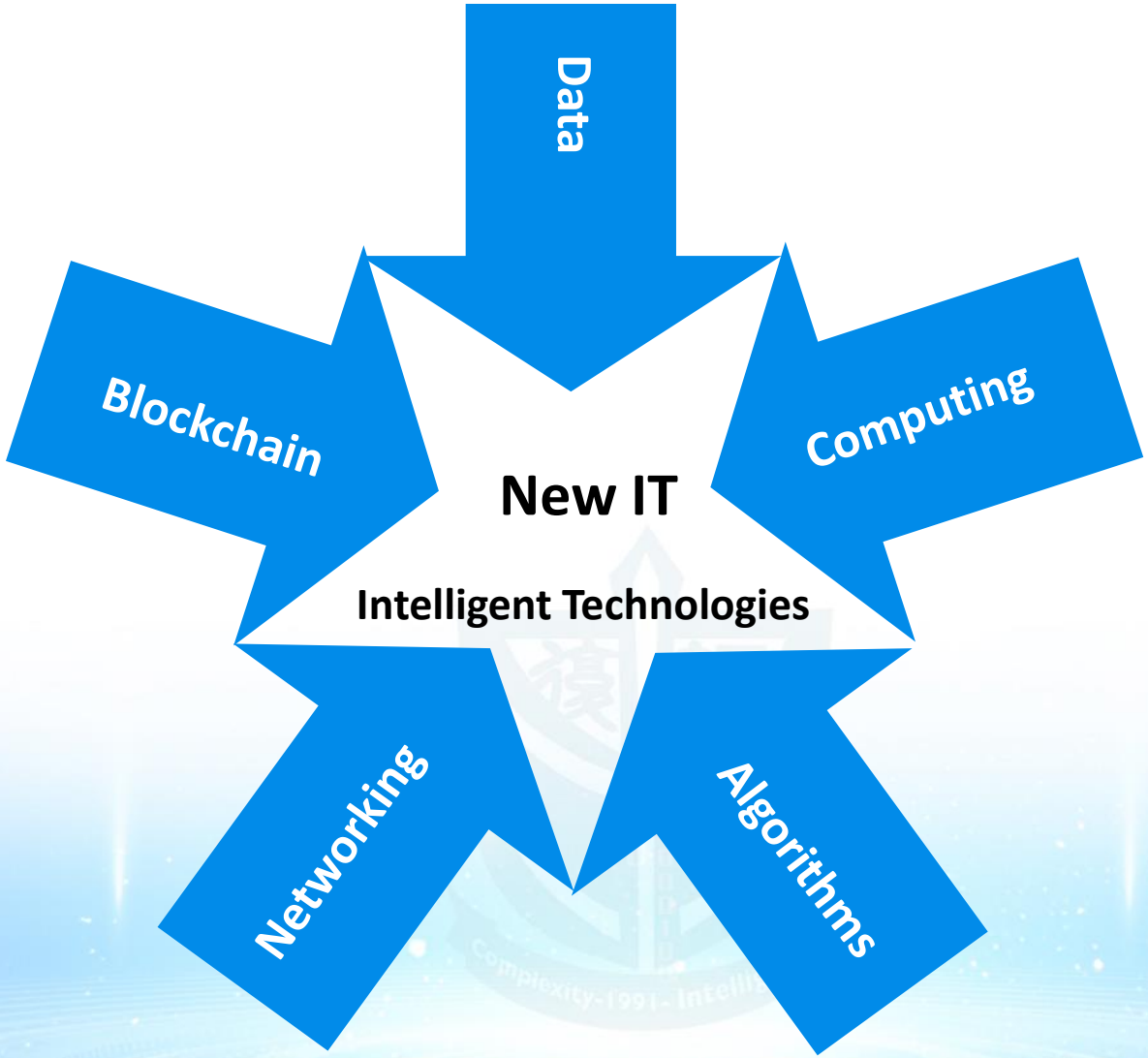
Grids 4.0

Grids 5.0

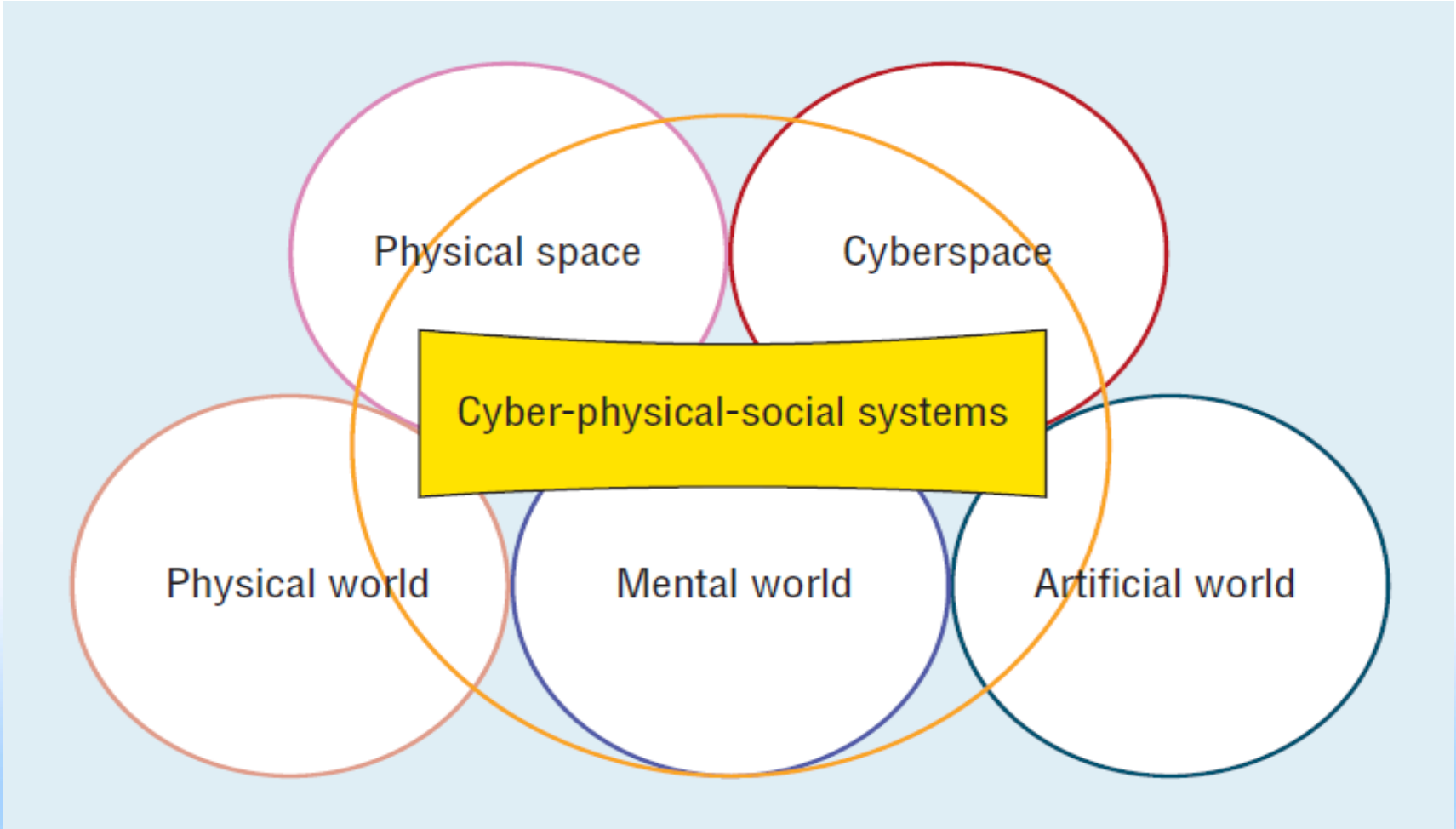
World III :
Artificial World

Entanglement
New IT

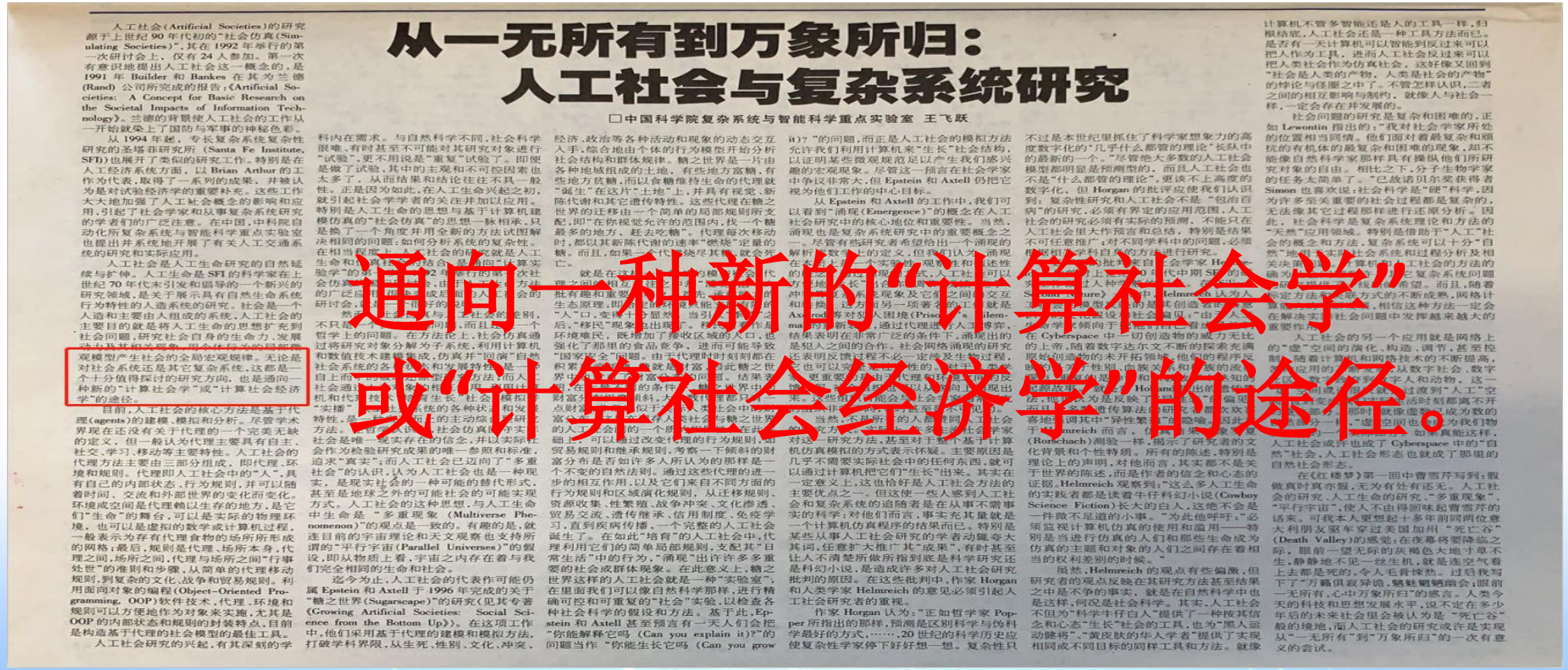
Five Forces in One for Intelligent Technology



Five Spaces: From CPS to CPSS



Our First Paper on CSP: Cyber-Social-Physical (2003)



从一无所有到万象所归：人工社会与复杂系统研究

□中国科学院复杂系统与智能科学重点实验室 王飞跃

人工社会(Artificial Societies)的研究源于上世纪90年代初的"社会仿真(Simulating Societies)",其在1992年举行的第一次研讨会上，仅有24人参加。第一次有意识地提出人工社会这一概念的，是1991年Builder和Bankes在其为兰德(Rand)公司所完成的报告:《Artificial Societies: A Concept for Basic Research on the Societal Impacts of Information Technology》。兰德的背景使人工社会的工作从一开始就染上了国防与军事的神秘色彩。

从1994年起，专长复杂系统复杂性研究的圣塔菲研究所(Santa Fe Institute, SFI)也展开了类似的研究工作。特别是在人工经济系统方面，以Brian Arthur的工作为代表，取得了一系列的成果，并被认为是对试验经济学的重要补充。这些工作大大地加强了人工社会概念的影响和应用，引起了社会学家和从事复杂系统研究的学者们的广泛注意。在中国，中科院自动化所复杂系统与智能科学重点实验室也提出并系统地开展了有关人工交通系统的研究和实际应用。

人工社会是人工生命研究的自然延续与扩伸。人工生命是SFI的科学家在上世纪70年代末引发和倡导的一个新兴的研究领域，是关于展示具有自然生命系统行为特性的人造系统的研究。社会是一个人造和主要由人组成的系统，人工社会的主要目的就是将人工生命的思想扩充到社会问题，研究社会自身的生命力、发展动力及其相关现象，用个体行为的局部微观模型产生社会的全局宏观规律。无论是对社会系统还是其它复杂系统，这都是一个十分值得探讨的研究方向，也是通向一种新的"计算社会学"或"计算社会经济学"的途径。

目前，人工社会的核心方法是基于代理(agents)的建模、模拟和分析。尽管学术界现在还没有关于代理的一个完美无缺的定义，但一般认为代理主要具有自主、社交、学习、移动等主要特性。人工社会的代理方法主要由三部分组成，即代理、环境和规则。代理即人工社会中的"人"，具有自己的内部状态、行为规则，并可以随着时间、交流和外部世界的变化而变化。环境或空间是代理赖以生存的地方，是它们"生命"的舞台，可以是实际的物理环境，也可以是虚拟的数学或计算机过程，一般表示为存有代理食物的场所所形成的网格；最后，规则是代理、场所本身，代理之间、场所之间、代理与场所之间"行事处世"的准则和步骤，从简单的代理移动规则，到复杂的文化、战争和贸易规则。利用面向对象的编程(Object-Oriented Programming, OOP)软件技术，代理、环境和规则可以方便地作为对象来实施，尤其是OOP的内部状态和规则的封装特点，目前是构造基于代理的社会模型的最佳工具。

人工社会研究的兴起，有其深刻的学科内在需求。与自然科学不同，社会科学很难，有时甚至不可能对其研究对象进行"试验"，更不用说是"重复"试验了。即便是做了试验，其中的主观和不可控因素也太多了，从而结果和结论往往不具一般性。正是因为如此，在人工生命兴起之初，就引起社会学学者的关注并加以应用。特别是人工生命的思想与基于计算机建模仿真的"社会仿真"的思想一脉相承，只是换了一个角度并用全新的方法试图解决相同的问题：如何分析系统的复杂性。在相当程度上，人工社会的研究就是人工生命和[illegible]的结合，是面向"计算实验学"的[illegible]2年举行的第一次社会仿[illegible]，由[illegible]方法的广泛应[illegible]成后的第[illegible]会的研讨会，[illegible]好的[illegible]

然[illegible]与[illegible]社会的差别，不只是[illegible]问题，而且是一个哲学上的问题。在方法论上，社会仿真通过将研究对象分解为子系统，利用计算机和数值技术建模集成，仿真并"回演"自然社会系统的各种状态和发展特性，是一自上而[illegible]型的主动综合研究方法；而人社会通过[illegible]的[illegible]机和代[illegible]"实播"[illegible]系统的各种状[illegible]特性，是一种[illegible]的主动综合研究方法。[illegible]社会仿真的[illegible]社会是唯一现实存在的信念，并以实际社会作为检验研究成果的唯一参照和标准，追求"真实"；而人工社会已迈向了"多重社会"的认识，认为人工社会也是一种现实，是现实社会的一种可能的替代形式，甚至是地球之外的可能社会的可能实现方式。人工社会的这种思想，与人工生命中生命是"多重现象(Multiverse Phenomenon)"的观点是一致的。有趣的是，就连目前的宇宙理论和天文观察也支持所谓的"平行宇宙(Parallel Universes)"的假设，即从物质上看，宇宙之内存在着与我们完全相同的生命和社会。

迄今为止，人工社会的代表作可能仍属Epstein和Axtell于1996年完成的关于"糖之世界(Sugarscape)"的研究(见其专著《Growing Artificial Societies: Social Science from the Bottom Up》)。在这项工作中，他们采用基于代理的建模和模拟方法，打破学科界限，从生死、性别、文化、冲突、经济、政治等各种活动和现象的动态交互入手，综合地由个体的行为模型开始分析社会结构和群体规律。糖之世界是一片由各种地域组成的土地，有些地方富糖，有些地方贫瘠，而以食糖维持生命的代理就"诞生"在这片"土地"上，并具有视觉、新陈代谢和其它遗传特性。这些代理在糖之世界的迁移由一个简单的局部规则所支配，即"在你视觉允许的范围内，找一个糖最多的地方，赶去吃糖"。代理每次移动时，都以其新陈代谢的速率"燃烧"定量的糖。而且，如果一个代理燃尽其糖，就会死亡。

就是在这样[illegible]的模[illegible]代理之间的[illegible]相互[illegible]"[illegible]批有趣和重要[illegible]先[illegible]生态原理，即[illegible]"人"口，变得十分显[illegible]当引[illegible]后，"移民"现象出现[illegible]。移[illegible]作是[illegible]"国家安全"问题。由于代理时时刻刻都在积累[illegible]就是财富[illegible]的[illegible]界[illegible]财富分[illegible]点财[illegible]富[illegible]的人[illegible]会[illegible]的一个[illegible]础[illegible]可以通过改变代理的行为规则，如贸易规则和继承规则，考察一下倾斜的财富分布是否如许多人所认为的那样是一个不变的自然法则。通过这些代理的进一步的相互作用，以及它们来自不同方面的行为规则和区域演化规则，从迁移规则、资源收集、性繁殖、战争冲突、文化渗透、贸易交流、遗传继承、信用制度、免疫学习，直到疾病传播，一个完整的人工社会诞生了。在如此"培育"的人工社会中，代理利用它们的简单局部规则，支配其"日常生活"中的行为，"涌现"出许许多多重要的社会或群体现象。在此意义上，社会仿真的世界这样的人工社会就是一种"实验室"，在里面我们可以像自然科学那样，进行精确可控和可重复的"社会"实验，以检查各种社会科学的假设和方法。基于此，Epstein和Axtell甚至预言有一天人们会把"你能解释它吗(Can you explain it)?"的问题当作"你能生长它吗(Can you grow it)?"的问题，而正是人工社会的模拟方法允许我们利用计算机来"生长"社会结构，以证明某些微观规范足以产生我们感兴趣的宏观现象。尽管这一预言在社会学家中争议非常大，但Epstein和Axtell仍把它视为他们工作的中心目标。

从Epstein和Axtell的工作中，我们可以看到"涌现(Emergence)"的概念在人工社会研究中的核心地位和重要性。当然，涌现也是复杂系统研究中的重要概念之一。尽管有些研究者希望给出一个涌现的解析数学上的定义，但我们认为涌现[illegible]在本[illegible]上[illegible]个实验性观[illegible]生和[illegible]述性的[illegible]上[illegible]代中期SFI的[illegible]Structure)"中[illegible]Helmreich认为人[illegible]Axtrod等对人[illegible]困境(Prisoner's Dilemma)[illegible]新型[illegible]，通过代理进[illegible]人工博弈，结果表明在非常广泛的条件下，涌现出的是犯人之间的合作。社会网络涌现的研究还表明反馈过程不必一定涉及生物过程，它也可以完[illegible]性的。对于[illegible]更重要[illegible]由代理[illegible]的反[illegible]源故事[illegible]就[illegible]而且[illegible]会[illegible]现[illegible]。[illegible]非[illegible]至[illegible]不[illegible]。[illegible]当然不是所[illegible]的人[illegible]同一[illegible]会[illegible]方[illegible]对这一研究方法，甚至对于整个基于计算机仿真模拟的方式表示怀疑。主要原因是几乎不需要实际社会中的任何东西，就可以通过计算机把它们"生长"出来。其实在一定意义上，这也恰好是人工社会方法的主要优点之一。但这使一些人感到人工社会和复杂系统的追随者是在从事不需事实的科学；对他们而言，事实充其量就是一个计算机仿真程序的结果而已。特别是某些从事人工社会研究的学者动辄夸大其词，任意扩大推广其"成果"，有时甚至让人不清楚所做所指到底是科学研究还是科幻小说，是造成许多对人工社会研究批判的原因。在这些批判中，作家Horgan和人类学家Helmreich的意见必须引起人工社会研究者的重视。

作家Horgan认为："正如哲学家Popper所指出的那样，预测是区别科学与伪科学最好的方式，……20世纪的科学历史应使复杂性学家停下好好想一想。复杂性只不过是本世纪里抓住了科学家想象力的高度数字化的'几乎什么都管的理论'长队中的最新的一个。"尽管绝大多数的人工社会模型都明显是预测型的，而且人工社会也不是"什么都管的理论"，更谈不上高度的数字化，但Horgan的批评应使我们认识到：复杂性研究和人工社会不是"包治百病"的研究，必须有界定的应用范围。人工社会的研究必须有实际的预测，不能只在人工社会里大作预言和总结，特别是结果不可任意推广；对不同学科中的问题，必须[illegible]相对学科自[illegible]的方法进行研究。

[illegible]的批[illegible]自社会学家Ho[illegible]在Cyberspace中一切创造物的威力无比的上帝，随着数字达尔文不断的探索充满原始创造物的未开拓领域，他们的程序反[illegible]性别、血族关系和[illegible]族的流[illegible]Helmreich而言，[illegible]Rorschach)测验一样，揭示了研究者的文化背景和个性特质。所有的陈述，特别是理论上的声明，对他而言，其实都不是关于世界的陈述，而是作者的信念和心态的证据。Helmreich观察到："这么多人工生命的实践者都是读着牛仔科幻小说(Cowboy Science Fiction)长大的白人，这绝不会是一件微不足道的小事。"为此他呼吁："必须监视计算机仿真的使用和滥用——特别是当进行仿真的人们和那些生命成为仿真的主题和对象的人们之间存在着相当的权利差别的时候。"

虽然，Helmreich的观点有些偏激，但研究者的观点反映在其研究方法甚至结果之中是不争的事实，就是在自然科学中也是这样，何况是社会科学。其实，人工社会不但为"科学牛仔自人"提供了一种按其信念和心态"生长"社会的工具，也为"黑人运动健将"、"黄皮肤的华人学者"提供了实现相同或不同目标的同样工具和方法。就像计算机不管多智能还是人的工具一样，归根结底，人工社会还是一种工具方法而已。是否有一天计算机可以智能到反过来可以把人作为工具，进而人工社会反过来可以把人类社会作为仿真社会，这好像又回到"社会是人类的产物，人类是社会的产物"的悖论与怪圈之中了。不管怎样认识，二者之间的相互影响与制约，就像人与社会一样，一定会存在并发展的。

社会问题的研究是复杂和困难的，正如Lewontin指出的："我对社会学家所处的位置相当同情。他们面对着最复杂和顽抗的有机体的最复杂和困难的现象，却不能像自然科学家那样具有操纵他们所研究对象的自由。相比之下，分子生物学家的任务太简单了。"已故诺贝尔奖获得者Simon也喜欢说：社会科学是"硬"科学，因为许多至关重要的社会过程都是复杂的，无法像其它过程那样进行还原分析。因此，社会科学是复杂系统理论和方法的"天然"应用领域。特别是借助于"人工"社会的概念和方法，复杂系统可以十分"自然"地[illegible]实[illegible]社会系统和过程分析及相关决策[illegible]计算机[illegible]人工社会的方法的确为[illegible]希望。而且，随着[illegible]定方法和[illegible]方式的不断成熟，网格计算[illegible]，相信这种方法一定会在解决实[illegible]社会问题中发挥越来越大的重要作用。

人工社会的另一个应用就是网络上的"虚"空间的演化、构造、调节，甚至控制。随着计算机和网络技术的不断提高，[illegible]应用的[illegible]从数字社会、数字[illegible]字人和动物，这一[illegible]过度到"人工"空[illegible]那时就像虚构已成为数的[illegible]一样，"虚"空间也[illegible]为我们物[illegible]部分。如果真能这样，人工社会或许也成了Cyberspace中的"自然"社会，人工社会形态也就成了那里的自然社会形态。

在《红楼梦》第一回中曹雪芹写到：假做真时真亦假，无为有处有还无。人工社会的研究、人工生命的研究，"多重现象"、"平行宇宙"，使人不由得回味起曹雪芹的话来。可我本人更想起十多年前同两位意大利朋友驱车穿过美国加州"死亡谷"(Death Valley)的感觉：在夜幕将要降临之际，眼前一望无际的灰褐色大地寸草不生，静静地不见一丝生机，就是连空气看上去都是死的，令人毛骨悚然。过后我写下了"万籁俱寂异境，魑魅魍魉幽会；眼前一无所有，心中万象所归"的感言。人类今天的科技和思想发展水平，说不定在多少年后的未来社会里会被认为是"死亡谷"般的境地，而人工社会的研究或许是实现从"一无所有"到"万象所归"的一次有意义的尝试。

通向一种新的"计算社会学"或"计算社会经济学"的途径。

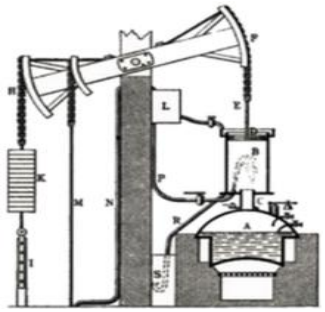
王飞跃, 从一无所有到万象所归：人工社会与复杂系统研究, 科学时报(纵横版面),2003.03.17.

From Industries 1.0 to Industries 5.0

Complexity`s GDP added value

Complexity

Industries 1.0



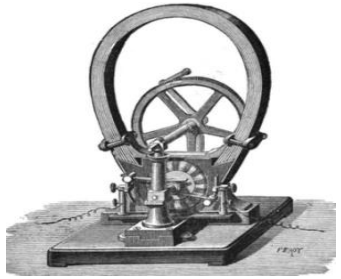
Mechanical

Atmospheric engine was the first Commercial True steam engine using a piston, Thomas Newcomen, 1705

GDP 0.7Trillion

1700s

Industries 2.0



Electrical

The first **DC Motor** was designed by Gramme, 1869

GDP 2.8 Trillion

1870s

Industries 3.0

Information

The first **PLC** was developed by Digital Equipment Corporation (DEC) (PDP-14, 1969)

GDP 20 Trillion

1970s

Industries 4.0

Network

Router Cyber-Physical Systems (CPS, 2000)

GDP 90 Trillion

2000s

Industries 5.0

Parallel

Parallel Machine?
Intelligent Machine?
Unmanned Plane?

Cyber-Physical-Social Systems

(CPSS, 2010)

GDP 175, 338 Trillion

The coming future

What is Industries 4.0 ?

The Core of Industries 4.0 = ICT + CPS

Forschungsunion

Wirtschaft und Wissenschaft
begleiten die Hightech-Strategie

acatech

NATIONAL ACADEMY OF
SCIENCE AND ENGINEERING

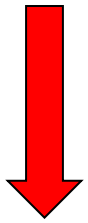
What is ICT？What is CPS？

	ICT	CPS
Industrie 4.0 Historical Interpretation	Information and Communication Technology 信息与通讯技术	Cyber Physical Systems 信息物理系统
Industries 5.0 Today's Interpretation	Intelligence Connectivity Technology 智能互联技术	Cyber Physical Social (Systems) 社会物理信息（系统）

Industrie 4.0 vs Industries 5.0

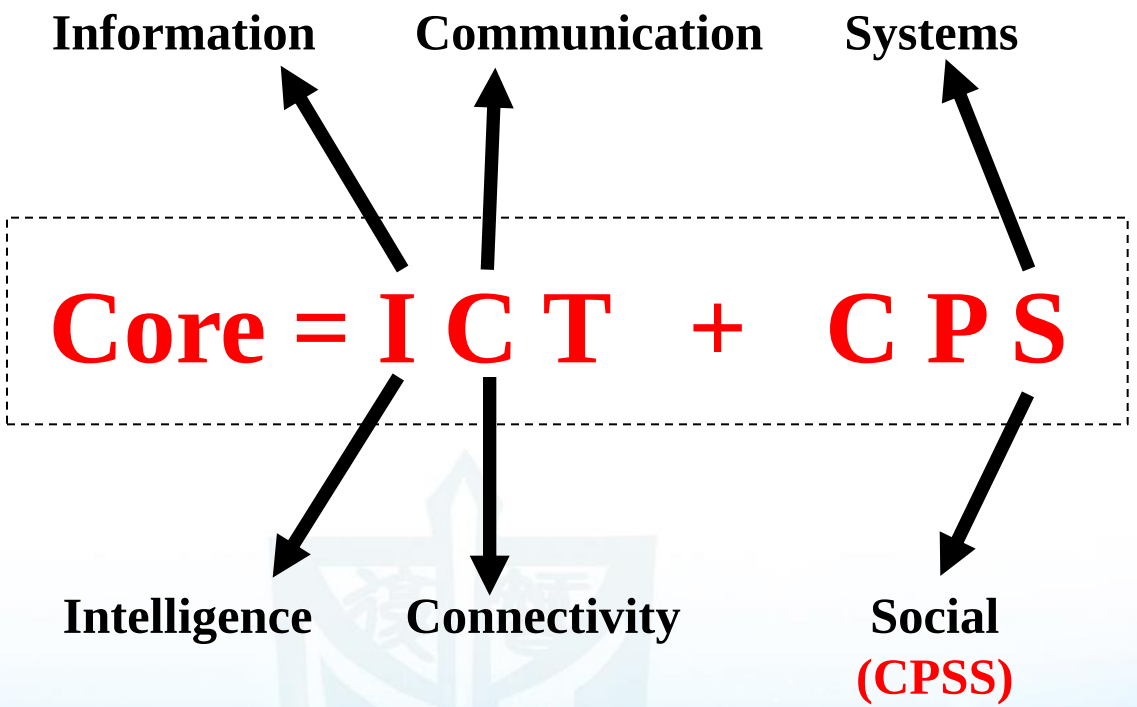
Industrie 4.0

Historical Interpretation

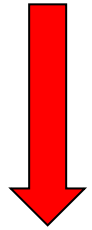


Industries 5.0

Today's Interpretation



Industrial Automation

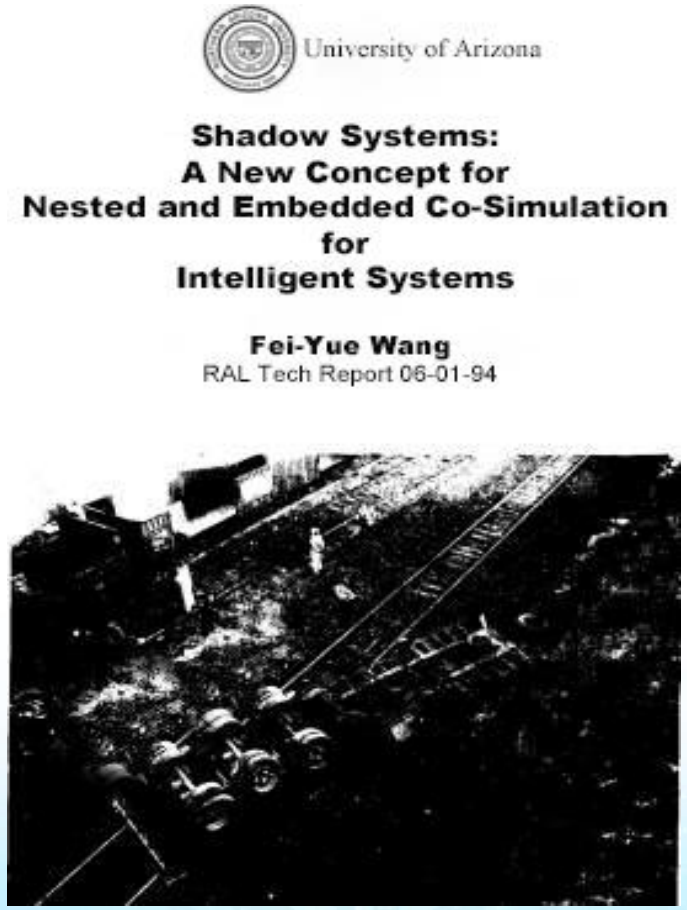


Knowledge Automation

ICT = Intelligence and Connectivity Technology

CPSS = Cyber Physical Social Systems

Our First Tech Report on Parallel Systems (1994)



Fei-Yue Wang. **Shadow systems: a new concept for nested and embedded co-simulation for intelligent systems**[R]. *RAL Technical Report*, The University of Arizona, Tucson, Arizona, USA, 1994.

Our First Paper on Industries 4.0 and Industries 5.0 (2000)

基于网络的智能家居系统的现状和发展趋势

王飞跃　黄小池

（中美科龙智能控制联合研发中心，中国北京，顺德和美国 Tucson）

The Status Quo and Future Prospective of Internet – based Intelligent Residential System

Wang Feiyue, Huang Xiaochi

(Sino – U.S. KELON Intelligent Control R&D Center

Guangdong Kelon Electrical Appliance Holdings Co., Ltd)

摘要：本文首先讨论了基于网络的智能家居系统在人类社会和经济生活中的作用，分析了其服务内容和潜在的市场规模，以及国际上现有的产品和技术现状。文章的重点是讨论网关和相应 OSGi 开放式服务网关标准在智能家居系统中核心作用和相关的关键技术问题。最后，介绍了中美科龙智能控制联合研发中心在相关方面的部分工作及其对未来发展趋势和应用前景的展望。

关键词：智能家居系统　OSGi　家庭综合服务器(iHS)　家庭操作平台(HOP)　代理式智能集散控制系统(aDCS)。

Abstract: After a discussion on the application of Internet – based intelligent residential system in human society and economic life, the services and potential market, and the present products and technology around the world are analyzed. The emphasis is put on the key position and the correlated crucial technological problems of gateways and OSGi (Open Service Gateway initiative). Finally, some related research at Sino – U.S. Kelon Intelligent Control R&D Center is introduced, thereby gives a prospective in the future.

Key words: Intelligent Residential System, OSGi, iHS, HOP, aDCS

1. Fei-Yue Wang, Xiaochi Huang. "The Status Quo and Future Prospective of Internet-based Intelligent Residential Systems," *Journal of home appliance science and technology*, vol. 6, pp. 56-61, 2000.
2. Fei-Yue Wang, "Smart Appliance in Smart Home: Networked Houses and Their Future", *The First Science and Technology Conference on Home Appliance*, Sept. 2, 2000,Shanghai

Our First Paper on Parallel Industries and Smart Enterprises (2004)

第 19 卷 第 5 期 控 制 与 决 策 2004 年 5 月
Vol. 19 No. 5 *Control and Decision* May 2004

文章编号：1001-0920(2004)05-0485-05

平行系统方法与复杂系统的管理和控制

王 飞 跃
（中国科学院 复杂系统与智能科学重点实验室，北京 100080）

摘 要：提出平行系统方法的基本思想、概念和运行的基本框架，并讨论了控制系统与平行系统的关
平行系统是控制系统和计算机仿真随着系统复杂程度的增加以及计算技术和分析方法的进一步发
一个更高的台阶，是弥补很难甚至无法对复杂系统进行精确建模和实验之不足的一种有效手段，也
行管理和控制的一种可行方式.

关键词：平行系统；计算实验；人工社会；人工生命；复杂系统；涌现方法
中图分类号：TP18 **文献标识码**：A

Parallel system methods for management and control of complex systems

WANG Fei-yue
(Key Laboratory of Complex Systems and Intelligence Science, Chinese Academy of Sciences, Beijing 100080, China. E-mail: tsm19@vip.sina.com)

Abstract: The basic idea, concepts, and framework of management and control for complex systems based on parallel systems methods are presented. The relationship of control systems and parallel systems is discussed. Parallel system methods are a further development and natural extension of control systems and computer-based modeling and simulation, resulting from new and recent advances in computing structure, algorithms, and technology. Parallel system methods might provide effective tools for control and management of complex systems that can not be modeled precisely or experimented repeatedly.

Key words: parallel systems; computational experiments; artificial societies; artificial life; complex systems; emergence

Fei-Yue Wang. **Parallel System Methods for Management and Control of Complex Systems**. *Control and Decision*, 2004, Vol. 19, No. 5, pp. 485-489.

Emergence of Intelligent Industries: From CPS to CPSS (2010)

CYBER-PHYSICAL-SOCIAL SYSTEMS

Editor: **Daniel Zeng**, University of Arizona, zeng@email.arizona.edu

The Emergence of Intelligent Enterprises: From CPS to CPSS

Fei-Yue Wang, *Chinese Academy of Sciences*

Welcome to the inaugural issue of the Cyber-Physical-Social Systems (CPSS) department!

In recent years, Internet use and cyberspace activities have created an overwhelming demand for the rapid development and application of CPSS, raising compelling technological, economic, and social implications. In this issue, I would like to begin by addressing the philosophical and scientific foundation of CPSS. I believe any study of

When *IEEE Intelligent Systems* solicited ideas for a new department at its 2008 Spring Editorial Board meeting, the suggestion of CPS received overwhelming support. The board approved the proposal for a new CPS department in 2009 and appointed Daniel Zeng as its founding editor.

Although I had promised to write the first article for the new department, as the new editor in chief, I was hesitant to execute the plan. This was because the current CPS R&D effort has concentrated heavily on networked or next-generation

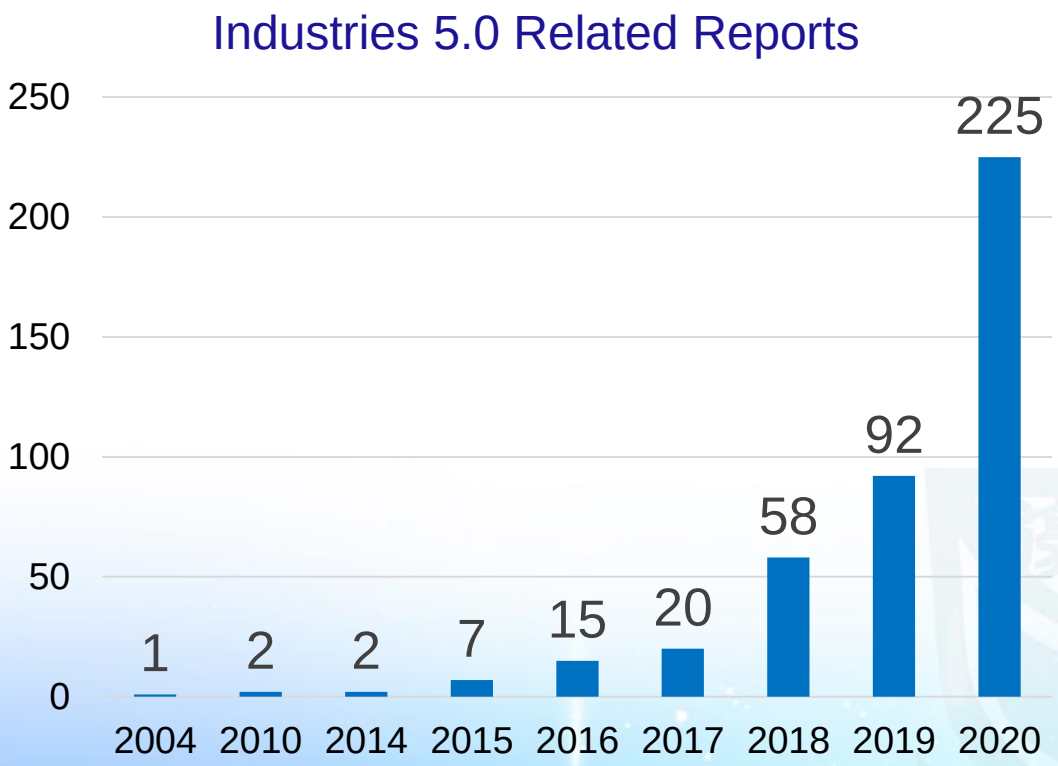

科學時報

繁华难现？蓓蕾初绽！

迎接智能产业的兴起

Fei-Yue Wang, **The Emergence of Intelligent Enterprises: From CPS to CPSS**, *IEEE Intelligent Systems*, 2010, Vol. 25, No. 4, pp. 85-88.

The Spread of Industries 5.0 Concept



Parallel Intelligence

IEEE TRANSACTIONS ON COMPUTATIONAL SOCIAL SYSTEMS, VOL. 7, NO. 5, OCTOBER 2020 1105

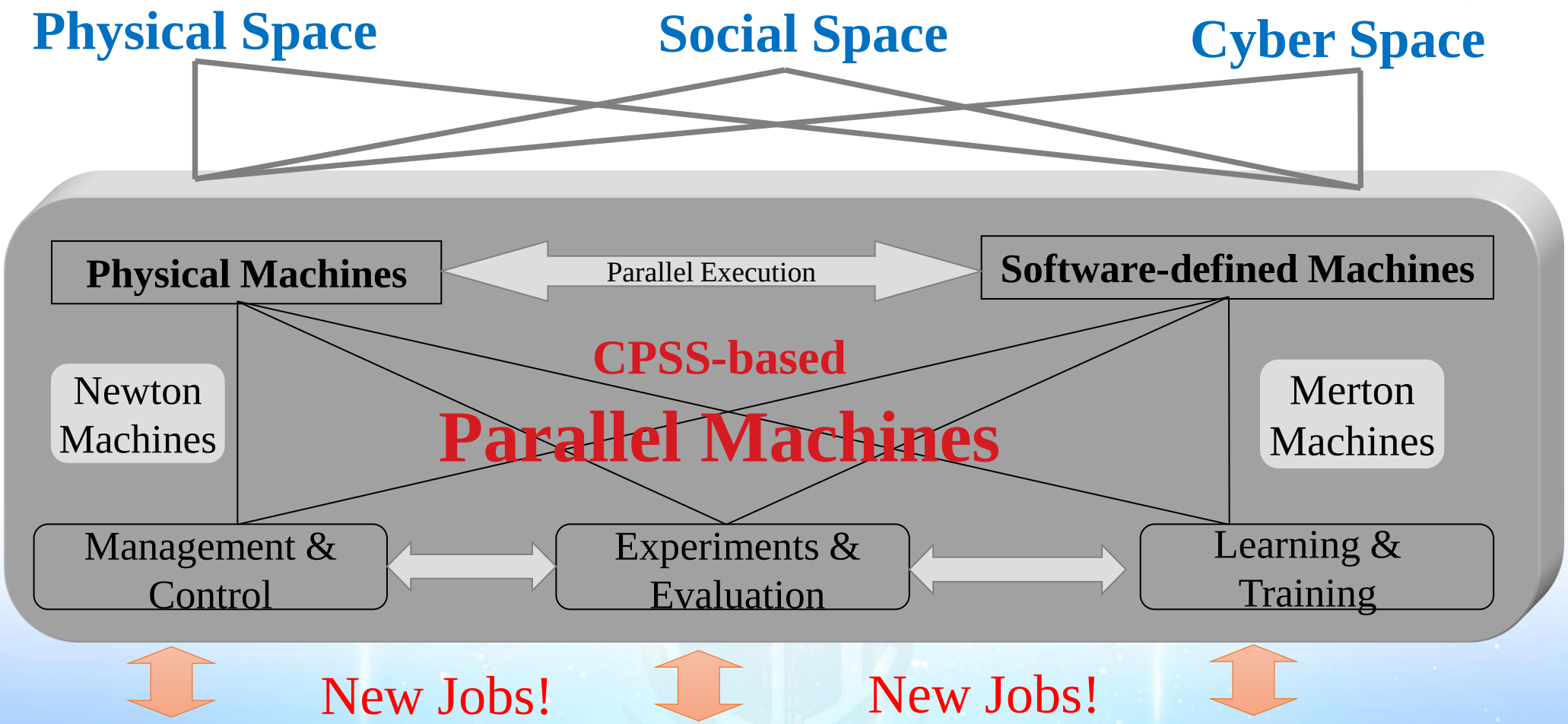
Parallel Intelligence: Belief and Prescription for Edge Emergence and Cloud Convergence in CPSS

Fei-Yue Wang, *Fellow, IEEE*

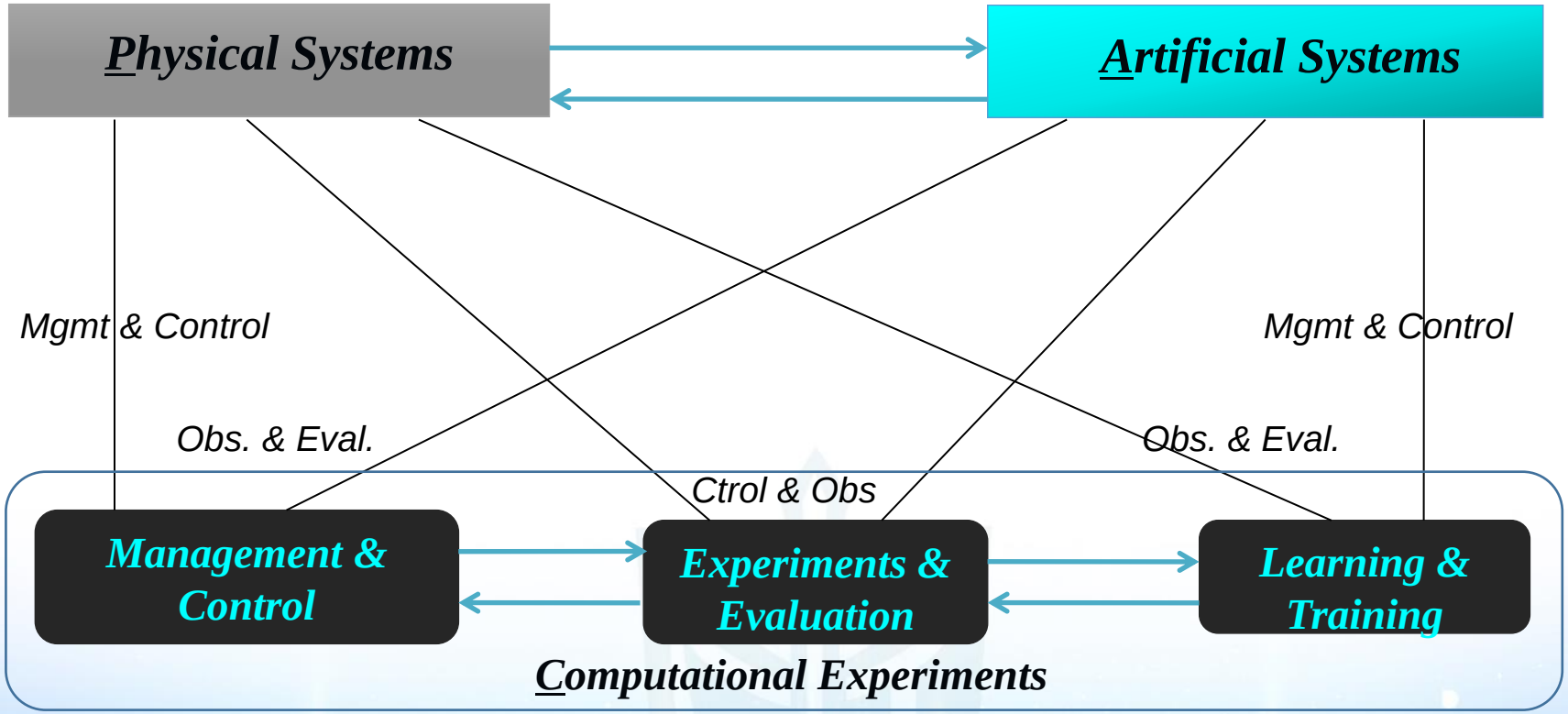
WELCOME to the new issue of IEEE TRANSACTIONS ON COMPUTATIONAL SOCIAL SYSTEMS (TCSS). First of all, on behalf of the Board of Governors and Prof. Enrique Herrera Viedma, Vice President for Publication, of efficiently obtain a good solution to the PGI problem. They compare the performance of ISCP with four other baselines on a large-scale product copurchasing data set. The results show that their proposed ISCP algorithm outperforms other

Fei-Yue Wang, "Parallel Intelligence: Belief and Prescription for Edge Emergence and Cloud Convergence in CPSS", IEEE Transactions on Computational Social Systems, 2020, Vol. 7, No. 5, pp. 1105-1110.

The Machine of Parallel Intelligence



Parallel Intelligence: The ACP Approach

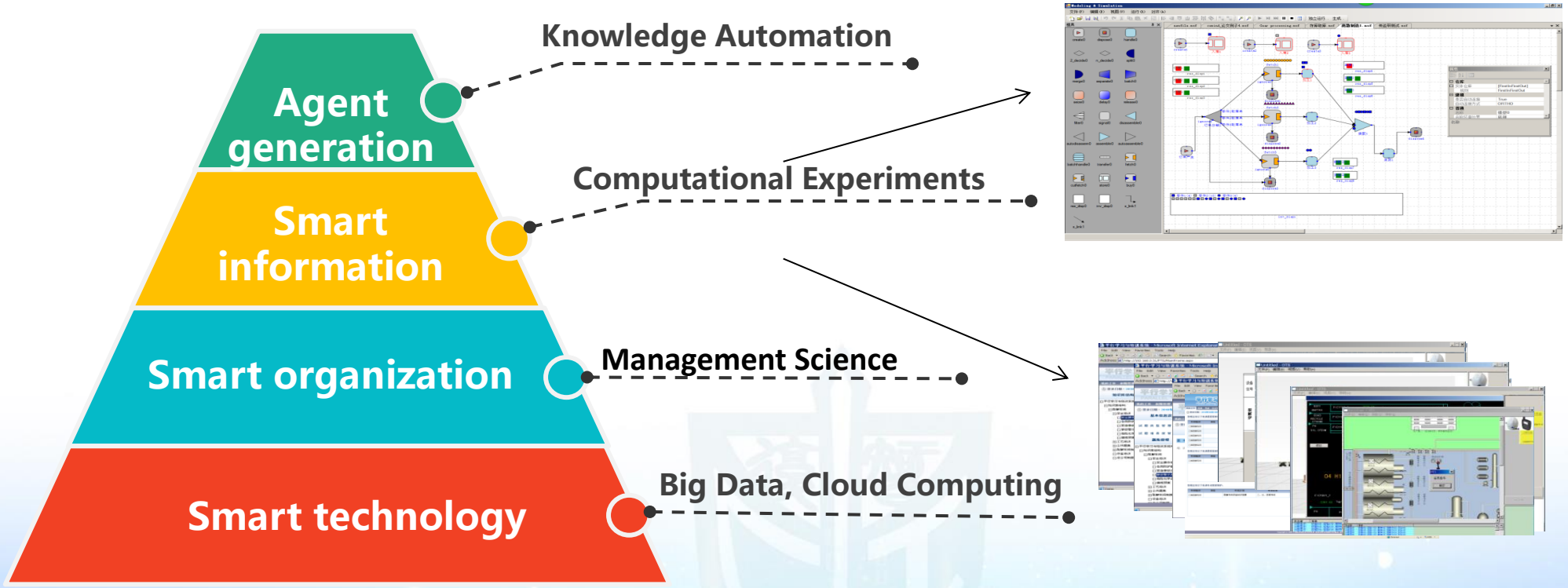


ACP = Artificial Societies + Computational Experiments + Parallel Execution

Fei-Yue Wang, Wang Xiao, Li Li, et al, "**Steps toward Parallel Intelligence**". *IEEE/CAA JAS*, 2016, Vol. 3, No. 4, pp. 345-348

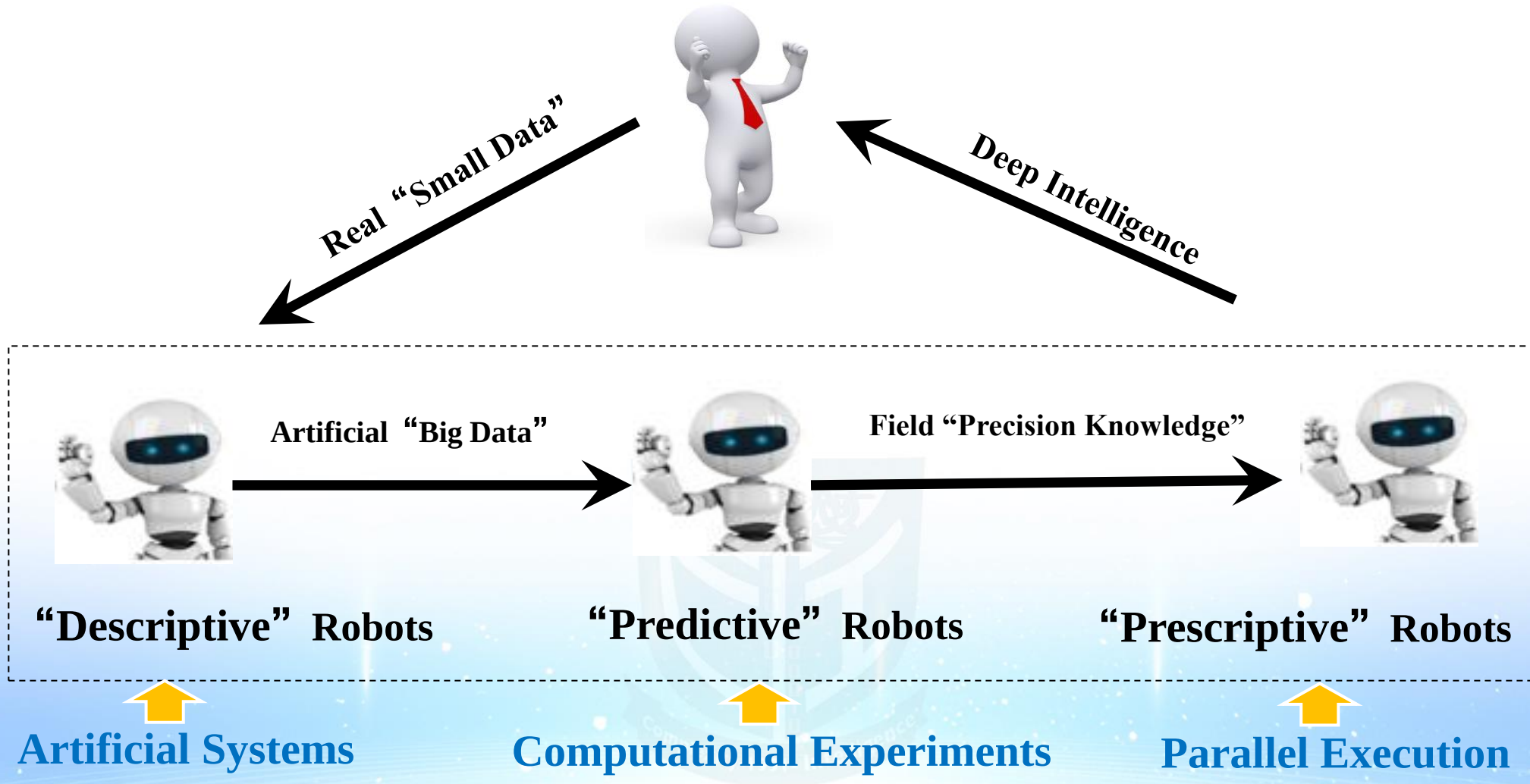
Knowledge Automation

Industrial Age needs Industrial Automation, Intelligent Age needs Knowledge Automation !



John McCarthy, Founder of AI：AI = Automation of Intelligence
= Knowledge Automation

Knowledge Robots: Descriptive, Predictive, Prescriptive



Technical Features of Blockchain: TRUE (真) + DAO(道)

TRUE = 真 = Trustable + Reliable + Usable + Effective + Efficient

DAO = 道 = Distributed + Decentralized +

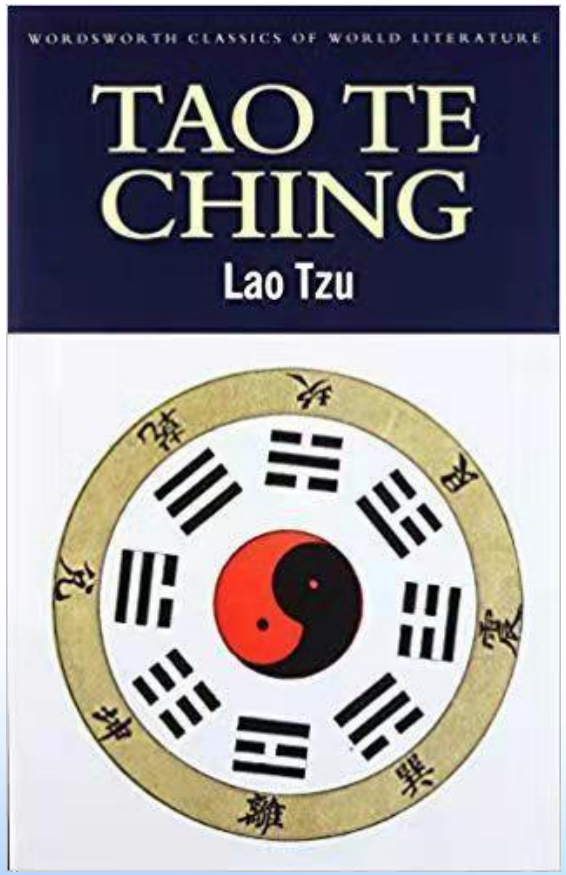
Autonomous + Automated +

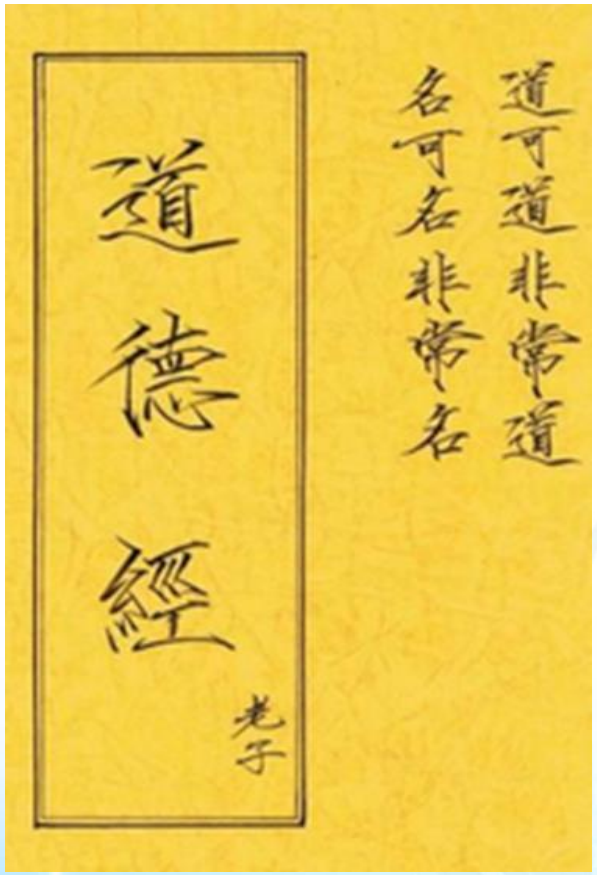
Organized + Ordered

= $D^2A^2O^2$

= Square DAO ➡ Parallel DAO ➡ Parallel Intelligence

What is TRUE (真) DAO(道):“True Road” or “True Journey”





Tao Te Ching
(The Scripture of Ethics)

DAO（道）is the essential and core concept in the ancient Chinese Philosophy, also means Road or Journey in plain Chinese.

DAO of Blockchain and New Commodity of Intelligent Economy

Two kinds of scarce resources in modern economic system:

Attention (注意力) and Trust (信任)

- **Herbert A. Simon**, who is the winner of the Nobel Prize in economics in 1978, as well as one of the founder of cognitive science and artificial intelligence, has said that **attention and trust cannot be regarded as commodities since they cannot be produced on a large scale**[1].

- However, once the "DAO" of the blockchain and the knowledge robot system on this "DAO" are established, “Trust” and “Attension” will inevitably become a new "commodity" of intelligent economy, and will rapidly evolved into an infinite intelligent market in the artificial world with the help of intelligent Internet[2] .

1. Simon H A, “Designing organizations for an information-rich world”. *Martin Greenberger Computers Communication & the Public Interest the Johns*, 1971, Vol. 70, pp. 37-72.
2. 王飞跃, “智能经济的“真”与“道”：新商品、新空间、新边际”, 新经济导刊, 2019, pp. 4-7.

Essence and Appearance of Blockchain Intelligence

Essence:

Blockchain makes the traditional "Attention"(注意力) and "Trust" (信用力) which are difficult to circulate and commercialize become the circulating goods that can be mass produced, and it revolutionizes the scope of economic activities and the way to improve efficiency.

Appearance:

Blockchain = Trust machines (信用机器) + Truth machines (真相机器)

DAO (“道”) of Blockchain Intelligence: The Cornerstone of Intelligent Economy and Smart Society

Intelligent Economy

Digital cryptocurrency

“Formal” ICO

- The blockchain based digital cryptocurrency will become the intelligent medium in the circulation of the intelligent economy and intelligent network
- All kinds of "formal" ICO will become an effective supplement to the intelligent economy and financial system

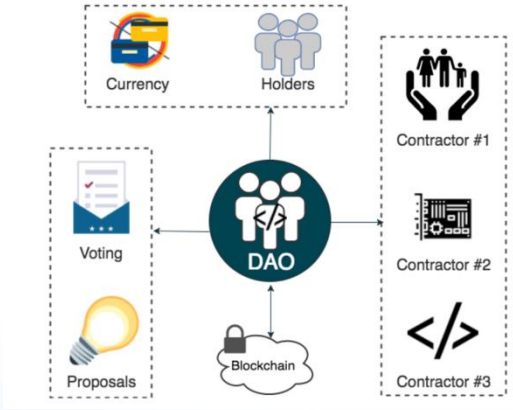
Smart Society

D	Decentralized 去中心化	Decentralized 分布式
A	Autonomous 自主式	Automated 自动化
O	Organized 组织化	Ordered 有序性

Blockchain, especially the corresponding consensus mechanism and smart contract technologies, are most likely to become the cornerstone of building the DAO (“道”) of intelligent economy and smart society

DAO and Token Economy (通证经济)

DAO(去中心化自治组织): DAOs are organizations that are powered and run by smart contracts, and their management and operational rules are encoded on blockchain and can autonomously execute through smart contracts.



Token Economy(通证经济): Token refers to the negotiable digital rights and interests certificate, and Token economy is the economy of managing the token in Dao. Blockchain technology ensures the verifiable qualification, traceable circulation, personal privacy and transaction data security of Token.

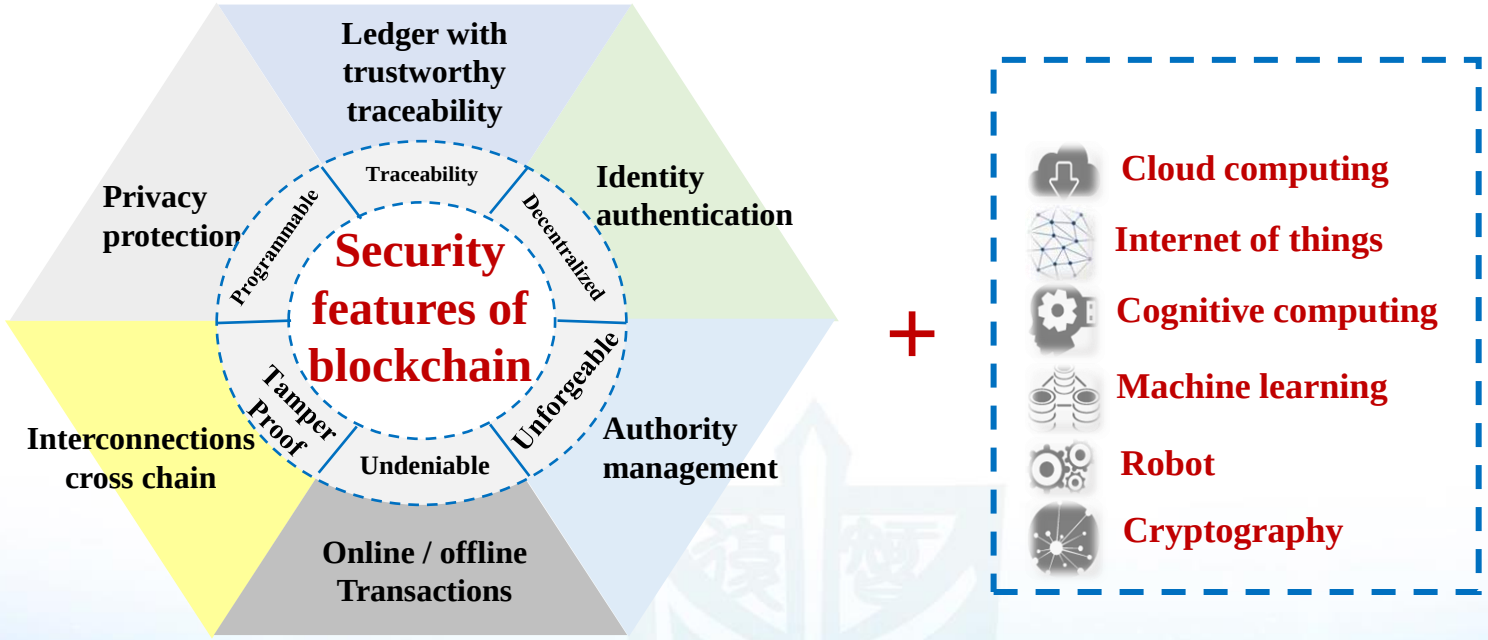
In DAO:

- Management is coded and programmed, and code is constitution.
- Organizations are distributed instead of pyramidal.
- Management is community autonomy, instead of bureaucracy
- Organizations no longer need companies to operate, but are replaced by highly autonomous communities

The significance of Token economy:

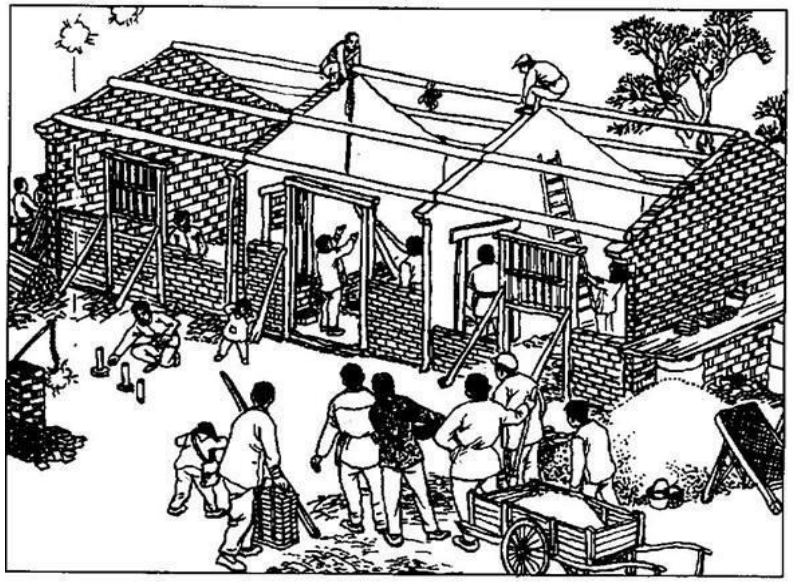
- ✓ Rights, responsibilities and benefits are written into the smart contract to realize the reasonable distribution of multi-party interests
- ✓ Realize the unity of producers, participants and consumers
- ✓ Form a distributed network among unfamiliar collaborators
- ✓ Driven by the resource endowment, complementary advantages and win-win interests of the participants

Security and Trust: The Core of Intelligent Economy



Xuan Han, Yong Yuan, Fei-Yue Wang, "Security Problems on Blockchain: The State of the Art and Future Trends", *Acta Automatica Sinica*, 2019, Vol.45, No. 1, pp. 206-225.
韩璇, 袁勇, 王飞跃. "区块链安全问题: 研究现状与展望", 自动化学报, 2019, Vol.45, No. 1, pp. 206-225.

Blockchain + AI = Reinforced Cement Foundation of Intelligent System



Without blockchain, it's like building a house in the sand

With blockchain intelligence, it's like building high-rise buildings on reinforced concrete foundation

Blockchain provides a reliable, available and efficient data foundation for AI.

袁勇, 周涛, 周傲英, 段永朝, 王飞跃, "区块链技术：从数据智能到知识自动化", 自动化学报, 2017, Vol. 43, pp. 1485-1490.

Dreyfus Report: Artificial Intelligence, Tree Climbing and Alchemy

Dreyfus Report

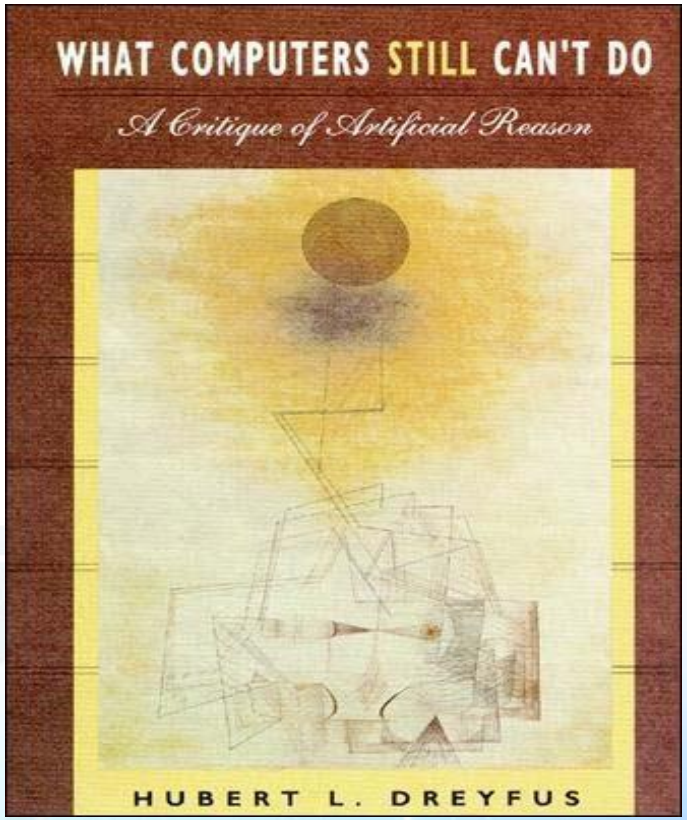
ALCHEMY AND ARTIFICIAL INTELLIGENCE

Hubert L. Dreyfus

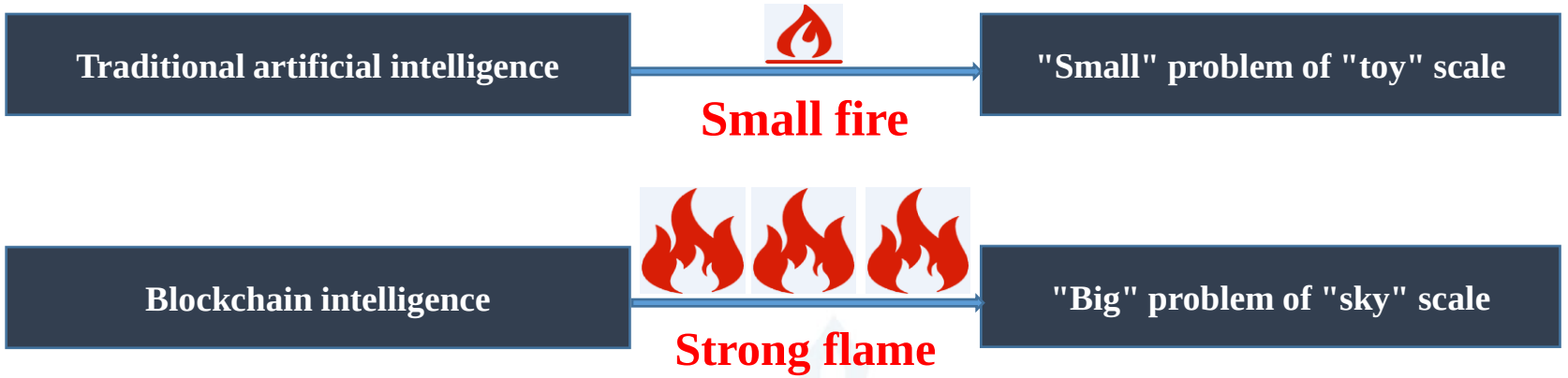
December 1965

"The first person to climb a tree can claim that this is a significant advance in flying to the moon."

——Hubert L. Dreyfus put forward the above sharp metaphor in Dreyfus Report entitled "Alchemy and Artificial Intelligence", in view of the statement that the remarkable progress in the field of AI is gradually approaching the ultimate goal.



From the Alchemy of Artificial Intelligence to the Strong Flame of Blockchain Intelligence



Big data changes means of production, robots change productivity, and blockchain revolutionizes production relations

The First Monograph--Blockchain: Theory and Method

From

Dream and flicker fly together ,
Reason shares the same color with crazy ;
(梦想与忽悠齐飞，理性共疯狂一色；)

To

A lonely wild duck flies with the sunset clouds,
The autumn river mirrors the color of the sky.
(落霞与孤鹜齐飞，秋水共长天一色。)

Yong Yuan, Fei-Yue Wang. Blockchain: Theory and Method[M]. Tsinghua University Press, 2019.袁勇, 王飞跃. 区块链理论与方法[M]. 清华大学出版社, 2019.

Military Blockchain: From Asymmetric Warfare to Symmetric Peace

第 4 卷 第 3 期 指 挥 与 控 制 学 报 Vol. 4, No. 3
2018 年 9 月 JOURNAL OF COMMAND AND CONTROL September, 2018

军事区块链：从不对称的战争到对称的和平

王飞跃 [1,2,3] 袁 勇 [1,2] 王 帅 [1,4] 李娟娟 [1,2] 秦 蕊 [1,2]

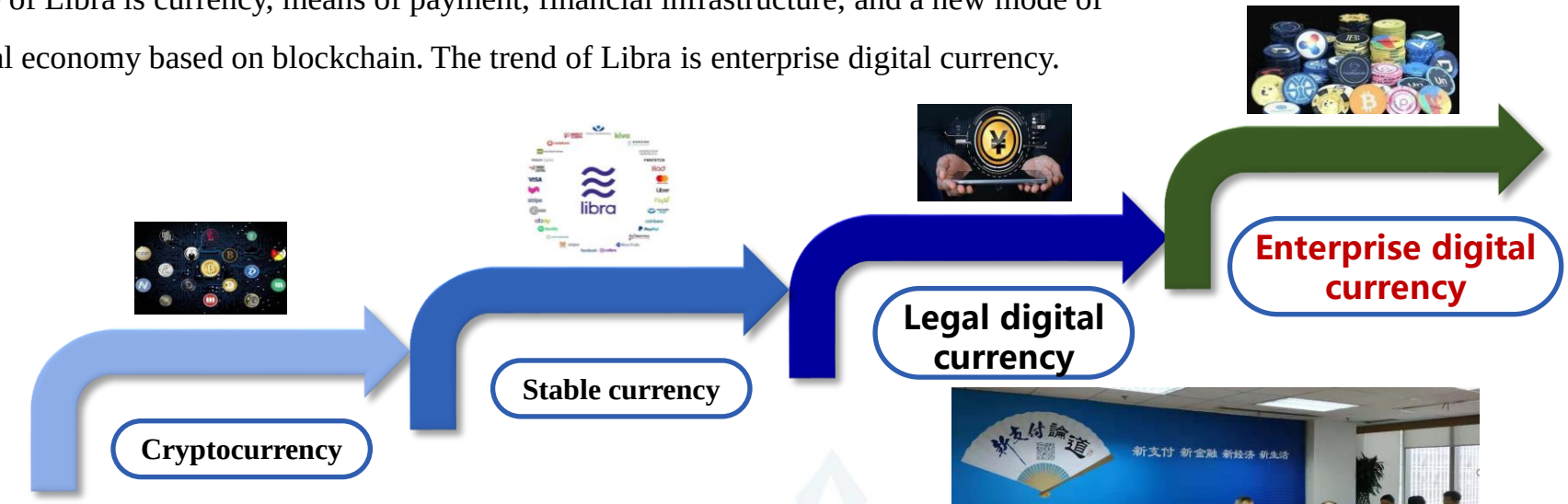
摘 要 针对未来战争形态将从物理世界的核威慑发展为跨域“三战合一”的智威慑的时代背景，提出军事区块链的内涵、方法与应用，详细阐述了区块链“真 (TRUE)”和“道 (DAO)”的技术特点，即可信 (Trustable)、可靠 (Reliable)、可用 (Usable)、高效 (Efficient, Effective) 以及分布式与去中心化 (Distributed, Decentralized)、自主性与自动化 (Autonomous, Automated)、组织化与有序性 (Organized, Ordered)，指出区块链将成为军事智能的基石. 分析了区块链的军事意义，并以军事信息系统、军事管理自动化以及无人机集群为例，介绍了区块链在军事领域的潜在应用方向. 提出了平行军事区块链的概念框架、基础理论和研究方法体系. 区块链将有助于跨越不对称信息与有限理性鸿沟，将不对称的战争变为对称的和平.

关键词 区块链, 军事区块链, 平行智能, 知识自动化, 智能合约

Business Blockchain: From Asymmetric Competition to Symmetric Benefit

Blockchain + Digital Currency: Facebook Libra

The core of Libra is currency, means of payment, financial infrastructure, and a new mode of digital economy based on blockchain. The trend of Libra is enterprise digital currency.



People's Bank of China:

- Promot the research and development of digital currency of the central bank (Research Bureau)
- Libra should be included in the regulatory framework of the central bank (payment department)

Y. Yuan, F.-Y. Wang, "Blockchain and Cryptocurrencies: Model, Architecture and Applications", *IEEE Trans. on Systems, Man, and Cybernetics: Systems,* 2018, Vol. 48, No.9, pp. 1421-1428.

The Trend of Blockchain Intelligence: From Machine Consensus to Human-Machine Hybrid Consensus

Human-machine hybrid intelligence consensus

Smart contract ↓ Intelligent components

Parallel driven by data and knowledge

Distributed social intelligence

Negotiation, coordination and cooperation based on agent

Decentralized Decision Consensus

Human-machine integration
Human-in-the-Loop

Electoral consensus
Paxos、Raft

Validation consensus
PoW、PoS...

Random consensus
Algorand、PoET

Alliance consensus
DPoS

Hybrid consensus
PoW+PoS

Decentralized Algorithm Consensus

Yong Yuan, Xiaochun Ni, Shuai Zeng, Fei-Yue Wang, Blockchain Consensus Algorithms: The State of the Art and Future Trends, Acta Automatica Sinica, 44(11): 2011-2022, 2018.(袁勇, 倪晓春, 曾帅, 王飞跃, 区块链共识算法的发展现状与展望, 自动化学报, 44(11): 2011-2022, 2018)
徐忠, 邹传伟, 区块链能做什么, 不能做什么, 金融研究, 11:1-16, 2018.

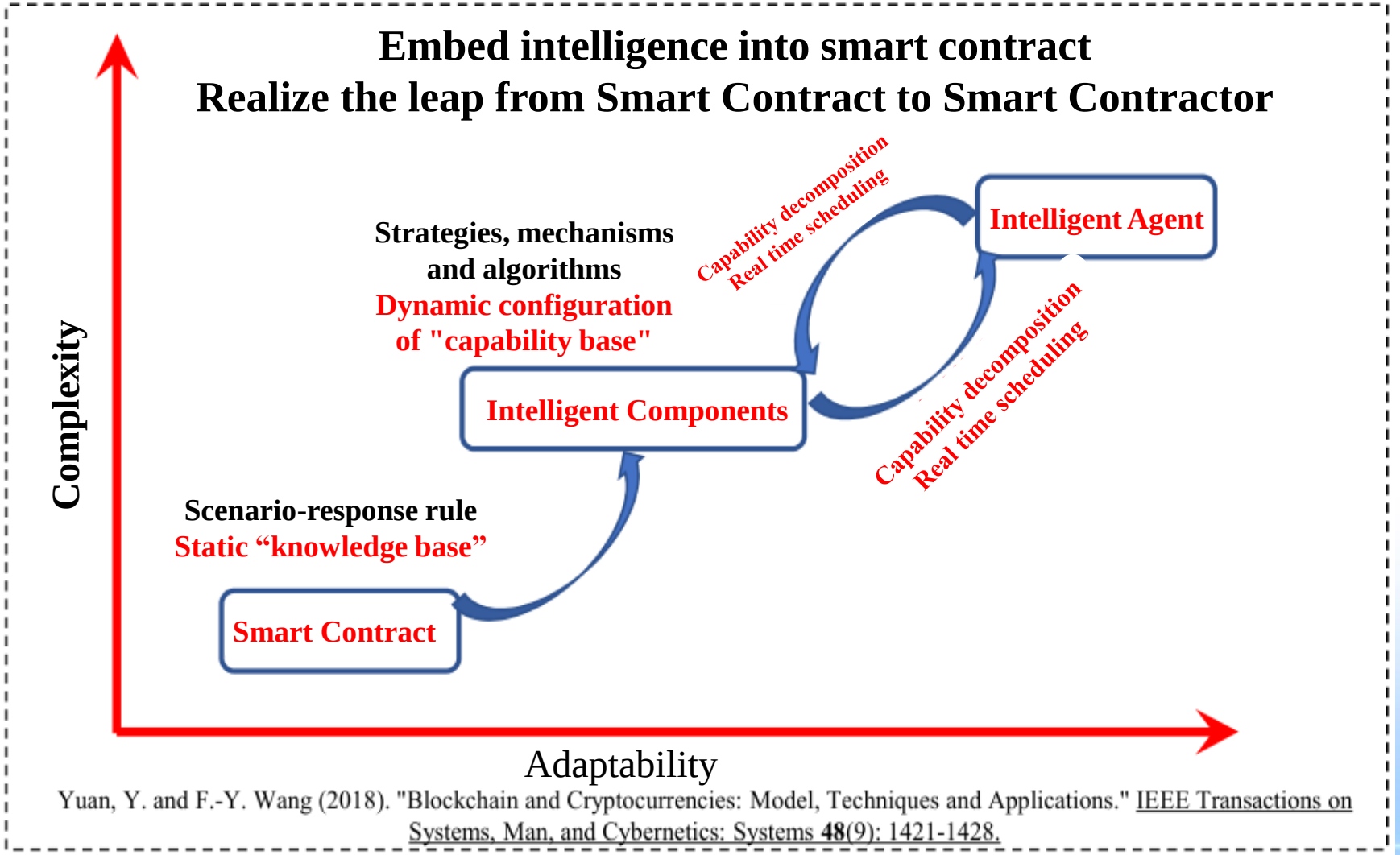
Trend of Blockchain Intelligence: From Static Smart Contract to Dynamic Configurable Intelligent Component

Human-machine hybrid intelligence consensus

Smart contract ↓ Intelligent components

Parallel driven by data and knowledge

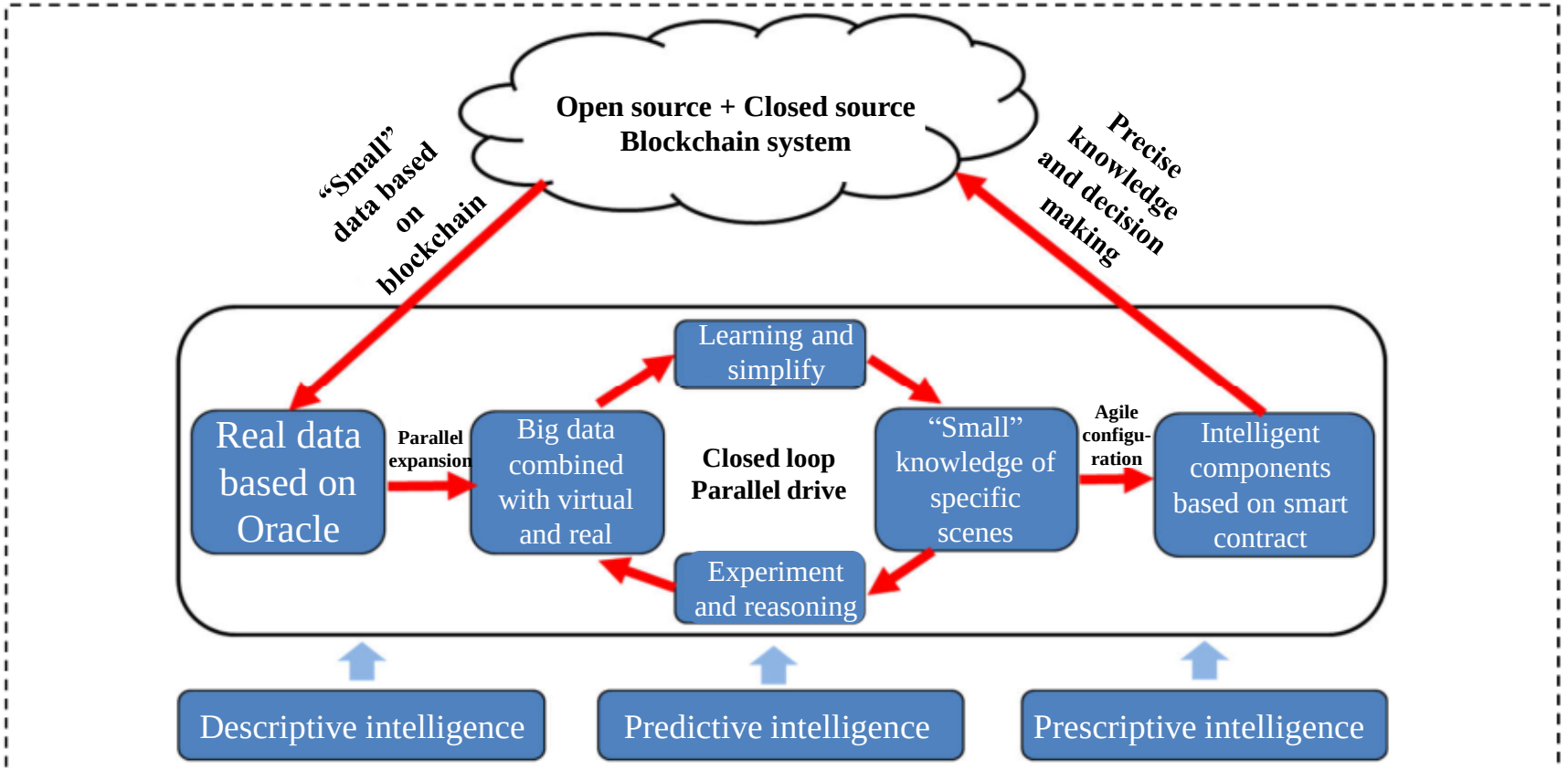
Distributed social intelligence



Yuan, Y. and F.-Y. Wang (2018). "Blockchain and Cryptocurrencies: Model, Techniques and Applications." IEEE Transactions on Systems, Man, and Cybernetics: Systems **48**(9): 1421-1428.

Trend of Blockchain Intelligence: Intelligent Decision Driven by Data and Knowledge in Parallel

- Human-machine hybrid intelligence consensus
- Smart contract ↓ Intelligent components
- **Parallel driven by data and knowledge**
- Distributed social intelligence



Shuai Wang, Yong Yuan, Fei-Yue Wang, Decentralized Knowledge Graph for Deep Recommender Systems based on Blockchain-Powered Smart Contract, IEEE-TNNLS, submitted

Trend of Blockchain Intelligence: Blockchain Enabled Distributed Social Intelligence

- Human-machine hybrid intelligence consensus
- Smart contract ↓ Intelligent components
- Parallel driven by data and knowledge
- Distributed social intelligence

Intelligent blockchain promotes the distributed intelligent ecosystem and stimulates social intelligence, which is the core infrastructure of building a smart society

Wang, F.-Y., Y. Yuan, J. Zhang, R. Qin and M. H. Smith (2018). "Blockchainized Internet of Minds: A New Opportunity for Cyber-Physical-Social Systems." IEEE Transactions on Computational Social Systems **5**(4): 897-906.

Our Work

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5. 王飞跃, 袁勇, 王帅, 李娟娟, & 秦蕊. (2018). 军事区块链：从不对称的战争到对称的和平. 指挥与控制学报.
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15. R. Qin, Y. Yuan, S. Wang, F.-Y. Wang, Economic Issues in Bitcoin Mining and Blockchain Research, in: IEEE/IFAC Conference on Blockchain and Knowledge Automation, China, 2018.
16. S. Wang, Y. Yuan, X. Wang, J. Li, R. Qin, F.-Y. Wang, An Overview of Smart Contract: Architecture, Applications, and Future Trends, in: 2018 IEEE Intelligent Vehicles Symposium, Changshu, Jiangsu, China, 2018.
17. S. Zeng, X. Ni, Y. Yuan, F.-Y. Wang, A Bibliometric Analysis of Blockchain Research, in: 2018 IEEE Intelligent Vehicles Symposium, Changshu, Jiangsu, China, 2018.
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Parallel Economy: Parallel Intelligence and Intelligent Economy

Blockchain makes the traditional "**Attention**" and "**Trust**" which are difficult to circulate and commercialize become the circulating goods that can be mass produced, develops the artificial world, revolutionizes the scope of economic activities and the way to improve the efficiency, and forms the intelligent economic foundation based on parallel intelligence.

Parallel Economics

Parallel Economics: A New Supply–Demand Philosophy via Parallel Organizations and Parallel Management

Fei-Yue Wang, *Fellow, IEEE*

WELCOME to the new issue of IEEE TRANSACTIONS ON COMPUTATIONAL SOCIAL SYSTEMS (TCSS). First, I would like to share the news of my resignation from

by making choices. Therefore, in addition to doctors and hospitals, we should have "*eospitals*" for economic hospitals or "*fospitals*" for financial hospitals for the economic

Fei-Yue Wang, "Parallel Economics: A New Supply–Demand Philosophy via Parallel Organizations and Parallel Management", *in IEEE Transactions on Computational Social Systems*,Aug. 2020, Vol. 7, No. 4, pp. 840-848 .

Parallel Intelligent Industry and Economy

Why smart economy?

- Social demand and inflection point
  - With the development of industrial economy, we have encountered various "bottlenecks" and "traps" such as "global warming", "development limit", "technological singularity"
  - For the further development and upgrading of economy, there must be new growth mode and market space

The only way to upgrade and transform industrial economy

- Promote intelligent technology, develop artificial world and expand commodity scope
- Form effective and personalized knowledge products and its intelligent economy
  - Specialization
  - Human machine division
  - Virtual-real division
- From "invisible hand" to "intelligent hand"
- From industrial society to smart society

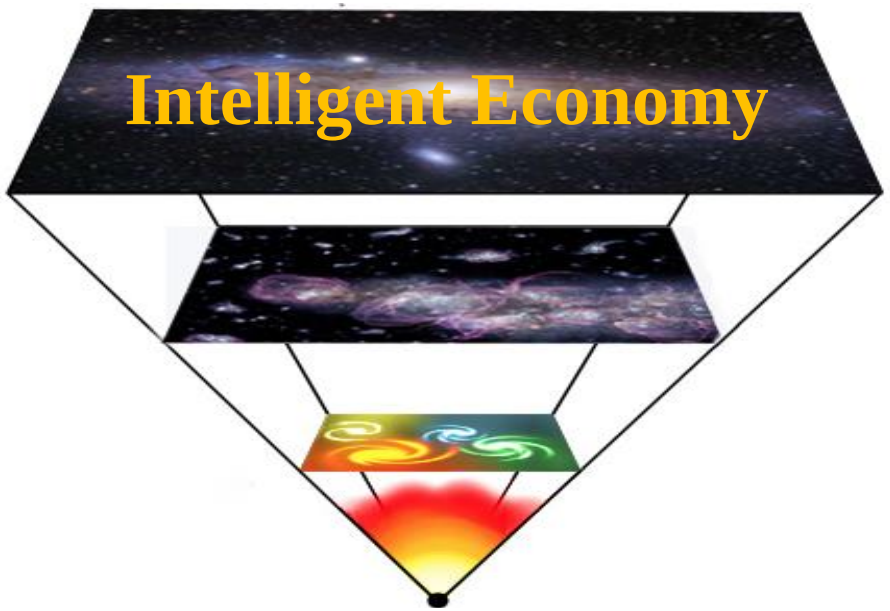
What is intelligent economy?

The new thinking in the era of developing artificial world:
From industrial automation to intelligent automation, and build intelligent economy
BEI（Big Economy of Intelligence）

Parallel strategic thinking

New Edge of Intelligent Economy: Singularity Life!

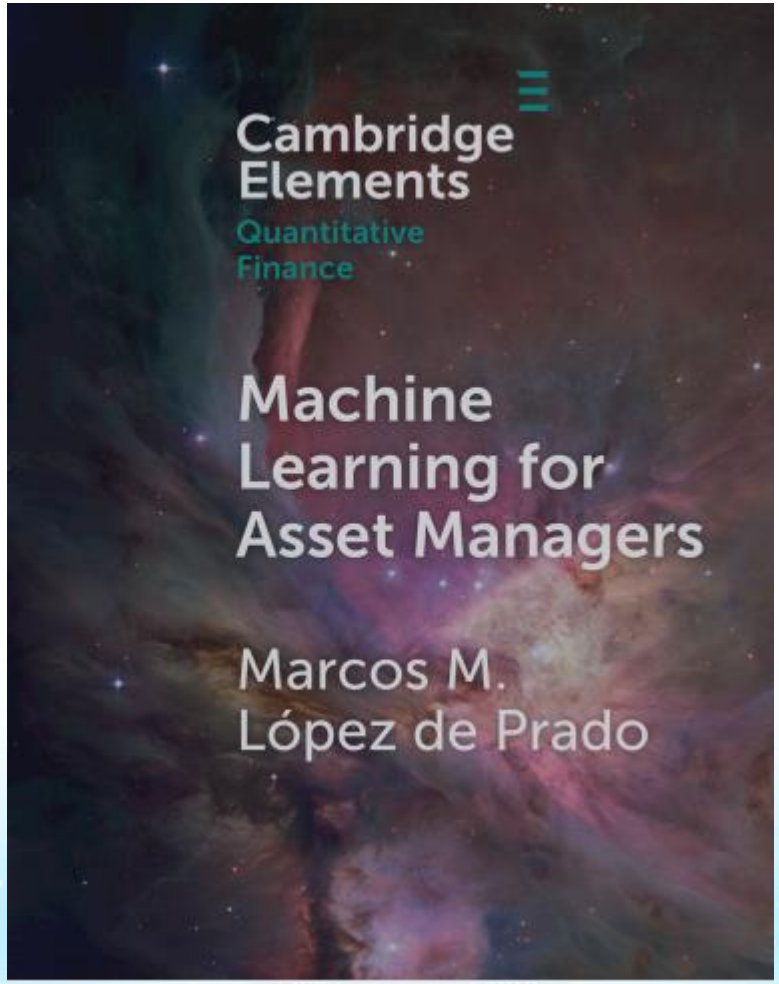
We all have



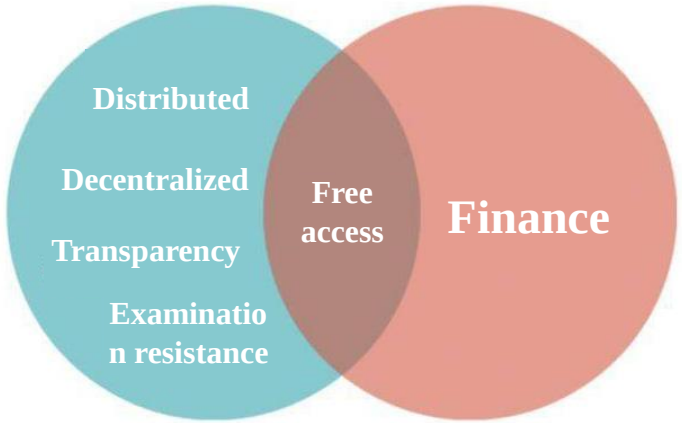
We all win and tolerance together

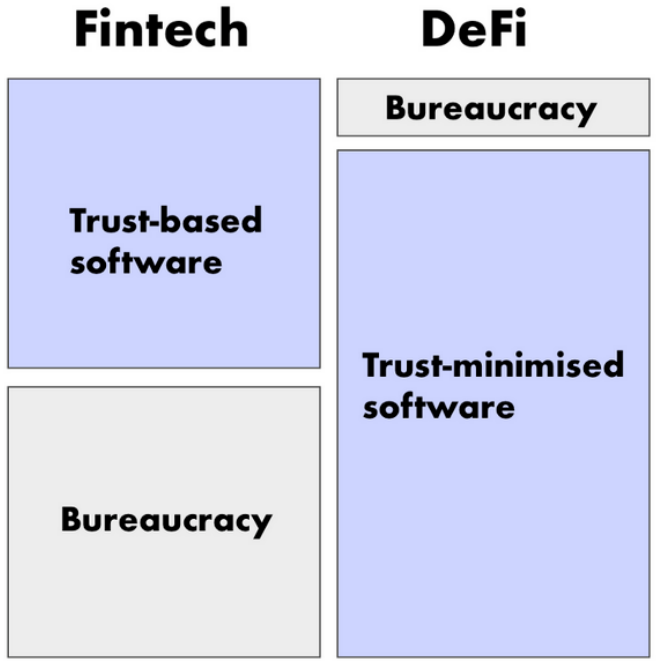
Create From Nothing

Translations: Mechine Learning for Asset Managers



Defi: Decentralized Finance（分布式金融）





Decentralized Finance: The applications of various financial fields developed from the open decentralized network aims to establish a multi-level financial system, re create and improve the existed financial system based on blockchain technology and cryptocurrency.

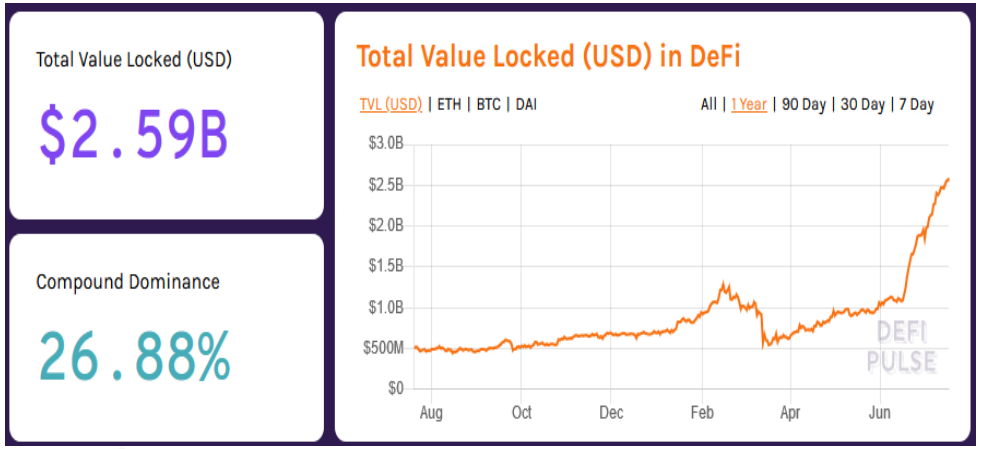
Fintech tooted in institutions and trust
DeFi is not constrainted by system and has very low dependence on trust

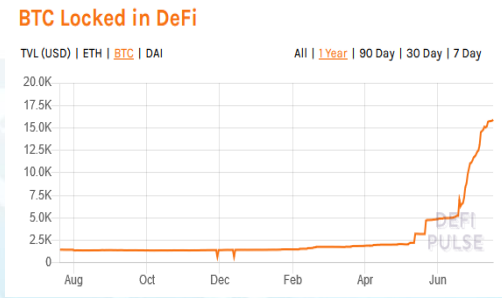
DeFi: From the Embryonic Stage to the Future

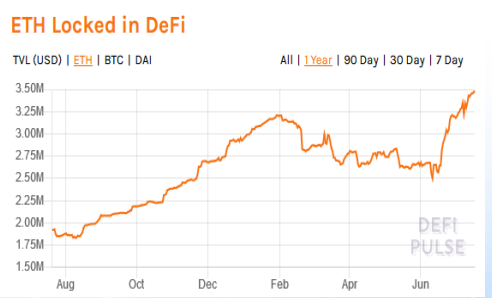
Top 10 DeFi Protocols by Market Capitalization

Total Market Cap: $8,414,648,222 Tweet

#	Name	Market Cap	# of tokens	Top Assets
1	Compound	$3,278,166,141	10	
2	ERC20	$1,762,225,020	15	
3	Synthetix	$692,326,506	38	
4	Aave	$672,871,964	18	
5	MakerDAO	$556,630,620	3	
6	Balancer	$415,446,642	269	
7	DeFi Money Market	$376,323,327	4	
8	Fulcrum	$214,056,214	10	
9	Bitcoin	$129,245,283	5	
10	Bancor Network	$125,468,493	41	

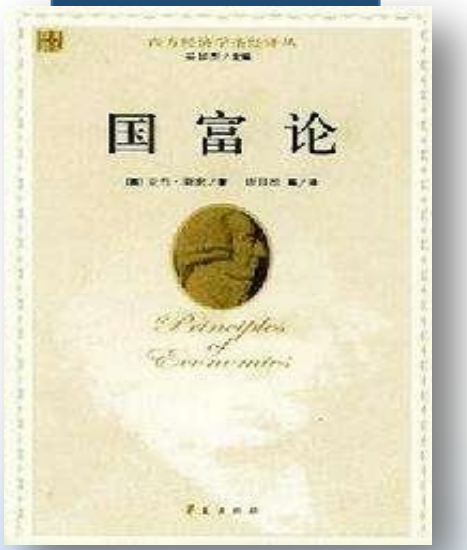






The Parallel Future of Economic Society

Specialization → **Man-machine division** → **Virtual-real division**



Contemporary Economy

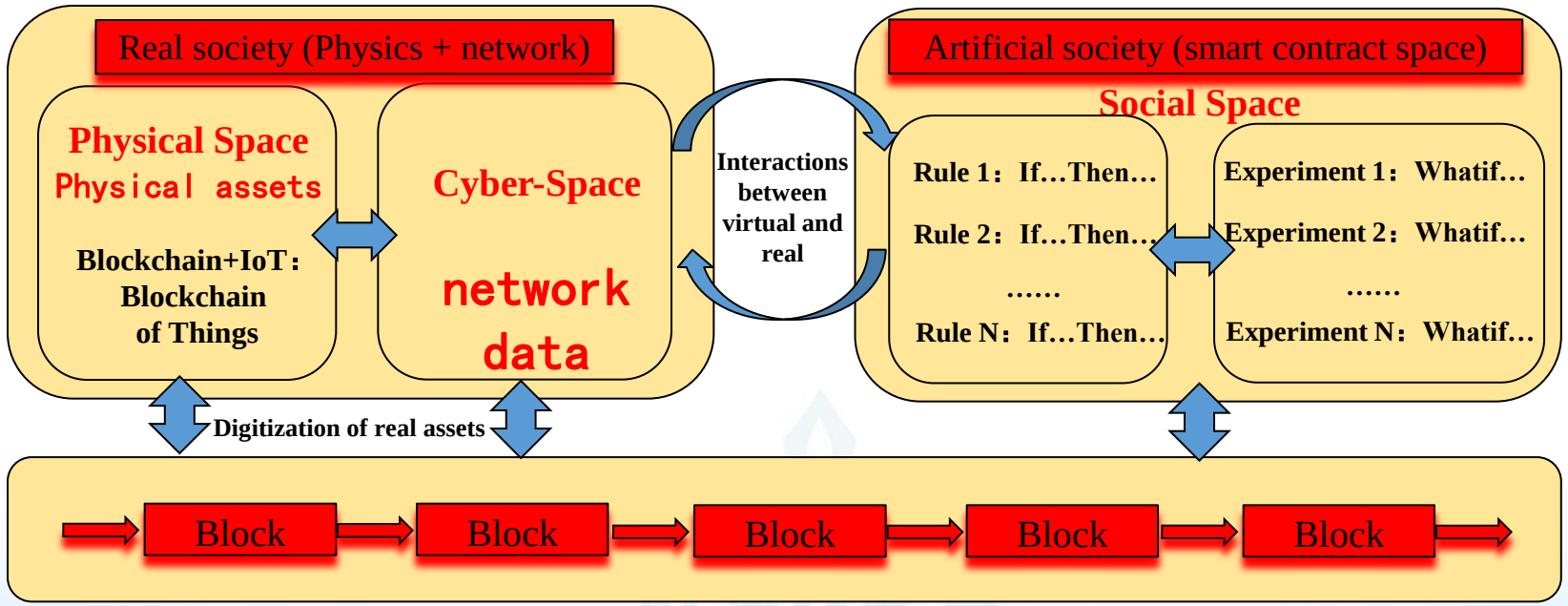
Robot Economy

Emerging Economy

Parallel Economy

Intelligent Economy

Smart Society Management based on Parallel Blockchain



The technical essence of blockchain coincides with parallel methods, which can effectively support modeling of physical and cyberspace, experiment optimization based on Intelligent contract, and parallel interaction of virtual and real systems.

Parallel Management

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The State Key Laboratory for Management and Control of Complex Systems (2011)

Research in SKL-MCCS

Parallel Management and Parallel Control

- Parallel Control
- Parallel Management
- Computational Intelligence
- Cyber-based agent method

Parallel Robotics and Parallel Manufacturing

- Industrial Robots
- Bionic Robots
- Multi-Robots Coordination

Parallel Medicine and Parallel Health

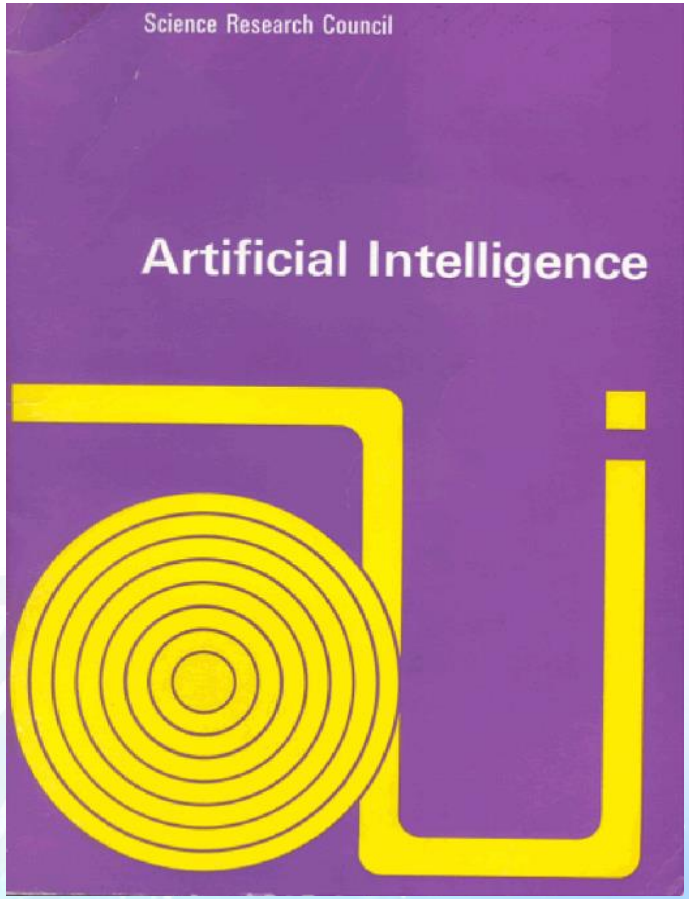
- Multi-mode Information Fusion
- Optical Transmission Model
- Early Detection of Tumors

Parallel Societies and Parallel Ecology

- Big-Data Based Perception and Fusion
- Big-Data Based Management
- Early Warning and Visualization of Space-Time Situation

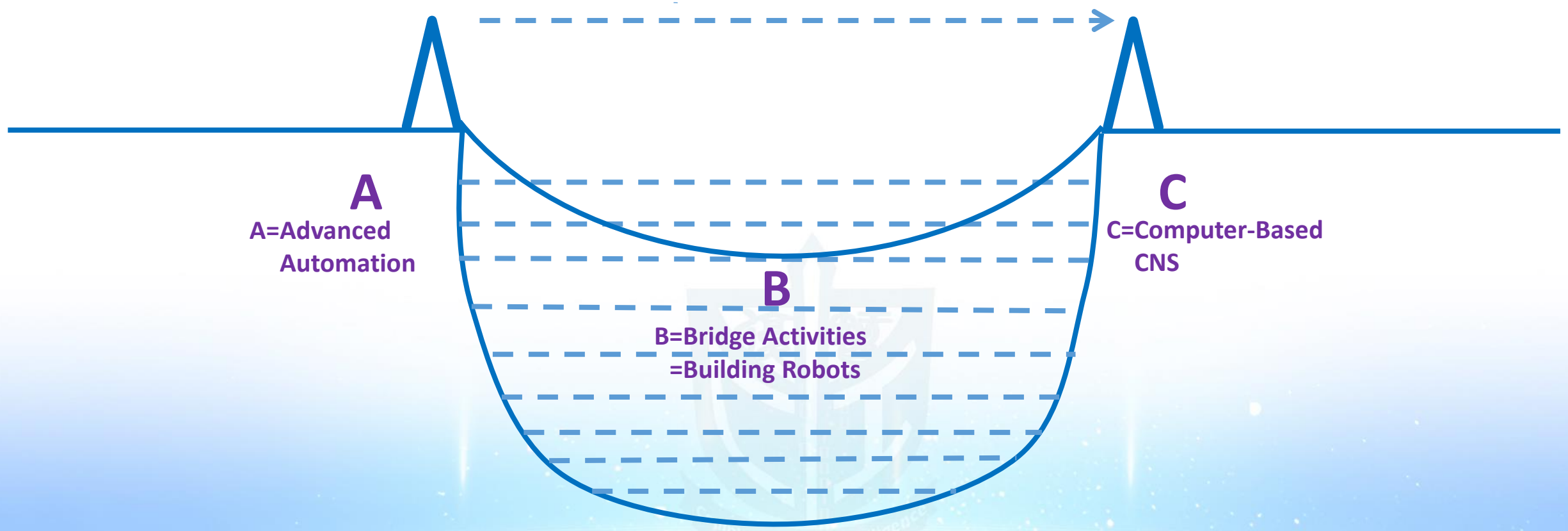
Why Parallel Intelligence ?

Lighthill (1924 – 1998)

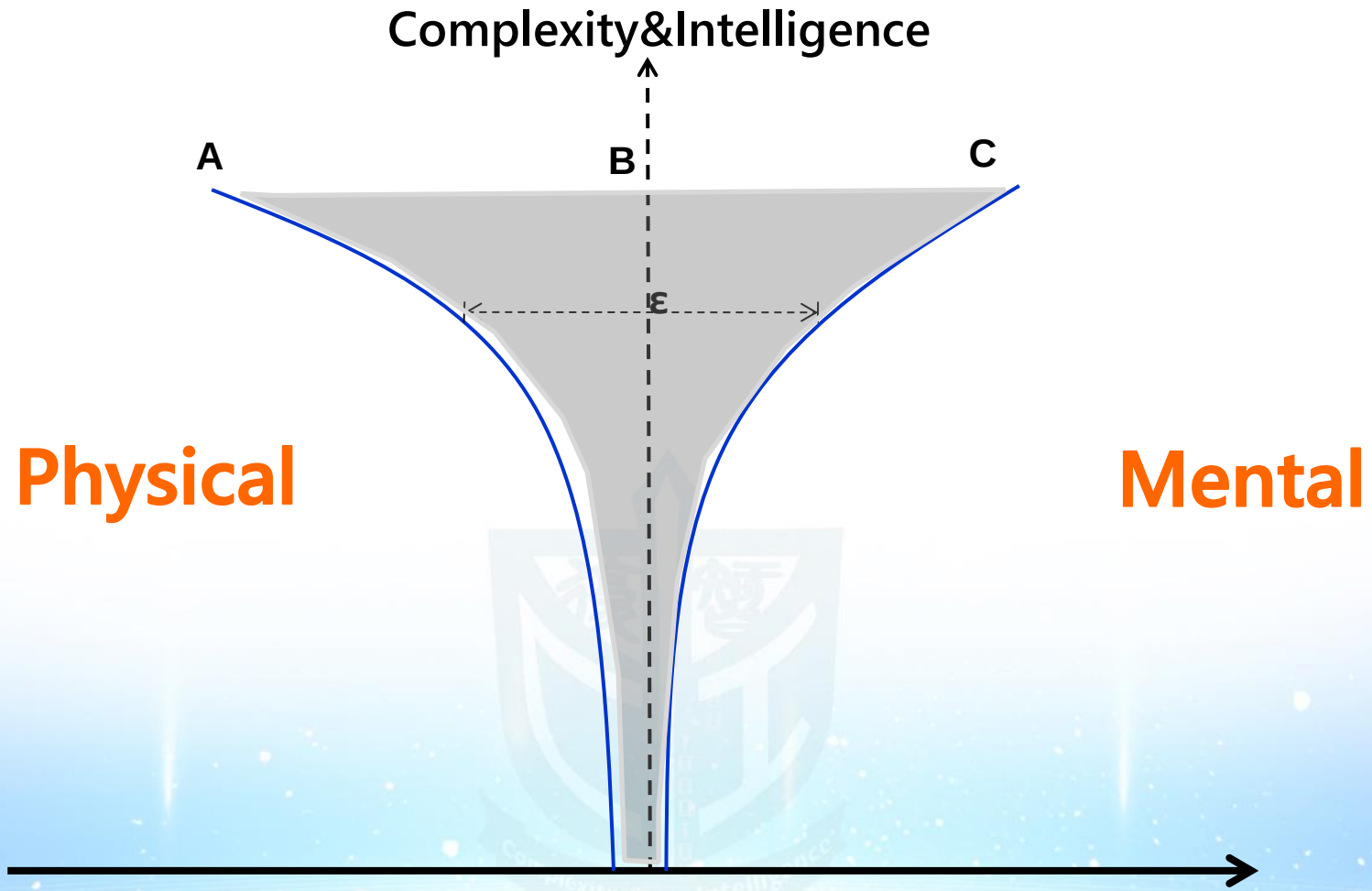


Lighthill Report, 1973

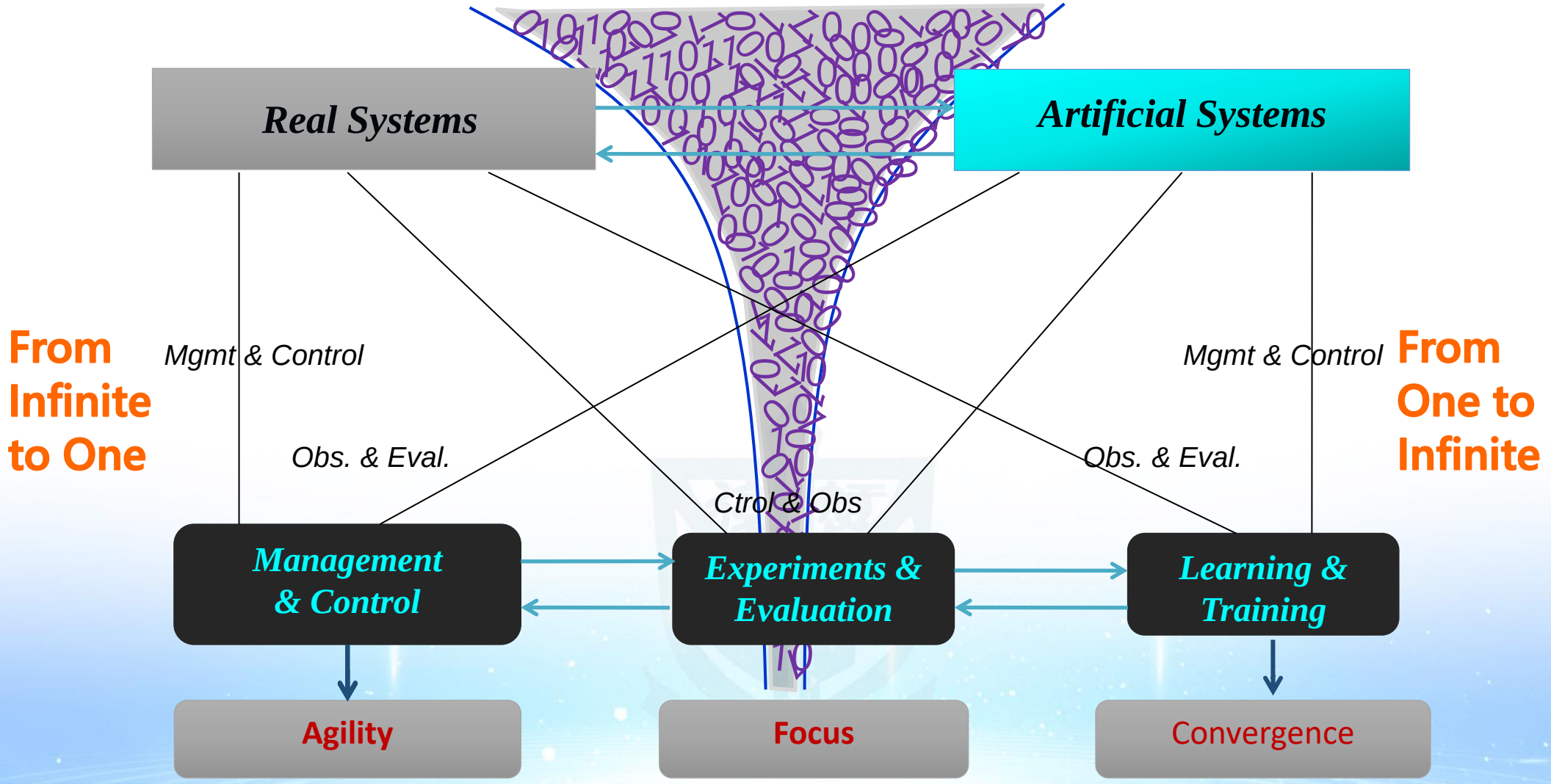
Lighthill's Picture of AI: ABC



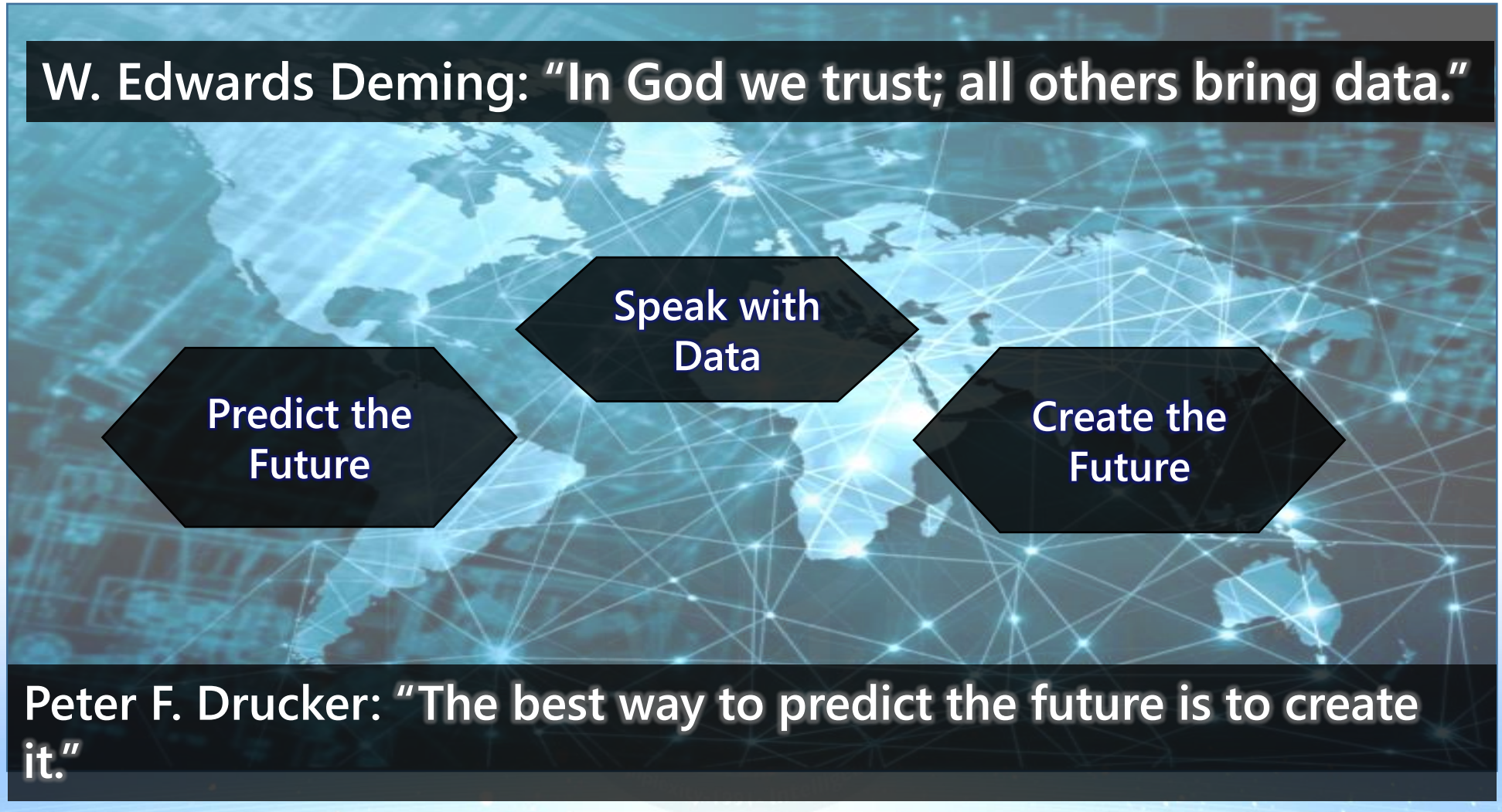
The Lighthill Gap



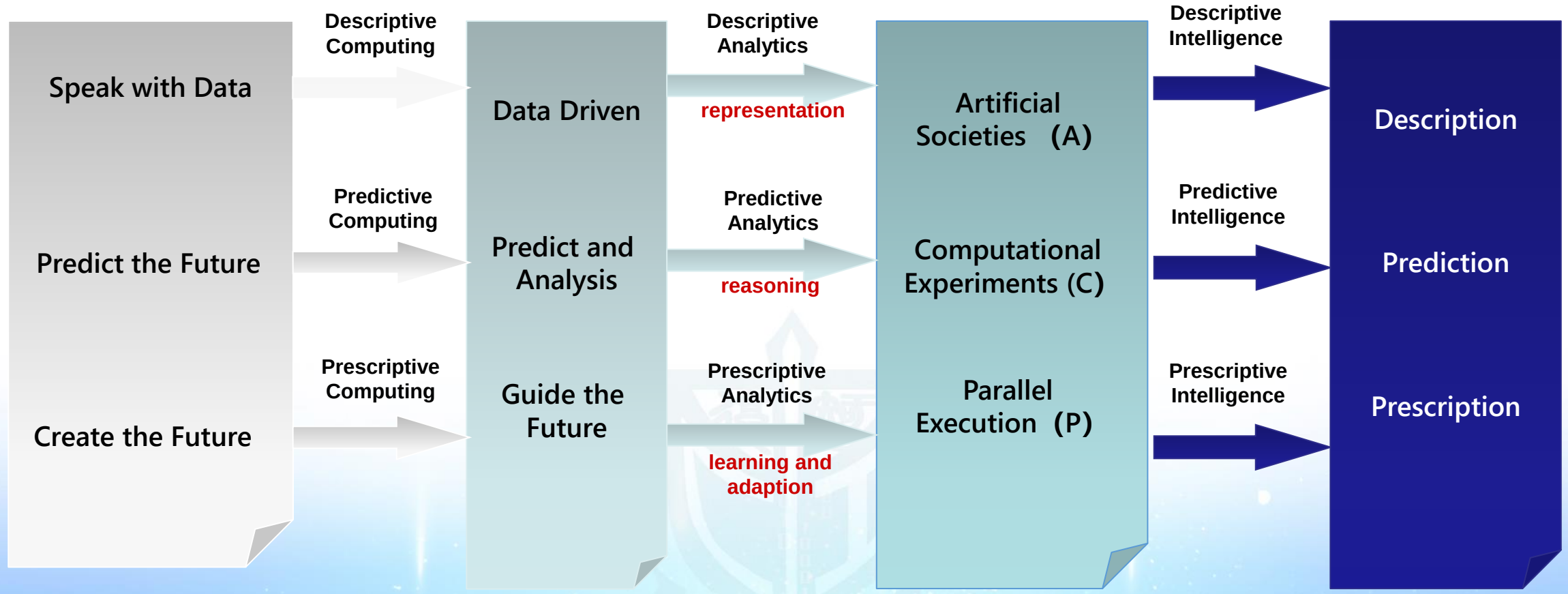
Parallel Systems: Bridge the Gap



The Nature of Big Data



Big Data Analytics and DPP



Method: Parallel Data

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2017 年 8 月

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PR & AI

Vol.30 No.8
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平行数据：从大数据到数据智能*

刘 昕[1] 王 晓[2,3] 张卫山[1] 汪建基[4] 王飞跃[2,3,5]

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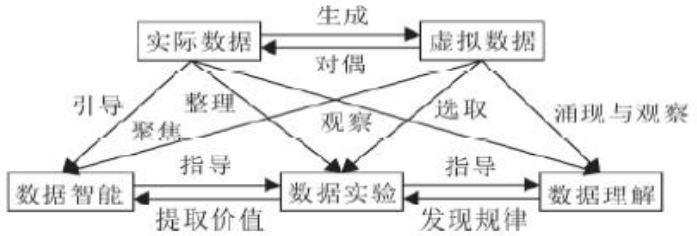
[3](青岛智能产业技术研究院 平行工作室 青岛 266111)
[4](西安交通大学 人工智能与机器人研究所 西安 710049)
[5](国防科学技术大学 军事计算实验与平行系统技术研究中心 长沙 410073)

摘 要 为了解决实际问题，大数据分析处理系统需要获取数据，然而实际场景中收集到的实际数据通常不完备．另外，大多数问题的解决方案通常是由问题引导或者仅仅进行数据分析，运行参数调整和设定带有较大的盲目性，难以达到应用的智能性．为此，文中提出平行数据的概念和框架，根据实际数据经计算实验产生真正的虚拟大数据，结合默顿定律，以期待的解决方案与问题进行广义对偶，引导大数据聚焦到实际问题．实际数据与虚拟数据动态互动，平行演化，形成一个虚实相生、数据动态变化的过程，最终使数据具备智能，进而解决未知的问题．平行数据不但是一种数据表示形式，更是一种数据演化机制与方式，其特色是虚实互动，所有数据的动力学轨迹构成了数据动力学系统．平行数据为数据处理、表示、挖掘和应用提供了一个新的范式．

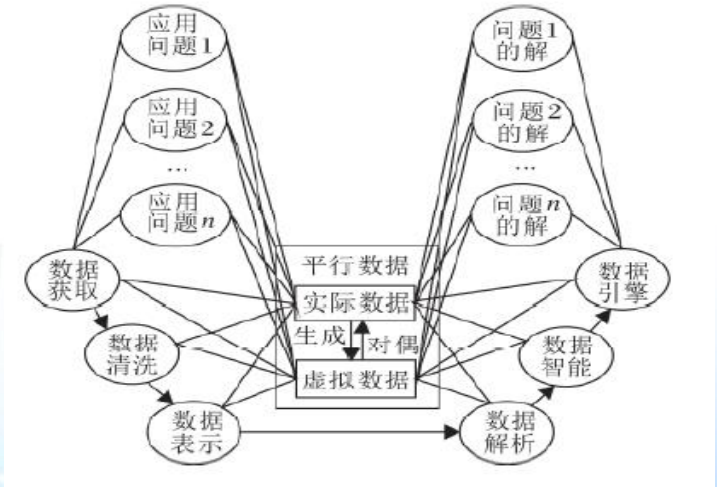
关键词 大数据，平行数据，智能数据，计算实验，智能数据合约，数据动力学轨迹，平行数据机器，数据智能
中图法分类号 TP 391 DOI 10.16451/j.cnki.issn1003-6059.201708001
引用格式 刘 昕，王 晓，张卫山，汪建基，王飞跃．平行数据：从大数据到数据智能．模式识别与人工智能，2017，30(8)：673-681.

Parallel Data: From Big Data to Data Intelligence

LIU Xin[1], WANG Xiao[2,3], ZHANG Weishan[2], WANG Jianji[4], WANG Feiyue[2,3,5]
[1](*College of Computer and Communication Engineering, China University of Petroleum, Qingdao* 266580)
[2](*The State Key Laboratory for Management and Control of Complex Systems, Institute of Automation, Chinese Academy of Sciences, Beijing* 100190)
[3](*Parallel Workshop, Qingdao Academy of Intelligent Industries, Qingdao* 266111)
[4](*Institute of Artificial Intelligence and Robotics, Xi'an Jiaotong University, Xi'an* 710049)
[5](*Research Center of Military Computational Experiments and Parallel Systems, National University of Defense Technology, Changsha* 410073)



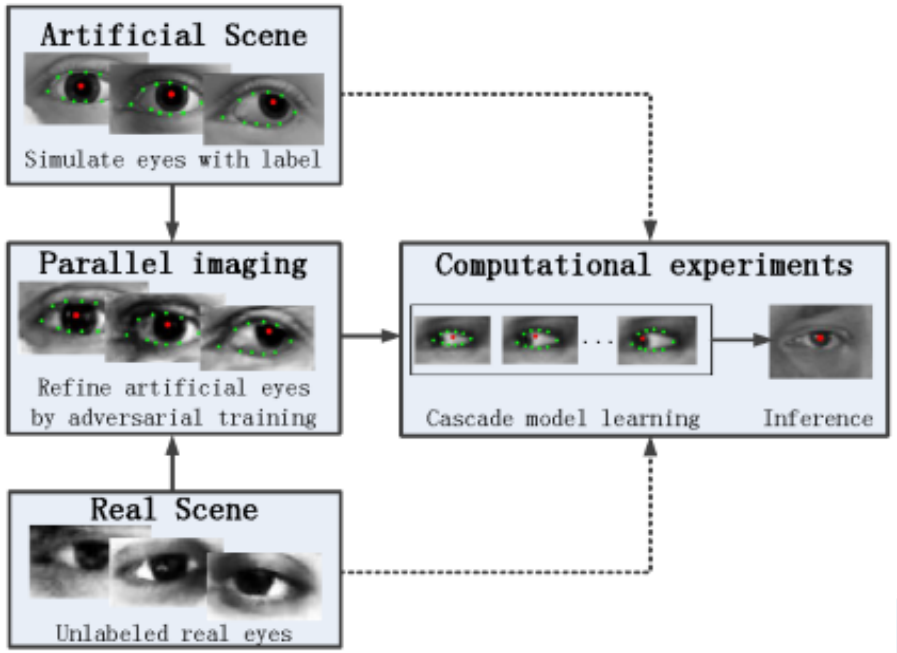
Framework of parallel data

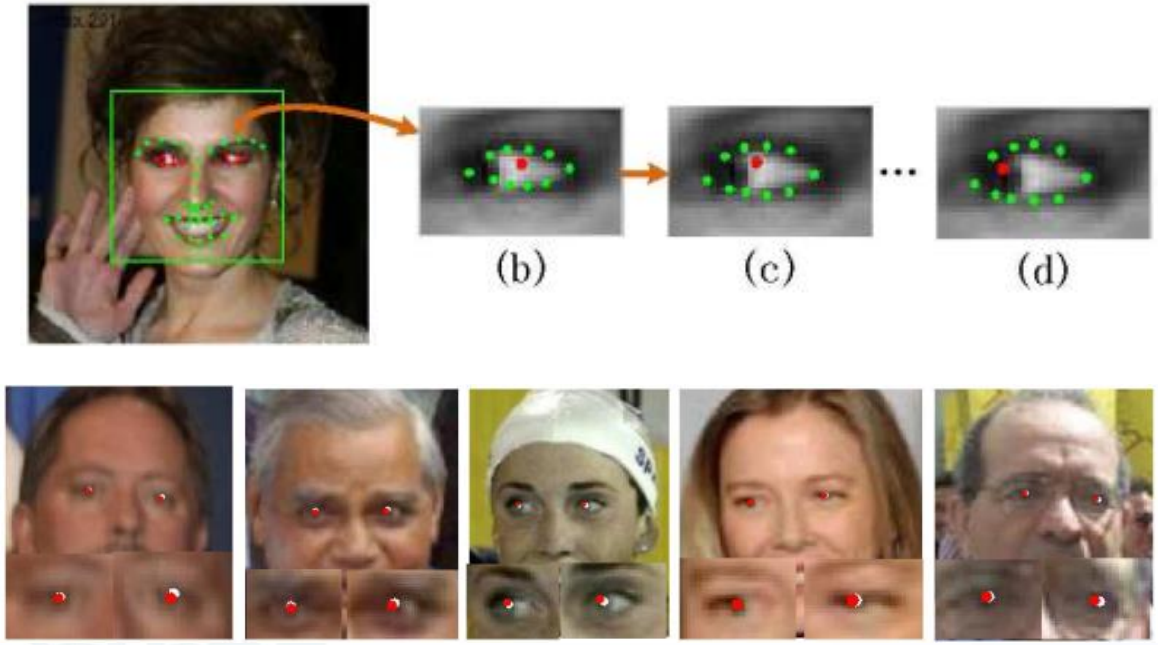


New paradigm for parallel data

Liu Xin, Wang Xiao, Zhang Weishan, Wang Jianji, Wang Fei-Yue, "**Parallel Data: From Big Data to Data Intelligence**", *Pattern Recognition & Artificial Intelligence*, 2017, Vol. 30, No. 8, pp. 673-681.

Method: Parallel Imaging





① Vehicle License Plate Recognition Based on Extremal Regions and Restricted Boltzmann A Joint Cascaded Framework for Simultaneous Eye Detection and Eye State Estimation. Pattern Recognition.

② Cascade Learning from Adversarial Synthetic Images for Accurate Eye Detection. Pattern Recognition, (accepted).

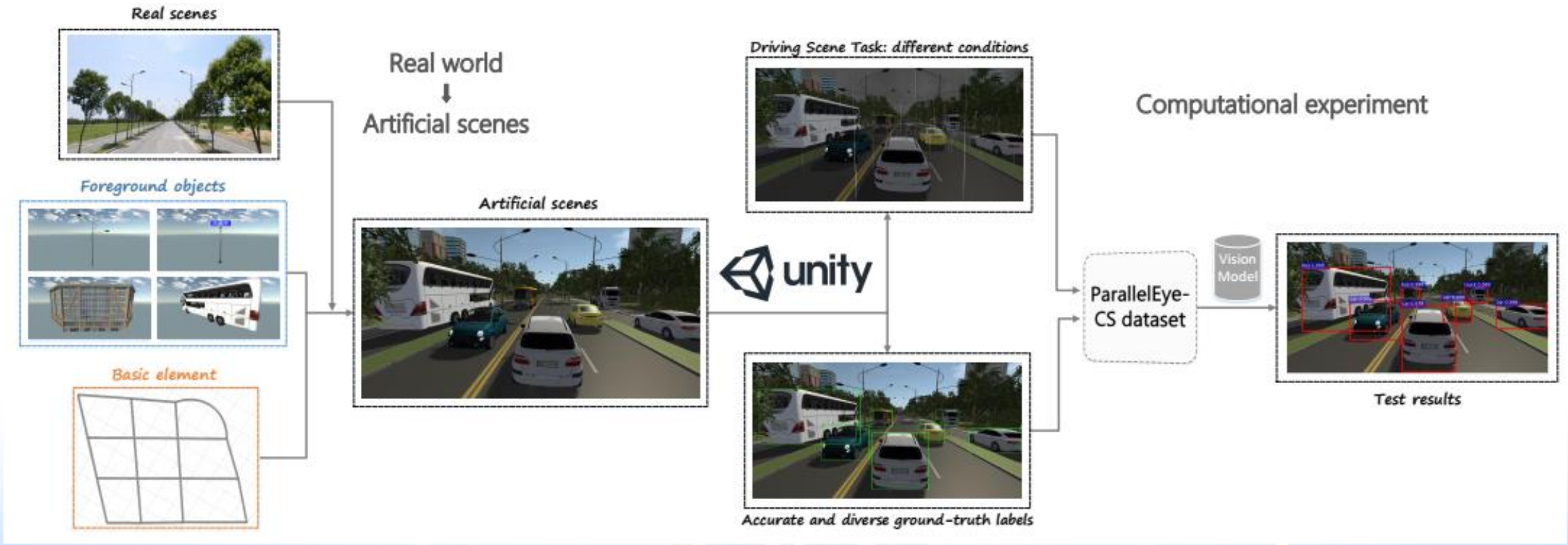
Wang Kunfeng, Lu Yue, Wang Yutong, Xiong Ziwei, Wang Fei-Yue, "**Parallel Imaging: A New Theoretical Framework for Image Generation**" . *Pattern Recognition & Artificial Intelligence*, 2017, Vol. 30, No. 7, pp.577-587.

Method: Parallel Vision

Using parallel vision and deep learning to realize monitoring of driver head and eyes conditions.

1. Wang, K., Gou, C., Zheng, N., Rehg, J. M., & Wang, F. Y, "**Parallel Vision for Perception and Understanding of Complex Scenes: Methods, Framework, and Perspectives**. *Artificial Intelligence Review*, 2017, Vol. 48, No. 3, pp. 299-329.
2. Gou, C., Wu, Y., Wang, K., Wang, K., Wang, F. Y., & Ji, Q, "**A joint cascaded framework for simultaneous eye detection and eye state estimation**", *Pattern Recognition*, 2017, Vol. 67, pp. 23-31.

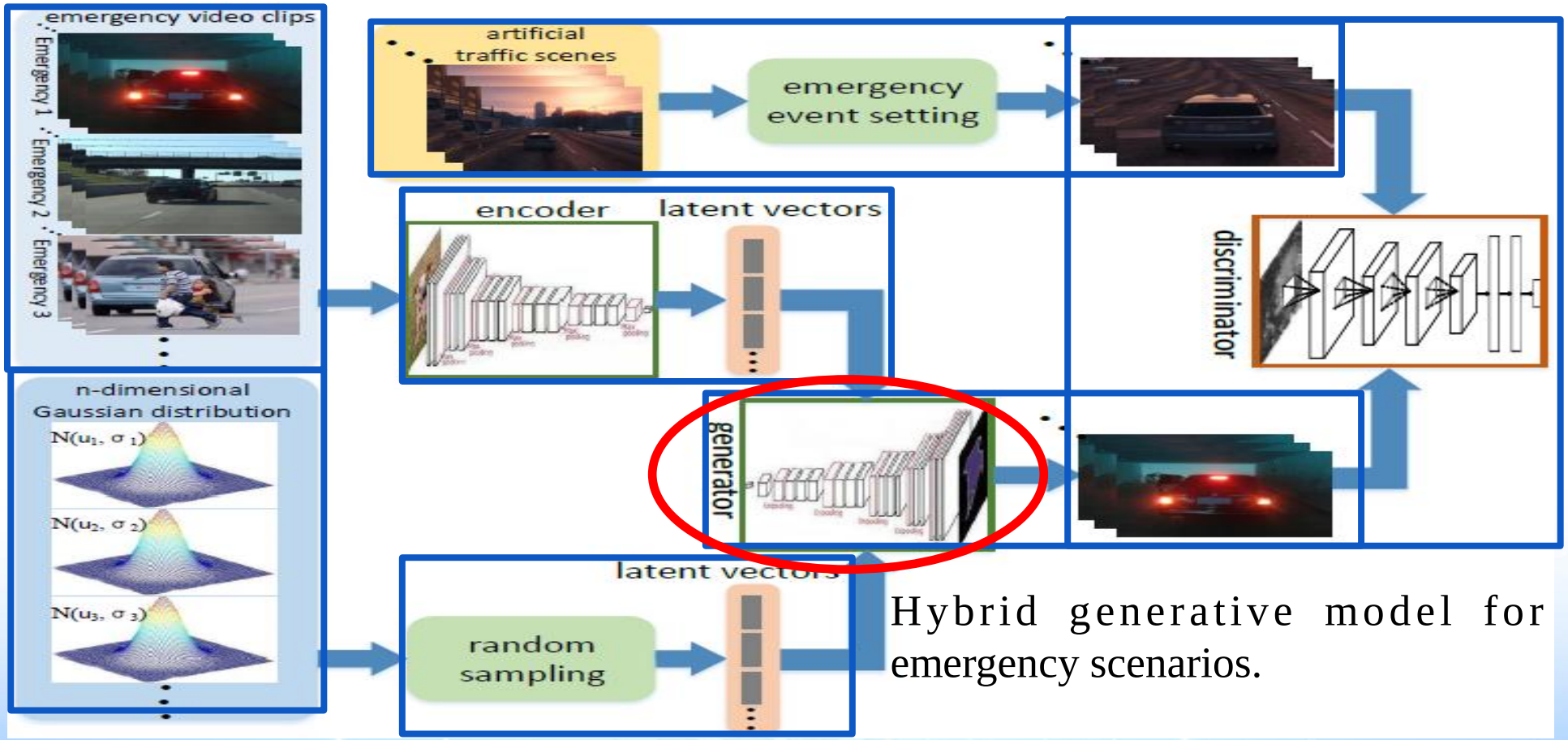
Method: Parallel Perception



Previous vehicle intelligence testing focuses mainly on real-scenario testing, which covers very limited testing scenarios and tasks. Virtual testing is regarded as a supplement of real-scenario testing.

We construct virtual scenes on computers by simulating the real region of vehicle intelligence testing in Changshu (CS), China, and generate a virtual testing set, named ParallelEye-CS, for testing the visual intelligence of intelligent vehicles.

Method: Parallel Planning



Hybrid generative model for emergency scenarios.

Long Chen, Xuemin Hu, Wei Tian, Hong Wang, Dongpu Cao, Fei-Yue Wang, "**Parallel Planning: A New Motion Planning Framework for Autonomous Driving**", *IEEE/CAA Journal of Automatica Sinica*, July 2018, pp. 1-12.

Method: Parallel Testing

SCIENCE ROBOTICS | FOCUS

ARTIFICIAL INTELLIGENCE

Parallel testing of vehicle intelligence via virtual-real interaction

Li Li[1]*, Xiao Wang[2,3]*, Kunfeng Wang[2,3]*, Yilun Lin[2,3,4]*, Jingmin Xin[5]*, Long Chen[6,7], Linhai Xu[5], Bin Tian[2,7], Yunfeng Ai[4,7], Jian Wang[7,8], Dongpu Cao[7,8,9], Yuehu Liu[5], Chenghong Wang[10,11], Nanning Zheng[5†], Fei-Yue Wang[2†]

A self-driven closed-loop parallel testing system implements more challenging tests to accelerate evaluation and development of autonomous vehicles.

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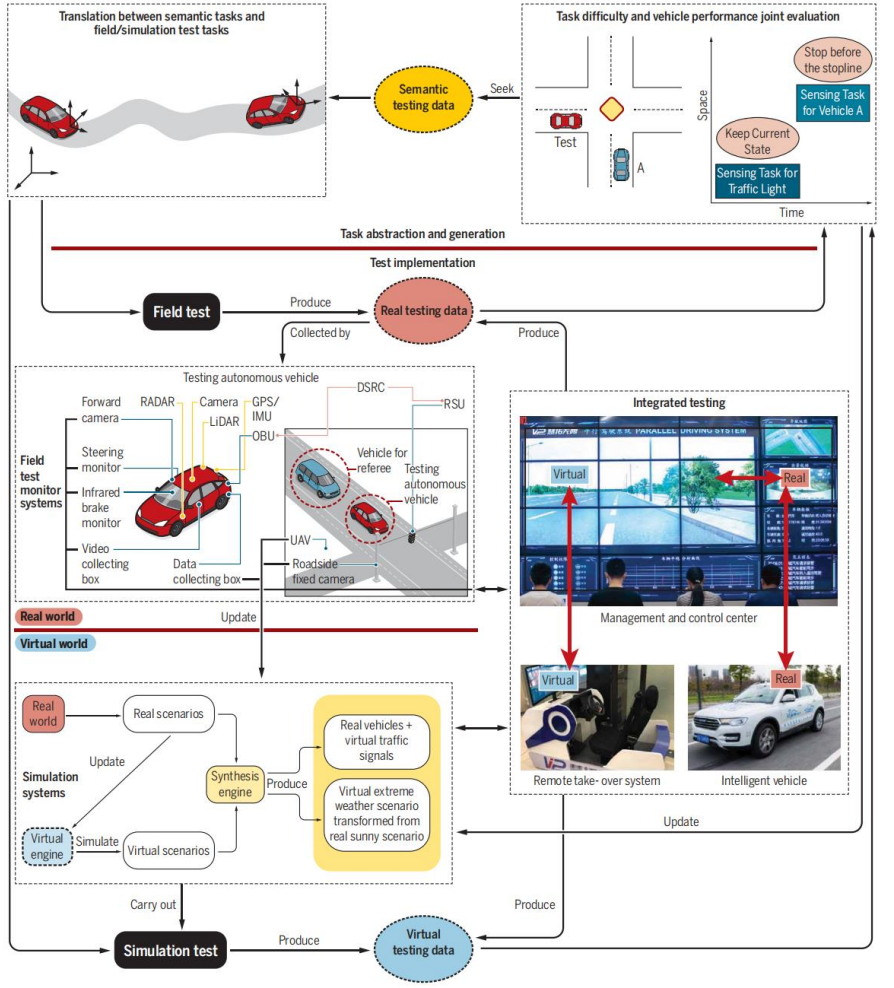
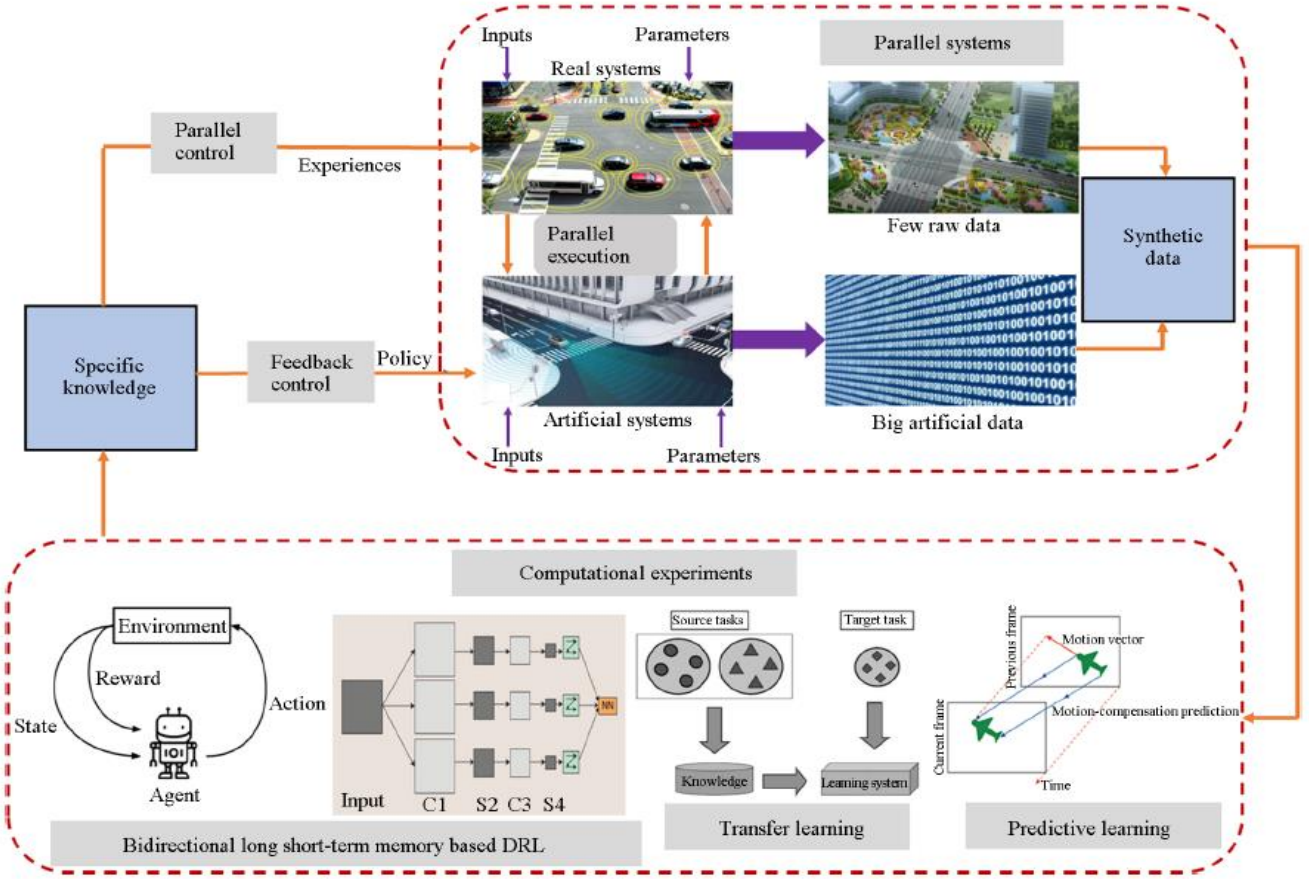


Li Li. *et al*, Parallel testing of vehicle intelligence via virtual-real interaction, *Science Robotics*, eaaw4106(2019).

Principal Theory: An artificial system which is parallel to the actual traffic system will be established, and the integrated test can be carried out through its interaction with the simulation test system.

Algorithms: Parallel Reinforcement Learning



IEEE/CAA JOURNAL OF AUTOMATICA SINICA, VOL. 5, NO. 4, JULY 2018 827

Parallel Reinforcement Learning: A Framework and Case Study

Teng Liu, *Member*, *IEEE*, Bin Tian, Yunfeng Ai, Li Li, *Fellow*, *IEEE*, Dongpu Cao, *Member*, *IEEE*, and Fei-Yue Wang, *Fellow*, *IEEE*

Abstract—**In this paper, a new machine learning framework is developed for complex system control, called parallel reinforcement learning. To overcome data deficiency of current data-driven algorithms, a parallel system is built to improve complex learning system by self-guidance. Based on the Markov chain (MC) theory, we combine the transfer learning, predictive learning, deep learning and reinforcement learning to tackle the data and action processes and to express the knowledge. Parallel reinforcement learning framework is formulated and several case studies for real-world problems are finally introduced.**

Index Terms—**Deep learning, machine learning, parallel reinforcement learning, parallel system, predictive learning, transfer learning.**

I. Introduction

MACHINE learning especially deep reinforcement learning (DRL) experiences an ultrafast development in recent years [1], [2]. No matter in traditional visual detection

One of the issues is lack of generalization capability to new goals [3]. DRL agents need to collect new data and learn new model parameters for a new target. It is computationally expensive to retrain the learning model. Hence, we need to utilize the limited data well to accommodate the environments via learning.

Another issue is data inefficiency [8]. Acquiring large-scale action and interaction data of real complex systems is arduous. To explore control policy by themselves is very difficult for the learning systems. Thus, it is necessary to create a large number of observations for action and knowledge from the historical available data.

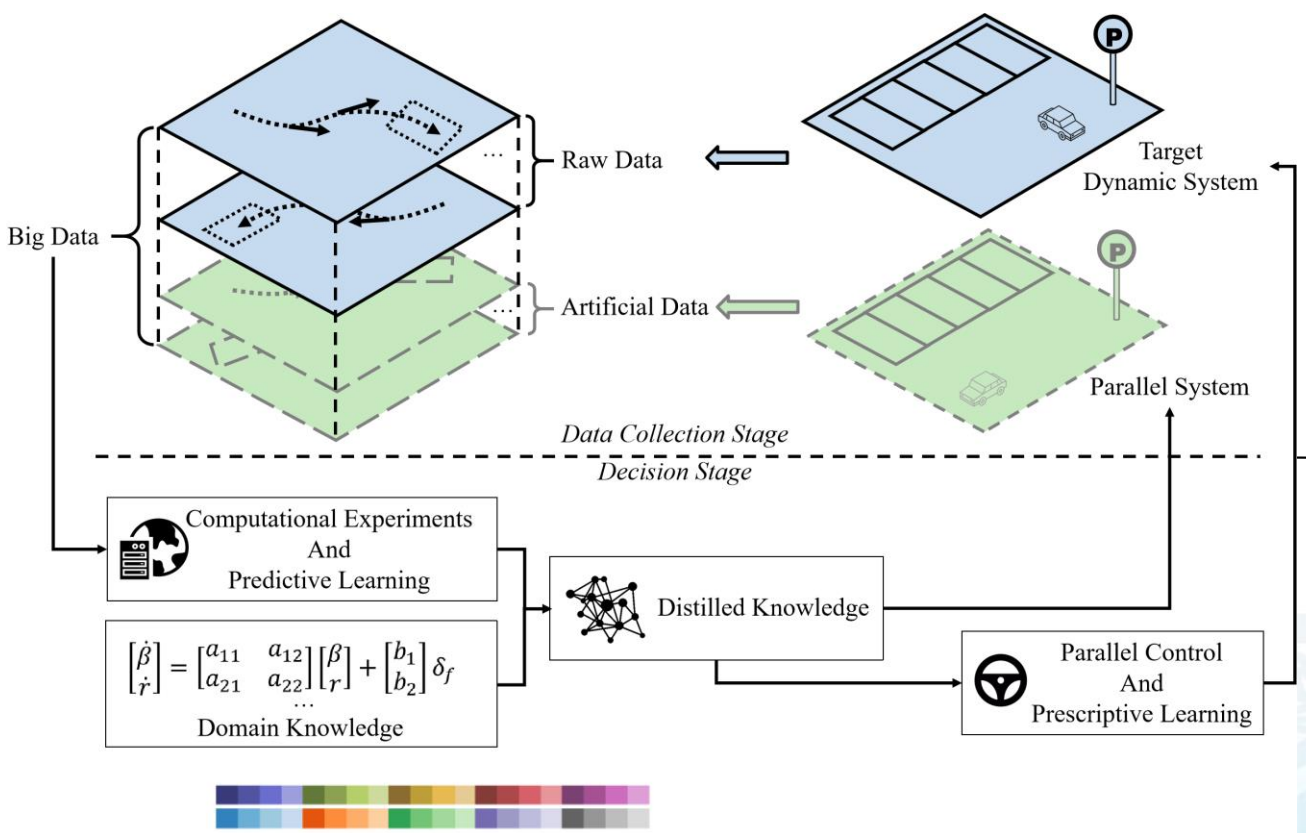
Finally, the issue is data dependency and distribution. In practical systems, data samples dependency is often uncertain and probability distribution is usually variant. So, it is hard for DRL agents to consider the state, action and knowledge of a learning system in an integrated way.

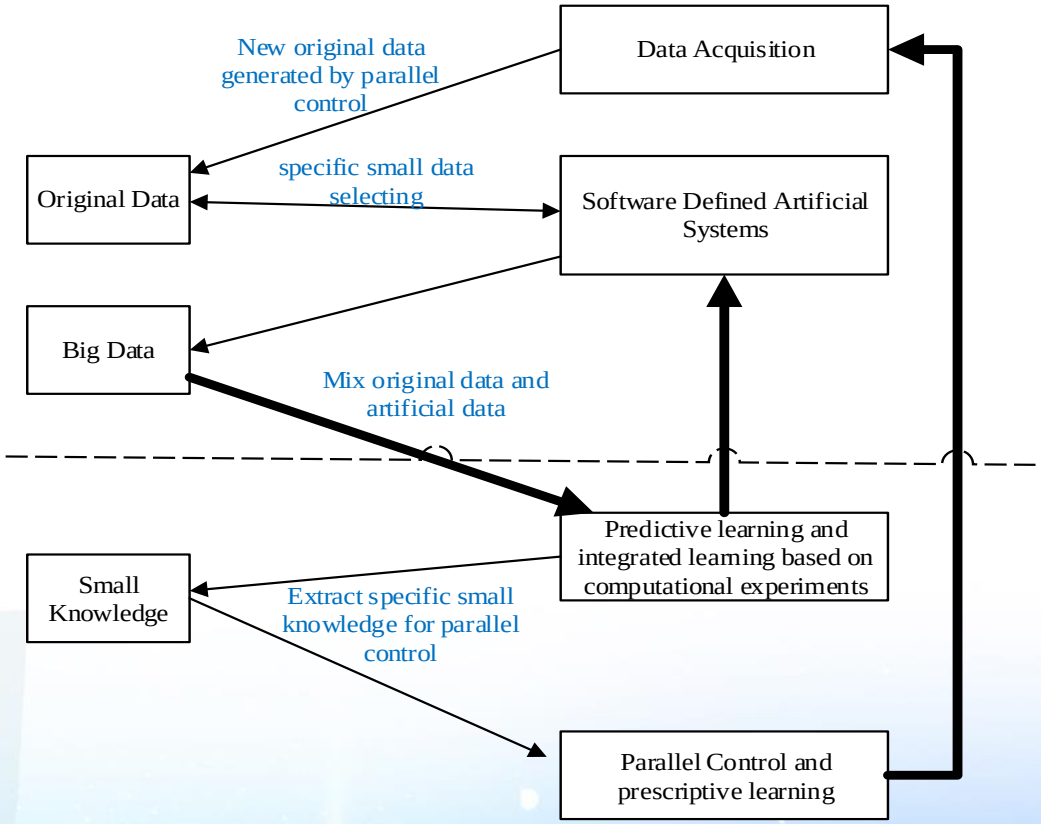
In order to address these difficulties, we develop a new

Parallel reinforcement learning framework

Liu Teng, Tian Bin , Ai Yunfeng, Li Li, Cao Dongpu, Wang Fei-Yue,"**Parallel Reinforcement Learning: A Framework and Case Study**", *Acta Automatica Sinica*, 2018, Vol. 5, No. 4, pp. 827-835.

Algorithms: Parallel Learning





The theoretical framework of parallel learning

Li Li, Lin Yilun, Cao Dongpu, Zheng Nanning, Wang Fei-Yue, "**Parallel Learning — A New Framework for Machine Learning**", *Acta Automatica Sinica*, 2017, Vol. 43, No. 1, pp. 1-8.

Method: Parallel Blockchain

Cyber-Physical-Social Systems

Physical Space

Mental Space

Artificial Space

Blockchain + Internet of Things

Block → Block → Block → Block → Block

Wang Fei-Yue, Yuan Yong, Rong Chunming, Zhang Jun, "Parallel Blockchain: An Architecture for CPSS-Based Smart Societies", *IEEE Transactions on Computational Social Systems,* 2018,Vol. 5, No. 2, pp.303-310.

Yuan Yong, Wang Fei-Yue, "Parallel Blockchain: Concept, Methods and Issues Acta Automatica Sinica", 2017, Vol. 43, No. 10, pp. 1703-1712.

Parallel Driving: Intel Collaborative Research Center

Intel Collaborative Research Institute on Intelligent and Automated Connected Vehicles (ICRI-IACV) is launched to devote synergized efforts to academic research and industrial development of CPSS-based parallel driving. **ICRI-IACV is launched by Intel, Institute of Automation, Chinese Academy of Sciences and Tsinghua University.**




青岛高新区

青岛智能产业技术研究院

QINGDAO ACADEMY OF INTELLIGENT INDUSTRIES

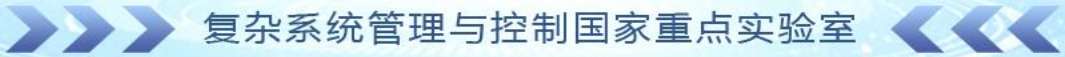
中科院自动化研究所青岛智能产业技术研究中心

CASIA CENTER FOR INTELLIGENT SYSTEMS AND IECHNOLOGY,CHINESE ACADEMY OF SCIENCES

青岛·高新技术产业开发区

2013





CAS Qingdao Academy of Intelligent Industries (2013)

QA:
Question & Answer
Basic Science

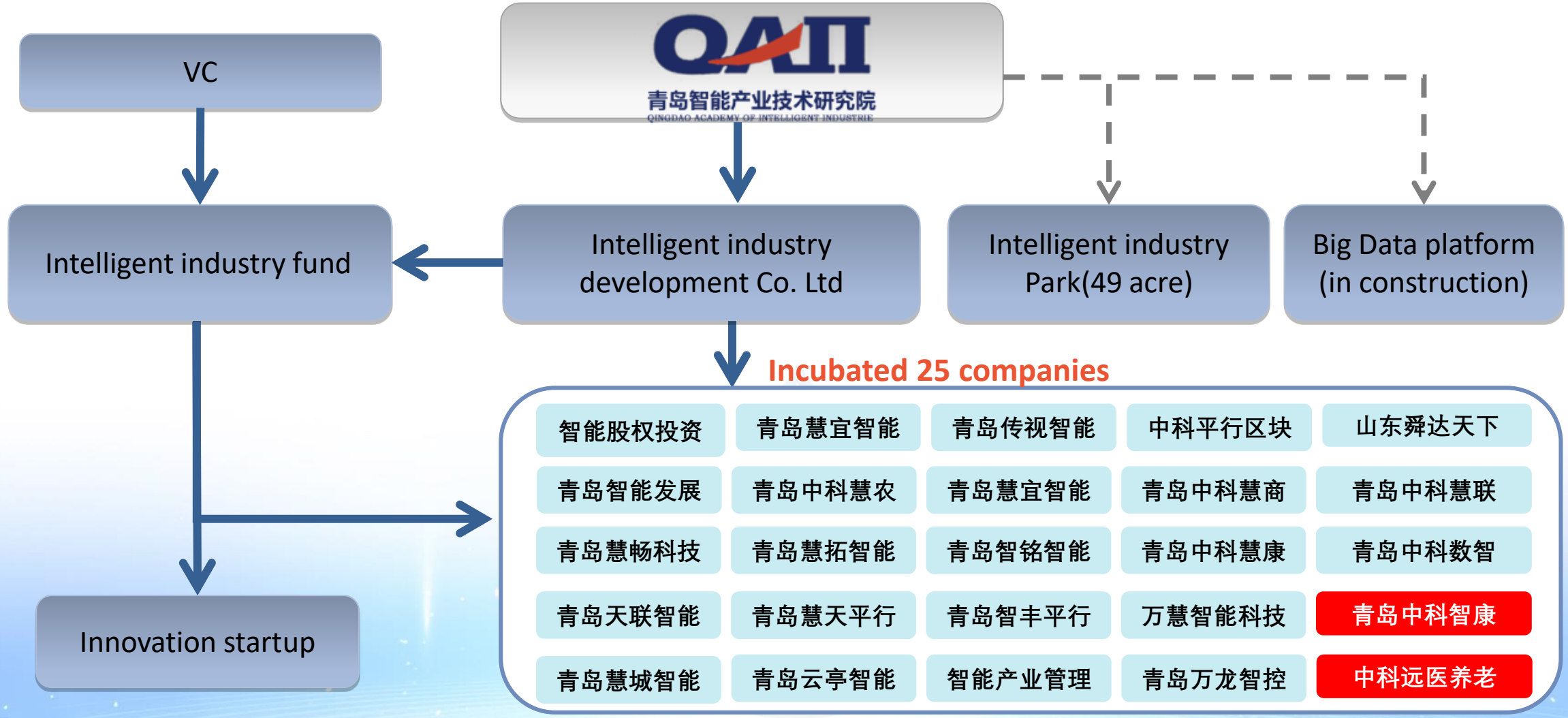
II:
Intelligent Industries
Parallel Intelligence

AI: Artificial

Headquater for Innovation, Makers and Commercialization.

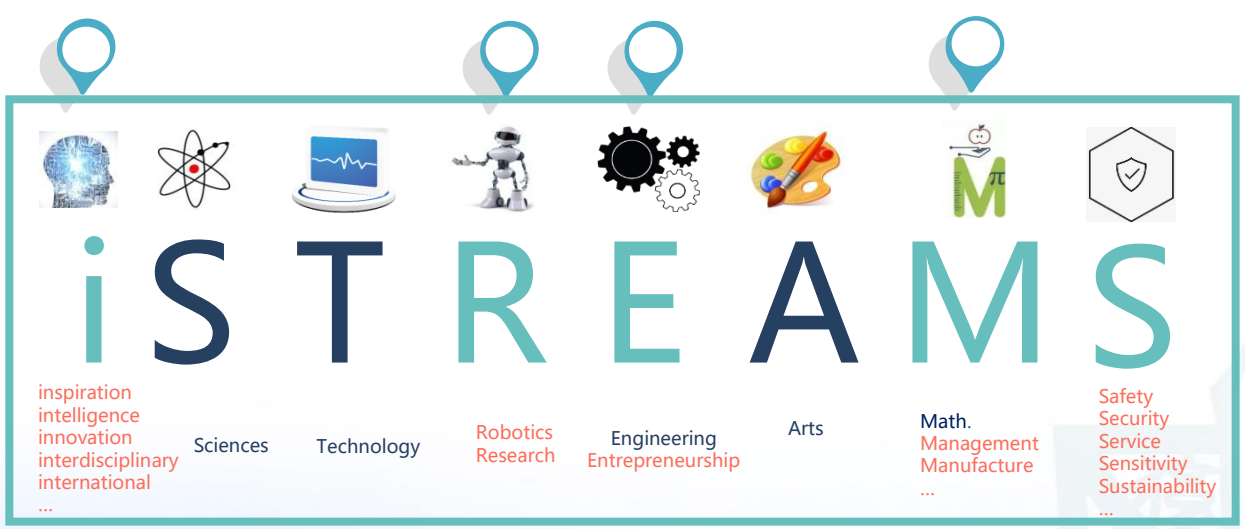
Welcome to QAII

QAII: Commercialization



Education First: A Smart Journey

智能航程



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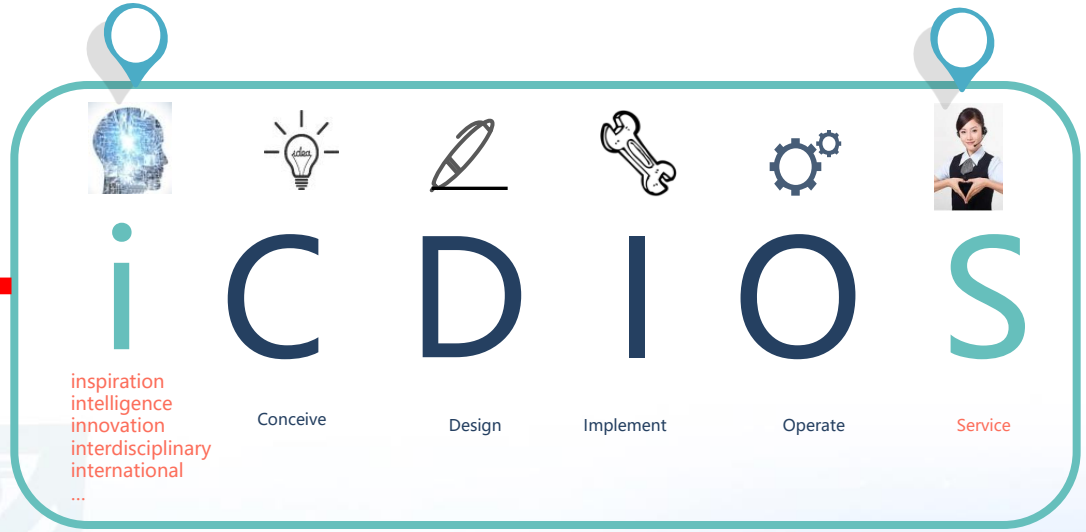
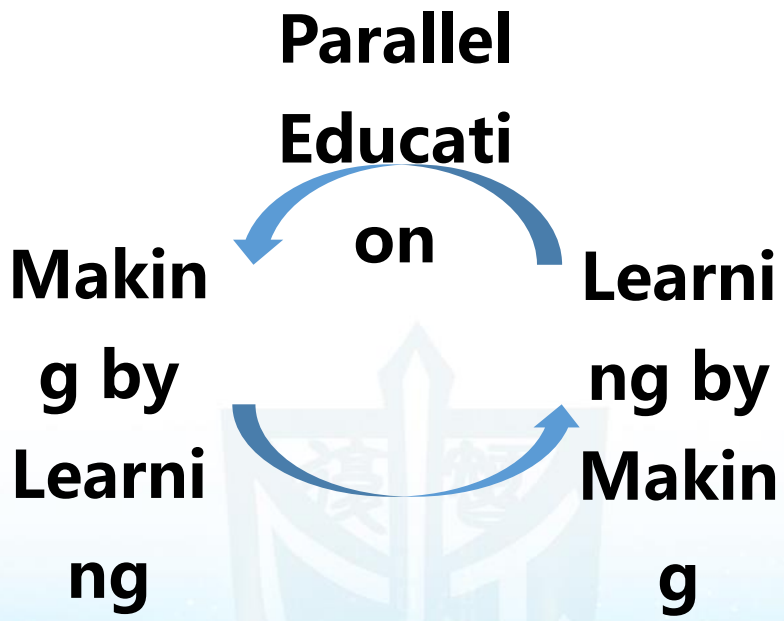


智航 iSTREAMS

智程 iCDIOS

Innovation in Education:From iSTREAM to iCDIOS



Seymour·Papert (1928-2016)

Fei-Yue Wang. **From iSTREAM to iCDIOS**: New IT for New Education of K-12 and Beyond, 2017 ASEE International Forum, June 28, 2017, Columbus, OH.

STEM → iSTREAMS








i S T R E A M S

i Inspiration, Intelligence, Innovation, Interdisciplinary, International, …

S Sciences

T Technology

R Robotics, Research

E Engineering, Entrepreneurship

A Arts

M Math, Management, Manufacture, …

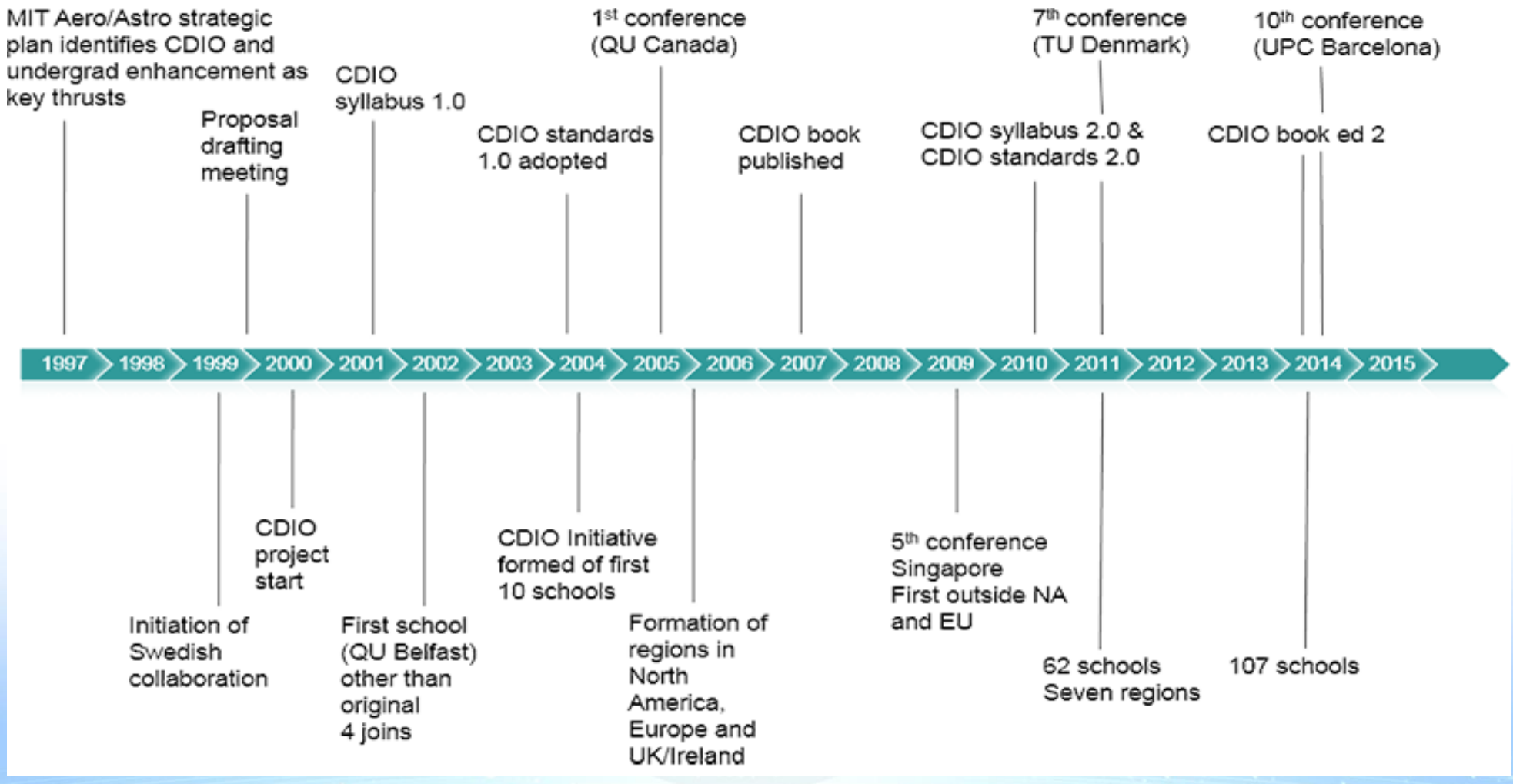
S Safety, Security, Service, Sensitivity, Sustainability, Smartness, …

Learning by Making

CDIO

- CDIO means Conceive, Design, Implement, and Operate.
- CDIO is an innovative educational framework for producing the next generation of engineers.
- In the late 1990s, MIT's Department of Aeronautics and Astronautics engaged in a rigorous process to determine the knowledge, skills and attitudes that graduating engineers should possess.
- MIT conceived that CDIO framework and joined three Swedish universities in 2000 to form the CDIO initiative with funding from the Wallenberg Foundation.
- CDIO mainly includes a vision, a syllabus and 12 standards.
- Edward Crawley received the 2011 Bernard M. Gordon Prize for his work in CDIO from the National Academy of Engineer.

CDIO


MIT Aero/Astro strategic plan identifies CDIO and undergrad enhancement as key thrusts
Proposal drafting meeting
CDIO syllabus 1.0
CDIO standards 1.0 adopted
1st conference (QU Canada)
CDIO book published
CDIO syllabus 2.0 & CDIO standards 2.0
7th conference (TU Denmark)
10th conference (UPC Barcelona)
CDIO book ed 2
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Initiation of Swedish collaboration
CDIO project start
First school (QU Belfast) other than original 4 joins
CDIO Initiative formed of first 10 schools
Formation of regions in North America, Europe and UK/Ireland
5th conference Singapore First outside NA and EU
62 schools Seven regions
107 schools

CDIO-Based Social Manufacturing Laboratory

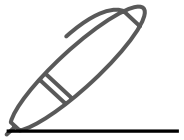
acquisition platform

Interactive discussion

Conceiving	Establishing system goals and requirements
	Defining Custom featu
	System modeling and to ens
	Management of
Designing	Design
	Staging the
	ng knowl
	Design of pro
	Design of c
	Integrated multi-design
Implementing	Process of designing and implementation
	Hardware manufacturing process
	Software manufacturing process
	Combination of hardware and software
	Testing, verification, certification and obtaining a certificate
	Implementation process management
Operating	Designing and optimization operations
	Trai
	System im
	Disposal treatment a
	Operat

A CDIO-Based Social Manufacturing Laboratory: Prototype for CPSS-Based Production Processes, 2016 ASEE Annual Conference, June 26-29, 2016, New Orleans, LA.

CDIO → iCDIOS


i C D I O S

Inspiration
Innovation
Intelligence
...

Conceive Design Implement Operate

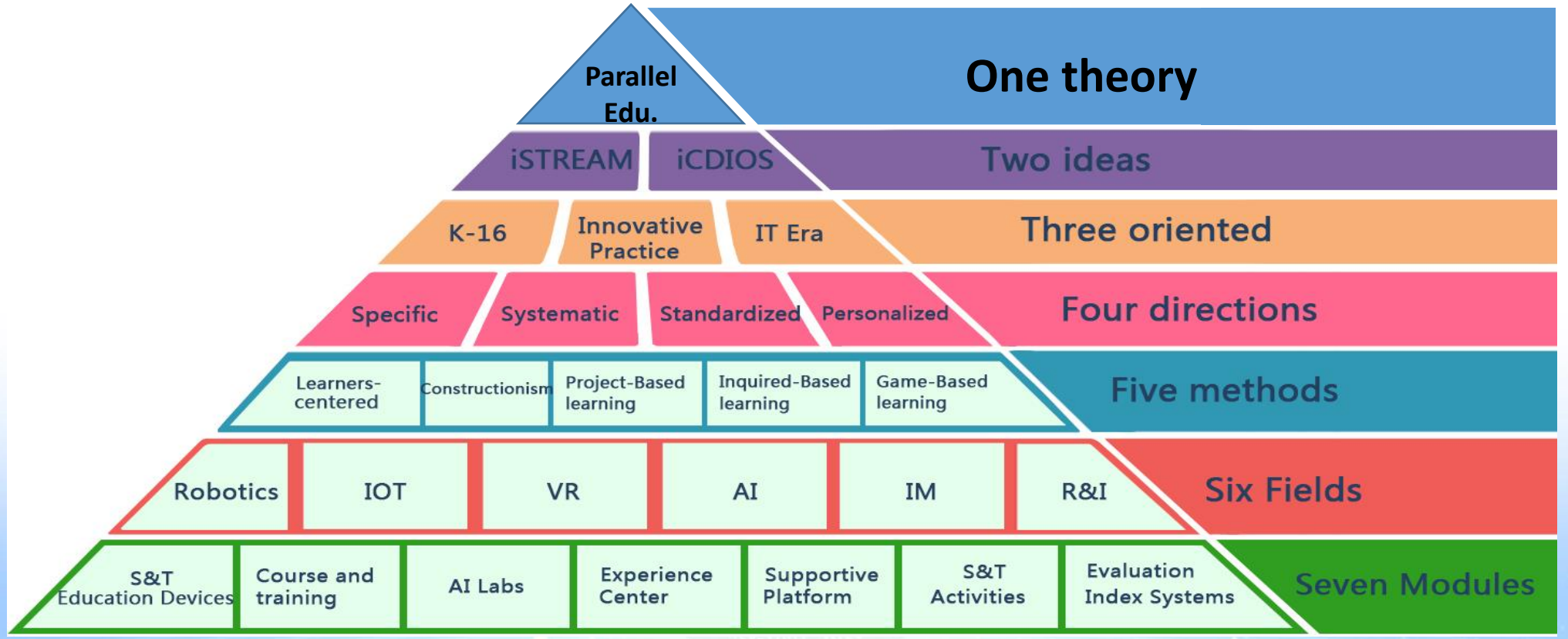
Service
Security
Sustainability

Making by Learning

Parallel Education: New Journey and New Destination

智能航程 = 智航 + 智程

Smart March + Smart Destination = 智航iSTREAM + 智程iCDIOS



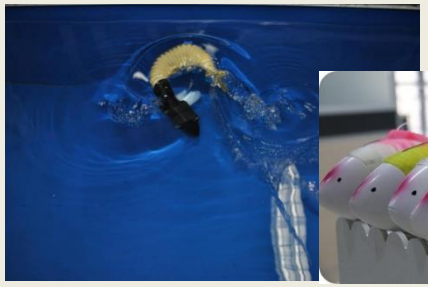
Education First: A Smart Journey

图形化编程无人机

取水无人机

智能机器人

VR



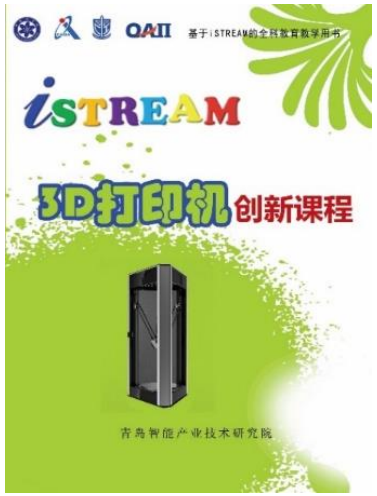
机器鱼

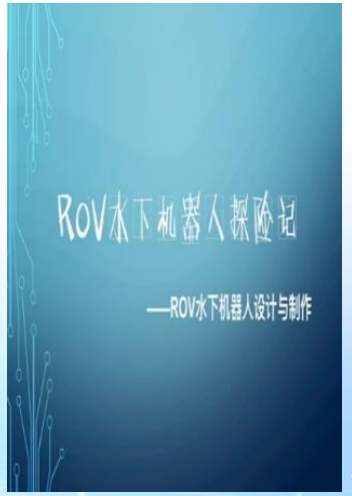
3D打印机

水下机器人

Education First: A Smart Journey

Education First: A Smart Journey





Education First: A Smart Journey（2017）

云南弥勒第三中学和五山乡中心小学智航助学助教基地

Education First: A Smart Journey（2018）

甘肃省定西市通渭县马营初级中学、平襄镇徐家川小学智航助学助教基地

Education First：A Smart Journey（2018）

陕西省榆林市米脂县镇子湾小学智航助学助教基地

Education First: A Smart Journey（2019）

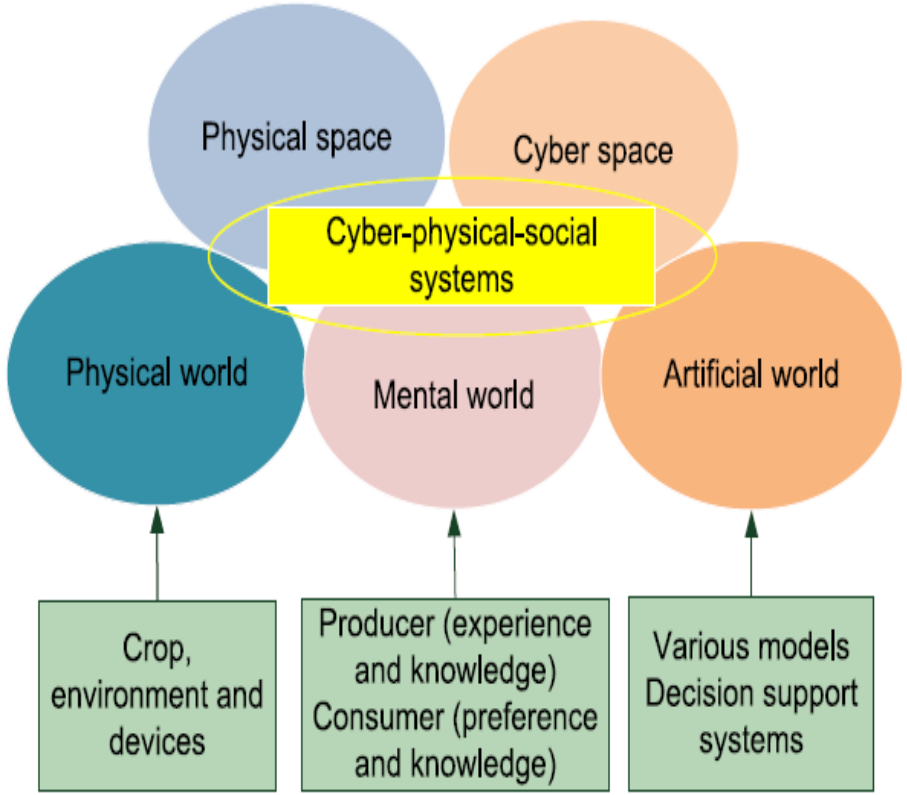
安徽桐城范岗初中、贵州册亨者楼中小学、云南屏边第一中学智航助学助教基地及捐赠仪式

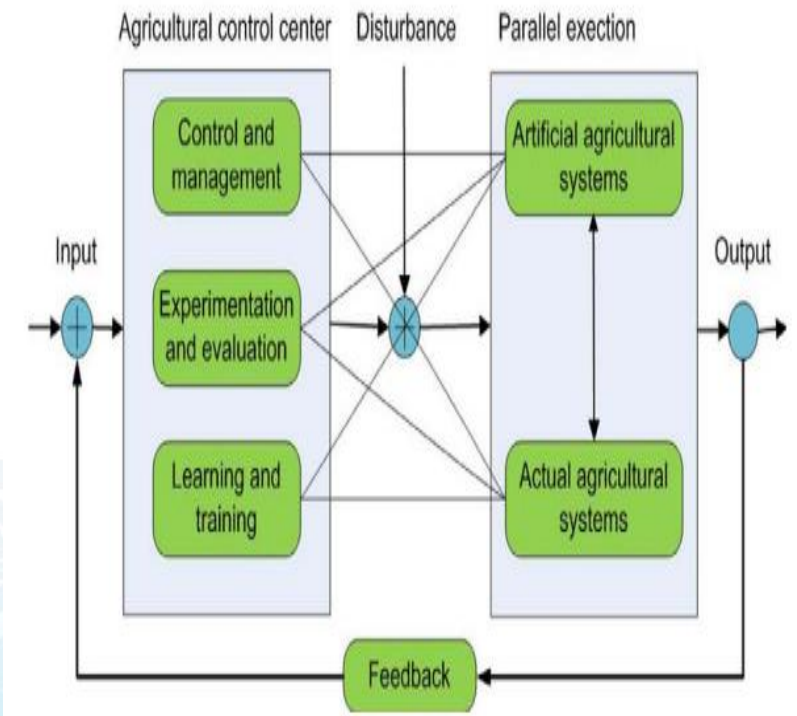
Education First：A Smart Journey（2019）

陕西横山武镇中心小学智航助学助教基地及捐赠仪式

Education First：A Smart Journey（2019）

Parallel Agriculture





康孟珍, 王秀娟, 华净, 王浩宇,王飞跃, “平行农业：迈向智慧农业的智能技术”, 智能科学与技术学报, 2019, Vol. 1, No. 2, pp. 107-117.
Mengzhen KANG,Xiujuan WANG,Jing HUA,Haoyu WANG,Fei-Yue WANG. “Parallel agriculture:intelligent technology toward smartagriculture”, CHINESE JOURNAL OF INTELLIGENT SCIENCE AND TECHNOLOGIE, 2019, Vol. 1, No. 2, pp. 107-117.

Parallel Cities

虚实互动的平行城市：基本框架、方法与应用

吕宜生[1]，王飞跃[1,2]，张宇[3]，张晓东[3]

（1. 中国科学院自动化研究所复杂系统管理与控制国家重点实验室，北京 100190；
2. 中国科学院大学人工智能学院，北京 101408；
3. 北京市城市规划设计研究院，北京 100045）

摘　要：概述了平行城市的概念、框架、方法与应用。平行城市是基于 ACP 方法的平行智能在城市领域中的应用。实际城市和与之对应的虚拟空间中的人工城市平行运行、虚实互动，物理空间映射于虚拟空间，人工城市系统描述、预测、引导实际城市系统，虚实闭环，迭代优化，实现智慧城市管理的新模式。

关键词：平行系统；平行城市；数字孪生；ACP 方法

吕宜生, 王飞跃, 张宇, 张晓东, “虚实互动的平行城市：基本框架、方法与应用”, 智能科学与技术学报, 2019, Vol. 1, No. 3, pp. 311-317.
Yisheng LYU,Fei-Yue WANG,Yu ZHANG,Xiaodong ZHANG, “Parallel Cities:Framework,Methodology,and Application”, CHINESE JOURNAL OF INTELLIGENT SCIENCE AND TECHNOLOGIE, 2019, Vol. 1, No. 3, pp. 311-317.

Parallel Security

平行安全：基于 CPSS 的生成式对抗安全智能系统

李泓东[1]，张俊[2,3]，陶耀东[1]，王伟[1]，顾元祥[4]，王飞跃[2,5,6]

（1. 北京交通大学，北京 100044；2. 中国科学院自动化研究所，北京 100190；
3. 武汉大学，湖北 武汉 430000；4. 爱迪德公司，加拿大 渥太华 K2T1G5；
5. 中国科学院大学，北京 100049；6. 青岛智能产业技术研究院，山东 青岛 266109）

摘　要：人工智能、大数据等新一代信息技术的兴起使网络空间安全面临的威胁与挑战进一步复杂化。传统防御技术多采用“打补丁”式的被动检测防护机制，很难满足由新的攻击特征带来的安全防护需求。首次系统性地提出以平行智能 ACP 理论为基础思想的平行安全系统框架，利用生成式对抗模型、平行情报、平行区块链等方法，融入社会学、心理学和行为学等因素，建立了集描述性安全、预测性安全和引导性安全于一体的防护体系，旨在实现以“增强免疫力”为目标的预测引导防护。以工业互联网典型场景为实际案例，设计并研发了首个以平行安

李泓东,张俊,陶耀东, 等,“平行安全：基于CPSS的生成式对抗安全智能系统”, 智能科学与技术学报, 2020, Vol. 2, No. 2, pp. 194-202.
Yidong LI,Jun ZHANG,Yaodong TAO,Wei WANG,Yuanxiang GU,Fei-Yue WANG, “Parallel Security: Generative Adversarial Systems for Intelligent Security in CPSS”, CHINESE JOURNAL OF INTELLIGENT SCIENCE AND TECHNOLOGIE, 2020, Vol. 2, No. 2, pp. 194-202.

Parallel Nuclear Emergency Evacuation

Pedestrian Choice Modeling and Simulation of Staged Evacuation Strategies in Daya Bay Nuclear Power Plant

Linyao Yang, Xiao Wang, *Member, IEEE*, Jun Jason Zhang, *Senior Member, IEEE*, Min Zhou, *Student Member, IEEE*, and Fei-Yue Wang, *Fellow, IEEE*

***Abstract*— Considering the distances to exits, exits' capacities, the sizes of queues at exits, distances to the nuclear power plant, as well as individual characteristics, the exit choice model for pedestrians in the plume planning area is established based on a random forest model. This model is trained and verified with the survey data of residents around the Daya Bay Nuclear Power Plant collected from a serious game-based questionnaire system. Combining the pedestrian choice with the agent-based pedestrian behavior simulation model, the evacuation process of a nuclear accident is simulated. Based on the detailed evacuation simulation model, a comparative experiment is performed to evaluate the staged evacuation strategy in such scenarios. Simulation results indicate that staged evacuation may not be the best strategy all the time, and the number of groups highly impacts its**

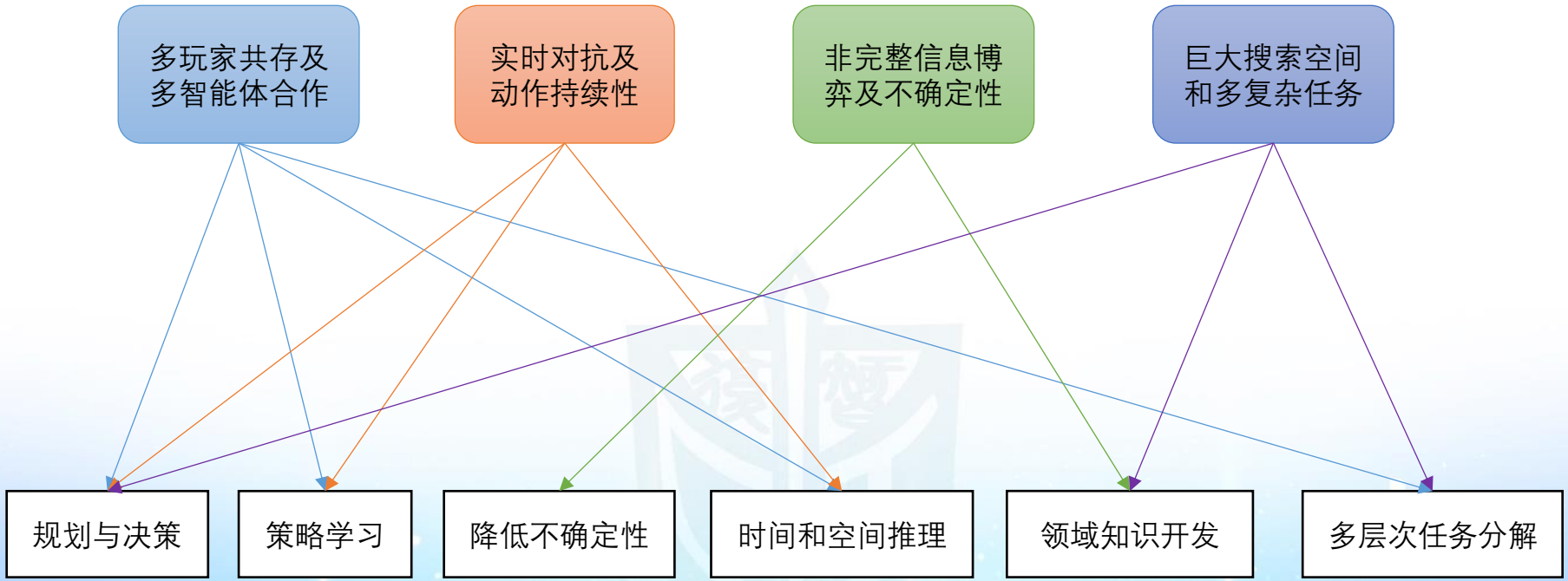
thus, a series of general guidance on nuclear emergency management has been made by international agencies, such as the International Atomic Energy Agency (IAEA) and the European Atomic Energy Community (EURATOM), as well as national government organizations [2], taking the National Nuclear Emergency Preparedness Plan [3] for instance.

As a crucial component of nuclear emergency management and response, the main objective of evacuation is to rapidly withdraw people from areas to be affected by radioactive materials to safe refuges [4]. In reality, it often refers to evacuating those people within 5–10 km away from the nuclear power plant to a safe zone outside this range. Simulations

L. Yang, X. Wang, J. J. Zhang, M. Zhou and F.-Y. Wang, "**Pedestrian Choice Modeling and Simulation of Staged Evacuation Strategies in Daya Bay Nuclear Power Plant**," in IEEE Transactions on Computational Social Systems, Vol. 7, No. 3, pp. 686-695, June 2020.

Parallel Games

多智能体实时策略游戏的难点与人工智能研究挑战的对应关系



Parallel Games

第 1 卷第 1 期 智能科学与技术学报 Vol.1 No.1
2019 年 3 月 Chinese Journal of Intelligent Science and Technology March 2019

游戏智能中的 AI——从多角色博弈到平行博弈

沈宇[1,2]，韩金朋[3]，李灵犀[4]，王飞跃[1,2,5]

（1. 中国科学院大学人工智能学院，北京 100049；

2. 中国科学院自动化研究所复杂系统管理与控制国家重点实验室，北京 100190；

3. 西安交通大学软件学院，西安 710049

4.印第安纳大学-普渡大学印第安纳波利斯分校电子与计算机工程系，美国 印第安纳波利斯 IN 46202；

5.青岛智能产业技术研究院， 山东 青岛 266109）

摘 要： 总结了国内外人工智能技术在游戏领域的研究进展，分析了游戏领域的研究进步对于现实社会的意义。

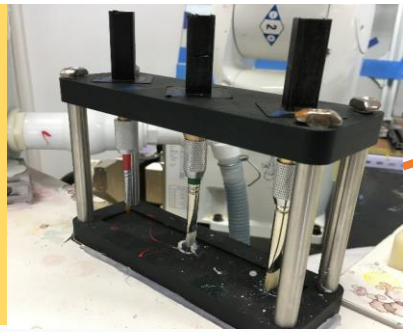
沈宇,韩金朋,李灵犀,王飞跃, “游戏智能中的AI——从多角色博弈到平行博弈”, 智能科学与技术学报, 2020,Vol2, No. 3, pp.205-213.
Yu SHEN,Jinpeng HAN,Lingxi LI,Fei-Yue WANG, “AI in game intelligence—from multi-role game to parallel game”, CHINESE JOURNAL OF INTELLIGENT SCIENCE AND TECHNOLOGIE, 2020,Vol2, No. 3, pp.205-213.

Parallel Art

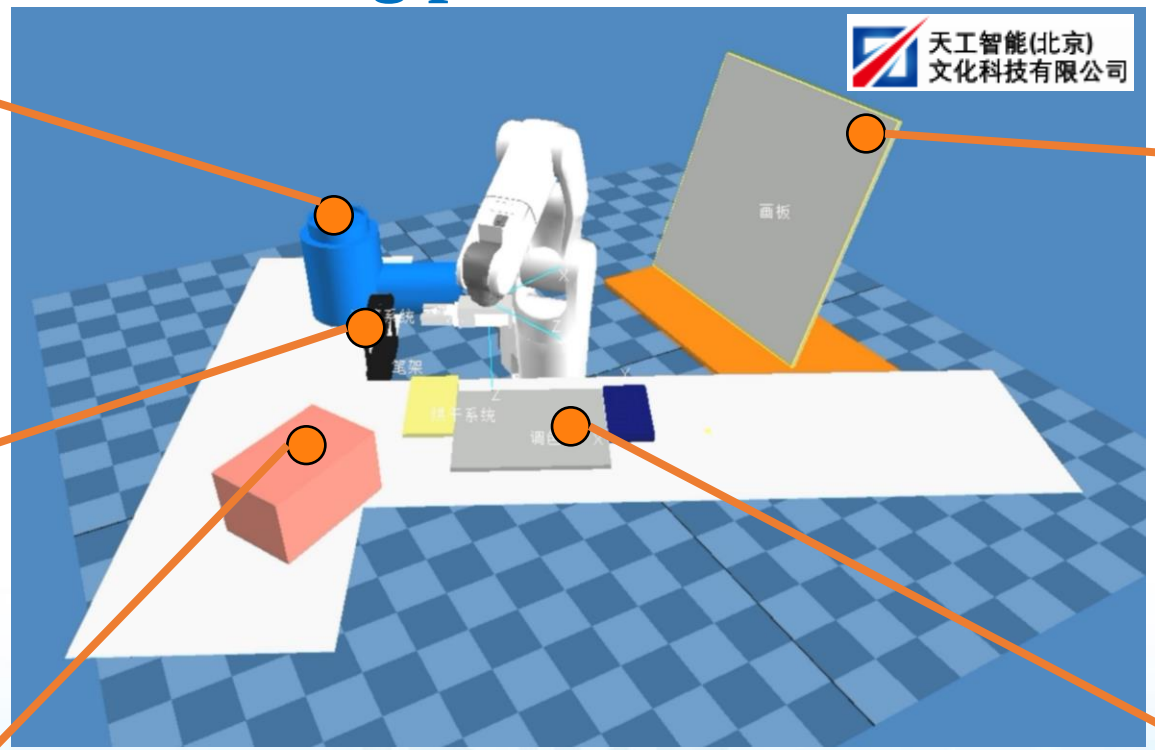
Painting process control

Washing bucket

penholder

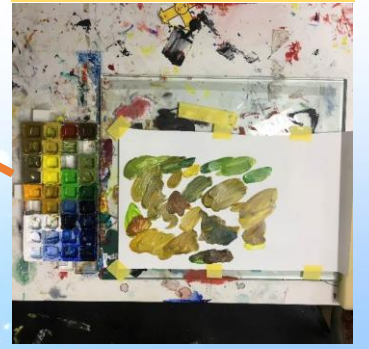


Air dryer

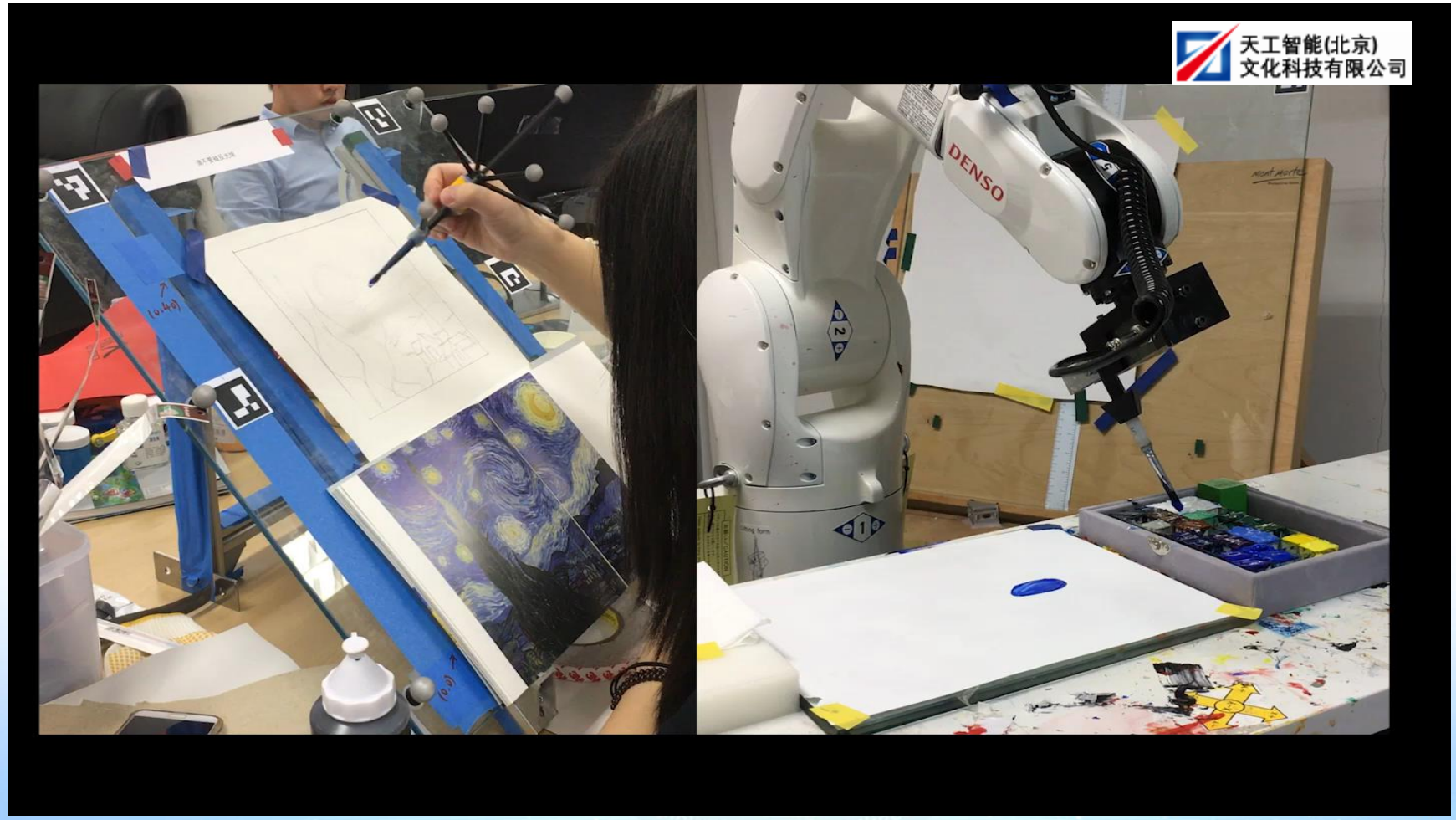


sketchpad

Paint box



Parallel Art



Parallel Art

第 1 卷第 4 期 智能科学与技术学报 Vol.1 No.4
2019 年 12 月 Chinese Journal of Intelligent Science and Technology December 2019

平行艺术：人机协作的艺术创作

郭超[1,2]，鲁越[1,2]，林懿伦[1]，卓凡[3]，王飞跃[1,2,4]

（1. 中国科学院自动化研究所复杂系统管理与控制国家重点实验室，北京 100190；
2. 中国科学院大学，北京 100049；
3. 中央美术学院，北京 100102；
4. 青岛智能产业技术研究院，山东 青岛 266109）

摘 要：近年来，机器艺术创作逐步得到了人们的重视和长足的发展，通过算法加工的作品，甚至纯粹由机器生成的作品越来越多地出现在人们的视野中。然而，这些作品在感官效果上与人类的艺术作品相去甚远，且不具备共情属性，因此难以被人类认可。与此同时，技术对艺术领域的冲击也引起了人们的担忧。针对目前机器和人在艺术创作中面临的技术问题和人机关系问题，提出了平行艺术理论体系。该体系旨在构建机器与人的伙伴关系，使人与机器在艺术创作中以平行的方式进行配合与协作。这也将为融合以人为主的情感关系与以机器为主的逻辑关系提供一个新思路。

郭超,鲁越,林懿伦,卓凡,王飞跃,“平行艺术：人机协作的艺术创作”, 智能科学与技术学报, 2019, Vol. 1, No. 4, pp. 335-341.
Chao GUO,Yue LU,Yilun LIN,Fan ZHUO,Fei-Yue WANG. Parallel art:artistic creation under human-machine collaboration. CHINESE JOURNAL OF INTELLIGENT SCIENCE AND TECHNOLOGIE, 2019, Vol. 1, No. 4, pp. 335-341.

Computational Aesthetics of Fine Art Paintings: The state of the Art and Outlook

第 46 卷 第 11 期 自 动 化 学 报 Vol. 46, No. 11
2020 年 11 月 ACTA AUTOMATICA SINICA November, 2020

绘画艺术图像的计算美学: 研究前沿与展望

鲁 越[1,2] 郭 超[1,2] 林懿伦[1] 卓 凡[3] 王飞跃[1]

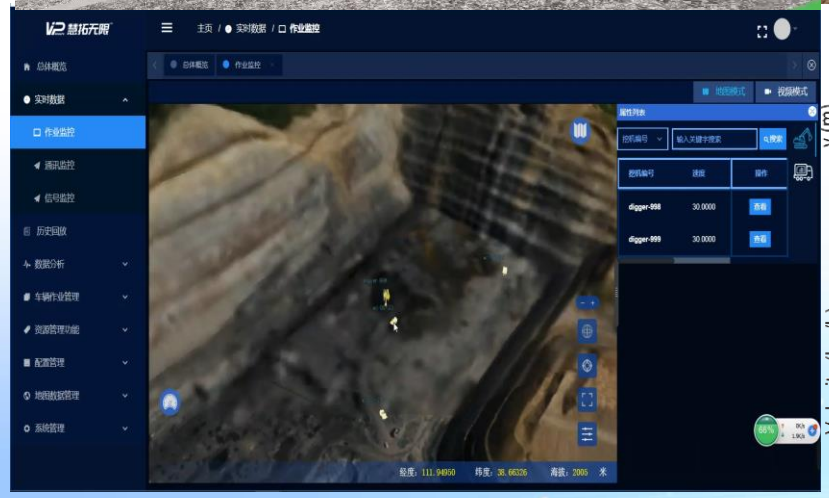
摘 要 绘画艺术是人类艺术创作的重要组成部分, 绘画艺术图像的计算美学是利用机器实现可计算的人类审美过程, 其在大规模绘画的自动化分析和机器对感性的计算建模上具有重要的应用价值和科学意义. 针对其交叉学科的特点, 本文首次从人类审美的感知、认知和评价三个关键过程出发, 将绘画艺术图像的计算美学研究完整地归纳为属性识别、内容理解和美学评价三方面研究内容, 对其中的问题建模、数据获取和前沿方法等关键科学问题进行了归纳总结, 并对绘画计算美学的三方面研究内容进行了对比、思考和展望.

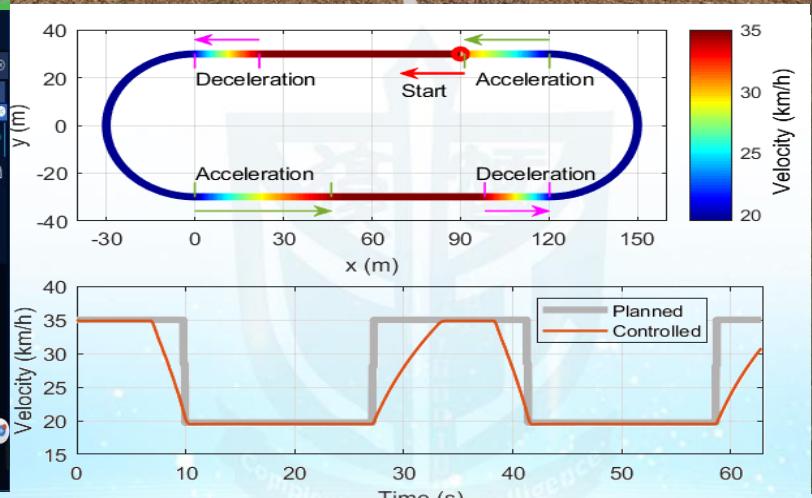
鲁越, 郭超, 林懿伦, 卓凡, 王飞跃. 绘画艺术图像的计算美学: 研究前沿与展望. 自动化学报, 2020, Vol. 46, No.11,pp. 2239−2259.
Lu Yue, Guo Chao, Lin Yi-Lun, Zhuo Fan, Wang Fei-Yue. Computational Aesthetics of Fine Art Paintings: The State of the Art and Outlook. *Acta Automatica Sinica*, 2020, Vol. 46, No.11,pp.2239−2259.

Parallel Mining

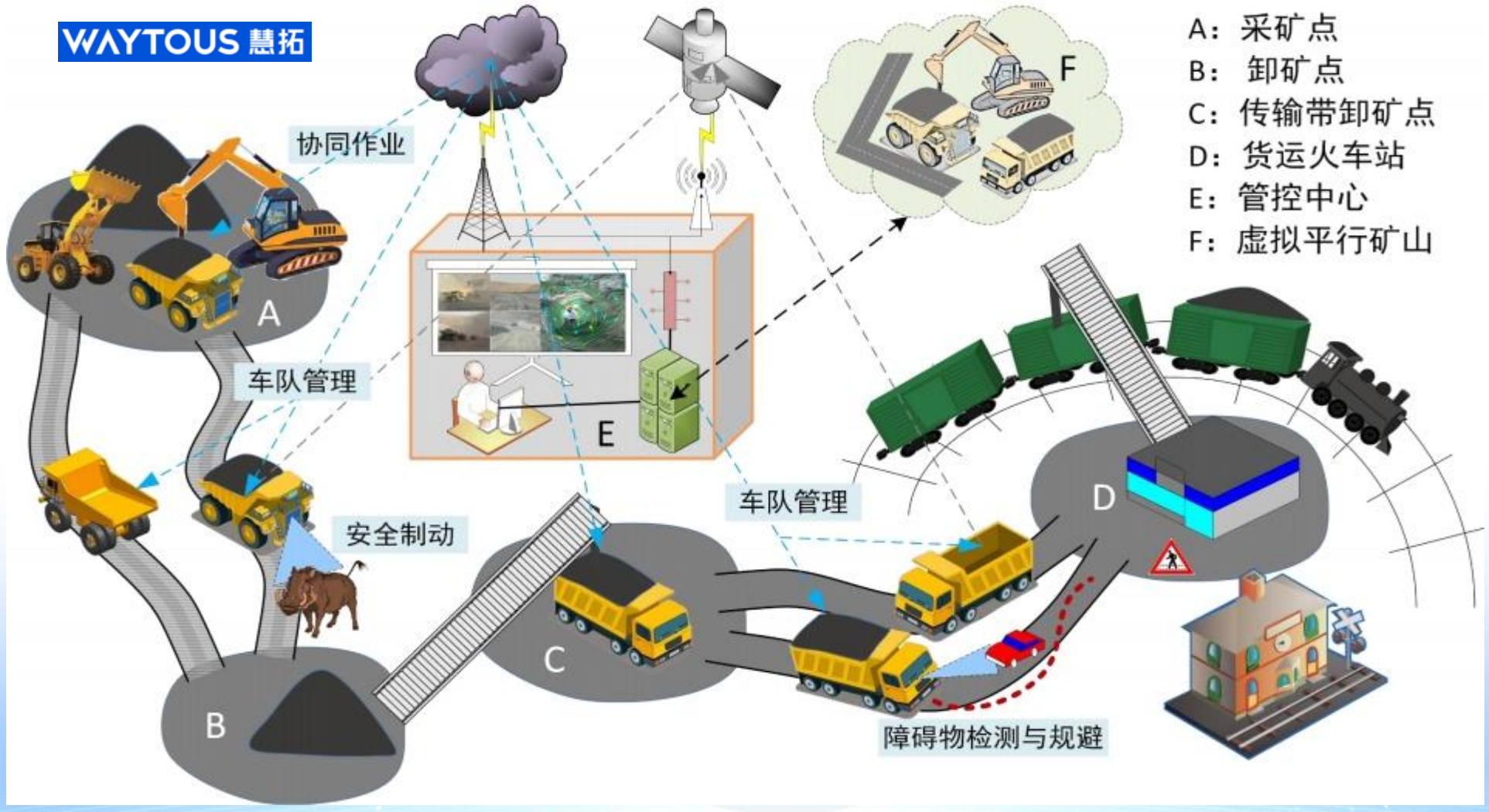
Parallel Mining

WAYTOUS 慧拓





Parallel Mining



Parallel Mining

全球首套极寒条件220吨矿用车无人驾驶编组(5台)

Parallel Mining

IEEE INTERNET OF THINGS JOURNAL, VOL. 7, NO. 2, FEBRUARY 2020 1011

Parallel End-to-End Autonomous Mining: An IoT-Oriented Approach

Yu Gao, Yunfeng Ai, Bin Tian, Long Chen, Jian Wang, Dongpu Cao, *Member, IEEE*, and Fei-Yue Wang, *Fellow, IEEE*

***Abstract*—This article proposes a new solution for end-to-end autonomous mining operations: Internet of Things (IoT)-based parallel mining, consisting of the concept definition, the solution given, and the concrete realization. The proposed parallel mining is inspired by the artificial societies (A) for modeling, computational experiments (C) for analysis, and parallel execution (P) for control (ACP) approach. The basic framework of parallel mining is given and its advantages are expounded. Then, the solution of parallel mining is proposed, which is mainly**

I. Introduction

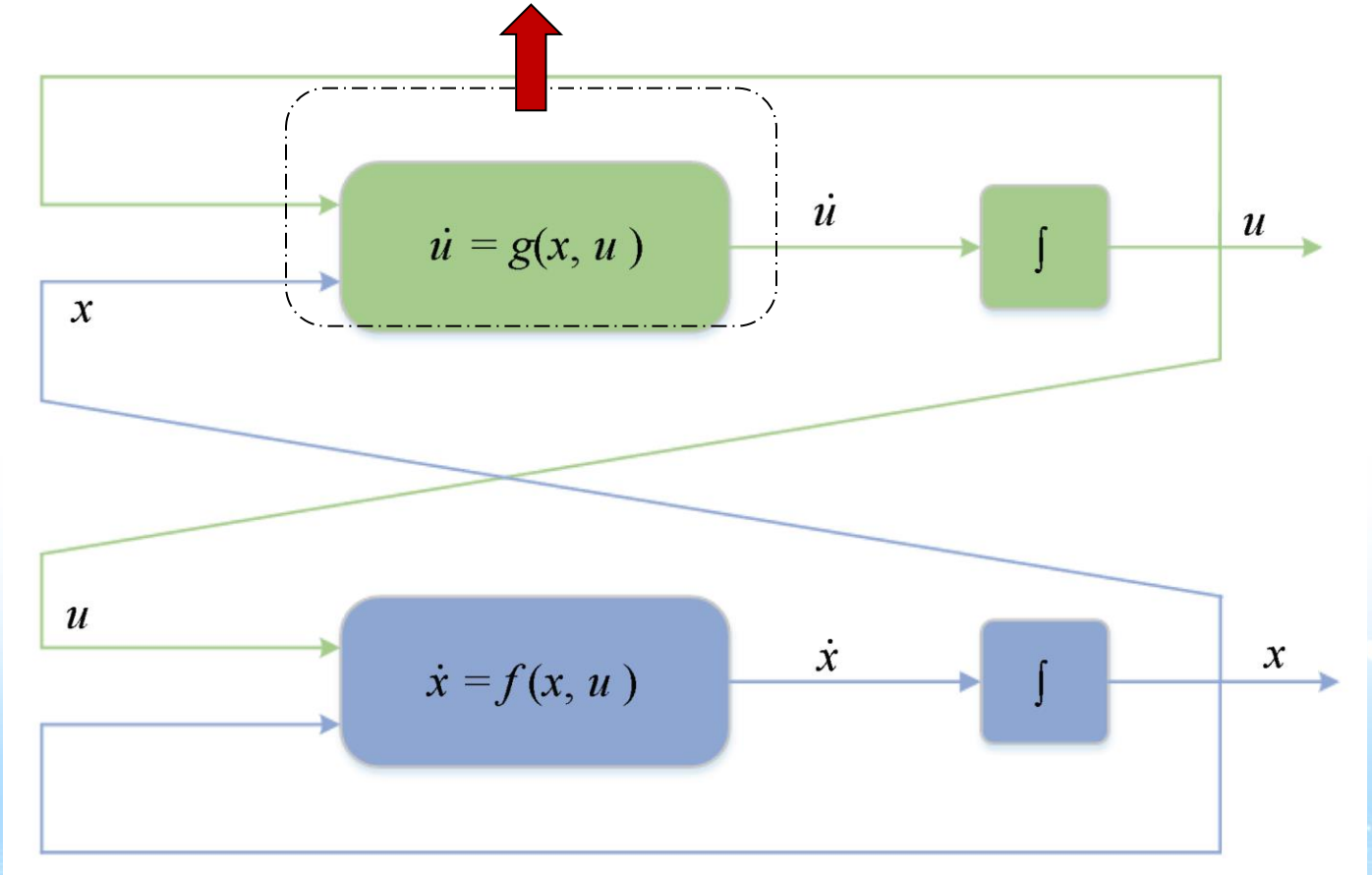
TODAY, the world has entered a new era of intellectualized development. Cyber, physical, and social systems can be integrated by the Internet of Things (IoT), which enables the perception, computation, and execution in an intelligent design paradigm [1]. Under such a background, the mining industry is facing many challenges, such as

Yu Gao, Yunfeng Ai, Bin Tian, Long Chen, Jian Wang, Dongpu Cao, Fei-Yue Wang, "Parallel End-to-End Autonomous Mining: An IoT-Oriented Approach", IEEE Internet of Things Journal, Feb. 2020, Vol. 7, No. 2, pp. 1011-1023.

Parallel Mining

Parallel Control

The derivative of control is used in parallel control, providing the basis for prescriptive control.



Parallel Control

IEEE/CAA JOURNAL OF AUTOMATICA SINICA, VOL. 7, NO. 4, JULY 2020

Parallel Control for Continuous-Time Linear Systems: A Case Study

Qinglai Wei, *Member*, *IEEE*, Hongyang Li, and Fei-Yue Wang, *Fellow*, *IEEE*

***Abstract*—In this paper, a new parallel controller is developed for continuous-time linear systems. The main contribution of the method is to establish a new parallel control law, where both state and control are considered as the input. The structure of the parallel control is provided, and the relationship between the parallel control and traditional feedback controls is presented. Considering the situations that the systems are controllable and incompletely controllable, the properties of the parallel control law are analyzed. The parallel controller design algorithms are given under the conditions that the systems are controllable and incompletely controllable. Finally, numerical simulations are carried out to demonstrate the effectiveness and applicability of the present method.**

of industrial control systems, the intelligent control theory, such as fuzzy control [6], neural network control [7], adaptive dynamic programming [8], [9], is attracted by researchers. Among these previous stages, most system control problems are analyzed by state feedback control methods in present study: we generally design state feedback controllers to form closed-loop systems, that is, the control laws are functions of the system states. However, the state feedback controllers have some disadvantages:

1) The traditional state feedback controllers are only related to the system states rather than the properties of the controllers

Q. Wei, H. Li, F. –Y. Wang, Parallel control for continuous-time linear systems: a case study, *IEEE/CAA Journal of Automatica Sinica*, 2020,Vol. 7, No 4, pp. 919-928.

Parallel Control

Parallel Control for Optimal Tracking via Adaptive Dynamic Programming

Jingwei Lu, Qinglai Wei, *Senior Member*, *IEEE*, and Fei-Yue Wang, *Fellow*, *IEEE*

***Abstract*—This paper studies the problem of optimal parallel tracking control for continuous-time general nonlinear systems. Unlike existing optimal state feedback control, the control input of the optimal parallel control is introduced into the feedback system. However, due to the introduction of control input into the feedback system, the optimal state feedback control methods can not be applied directly. To address this problem, an augmented system and an augmented performance index function are proposed firstly. Thus, the general nonlinear system is transformed into an affine nonlinear system. The difference between the optimal parallel control and the optimal state feedback control is analyzed theoretically. It is proven that the optimal parallel control with the augmented performance index function can be seen as the suboptimal state feedback control**

due to the development of science and computational capacity of computers, and the intelligent control is one of the most rapidly developing technologies recently [1]–[9]. In the area of intelligent control, adaptive dynamic programming (ADP), proposed by Werbos [10], [11], is an effective technique to solve optimal control problems of nonlinear systems. Such optimal control problems are often required to solve a nonlinear partial differential equation called the Hamilton-Jacobi-Bellman (HJB) equation [12]–[15], and the analytic solutions of the HJB equation can not be obtained directly in most cases. Thus, the ADP technique emerges to obtain the solution of the HJB equation forward-in-time and has attracted much

J. Lu, Q. Wei, F. –Y. Wang, "Parallel control for optimal tracking via adaptive dynamic programming", *IEEE/CAA Journal of Automatica Sinica*, 2020, Vol. 7, No. 6, pp. 1662-1674.

Parallel Control

第 2 卷第 3 期 智能科学与技术学报 Vol.2 No.3
2020 年 9 月 Chinese Journal of Intelligent Science and Technology September 2020

平行控制与数字孪生：经典控制理论的回顾与重铸

王飞跃 [1,2,3]

（1. 中国科学院自动化研究所复杂系统管理与控制国家重点实验室，北京 100190；
2. 中国科学院大学，北京 100049；3. 青岛智能产业技术研究院，山东 青岛 266109）

摘 要：简要回顾经典控制、智能控制、平行控制的起源与发展，针对具有高精度数字孪生模型的情况，给出相应的平行控制数学形式，并讨论其意义和应用。中心思想是对控制向量的时间导数进行建模，而不是对控制向量本身进行建模，由基于代数关系的控制变为基于微分方程的控制，从而使控制系统与被控系统在数学形式和内容上完全等价，为控制器的拟人化和智能化奠定基础。同时，采用同样思想得出的主动感知的平行传感方程，为智能平行传感器的设计提供了可能的方向。初步分析表明，这一变革具有重要意义，十分适合云边计算范式，值得进行深入探索和研究。

王飞跃, “平行控制与数字孪生：经典控制理论的回归与重铸”, 智能科学与技术学报, 2020,Vol. 2, No. 3, pp. 293-300.
F. –Y. Wang, “Parallel control and digital twins: control theory revisited and reshaped”, Chinese Journal of Intellignet Science and Technology, 2020,Vol. 2, No. 3, pp. 293-300.

Parallel Control

Elmo Motion Control

ACS MOTION CONTROL

DiGE 迪巨智能 Motion Intelligent

全球最强性能的伺服驱动器均来自以色列

基于Parallel Intelligent Control 平行智能控制

控制误差达到2 counts，接近理论极限

Parallel Sensing

1.2亿台/年 × 20000次/秒 = 2.4万亿/秒

全球高性能电机产量　　超实时数据闭环　　传感器数据生成量

编码器故障

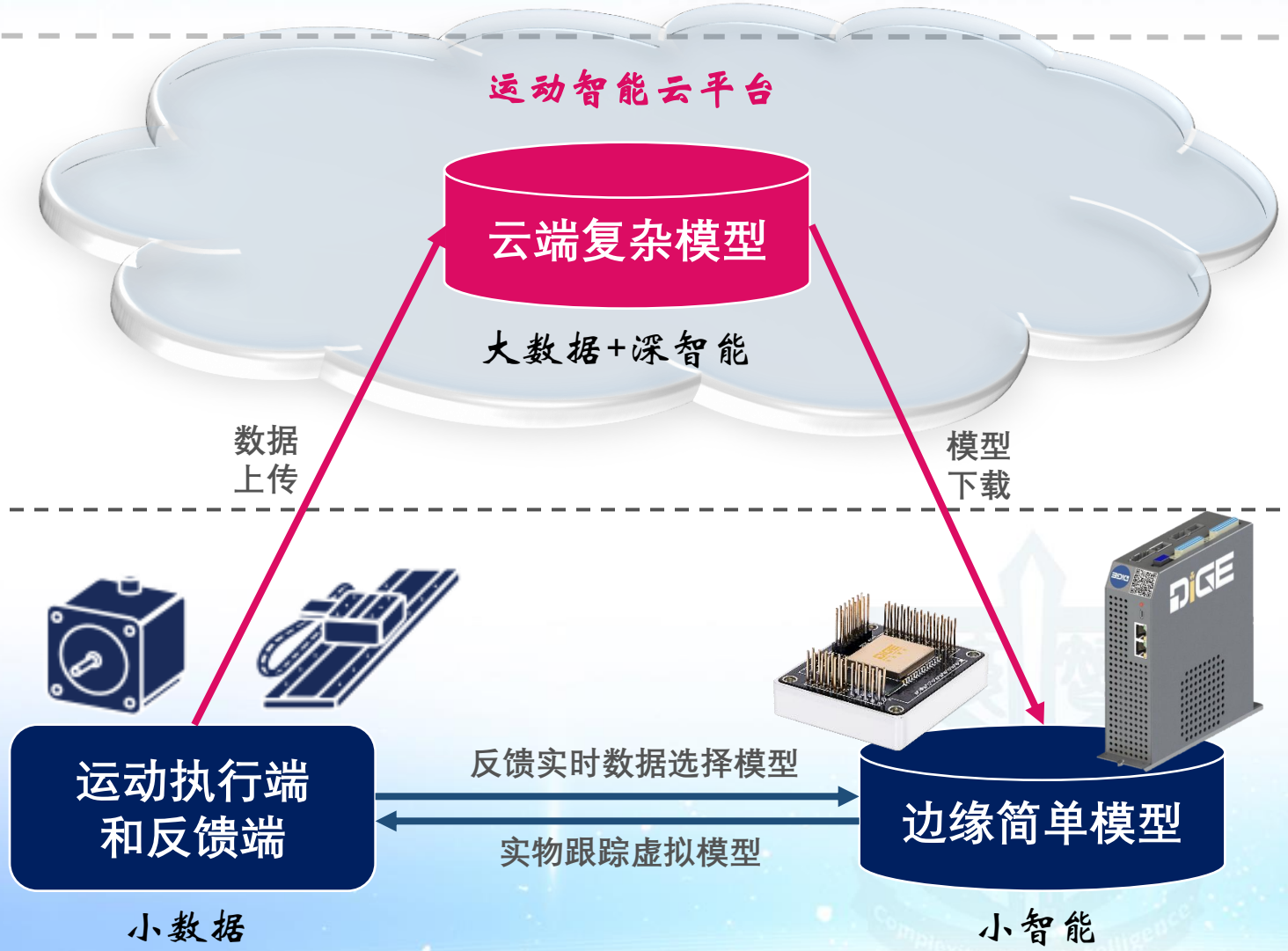
实时辨识生成平行电机

平行电机接管实物电机，通过无感控制，实现最后一道安全保障

虚拟编码器

“边缘简单，云端复杂”的运动智能通用技术架构具备快速落地条件

- 云端复杂模型将目标覆盖各类高端设备在不同工况、工艺的运动控制模型



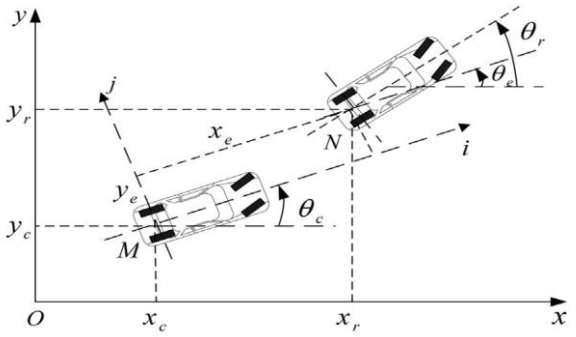
云端侧：

- 实时精准模型的构建和优化
- 基于模型的虚拟实验
- 各种复杂控制算法推荐生成
- 故障和特殊情况专家远程调试
- 电机监测、预测性维护

边缘侧：

- 超高实时性、本地总线通讯
- 各类传感器、执行器协议适配
- 提高边缘端算力，降低通讯压力

Parallel Control and Parallel Driving



Current and reference posture of a vehicle

$$\begin{cases} \dot{x}_e = \omega_c y_e - v_c + v_r \cos\theta_e \\ \dot{y}_e = v_r \sin\theta_e - \omega_c x_e \\ \dot{\theta}_e = \omega_r - \omega_c \\ \dot{v}_c = g_v(x_e, y_e, \theta_e, \omega_c, \omega_r, v_r) \\ \dot{\omega}_c = g_\omega(x_e, y_e, \theta_e, \omega_c, v_c, v_r) \end{cases}$$

The dynamic equations of the position error of the vehicle are given by:

$$\begin{cases} \dot{x}_e = \omega_c y_e - v_c + v_r \cos\theta_e \\ \dot{y}_e = v_r \sin\theta_e - \omega_c x_e \\ \dot{\theta}_e = \omega_r - \omega_c \end{cases}$$

Traditional state feedback controller:

$$\begin{cases} v_c = g_v(x_e, y_e, \theta_e, \omega_c, \omega_r, v_r) \\ \omega_c = g_\omega(x_e, y_e, \theta_e, \omega_c, v_c, v_r) \end{cases}$$

Algebraic Equation

Parallel controller:

$$\begin{cases} \dot{v}_c = g_v(x_e, y_e, \theta_e, \omega_c, \omega_r, v_r) \\ \dot{\omega}_c = g_\omega(x_e, y_e, \theta_e, \omega_c, v_c, v_r) \end{cases}$$

Differential Equation

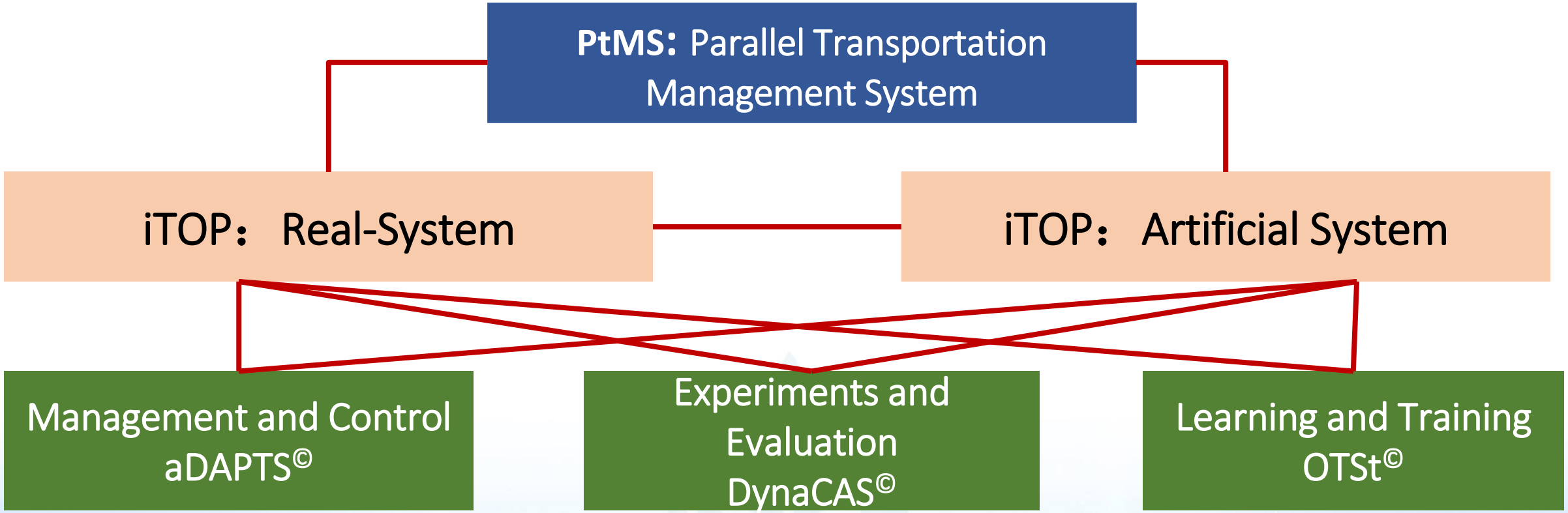
We proposed many algorithms to design the parallel controller and guarantee the stability and performance of the autonomous systems, such as pole-placement and parallel Lyapunov function.

1. Q. Wei, H. Li, F. –Y. Wang, "Parallel control for continuous-time linear systems: a case study", *IEEE/CAA Journal of Automatica Sinica*, 2020, Vol. 7, No. 4, pp. 919-928.
2. J. Lu, F. –Y. Wang, Q. Wei, Backstepping-based parallel control for a class of cascaded nonlinear systems. (To be submitted)

The Journey to Parallel Transportation

- 2003, Artificial Transportation Systems: From Computer Simulations to Computational Experiments, US DoT Workshop on Next Generation of Traffic Simulation, Sedona, Arizona.
- 2006, Artificial Transportation Systems: From Computer Simulations to Computational Experiments, IEEE ITSC, Toronto, Canada.
- 2010, Parallel Control and Management for ITS: Concepts, Methods, and Applications, IEEE T-ITS, pp.630-638.
- 2010, Parallel Control and Management for ITS: Concepts, Methods, and Applications, IEEE ITSC, Madeira Island, Portugal.

Parallel Transportation System Overview



Transportation Video Collection and Analysis System RoadScope©

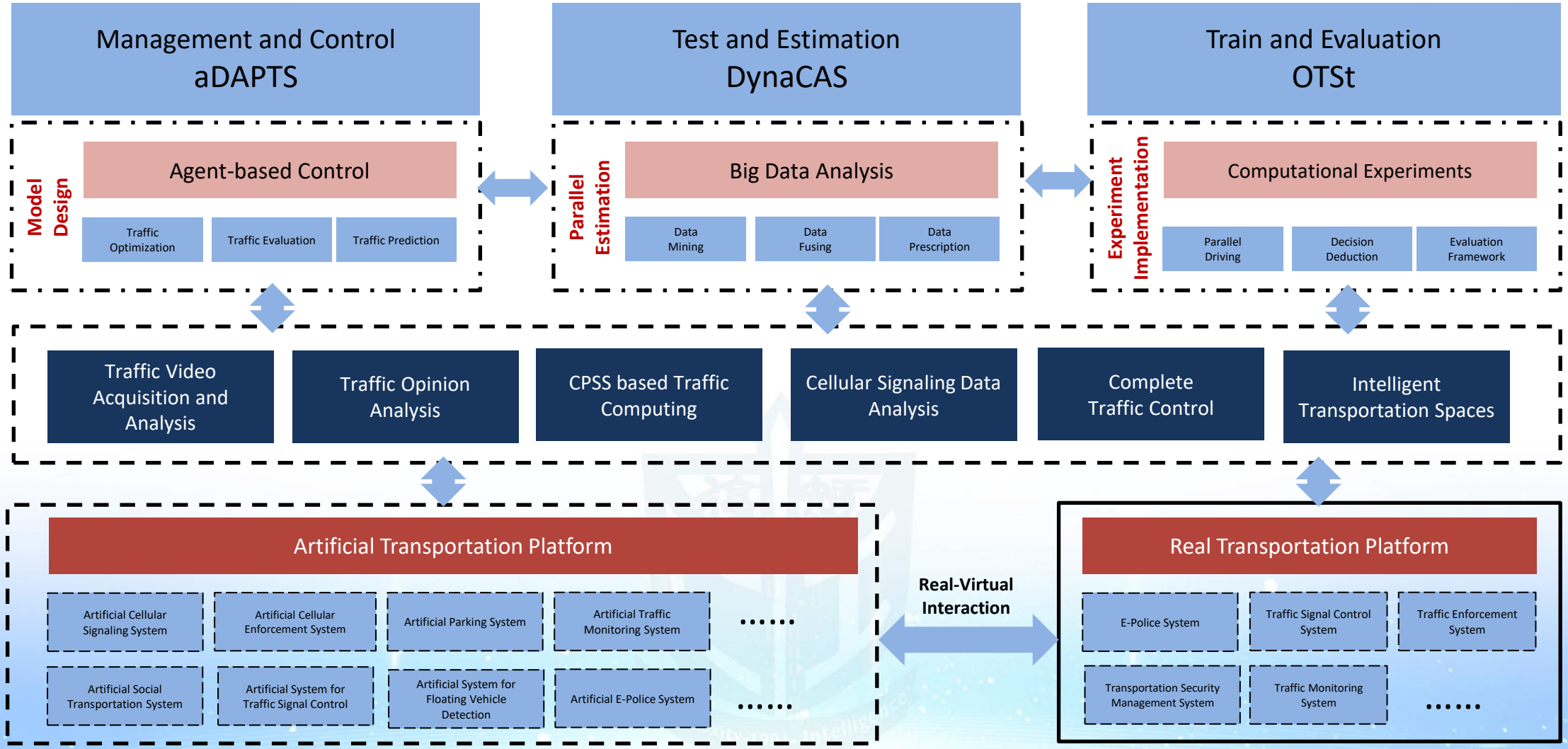
Networked Transportation Signal Controller GreenPass©

Artificial Transportation System TransWorld©

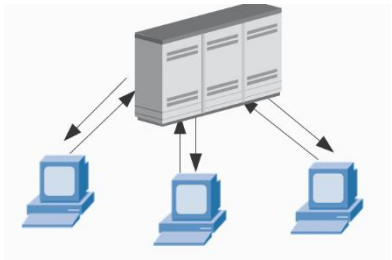
Cloud Computing Platform TransCloud ©

Transportation Information Dissemination Platform TransMedia ©

Parallel Transportation System Architecture

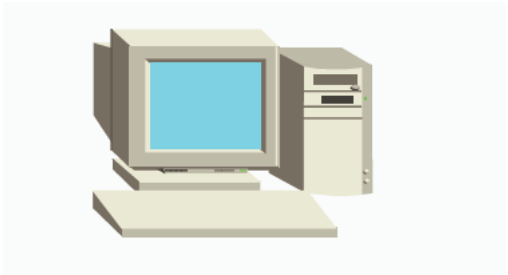


The Evolution of Computer System and Traffic Control



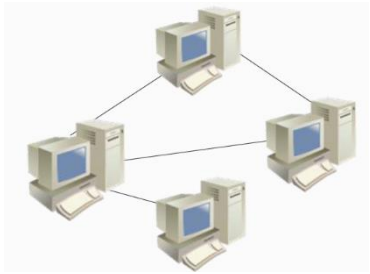
Mainframe

1940s-1950s



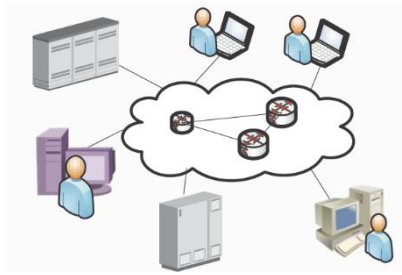
PC

1960s



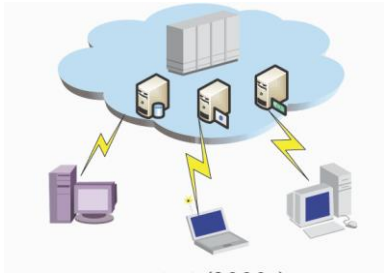
LAN

1970s



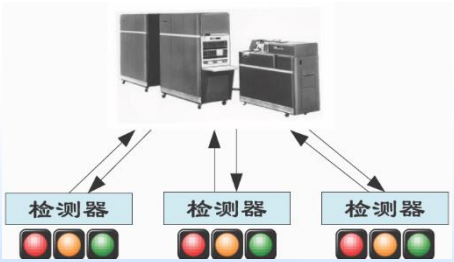
Internet

1980s-1990s



Cloud Computing

2000s

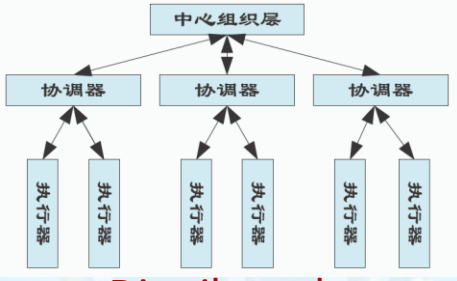


Centralized
Traffic Control

1960s

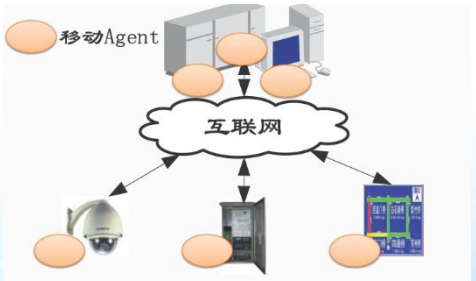
Single Intersection
Traffic Control

1970s-1980s



Distributed
Traffic Control

1980s-1990s



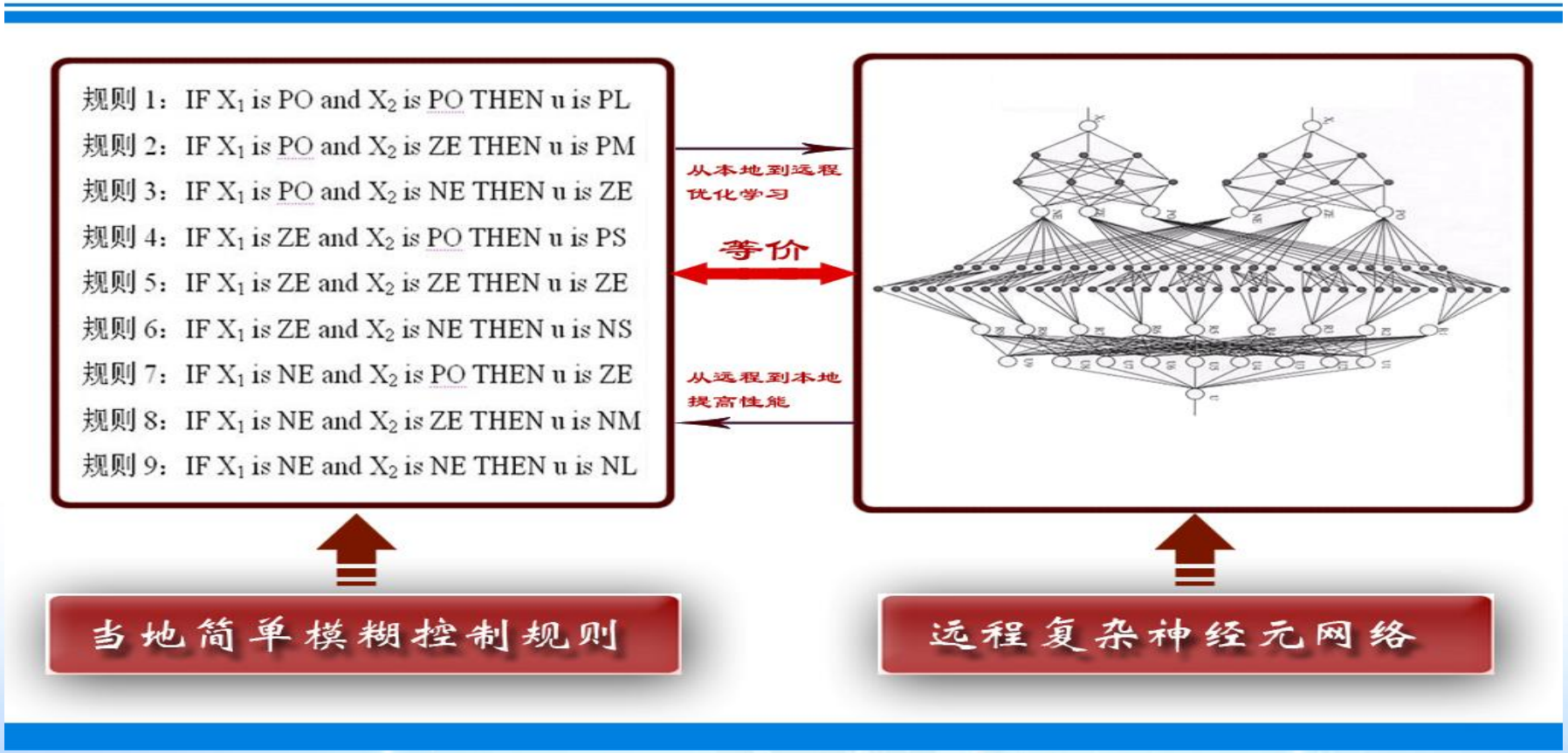
Agent-based
Traffic Control

2000s

Parallel
Traffic Control

2010s

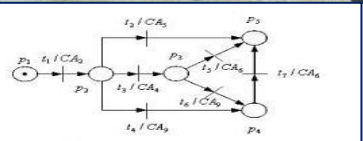
Motor Control, Arizona Lab Years: Idea of "Local Simple, Remote Complex"

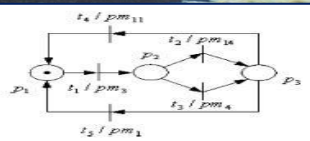


Fei-Yue Wang and Hung-man Kim, "Implementing Adaptive Fuzzy Logic Controllers with Neural Networks: A Design Paradigm", *Journal of Intelligent and Fuzzy Systems*, 1995, Vol. 3, No. 2, pp. 165-180.

“Local Simple, Remote Complex” for Robotic Excavation

Control Agent





Control Rules

Rule 1 –IF M_x is PL, THEN Δ_y is ZR, Δ_z is PL Δ_r is PS, and BV is PM

Rule 2 –IF M_x is PS, THEN Δ_y is PM, Δ_z is PL Δ_r is PL, and BV is PL

Rule 3 –IF M_x is ZR, THEN Δ_y is PM, Δ_z is PL Δ_r is PL, and BV is PL

Rule 4 –IF M_x is NS, THEN Δ_y is PM, Δ_z is PL Δ_r is PL, and BV is PL;

Rule 5 –IF M_x is NL, THEN Δ_y is PL, Δ_z is PL Δ_r is PL, and BV is PL;

Rule 6 –IF F_z is NL, THEN Δ_y is PL, Δ_z is PS Δ_r is PS, and BV is PS;

Rule 7 –IF F_z is NS, THEN Δ_y is PL, Δ_z is PM Δ_r is PS, and BV is PM;

Rule 8 –IF F_z is ZR, THEN Δ_y is PL, Δ_z is PL Δ_r is PS, and BV is PL;

Rule 9 –IF F_z is PS, THEN Δ_y is PL, Δ_z is PL Δ_r is PS, and BV is PL;

Rule 10 –IF F_z is PL, THEN Δ_y is PL, Δ_z is PL Δ_r is PS, and BV is PL;

Rule 11 –IF ΔF_y is PL, THEN Δ_y is PL, Δ_z is PL Δ_r is PL, and BV is PL;

Rule 12 –IF ΔF_y is PS, THEN Δ_y is PM, Δ_z is PL Δ_r is PM, and BV is PL;

Rule 13 –IF ΔF_y is NS, THEN Δ_y is PS, Δ_z is PL Δ_r is PL, and BV is PL

Rule 14 –IF ΔF_z is NL, THEN Δ_y is ZR, Δ_z is ZR Δ_r is PS, and BV is PS.

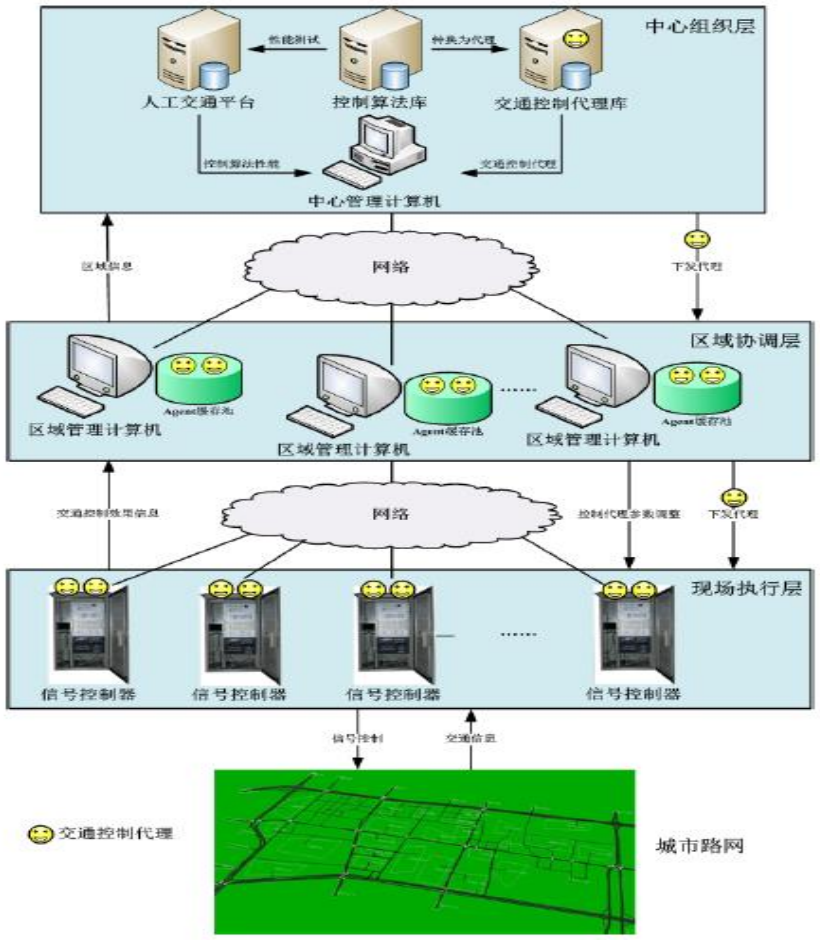
Caterpillar Technical Invention Award

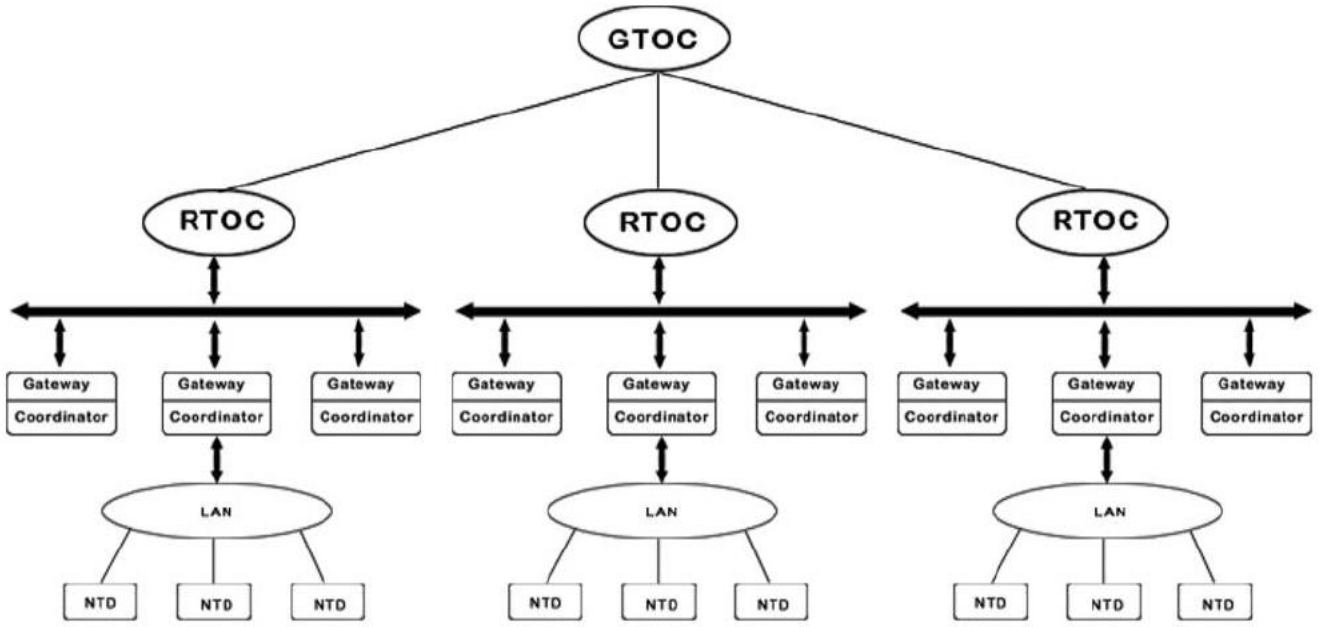
“Local Simple, Remote Complex” for Copper Leaching

BHP Outstanding Technical Achievement Award

- The world’s first agent based networked control system for copper leaching
- The operating cost reduced from $140,000 to $30,000 for each mine

Agent-based Distributed and Adaptive Platforms for Transportation Systems (aDAPTS)





Parallel Transportation

Networked Traffic Signal Controllers

1999	2001	2003	2005	2008	2010	2014
V1 VZ328	**V2** DSP	**V3** DSP	**V4** ARM9	**V5** ARM11	**V6** ARM11	**V7** ARM11

Parallel Transportation Platforms

V1.0（2006）

V2.0
(2008)

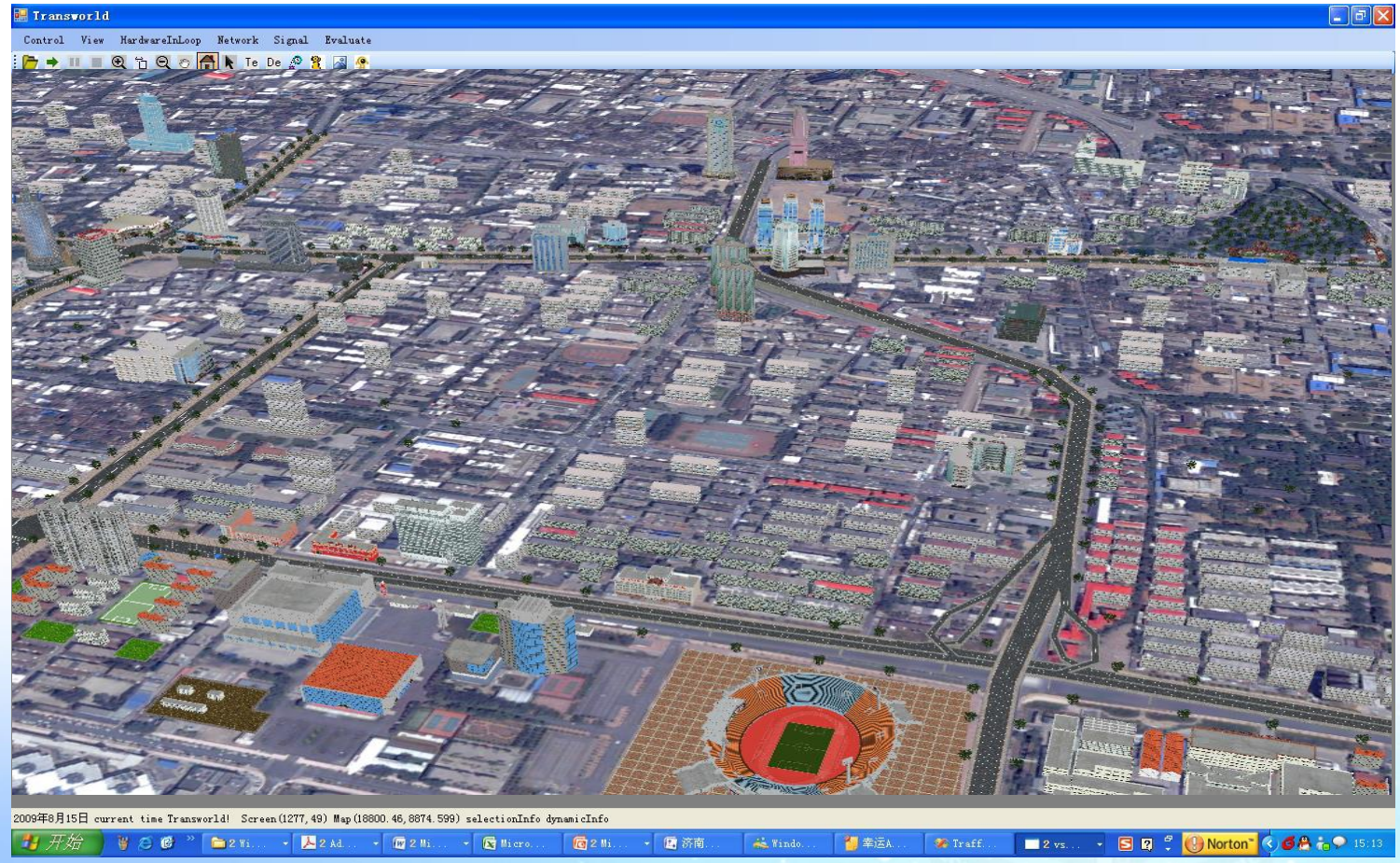
V3.0
(2012)

V4.0
(2014)

V5.0
(2017)

Parallel Transportation

Artificial transportation system of Jinan



area: 255 km²
junctions: 76
locations: 320

Residential area	137
Work area	62
School	51
Market	18
Park	10
Gym	9
Leisure area	14
Hospital	19

Traffic Pressure Experiments

Parallel Control and Management for Intelligent Transportation Systems: Concepts, Architectures, and Applications

Fei-Yue Wang, *Fellow, IEEE*

***Abstract*—Parallel control and management have been proposed as a new mechanism for conducting operations of complex systems, especially those that involved complexity issues of both engineering and social dimensions, such as transportation systems. This paper presents an overview of the background, concepts, basic methods, major issues, and current applications of Parallel transportation Management Systems (PtMS). In essence,**

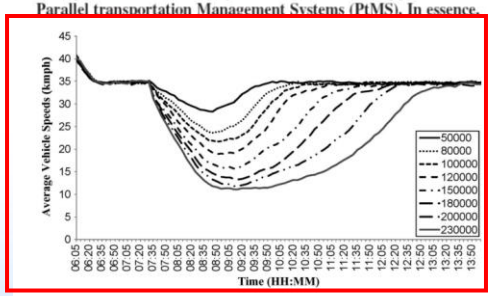
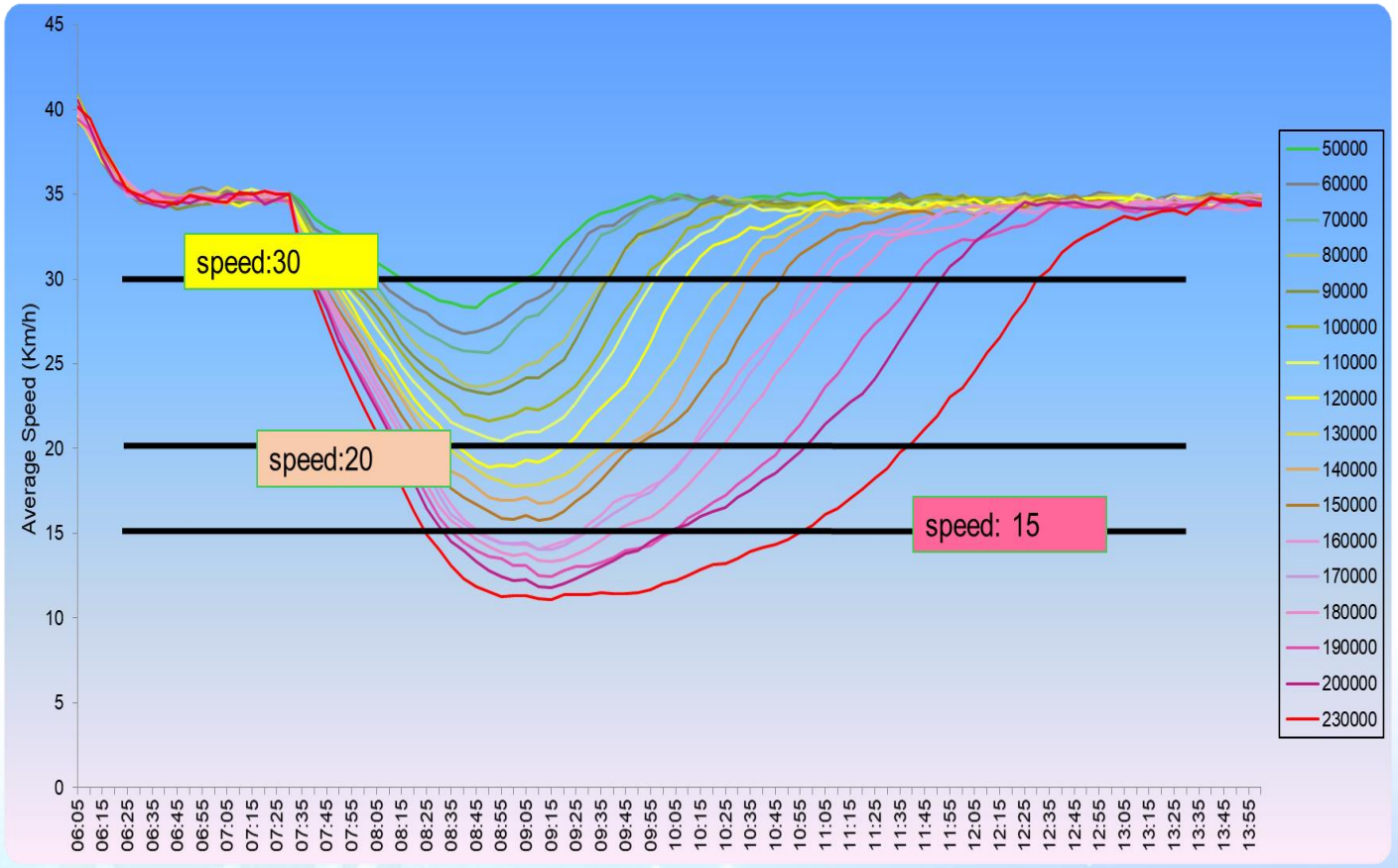


Fig. 12. Average speed of all vehicles in the traffic network of Jinan ATS.

However, we have experienced a few "road bumps" over the last few years in ITS research and applications, especially in relation to system-level traffic control and management. This can be verified from the distribution of papers which have appeared in the ITS flagship publication IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS (T-ITS). As

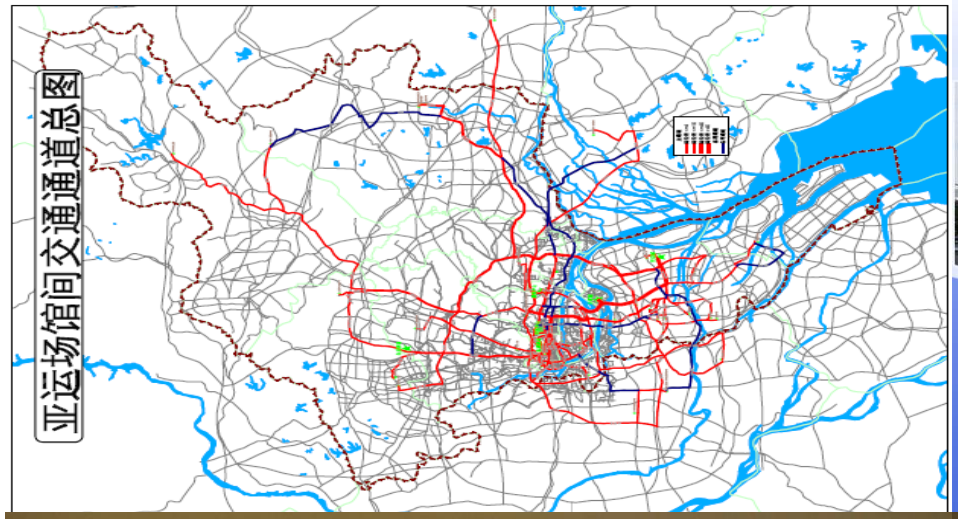
Fig. 14. Area of field study in Taicang for PtMS.

to about 10 km/h. Fig. 13 shows the cumulative distribution curve of average speeds under three population sizes, i.e., 50, 80, and 120 thousands, respectively. Three 15 quantiles of speed distributions, which are a common index used in urban traffic

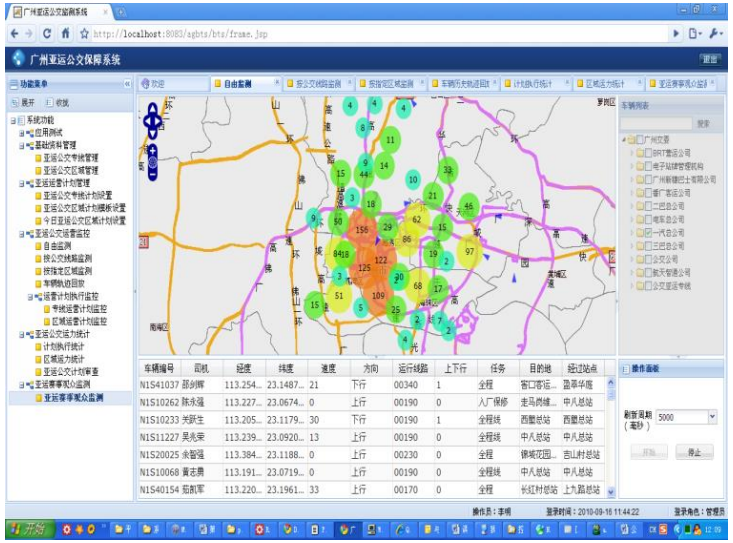


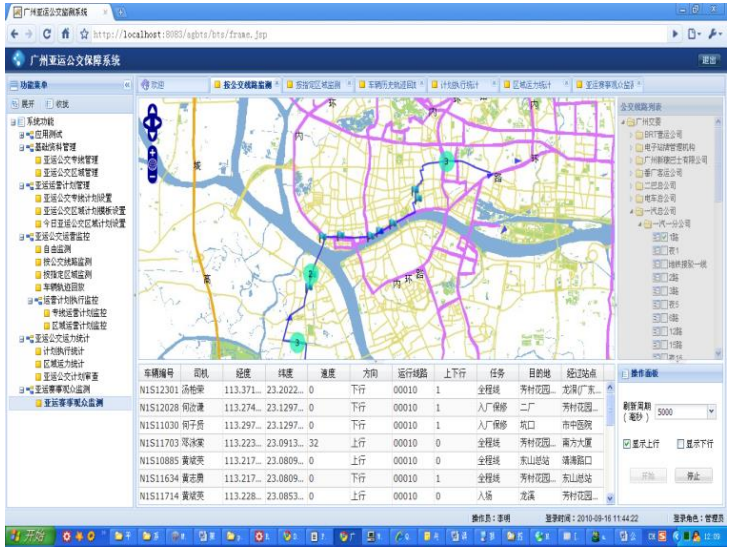
F. Wang, "**Parallel Control and Management for Intelligent Transportation Systems: Concepts, Architectures, and Applications**," in *IEEE Transactions on Intelligent Transportation Systems*, Vol. 11, No. 3, pp. 630-638, Sept. 2010.

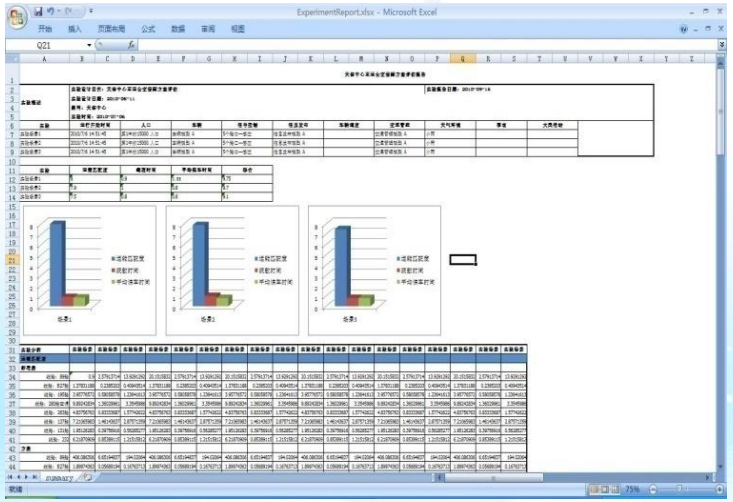
Guangzhou Asian Games Parallel Transportation System

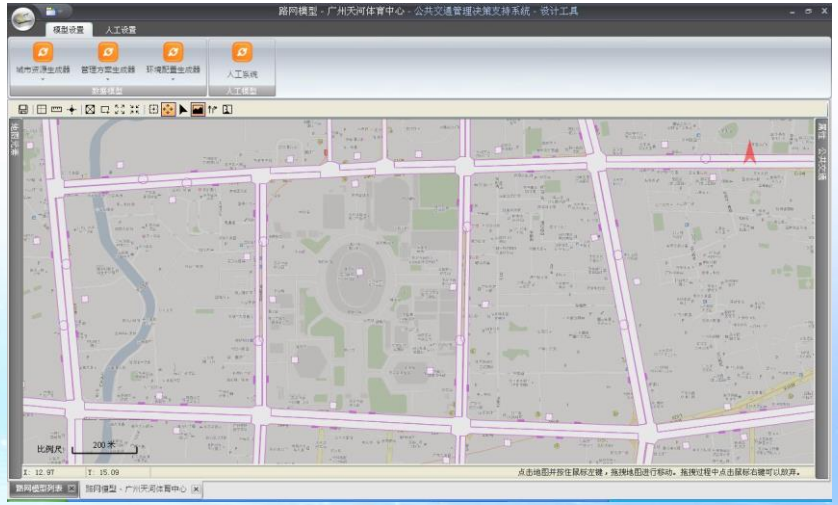


Parallel Public Transit Management Systems for Guangzhou Asian Games









Qingdao Parallel Transportation System

Artificial Transportations System

environment

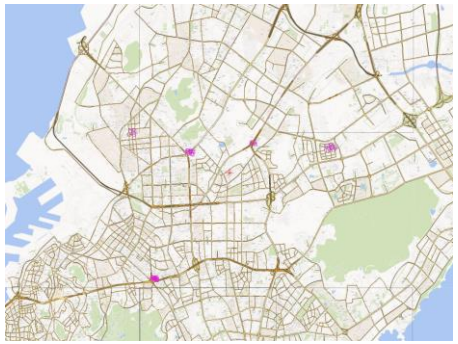
network

device

sensor

Real Transportations System

environment



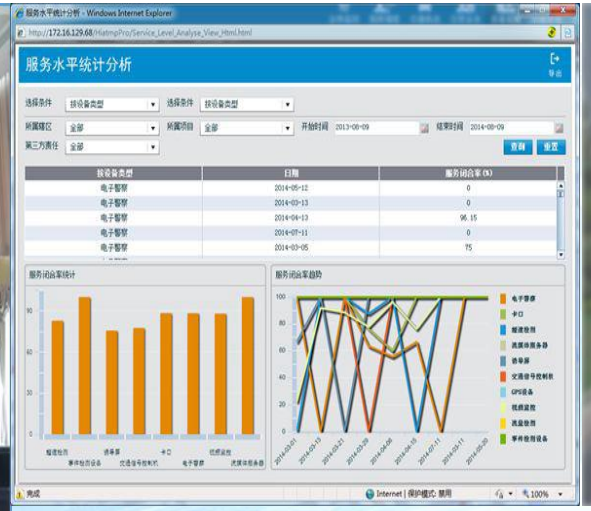
network

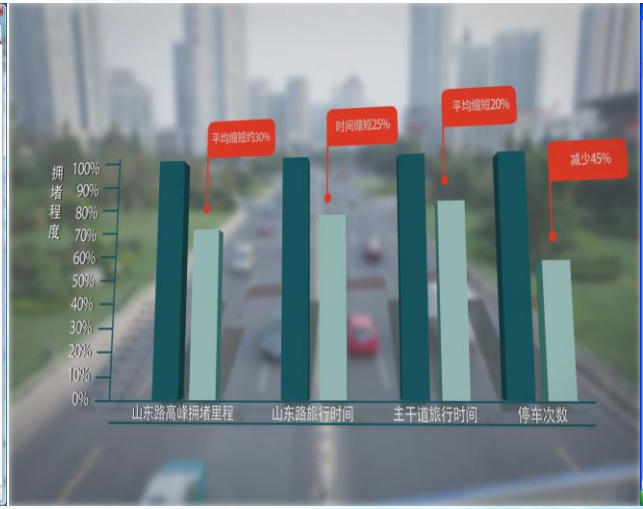
device

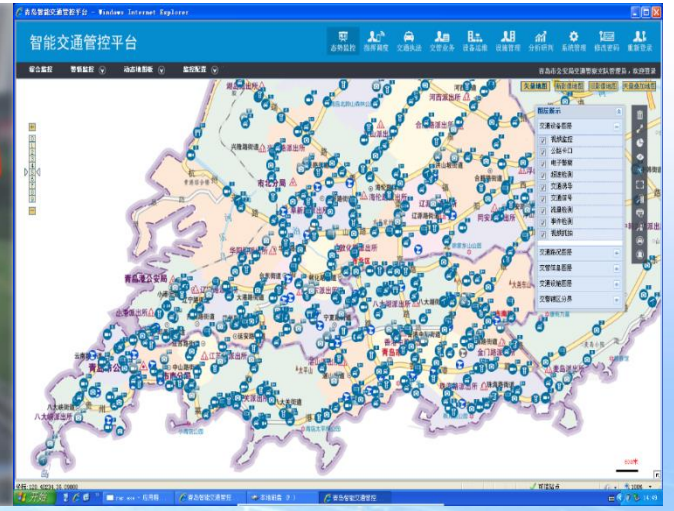
sensor

Performances of PtMS-QingDao

- Significantly improve Qingdao Transportation Operations
  - Arterial travel time: reduced by 20%
  - Number of vehicle stops on arterial streets: reduced by 45%
  - Congestion miles of major key roads: reduced by 30%
  - Average travel time: reduced by 25%
  - Travel efficiency: improved by 43.39%.







Hangzhou: Traffic Recommendation System

➢ Network Information

Intersections

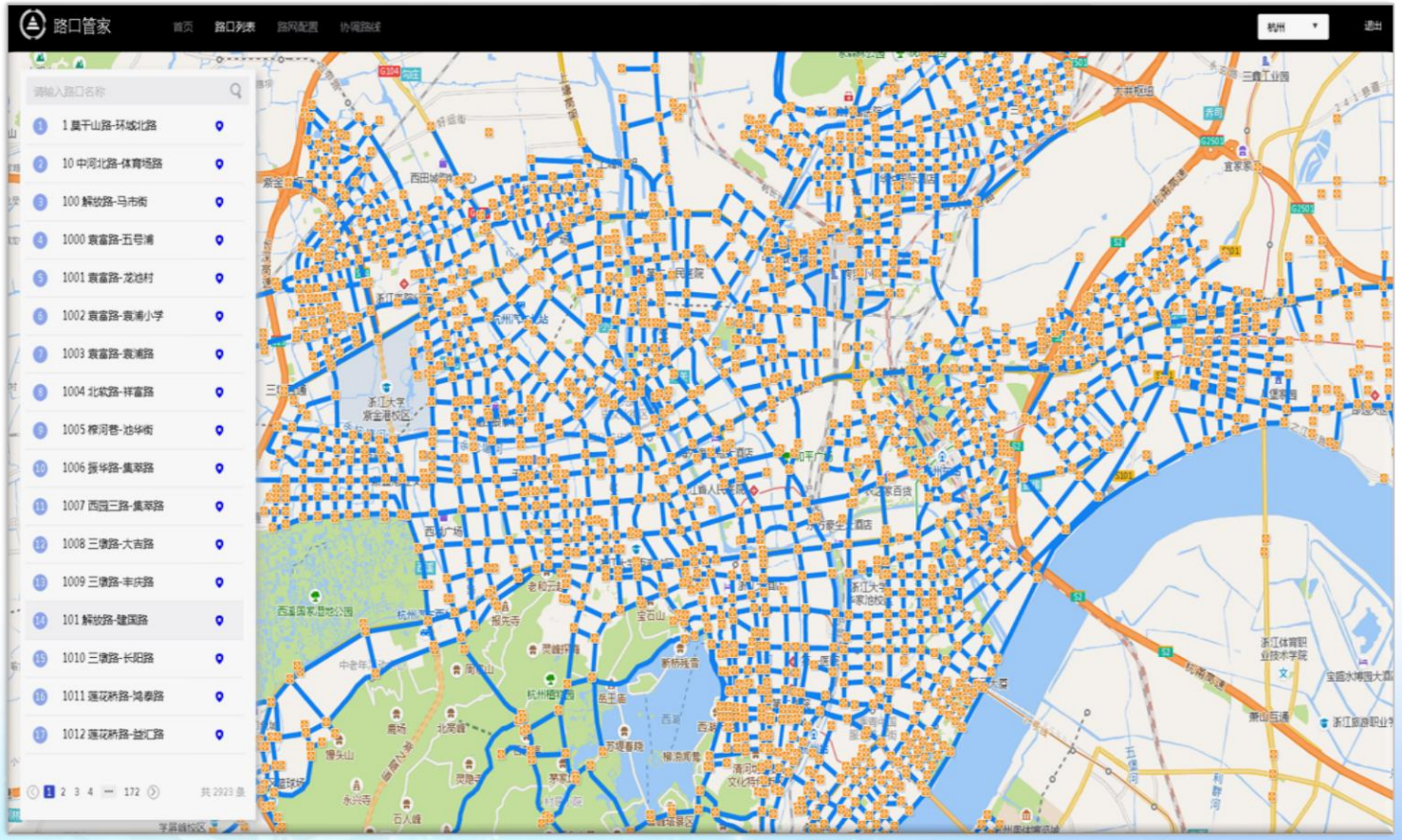
1500+

Arterials

300+

Roads

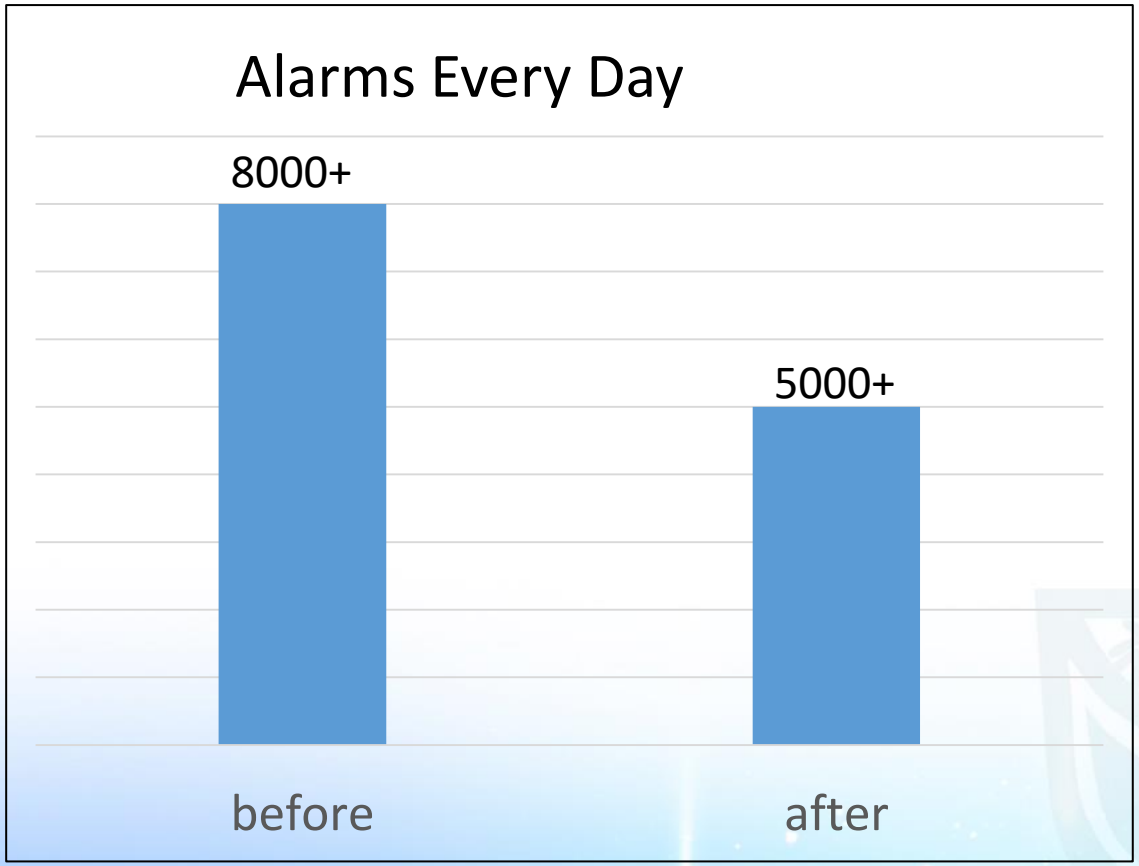
6000+

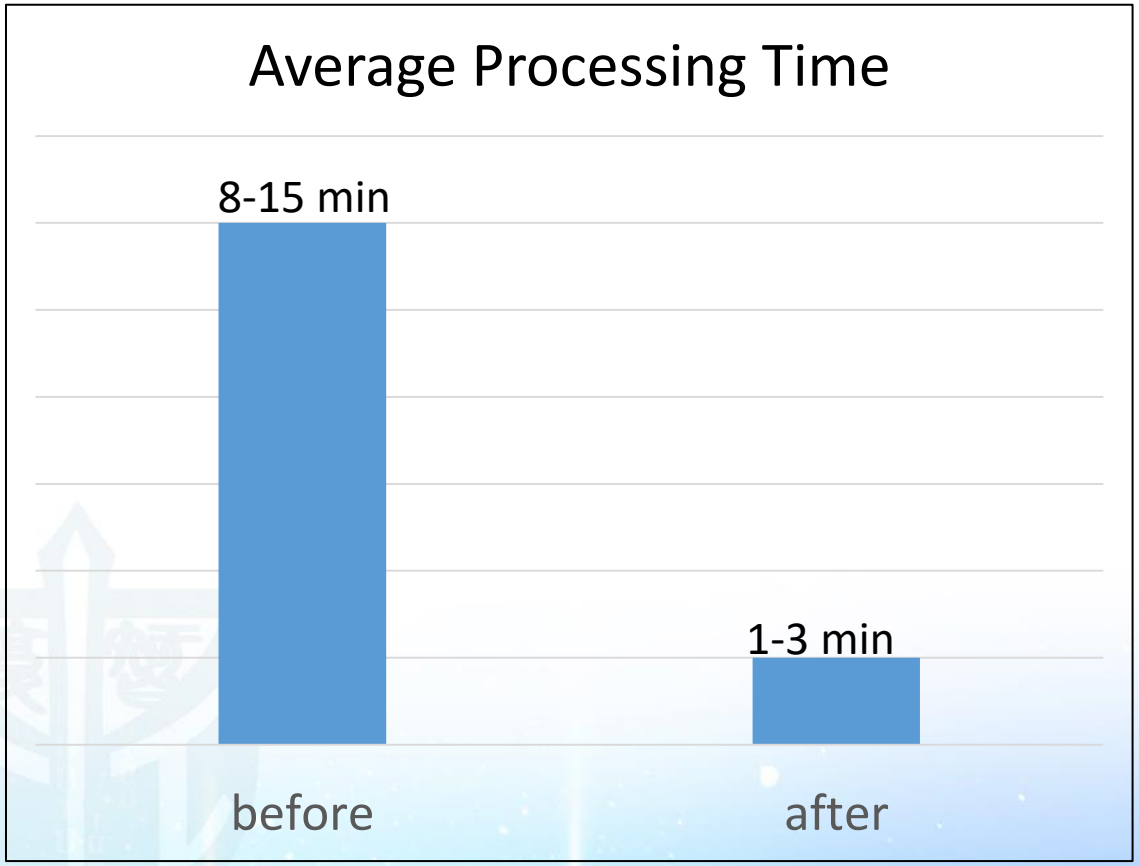


➢ Device information

- SCATS signal controller
- Network-wide video surveillance system

Performances





Test Period: 2018.12---2019.03

Performances

Congestion rank of Chinese cities for 2018 (Q1-Q3)

Change Rate	City Name	Congestion Delay Index (Peak)	Peak Average Speed (km/h)	All-day Congestion Delay Index	All-day Average Speed	Congestion Delay Index in Morning Peak	Average Speed in Morning Peak	Congestion Delay Index in Evening Peak	Average Speed in Evening Peak	Congestion Delay Index in Non-Peak	Average Speed in Non-Peak
3.3%	Shaoguan	1.612	27.53	1.450	30.60	1.443	30.82	1.769	25.03	1.396	31.79
-2.6%	Guilin	1.609	31.35	1.487	33.94	1.447	35.07	1.762	28.46	1.447	34.91
0.7%	Xianggang	1.599	38.16	1.517	40.12	1.505	40.88	1.689	35.85	1.490	40.83
4.3%	Wuxi	1.594	29.92	1.401	34.08	1.515	31.51	1.672	28.49	1.336	35.74
-2.4%	Zhongshan	1.592	29.89	1.429	33.32	1.476	32.31	1.706	27.82	1.375	34.66
-3.2%	Deyang	1.588	33.72	1.484	36.16	1.526	35.26	1.646	32.37	1.448	37.07
1.5%	Weifang	1.588	30.71	1.443	33.85	1.531	31.86	1.644	29.65	1.394	35.07
-3.8%	Hangzhou	1.586	25.73	1.498	27.25	1.540	26.53	1.631	24.98	1.468	27.80
-2.0%	Wenzhou	1.580	27.30	1.456	29.65	1.469	29.45	1.688	25.49	1.414	30.53

Change Rate vs 2017 Q2	City Name	Congestion Delay index in peak	Peak Speed	Congestion Delay index all day	Congestion delay index morning peak	Congestion delay index evening peak	Congestion delay index non peak	Free flow speed	Construction enclosure ratio (report analysis range)
-6.8%	Tangshan	1.655	27.14	1.466	1.643	1.666	1.403	44.91	2.9%
3.3%	Jinghua	1.651	22.60	1.487	1.606	1.695	1.432	37.32	2.0%
-4.1%	Hengyang	1.651	25.85	1.475	1.621	1.680	1.416	42.67	2.0%
-2.9%	Zhengzhou	1.651	29.38	1.482	1.626	1.676	1.425	48.50	5.3%
7.0%	Langfang	1.651	28.61	1.431	1.653	1.649	1.357	47.23	2.0%
4.1%	Suzhou	1.649	29.16	1.403	1.689	1.610	1.320	48.10	3.5%
-3.2%	Hangzhou	1.648	25.08	1.537	1.657	1.638	1.500	41.33	2.4%
8.1%	Suqian	1.642	26.20	1.514	1.628	1.655	1.470	43.01	2.6%

Change Rate vs 2018 Q2	Change Rate vs 2017 Q3	City Name	Congestion Delay Index in Peak	Actual Peak Speed km/h	Congestion Delay Index All Day	Congestion Delay Index Morning Peak	Congestion Delay Index Evening Peak	Congestion Delay Index Non Peak*
-1.6%	-1.9%	Taiyuan	1.642	30.00	1.44	1.62	1.67	1.38
-5.9%	-4.9%	Wuhan	1.622	30.05	1.42	1.59	1.65	1.35
-3.7%	-4.1%	Xining	1.619	31.05	1.48	1.52	1.72	1.44
-3.9%	-0.1%	Tianjin	1.618	29.25	1.41	1.64	1.60	1.35
-1.9%	-4.4%	Hangzhou	1.616	25.58	1.51	1.60	1.63	1.48
-4.1%	-7.3%	Luoyang	1.607	24.28	1.49	1.55	1.66	1.45

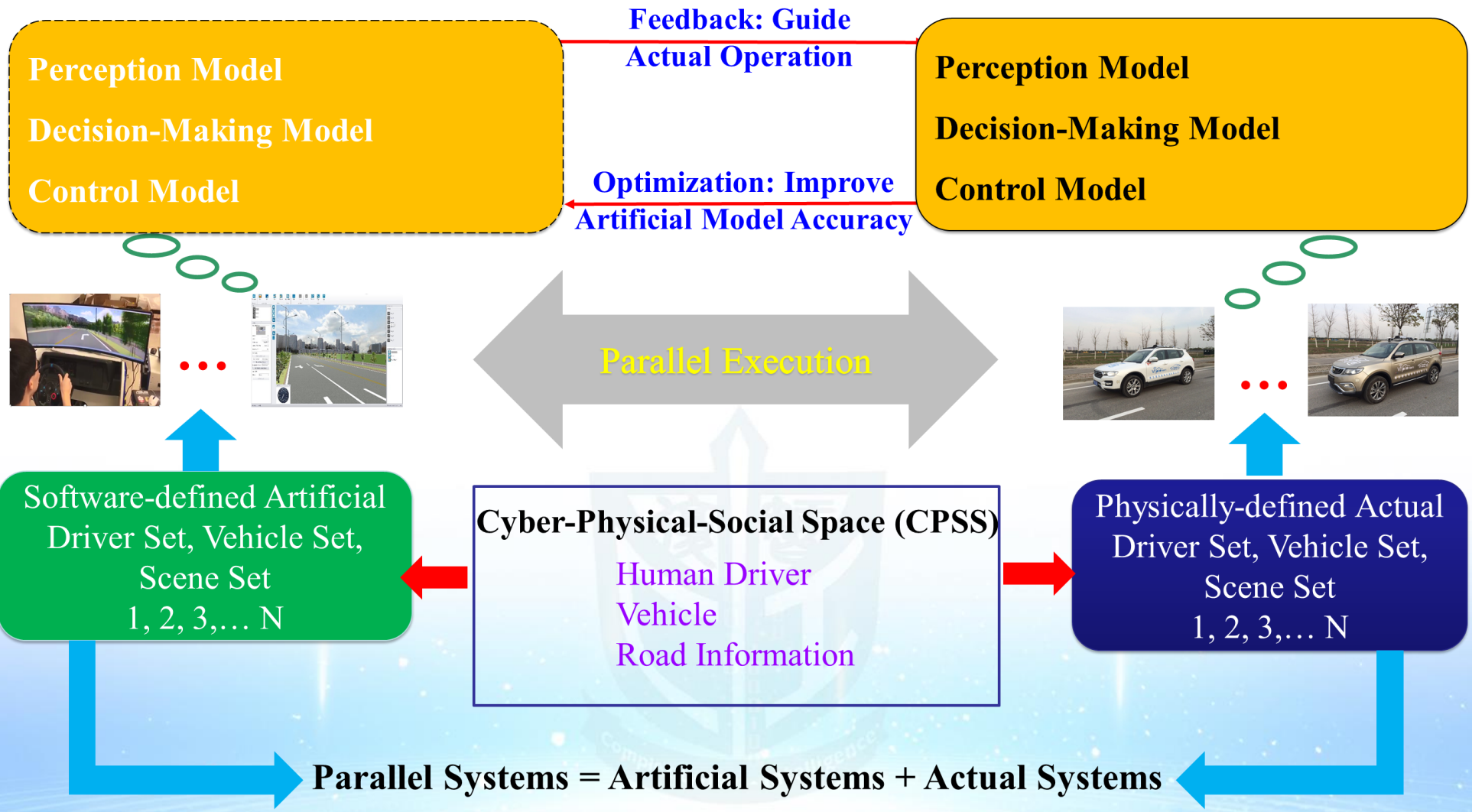
Hangzhou's congestion index:

2nd in 2015,

35th in 2018

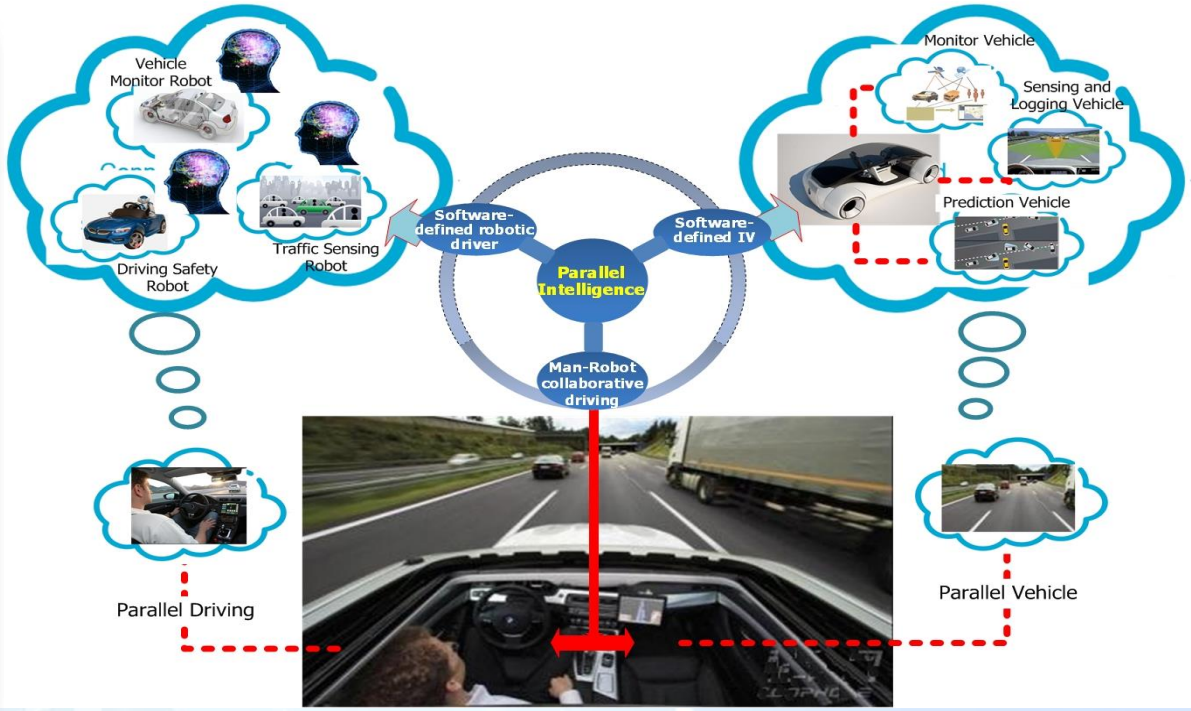
Source: Traffic Analysis Reports of Major Cities in China, https://report.amap.com/download_city.do

Parallel Driving



Parallel Test of Parallel Driving

IV Future Challenge (NSFC, 2009-2018)



Parallel Driving (ICVES, 2005-now)

IV Future Challenge (IVFC): From 2009 to Now

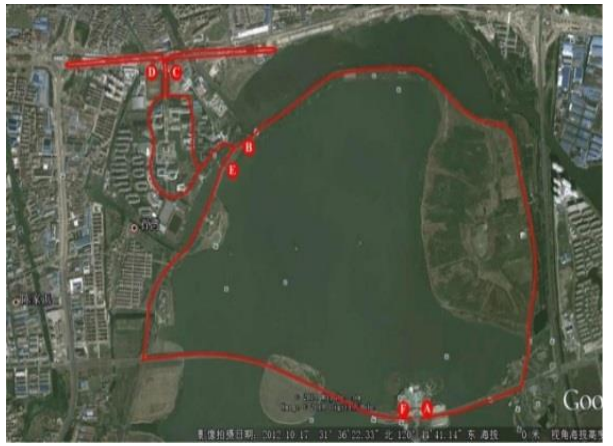
总裁判: 王飞跃

Ø 最长、最大、最深，参与队伍最多的智能车竞赛

Ø 中国智能车综合技术研发与测试中心(iVPC)

IVFC 2010: 10 Teams

IVFC 2014: Snapshots



IVFC 2016: Snapshots

Highway Test

Urban Test

International Parallel Driving Alliance (iPDA) Inaugural Conference

Held on June 27, 2018（2018.6.27, Changshu）

Our Papers on Vehicle Intelligent and Parallel Testing

IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS, VOL. 15, NO. 5, OCTOBER 2014 1969

Task-Specific Performance Evaluation of UGVs: Case Studies at the IVFC

WuLing Huang, Ding Wen, Jason Geng, and Nan-Ning Zheng, *Fellow, IEEE*

***Abstract*—Performance evaluation is considered as an important part of the unmanned ground vehicle (UGV) development; it helps to discover research problems and improves driving safety. In this paper, a task-specific performance evaluation model of UGVs applied in the Intelligent Vehicle Future Challenge (IVFC)** traced back to the previous work on robotic autonomous levels definition of the NASA SMART project, MIT Automation Level Framework [5] and the NIST annual Performance Metrics for Intelligent Systems Workshop, which is devoted

158 IEEE TRANSACTIONS ON INTELLIGENT VEHICLES, VOL. 1, NO. 2, JUNE 2016

Intelligence Testing for Autonomous Vehicles: A New Approach

Li Li, *Senior Member, IEEE*, Wu-Ling Huang, Yuehu Liu, *Member, IEEE*, Nan-Ning Zheng, *Fellow, IEEE*, and Fei-Yue Wang, *Fellow, IEEE*

***Abstract*—In this paper, we study how to test the intelligence of an autonomous vehicle. Comprehensive testing is crucial to both vehicle manufactories and customers. Existing testing approaches can be categorized into two kinds: scenario-based testing and functionality-based testing. We first discuss the shortcomings** tested and ensured, autonomous vehicles cannot be put into market.

To find an answer, the Defense Advanced Research Projects Agency (DARPA) had sponsored a series of competitions for

Artif Intell Rev
https://doi.org/10.1007/s10462-018-9631-5

CrossMark

Artificial intelligence test: a case study of intelligent vehicles

Li Li[1] · Yi-Lun Lin[2,5] · Nan-Ning Zheng[3] · Fei-Yue Wang[2,5] · Yuehu Liu[3] · Dongpu Cao[4,6] · Kunfeng Wang[2] · Wu-Ling Huang[2]

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Abstract To meet the urgent requirement of reliable artificial intelligence applications, we discuss the tight link between artificial intelligence and intelligence test in this paper. We highlight the role of tasks in intelligence test for all kinds of artificial intelligence. We explain

SCIENCE ROBOTICS | FOCUS

ARTIFICIAL INTELLIGENCE

Parallel testing of vehicle intelligence via virtual-real interaction

Li Li[1]*, Xiao Wang[2,3]*, Kunfeng Wang[2,3]*, Yilun Lin[2,3,4]*, Jingmin Xin[5]*, Long Chen[6,7], Linhai Xu[5], Bin Tian[2,7], Yunfeng Ai[4,7], Jian Wang[7,8], Dongpu Cao[7,8,9], Yuehu Liu[5], Chenghong Wang[10,11], Nanning Zheng[5†], Fei-Yue Wang[2†]

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A self-driven closed-loop parallel testing system implements more challenging tests to accelerate evaluation and development of autonomous vehicles.

Although researchers and automobile manufacturers have built several proving grounds (*1*) and testing datasets (*2*) dedicated to autonomous driving, tests for intelligent vehicles remain time-consuming, inefficient, and sometimes dangerous for people who use the same narios tested by simulations should also be re-evaluated and verified in field tests to validate the effectiveness of the simulation systems and the reliability of the hardware of autonomous vehicles.

Therefore, a human-in-loop simulation

We can rearrange the spatiotemporal ranges of task rectangles to sample different driving scenarios that belong to the same category so as to ensure that autonomous vehicles could work for these driving scenarios. Adding more semantic task atoms

Future of Transportation: Where Does ITS Go after AlphaGo?

Scanning the Issue and Beyond: Five Transportations in One—A New Direction for ITS From Qingdao

I had a great experience at the 18th IEEE International ITS Conference held from September 13 to 18, 2015, at Las Palmas de Gran Canaria, Spain. This has been one of the most enjoyable ITSC I have attended over the last 18 years. I am also pleased to announce that, during the conference, the Board of Governors of IEEE ITS Society has accepted our proposal to rename the Best Regular Paper Award for the IEEE Transactions on Intelligent Transportation Systems to the George N. Saridis Award for the IEEE Transactions on Intelligent Transportation Systems, effective next year. Dr. Saridis, the Founding Director of US NSF's Systems Engineering and Control Program and the Founding President of the IEEE Robotics and Automation Society, was a pioneer in Intelligent Control, Robotics, and Intelligent Transportation Systems, and led the effort in initiating research and development of those fields in 1970s.

Fig. 2. Saridis Award Proposers Fei-Yue Wang, Markos Papageorgiou, and Petros Ioannou at ITSC 2015.

SCANNING THE ISSUE

Vehicle Detection Techniques for Collision Avoidance Systems: A Review

A. Mukhtar, L. Xia, and T. Boon Tang

A comprehensive survey of the state-of-the-art on-road vision-based vehicle detection and tracking systems for collision avoidance system (CAS) is provided. The survey is structured in accordance with a vehicle detection process starting from sensor selection to vehicle detection and tracking. Emphases are placed on motorcycle detection techniques and sensor comparison in terms of cost and range parameters. Finally, an optimal choice with a low cost and reliable CAS design is proposed.

Routing in Internet of Vehicles: A Review

From:

Parallel Transportation

To:

Transportation 5.0

Wang, Fei-Yue, "**Five Transportations in One—A New Direction for ITS From Qingdao"**. IEEE Transactions on Intelligent Transportation Systems, 2015.

Technical Events and Activities of Transportation 5.0

2014 IEEE ITSS Technical Committee on Transportation 5.0

2015 IEEE ITSC Workshop on Transportation 5.0

2016 AI for ITS Section in ITSM

2016 IEEE ITSS Summer School on Frontiers in ITS: Transportation 5.0

2017 IEEE ITSC Workshop on Transportation 5.0

2019 IEEE ITSC Keynote on Parallel Transportation and Transportation 5.0

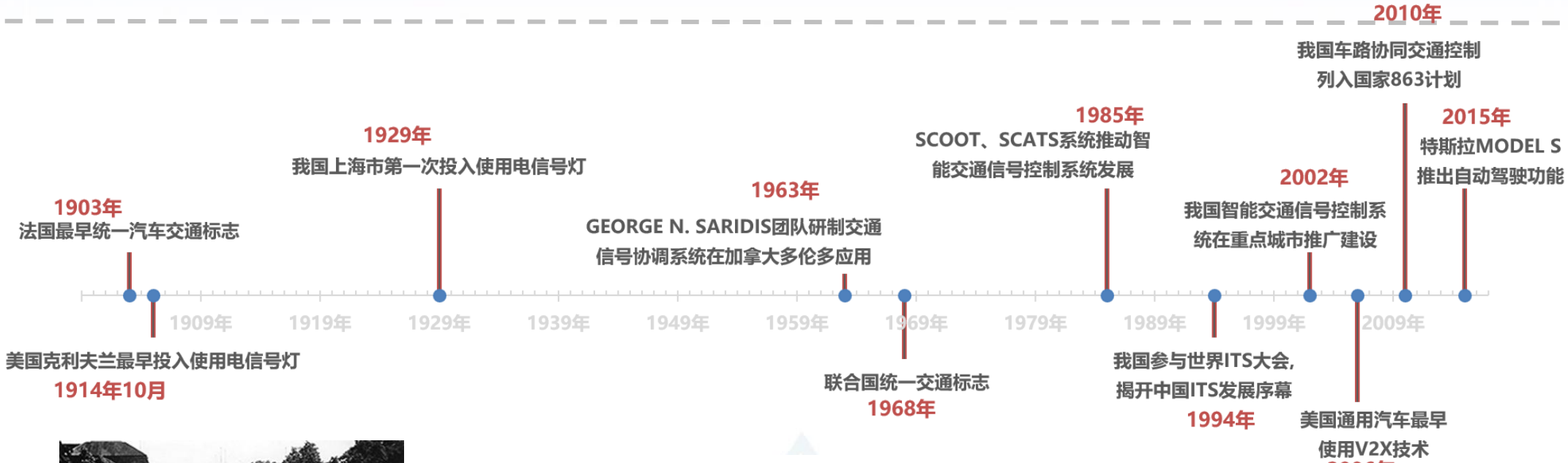
Prof. Fei-Yue Wang and his students at Crowd Sourcing and Social Transportation Workshop.

2015, Spain

2016, China

2017, Japan

Traffic Control in Hundred Years



德国柏林坡茨坦广场的五边交通灯塔
(1924年)

第 44 卷 第 4 期 自 动 化 学 报 Vol. 44, No. 4
2018 年 4 月 ACTA AUTOMATICA SINICA April, 2018

地面交通控制的百年回顾和未来展望

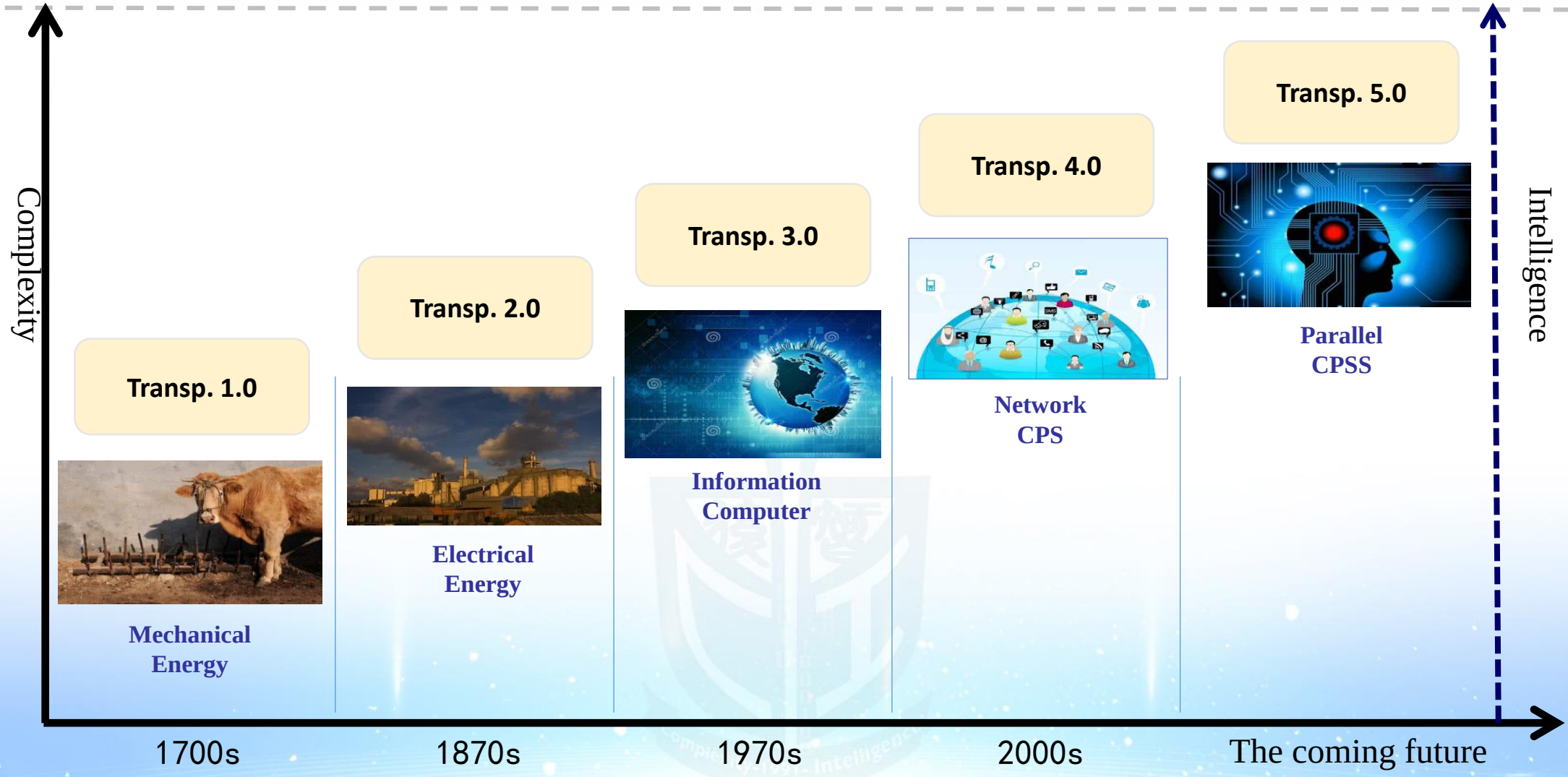
李 力 [1] 王飞跃 [2,3,4,5]

摘 要 从路权这个新的角度回顾了过去 100 年地面交通控制发展的几个关键转变点, 并结合目前新兴的网联车和无人车技术, 分析了今后 50 年地面交通控制的发展方向.

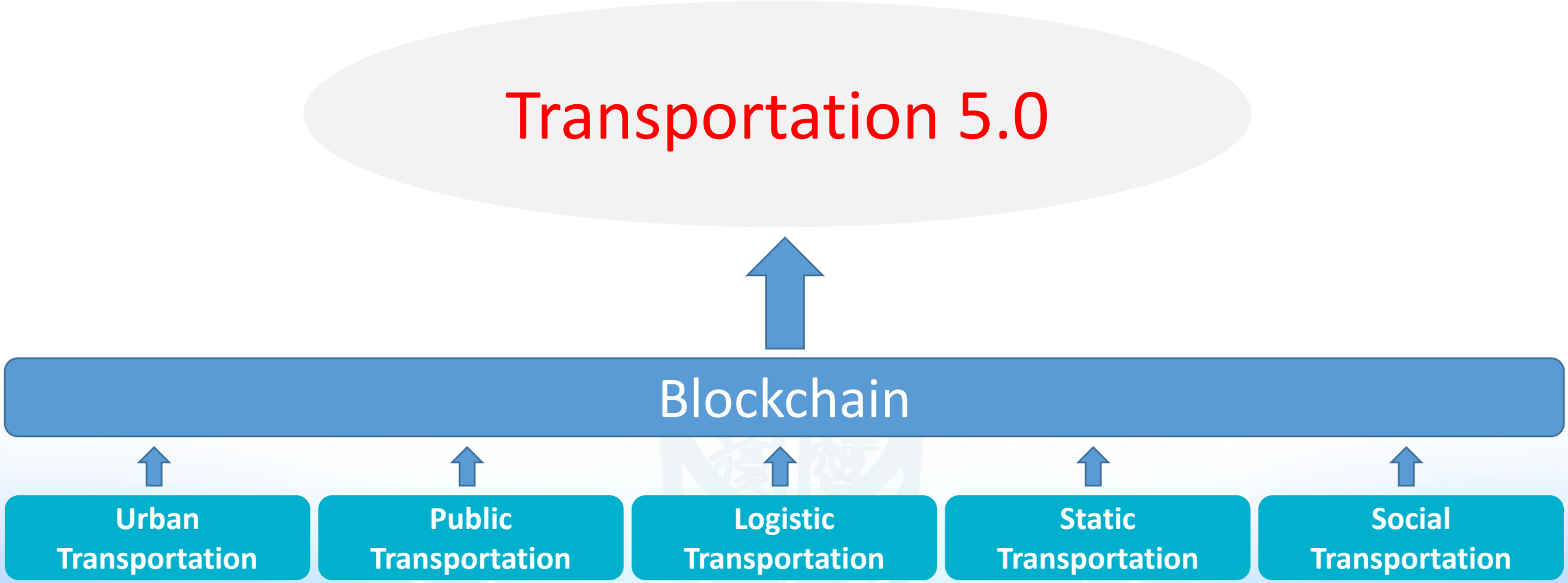
关键词 交通控制, 无人车, 自动驾驶, 路权
引用格式 李力, 王飞跃, 地面交通控制的百年回顾和未来展望, 自动化学报, 2018, 44(4): 577−583

李力，王飞跃，“地面交通控制的百年回顾和未来展望”，自动化学报，2018，Vol. 44, No. 4, pp. 577-583.
Li Li, Wang Fei-Yue. **Ground traffic control in the past century and its future perspective**. *Acta Automatica Sinica*, 2018, Vol. 44, No. 4, pp. 577-583.

Towards Transportation 5.0

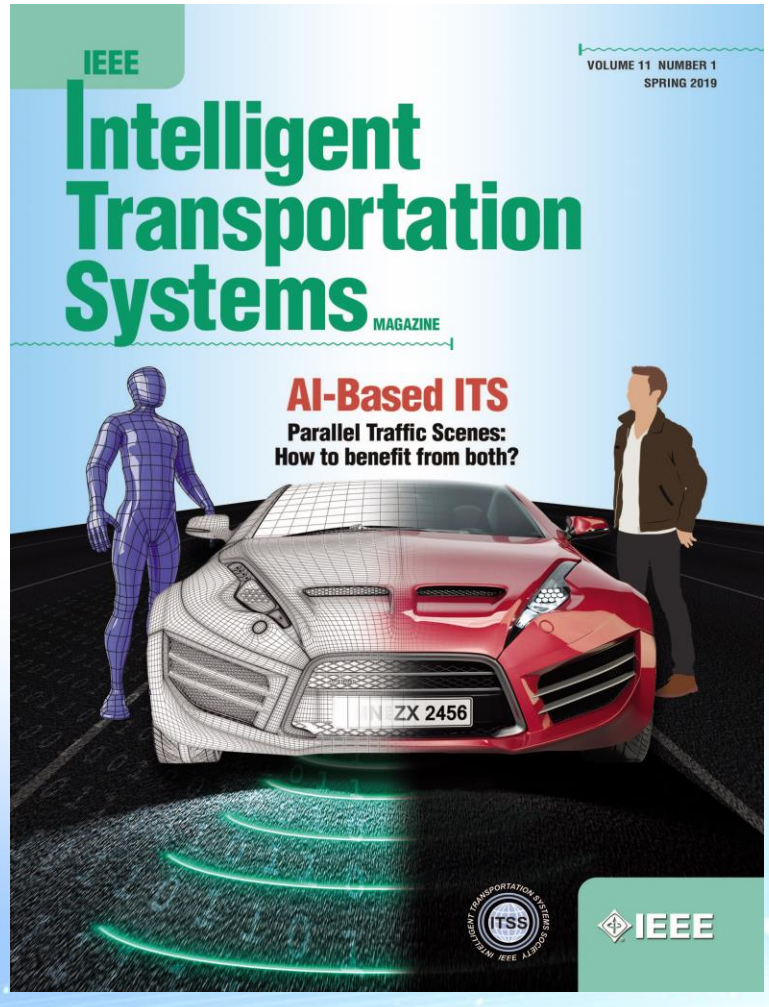


5 Transportations in One



Yuan Yong, Fei-Yue Wang. **Towards blockchain-based intelligent transportation systems**[C]//2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC). IEEE, 2016: 2663-2668.

The APEX of Parallel Transportation ?



Congratulations to

IEEE ITSM, and

Prof. Ljubo Vlacic for the

Awards for Publication EXcellence 2019

Award!

The George N. Saridis Best Transactions Paper Award

The 2014–2017 George N. Saridis Best Transactions Paper Award

Fei-Yue Wang, *Fellow, IEEE*, Azim Eskandarian, *Senior Member, IEEE*, Ljubo Vlacic, *Senior Member, IEEE*, and Petros Ioannou, *Fellow, IEEE*

IN 2015, the Board of Governors of IEEE Intelligent Transportation Systems Society had approved the proposal to name the Best Paper Award in IEEE TRANSACTIONS

2015:
The George N. Saridis Best Transactions Paper Award for Outstanding Research

Wang F Y, Eskandarian A, Vlacic L, et al, "The 2014–2017 George N. Saridis Best Transactions Paper Award", *IEEE Transactions on Intelligent Transportation Systems*, 2020, Vol.21, No. 12, pp. 4920-4921.

What is the Cover and APEX for Transportation 5.0 ?

The Mission:

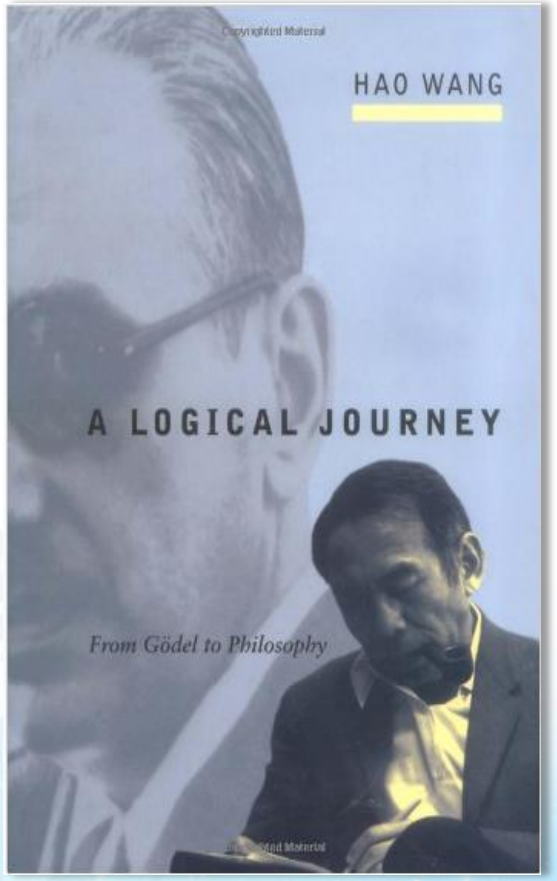
Towards Smart Cities via Transportation 5.0

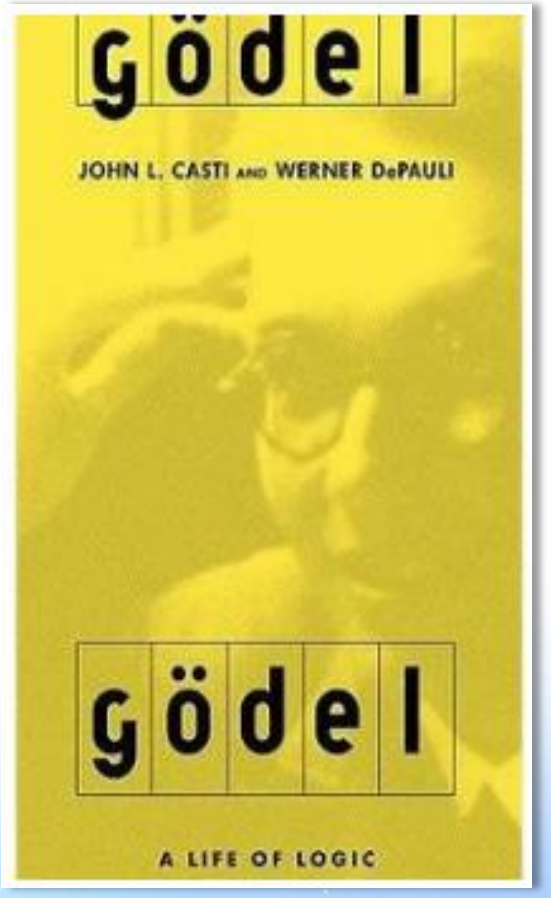
Is AI Safe? Is ITS Safe?

Where is Our Safety, Security and Sustainability?

Human and Machine: The Meaning of Godel Theorem

Godel: Either the human mind surpasses all computers or that mathematics is not created by the human mind, or both.





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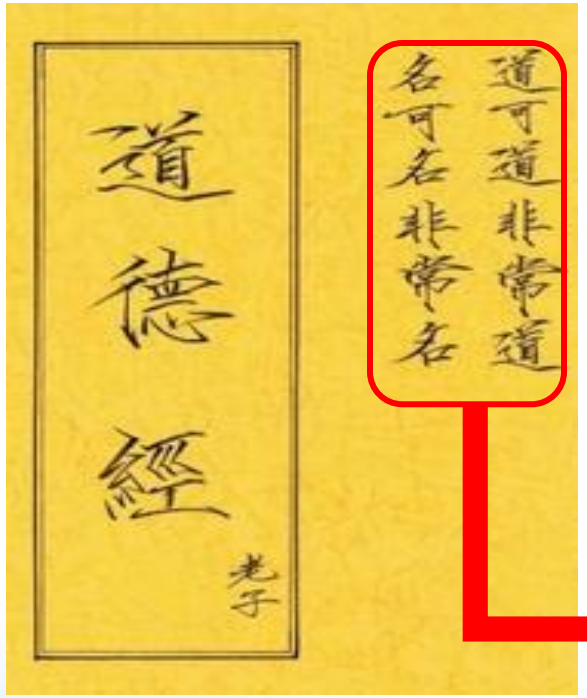
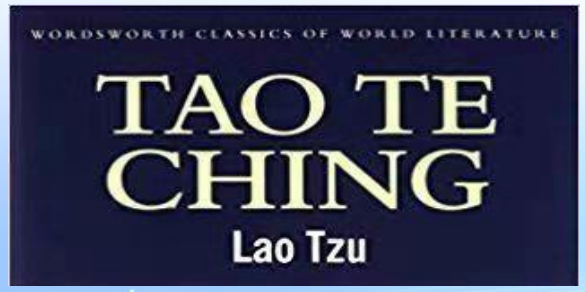
Wang: Generalized Godel Theorem





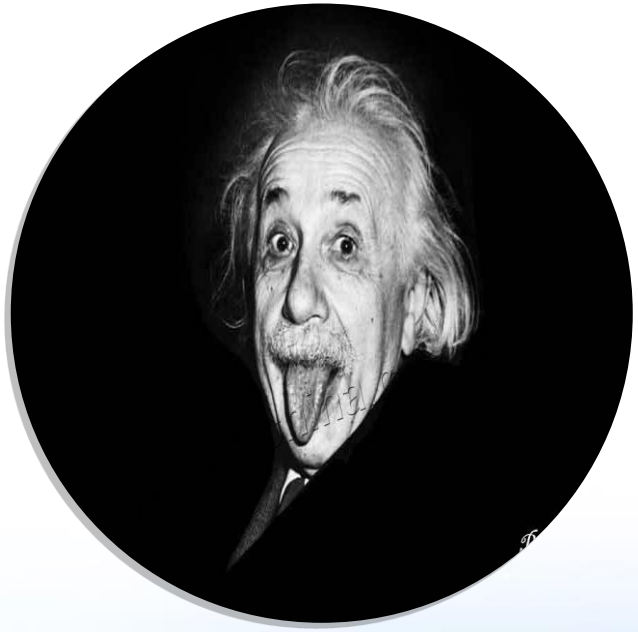
算法智能 << 语言智能 << 想

Algorithmic Intelligence	<<	Linguistic Intelligence	<<	Imaginative Intelligence
DAO		Speakable DAO		Thinkable DAO
道				可 道
非常道				

Einstein's View of Intelligence

The True sign of intelligence is not knowledge but imagination.

—Einstein

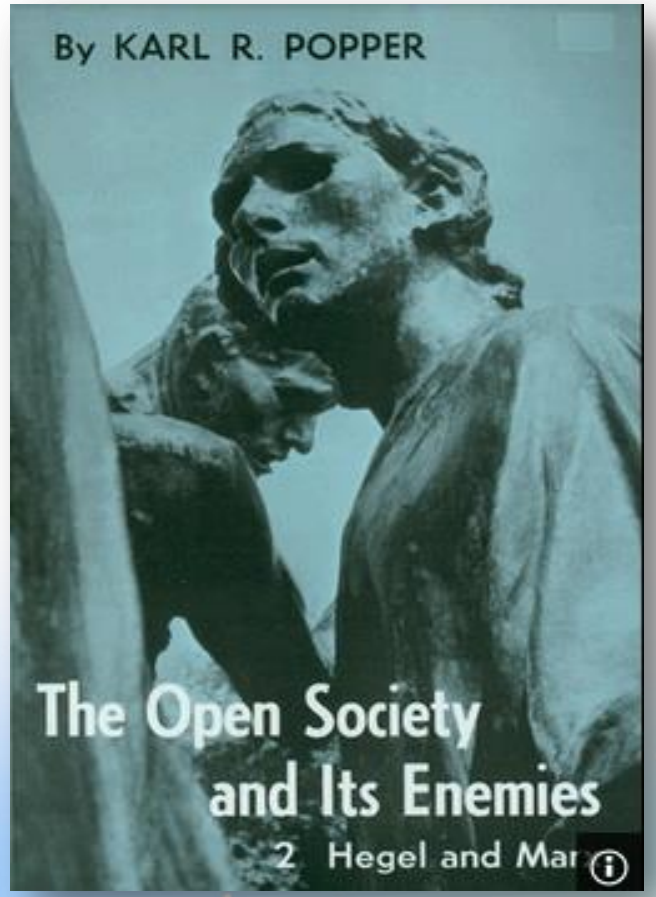


Albert Einstein
（1879.3.14-1955.4.18）

My Book in 2024: The Open Society and Its Friends

AI Will Provide 90+% of Our Future Jobs

POPPER'S BOOK:
THE OPEN SOCIETY AND ITS ENEMIES



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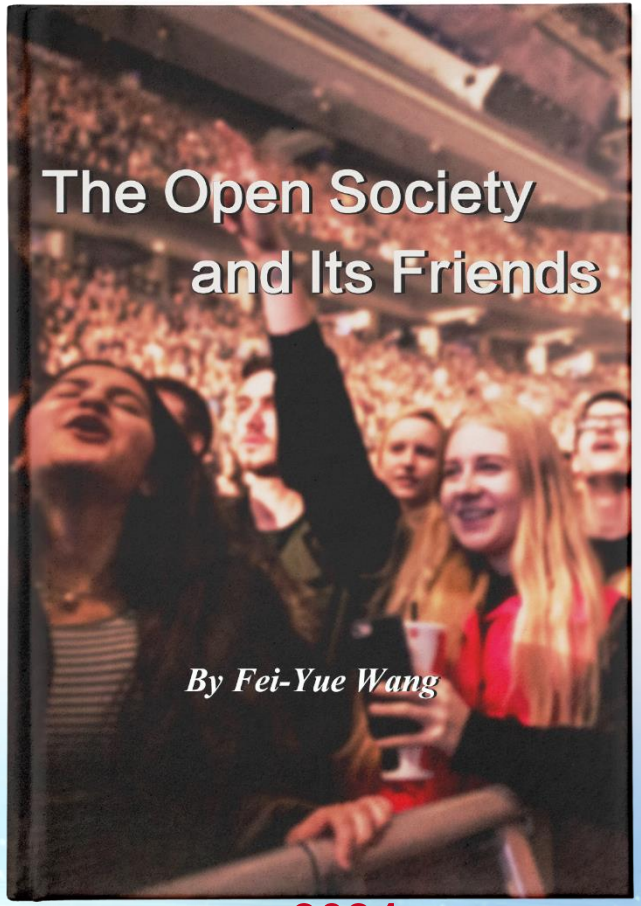
WANG'S BOOK:
THE OPEN SOCIETY AND ITS FRIENDS



2024

Towards the 6S World : "Safety, Security, Sustainability, Sensitivity, Service, Smartness"

THANK YOU