

互联网和区块链经济中的数学研讨会

Workshop on Mathematics in the Internet and Blockchain Economics

Date

2024-01-15 ~ 2024-01-19

Location

Venue: Room A-121, TSIMF

Organizer

Jing Chen(陈婧), Tsinghua University

Xiaotie Deng(邓小铁), Peking University

Sen Hu(胡森), University of Science and Technology of China

Zhiyi Huang(黄志毅), Hong Kong University

Proposal

Abstract

This workshop focuses on the mathematic advances of the rapidly growing fields of the Internet and blockchain economy. As the Internet flourishes and blockchain technology expands, it is essential to establish robust theories and technologies to guide their sustainable growth. This interdisciplinary workshop brings together experts in mathematics, theoretical computer science, game theory, economics, and operations research to discuss the latest advancements and identify key mathematical challenges in these domains. Ultimately, the workshop aims to facilitate scientific collaborations that will lead to innovative solutions for the technical challenges faced by the Internet and blockchain economies.

Significance

The primary goal of this workshop is to bring researchers from different places together to brain-storm on important challenges in the Internet and blockchain economy. The workshop will invite people at different career stages, from established experts to graduate-students-to-be, for educational and advisal purposes, which is critical for the healthy and long-term development of related domains.

Titles and Abstracts

零知识证明、安全多方计算等在区块链上的应用

Sen Hu(胡森)

上海数学与学科交叉研究院

Bio: 胡森, 上海数学与学科交叉研究院教授。胡森教授的研究领域为量子场论和弦理论, 在其数学构造特别是非微扰场论的构造, 做了一些有益的研究, 在国际专业杂志上发表 30 余篇研究论文。胡森教授是国际数学物理与理论物理杂志 IJMPA, MPLA, Ann Poincare 等的编委。

零知识证明在区块链中的应用

Wei Wu(吴伟)

北京诚仁意和科技有限公司

报告回顾区块链技术的发展和目前存在的问题, 提出区块链扩容前沿的 layer 2 zk rollup 方案, 介绍零知识证明特点及其在区块链中的各种应用, 重点介绍以太坊零知识证明扩容项目 zkevm 技术实践。

Bio: 北京航空航天大学软件工程硕士, 曾就职于五百强外企爱立信, 微软, 任高级工程师。近年来从事区块链与隐私计算技术的工程研发, 目前在知名区块链 layer2 零知识证明扩容项目任核心研发工程师, 架构师。

Altruism, Collectivism and Egalitarianism: On a Variety of Prosocial Behaviors in Binary Networked Public Goods Games

Yukun Cheng(程郁琨)

Jiangnan University

Binary Networked public goods (BNPG) game consists of a network $G=(V,E)$ with n players residing as nodes in a network and making a YES/NO decision to invest a public project. Examples of such public projects include face mask wearing during a pandemic,

crime reporting and vaccination, etc. Most of the conventional modes of BNPG games solely posit egoism as the motivation of players: they only care about their own benefits. However, a series of real-world examples show that people have a wide range of prosocial behaviors in making decisions. To address this property, we introduce a novel extension of BNPG games to account for three kinds of prosocial motivations: altruism, collectivism, and egalitarianism. We revise utility functions to reflect different prosocial motivations with respect to the welfare of others, mediated by a prosocial graph. We develop computational complexity results to decide the existence of pure strategy Nash equilibrium in these models, for cases where the prosocial graph is a tree, a clique or a general network. We further discuss the Prosocial Network Modification (PNM) problem, in which a principal can change the network structure within a budget constraint, to induce a given strategy profile with respect to an equilibrium. For all three types of PNM problems, we completely characterize their corresponding computational complexity results.

Bio: 程郁琨，博士，博士生导师，江南大学商学院教授。

《IEEE Open Journal of Computer Society》，《运筹学学报》、《Blockchain》等期刊编委，中国工业与应用数学学会区块链专委会委员、副秘书长，中国工业与应用数学学会金融科技与算法专委会委员，中国运筹学会副秘书长，中国运筹学会博弈论分会理事、副秘书长，中国运筹学会数学规划分会理事，中国计算机学会计算经济学专业组副主任，中国计算机学会理论计算专委会执委，江苏省运筹学会理事。主要研究领域为信息经济学、算法博弈论、组合优化，区块链技术与应用等。2010-2013 年期间，在浙江大学从事博士后研究工作。2012-2013 年，获国家留学基金委资助赴澳大利亚墨尔本大学访问。作为项目主持人和主要参与人，主持或参与了国家级科研项目 10 项，省部级科研项目 2 项。在运筹学领域国际顶级刊物《Mathematics of Operations Research》，计算机科学领域重要国际期刊《IEEE Transactions on Cloud Computing》、《IEEE Transactions on Computer》、《Theoretical Computer Science》，计算经济学领域国际顶级会议 TACM Conference on Economics and Computation, EC2022，区块链领域顶级国际会议 Financial Cryptography and Data Security, FC 2022，人工智能领域顶级会议 International Joint Conference on Artificial Intelligence, IJCAI2016 上发表高水平学术论文近 70 篇。江苏省高校“青蓝工程”中青年学术带头人，江苏省高校“青蓝工程”优秀青年骨干教师。获得 2021 年度江苏省高等学校科学技术研究成果奖三等奖，2018 年第八届博弈论及其应用国际学术会议青年优秀论文奖二等奖。

Mean Field Game Analysis in Blockchain Consensus Protocol Design

Lu Cao(曹露)
Peking University

A decentralized blockchain is a distributed ledger that is often used as a platform for exchanging goods and services. This ledger is maintained by a network of nodes that obeys a set of rules, called a consensus protocol, which helps to resolve inconsistencies among local copies of a blockchain. In this talk, we build a mathematical framework for the consensus protocol designer, specifying (a) the measurement of a resource which nodes strategically invest in and compete for to win the right to build new blocks in the blockchain; and (b) a payoff function for such efforts. Thus, the equilibrium of an associated stochastic differential game can be implemented by selecting nodes in proportion to this specified resource and penalizing dishonest nodes by its loss. This associated, induced game can be further analyzed using mean field games. The problem can be broken down into two coupled PDEs, where an individual node's optimal control path is solved using a Hamilton-Jacobi-Bellman equation, and where the evolution of states distribution is characterized by a Fokker-Planck equation. We apply a finite difference scheme to the reduced system of PDEs to compute the mean field equilibrium for both long-run steady states and evolutionary dynamics. As an example, we show how the mean field equilibrium can be applied to the Bitcoin blockchain mechanism design. We demonstrate that a blockchain can be viewed as a mechanism that operates in a decentralized setup and propagates properties of the mean field equilibrium over time, such as the underlying security of the blockchain.

Bio: 曹露, 北京大学, 北京国际数学研究中心博士后。研究兴趣包括均值场博弈、机制设计和安全多方计算等领域。主要探索这些概念在区块链共识协议设计中的应用, 并致力于去中心化系统开发数学解决方案。

Teaching Economics to the Machines

Ke Tang(汤柯)
Tsinghua University

Structural models in economics can offer appealing insights but often suffer from a poor fit with the data. In contrast, machine learning models offer rich flexibility but tend to suffer from over-fitting. We propose a novel framework that incorporates useful economic restrictions from a structural model into a machine learning model through transfer learning. The core idea is to first construct a neural-network representation of the structural model, and then update the network using information from real data. In an example application to option pricing, our hybrid model significantly outperforms

both the structural model and a conventional deep-learning model. The out-performance of the hybrid model is more significant when the sample size of real data is limited or under volatile market conditions.

Bio: 汤柯，清华大学社会科学学院经济所教授、所长。主要研究方向为商品市场（包括数据要素）、数字资产和金融科技。在 *Journal of Finance*、*Review of Financial Studies*、*Management Science*、*PNAS*、《中国社会科学》、《经济研究》等杂志上发表多篇论文。目前担任国际期刊 *Quantitative Finance* 的执行编辑、*Journal of Commodity Markets*、《经济学报》的副主编以及《管理科学学报》的领域编辑。研究成果得到美国期货管理委员会、联合国商品报告以及多家媒体的报道。获得过中宣部四个一批暨哲学社会科学领军人才、国家杰出青年科学基金、中组部“青年拔尖人才支持计划（万人计划）”等奖励，入选 2020、2021、2022 年爱思唯尔中国高被引学者。

CBDC & Smart contracts

Zhong Chen(陈钟)
Peking University

Bio: Zhong Chen, Ph.D., is Professor and Director of Metaverse Technology Institute in School of Computer Sciences at Peking University. Dr. Chen graduated and earned his Ph.D degree from Computer Science and Technology Department at Peking University in 1989, and then joined the faculty of computer science in Peking University. He became full professor in 1995. He was a visiting professor of UCLA from 2001 to 2002. He has been assumed the founding dean position of the School of Software and Microelectronics in Peking University from 2002 to 2010, chairman of CS department from 2011-2015. Prof. Chen is the fellow and managing director of China Computer Federation (CCF), deputy director of the Steering Committee of Higher Education on Computer Science and Technology of China, vice-chair of China Software Industry Association and vice-chair of China Open Source Software Promotion Union (COPU), director of FinTech and Algorithms Expert Committee of China Society for Industrial and Applied Mathematics (CSIAM), Co-Chairman of ZGC FinTech Industry Development Alliance. His research interests include Domain-specific Software Engineering (especially in Banking and Financing, e-Commerce, Digital Government etc.) enterprise digital transformation, smart service applications, Blockchain and Web3 etc. He has published more than 200 research papers and Five academic books. He has supervised 35 Ph.D. and more than 100 Masters. He received the 1st Prize National Higher Education Teaching Achievements Award in 2005 and Excellent Teacher Awards for Computer Science and Technology by China Teacher Development Foundation in 2019.

区块链共识认知一致性

Xiaotie Deng(邓小铁)

Peking University

Bio: 邓小铁，北京大学讲席教授，前沿计算研究中心执行主任，CCF 计算经济学专业组主任，中国工业与应用数学学会区块链专委会主任，北京大学人工智能研究院多智能体中心主任。主要研究方向为算法博弈论、计算经济学、区块链、组合优化。2008 年，因在算法博弈论领域的贡献当选 ACM Fellow；2019 年，因在不完全信息计算和交互环境计算领域的贡献当选 IEEE Fellow；2020 年当选欧洲科学院外籍院士；2021 年当选中国工业与应用数学学会会士 (CSIAM Fellow)、博弈论学会 (GTS) 理事、中国运筹学会博弈论分会荣誉理事；2021 年获 CCF 人工智能学会多智能体与多智能体系统研究成就奖；2022 年获 ACM 计算经济学“时间检验奖” (Test of Time Award)。

Algorithmic Mechanism Design Under an Uncertain Prior

Zhiyi Huang(黄志毅)

Hong Kong University

Bio: I am an associate professor of Computer Science at the University of Hong Kong. I work broadly on theoretical computer science. Before joining HKU, I was a postdoc at Stanford University from 2013 to 2014, working with Tim Roughgarden. I obtained my Ph.D. from the University of Pennsylvania under Sampath Kannan and Aaron Roth in 2013. During grad school, I interned at Microsoft Research Redmond under Nikhil R. Devanur in the summers of 2011 and 2012. Before that I got a bachelor degree from the first "Yao Class" under Andrew Yao at Tsinghua University in 2008. I was the recipient of the Best Paper Awards of FOCS 2020 and SPAA 2015, an Excellent Young Scientists Fund (HK & Macau) by NSFC, an Early Career Award by RGC Hong Kong, a Morris and Dorothy Rubinoff Dissertation Award, and a Simons Graduate Fellowship in Theoretical Computer Science.

Incentives for Early Arrival in Cooperative Games

Hu Fu(伏虎)

Shanghai University of Finance and Economics

In this talk I introduce cooperative games where players join sequentially, and the value generated by those who have joined at any point must be irrevocably divided among these players. We introduce two criteria for an ideal value division mechanism: that the players should have incentives to join early, and that the division should be considered

fair. For the latter, we require that each player's expected share in the mechanism should equal her Shapley value if the players' arrival order is uniformly at random. When the value generation function is submodular, allocating the marginal value to the player satisfies these properties. This is no longer true for more general functions. Our main technical contribution is a complete characterization of 0-1 value games for which desired mechanisms exist. We show that a natural mechanism, Rewarding First Critical Player (RFC), is complete, in that a 0-1 value function admits a mechanism with the properties above if and only if RFC satisfies them; we analytically characterize all such value functions. Moreover, we give an algorithm that decomposes, in an online fashion, any value function into 0-1 value functions, on each of which RFC can be run. In this way, we design an extension of RFC for general monotone games and the properties are proved to be maintained.

Bio: 伏虎是上海财经大学理论计算机中心副教授，研究兴趣主要为算法及其在经济问题中的应用。博士毕业于康奈尔大学，博士后先后工作于微软研究院新英格兰实验室和加州理工学院，并曾于加拿大英属哥伦比亚大学计算机系（UBC）执教。

Simple and Optimal Mechanism in Efficiency and Equality Trade-off

Qi Qi(祁琦)

Renmin University of China

Bio: 祁琦，中国人民大学高瓴人工智能学院院长聘副教授，博导，国家海外高层次青年人才，CCF 中国计算机学会计算经济学专业组秘书长。博士毕业于美国斯坦福大学，导师叶荫宇教授。曾任香港科技大学助理教授。主要研究方向为算法博弈论、机制设计、复杂性、优化和多智能体系统以及在互联网经济、广告、资源分配、交通及共享经济等领域的应用。在 OR、MOR、EJOR、GEB、TR-B 等期刊和 STOC、WINE、CCC、IJCAI、AAAI、NeurIPS 等会议上发表过论文。主持国家高层次人才计划及多项香港科学基金项目。任多个国际人工智能、互联网和博弈领域会议的资深程序委员及会议联合主席。

Improved Approximation Ratios of Fixed-Price Mechanisms in Bilateral Trades

Zihe Wang(王子贺)

Renmin University

We continue the study of the performance for fixed-price mechanisms in the bilateral trade problem, and improve approximation ratios of welfare-optimal mechanisms in several settings. Specifically, in the case where only the buyer distribution is known,

we prove that there exists a distribution over different fixed-price mechanisms, such that the approximation ratio lies within the interval of $[0.71, 0.7381]$. Furthermore, we show that the same approximation ratio holds for the optimal fixed-price mechanism, when both buyer and seller distributions are known. As a result, the previously best-known $(1 - 1/ + 0.0001)$ -approximation can be improved to 0.71. Additionally, we examine randomized fixed-price mechanisms when we receive just one single sample from the seller distribution, for both symmetric and asymmetric settings. Our findings reveal that posting the single sample as the price remains optimal among all randomized fixed-price mechanisms.

Bio: Zihe Wang received his bachelor's degree from Tsinghua Institute of Interdisciplinary Information in 2011. In 2016, he received his Ph.D. from the Institute of Interdisciplinary Information, Tsinghua University. The field of research is auction design, advised by Pingzhong Tang and Andrew Chi-Chih Yao. After graduation, he worked in Shanghai University of Finance and Economics for four years, and then transferred to Renmin University of China. He is currently an assistant professor at the Gaoling School of Artificial Intelligence. His research interests lie at the intersection of computer science and economic theory, namely computational problems in economics and economic problems in computer science. In particular, his interests include the computation of Nash equilibria in games, designing mechanisms to achieve the goals of the mechanism designer. When the optimal mechanism is complex, he is interested in how to design a simple mechanism that performs well enough.

Algorithms for Maximizing Social Welfare of Real-time Random Trading

Xujin Chen(陈旭瑾)

Chinese Academy of Sciences

In the online random trading problem, m sellers and n buyers arrive in a random sequential order to meet a decision maker. Each seller possesses an item and each buyer demands an item. All items are identical. Each agent (seller or buyer) has a positive valuation on one item and reveals his or her valuation to the decision maker when the agent arrives. The decision maker, who knows only m and n in advance, uses an online algorithm to make an irrevocable decision on whether or not to trade with the arriving agent at his/her arrival time. We design online algorithms for the online random trading to maximize the social welfare, i.e., the expected total valuation of the agents who possess items on hand at the end of trading process. For the single-buyer trading, our algorithm achieves a tight competitive ratio of $1 + 1/m$. For the single-seller trading, when n tends to infinity, we establish lower bound 3.258 and upper bound 4.189 on the competitive ratio. When both m and n are sufficiently large, our

algorithm achieves an asymptotic competitive ratio no more than $1 + O(m^{-1/3} \ln m)$.
(Joint work with Xiaodong Hu, Chenhao Wang, Xiaoying Wu, and Mengqi Zhang)

Bio: 陈旭瑾，2004 年获香港大学博士学位，现为中国科学院数学与系统科学研究院研究员。主要研究兴趣是组合优化的理论和算法，包括算法博弈论、网络优化、多面体组合等。曾获中国青年科技奖、中国运筹学会青年科技奖、国家优秀青年基金。入选国家中青年科技创新领军人才计划。

Xujin Chen received her Ph.D degree in Operations Research from Hong Kong University in 2004. She is currently a Professor at Academy of Mathematics and System Science, Chinese Academy of Sciences. Dr. Chen's research interests include Combinatorial Optimization (with an emphasis on polyhedral combinatoric and approximation algorithms), Algorithmic Game Theory (with an emphasis on network games), and Graph Theory (with an emphasis on structural graph theory). Dr. Chen received Excellent Young Scientists Fund of NNSFC (2013-2015), the first place Youth Award of Science & Technology of the Operations Research Society of China in 2010, and China Youth Science and Technology Award in 2020. She has been selected as a leading talent in science and technology innovation under the National "Ten Thousand Talents Program".

We-TIPS: Transaction Selection Game in DAG-based Blockchain

Zhixuan Fang(房智轩)
Tsinghua University

The DAG-based blockchain systems possess the capability to support high-concurrency transaction processing, making it a viable solution for addressing blockchain scalability issues. As a core step in enhancing transaction concurrency for DAG blockchain systems, the efficiency of transaction selection by nodes significantly influences the system's transaction throughput performance. This talk will discuss the process of transaction selection by nodes, highlighting two dilemmas faced in this process: the node profit dilemma and the system throughput dilemma. Through modeling analysis based on game theory, we examine the core reasons behind these two dilemmas. Additionally, by proposing a signaling mechanism based on Bloom filters, we significantly improve the efficiency of transaction selection, reduce collisions of repeated transactions, and simultaneously improve both node profits and system throughput performance.

Bio: Zhixuan Fang is a tenure-track assistant professor at the Institute for Interdisciplinary Information Sciences (IIIS) at Tsinghua University, Beijing, China. His research interests are in the design and analysis of multi-agent systems, blockchain and networked systems. He received his Ph.D. degree in computer science from

Tsinghua University, China, in 2018, and his B.S. degree in physics from Peking University, China, in 2013.

Auction Design for Bidders with Ex Post ROI Constraints

Xiaohui Bei(贝小辉)

Nanyang Technological University

Motivated by practical constraints in online advertising, we investigate single-parameter auction design for bidders with constraints on their Return On Investment (ROI) – a targeted minimum ratio between the obtained value and the payment. We focus on ex post ROI constraints, which require the ROI condition to be satisfied for every realized value profile. With ROI-constrained bidders, we provide a full characterization of the allocation and payment rules of dominant-strategy incentive compatible (DSIC) auctions. In particular, we show that given any monotone allocation rule, the corresponding DSIC payment should be the Myerson payment with a rebate for each bidder to meet their ROI constraints. Furthermore, we also determine the optimal auction structure when the item is sold to a single bidder under a mild regularity condition. This structure entails a randomized allocation scheme and a first-price payment rule, which differs from the deterministic Myerson auction and previous works on ex ante ROI constraints.

Bio: Xiaohui Bei is an Associate Professor in the Division of Mathematical Sciences at Nanyang Technological University. He obtained his Ph.D. from Tsinghua University in 2012. His research interests include topics in resource allocation, computational economics, and general algorithm design. He has published more than 40 publications at top-tier computer science conferences and journals. He is also the recipient of the Microsoft Research Asia Fellowship and the Nanyang Assistant Professorship.

Fair Scheduling for Time-dependent Resources

Minming Li(李闵溟)

City University of Hong Kong

We study a fair resource scheduling problem, where a set of interval jobs are to be allocated to heterogeneous machines controlled by intellectual agents. Each job is associated with release time, deadline, and processing time such that it can be processed if its complete processing period is between its release time and deadline. The machines gain possibly different utilities by processing different jobs, and all jobs assigned to the

same machine should be processed without overlap. We consider two widely studied solution concepts, namely, maximin share fairness and envy-freeness. For both criteria, we discuss the extent to which fair allocations exist and present constant approximation algorithms for various settings.

Bio: Minming Li is currently a professor in Department of Computer Science, City University of Hong Kong. He received his Ph. D. and B.E. degree in the Department of Computer Science and Technology at Tsinghua University in 2006 and 2002 respectively. His research interests include algorithmic game theory, combinatorial optimization and algorithm design and analysis for scheduling problems.

Optimal Private Payoff Manipulation against Commitment in Stackelberg Equilibria

Yurong Chen (陈昱蓉)
Peking University

To take advantage of strategy commitment, a useful tactic of playing games, a leader must learn enough information about the follower's payoff function. However, this leaves the follower a chance to provide fake information and influence the final game outcome. Through a carefully contrived payoff function misreported to the learning leader, the follower may induce an outcome that benefits him more, compared to the ones when he truthfully behaves.

We study the follower's optimal manipulation via such strategic behaviors in extensive-form games. For all the settings considered in this paper, we characterize all the possible game outcomes that can be induced successfully. We show that it is polynomial-time tractable for the follower to find the optimal way of misreporting his private payoff information.

We note that the tractability results of the follower's optimal manipulation hold even without full knowledge of leader's function, but only has access to an oracle to leader's optimal commitments. Due caution is needed to exploit the power of commitment under asymmetric information settings.

Bio: Yurong is a fifth-year Ph.D. candidate at Peking University, advised by Xiaotie Deng. During grad school, she visited the University of Hong Kong in Spring 2023, hosted by Zhiyi Huang. Before that, she completed her B.S. degree in mathematics in Hua Luogeng Honors Class at Beihang University, where she achieved top rank in class. Yurong is a recipient of the Best Student Paper Award at WINE 2022.

Tarski Fixed Point Theorem and Recent Progress on its Complexity

Yuhao Li(李毓浩)
Columbia University

Tarski's fixed point theorem has extensive applications in many fields, including for example verification, semantics, game theory and economics. The complexity of finding a Tarski fixed point has recently gained a lot of attention.

In this talk, I will introduce the problem of computing a Tarski fixed point over a k -dimensional grid $[n]^k$, people's surprising journey over the past few years, and our recent progress toward a better understanding of it.

Bio: Yuhao Li is a PhD student in the theory group at Columbia University, where he is fortunate to be advised by Prof. Xi Chen and Prof. Rocco Servedio. Prior to that, he got a B.Sc. degree in computer science from Peking University, where he was fortunate to be advised by Prof. Xiaotie Deng.

His research interests broadly lie in theoretical computer science, especially complexity theory and game theory.