Research Statement

Lau Hoong Chuin
School of Computing and Information Systems,
Singapore Management University
Tel: (65) 6828-0229; Email: hclau@smu.edu.sg
01 January 2024

Background

Working at the interface of Artificial Intelligence and Operations Research, I am interested in combining machine learning and combinatorial optimization for complex decision-making in business. More specifically, I am interested to study use-inspired data-driven resource planning, scheduling and coordination problems in logistics, transportation, and safety/security.

The common thread running through my research is a focus on going beyond papers to build usable novel tools and prototypes, a number of which have been testbedded and deployed in industry. To achieve this end-to-end research agenda, I work actively with industry and government agencies that enable me to pursue academic research and translate them into impactful applications.

My research topics can be broadly classified into two broad areas:

I. Planning. Scheduling and Reinforcement Learning
II. Algorithm Engineering via Machine and Deep Learning
III. Quantum Algorithms for Combinatorial Optimization

I. Planning, Scheduling and Reinforcement Learning

Decision making over complex real-world social-technical systems (such as transportation systems, logistics systems, emergency response systems) involves solving combinatorial optimization problems that are dynamic and often having to consider human behaviour which may not be rational. Traditional OR methods using stochastic optimization and robust optimization are elegantly mathematically but cannot cope with the requirement of dynamism and the extent of uncertainty involving human behaviour. Furthermore, the effects of decisions may sometime be hard to measure quantifiably.

The approach I have taken in my research for the past 5 years is to combine machine learning with optimization for solving dynamic and stochastic optimization problems. I call it Machine-Learning informed Optimization (which is a focused aspect of what is commonly known as Data-Driven Optimization). Through observing and reasoning on historical data, one can derive a machine learning model to approximate the input/output behavior of a system that is hard to model by conventional means, and based on that,

decisions or policies can be derived that will be sensitive to the uncertain and dynamic environment.

This can be accomplished through various means.

One approach is to embed a Machine Learning Model into a Combinatorial Optimization decision model. In other words, the decision model is designed so that the optimization engine can exploit the structure of the empirical model to boost the search process. The underlying ML model can be a standard one, such as a decision tree or random forest, or more recently involve the use of Artificial Neural Networks (DQN for example) . These models will be embedded with Local Search, Integer Programming, Constraint Programming on the combinatorial optimization side to derive dynamic plans and policies.

As an illustration, in one recent paper,

> Deep Reinforcement Learning Approach to Solve Dynamic Vehicle Routing Problem with Stochastic Customers. In Proc. 30th *International Conference on Automated Planning and Scheduling* (ICAPS), 2020.

we studied a dynamic vehicle routing problem with stochastic demands, and proposed a solution approach that combines Deep RL model to approximate the value function which is embedded into the objective function of a routing heuristic based on Simulated Annealing, called DRLSA. Our approach enables optimized re-routing decision to be generated almost instantaneously. We evaluated DRLSA against the commonly used Approximate Value Iteration (AVI) and Multiple Scenario Approach (MSA). Our experiment results show that DRLSA can achieve on average, 10% improvement over myopic, outperforming AVI and MSA even with small training episodes on problems with degree of dynamism above 0.5.

Another approach is to use the ML model to design a Simulation model that in turn generates realistic scenarios for the decision model. This idea is a generalization of Sample Average Approximation (from the Operations Research literature), where samples are drawn not from simple distributions (such as normal distributions), but from learnt ML models which can be highly complex. Again the underlying ML model can be a neural network for example.

As an illustration, in one recent paper,

> Improving Law Enforcement Daily Deployment Through Machine Learning-Informed Optimization under Uncertainty. In Proc. *International Joint Conference on Artificial Intelligence* (IJCAI), 2019.

we developed a method to enable public law enforcement and emergency response agencies to better respond to crimes and emergency incidents. Using historical data, we

have developed ML (more precisely, Generative Adversarial Networks) models to predict incidents spatial-temporally with high accuracy, that enable the optimization models to generate daily deployment plans more effectively.

I worked on several real world domains. In the following we list three such domains.

a. Resource Planning, Scheduling and Coordination in Urban Networks: Urbanization and ageing economy introduce new challenges in sustainability and livability that entail proper resource optimization and coordination on large physical networks in operational settings, such as .

1. Logistics networks (multi-party freight consolidation and coordination for last-mile delivery)
2. Transport/Traffic networks (multi-agent coordination of vessels to enhance navigational safety)
3. Incident networks (resource scheduling for emergency response in public security and safety).

Selected Publications:

1. Logistics Networks

Ruidian Song, Hoong Chuin Lau, Xue Luo, Lei Zhao. Coordinated Delivery to Shopping Malls with Limited Docking Capacity. *Transportation Science*. Volume 56, Issue 2, March-April 2022.

Hoong Chuin Lau and Baoxiang Li. Solving the Winner Determination Problem for Online B2B Transportation Matching Platforms. *Transportation Research Part E: Logistics and Transportation Review* , Volume 150, June 2021.

Waldy Joe and Hoong Chuin Lau. Deep Reinforcement Learning Approach to Solve Dynamic Vehicle Routing Problem with Stochastic Customers. In Proc. 30th I*nternational Conference on Automated Planning and Scheduling* (ICAPS), Nice, France, June 2020.

D. Handoko, H. C. Lau and S. F. Cheng. Achieving Economic and Environmental Sustainability in Urban Consolidation Center with Bi-Criteria Auction. *IEEE Trans. Automation Science and Engineering*, 13:4, 2016.

L. Agussurja, H. C. Lau and S. F. Cheng. Achieving Stable and Fair Profit Allocation with Minimum Subsidy in Collaborative Logistics. In Proc. *AAAI Conference on Artificial Intelligence* (AAAI), Phoenix, Arizona, USA, February, 2016.

2. Transportation/Traffic Networks

Arambam Singh, Akshat Kumar and Hoong Chuin Lau. Hierarchical Multiagent Reinforcement Learning for Maritime Traffic Management. In Proc. 19th *International Conference on Autonomous Agents and Multiagent Systems* (AAMAS), Auckland, New Zealand, May 2020.

Saumya Bhatnagar, Akshat Kumar and Hoong Chuin Lau. Decision Making for Improving Maritime Traffic Safety Using Constraint Programming. In Proc. *International Joint Conference on Artificial Intelligence* (IJCAI), Macau, China, August 2019.

Lucas Agussurja, Shih-Fen Cheng and Hoong Chuin Lau. State Aggregation Approach for Stochastic Multi-Period Last-Mile Ride-Sharing Problem. *Transportation Science*, 53 (1), 148-166, 2019.

Arambam Singh, Duc Thien Nguyen, Akshat Kumar and Hoong Chuin Lau. Multiagent Decision Making For Maritime Traffic Management. In Proc. *AAAI Conference on Artificial Intelligence* (AAAI), Hawaii, USA, January 2019.

Lucas Agussurja, Akshat Kumar and Hoong Chuin Lau. Resource-Constrained Scheduling for Maritime Traffic Management. In Proc. *AAAI Conference on Artificial Intelligence* (AAAI), New Orleans, USA, February 2018.

Duc Thien Nguyen, Akshat Kumar and Hoong Chuin Lau. Collective Multiagent Sequential Decision Making Under Uncertainty. In Proc. *AAAI Conference on Artificial Intelligence* (AAAI 2017), San Francisco, USA, February 2017.

3. Incident Networks

Waldy Joe and Hoong Chuin Lau. Learning to Send Reinforcements: Coordinating Multi-Agent Dynamic Police Patrol Dispatching and Rescheduling via Reinforcement Learning. In Proc. 32nd *International Joint Conference on Artificial Intelligence* (IJCAI 2023), Macau, August 2023.

Waldy Joe, Hoong Chuin Lau and Jonathan Pan. Reinforcement Learning Approach to Solve Dynamic Bi-Objective Police Patrol Dispatching and Rescheduling Problem. *32nd International Conference on Automated Planning and Scheduling* (ICAPS 2022), June 2022, Singapore

Jonathan Chase, Siong Thye Goh, Phong Tran and Hoong Chuin Lau. OFFICERS: Operational Framework For Intelligent Crime-and-Emergency Response Scheduling. *32nd International Conference on Automated Planning and Scheduling* (ICAPS 2022), June 2022, Singapore.

J. Chase, P. Tran, L. Kang, T. Le and H. C. Lau. GRAND-VISION: An Intelligent System for Optimized Deployment Scheduling of Law Enforcement Agents. In Proc. *31st*

International Conference on Automated Planning and Scheduling (ICAPS-2021), August Guangzhou, China, 2021.

Jonathan Chase, Duc Thien Nguyen, Haiyang Sun and Hoong Chuin Lau. Improving Law Enforcement Daily Deployment Through Machine Learning-Informed Optimization under Uncertainty. In Proc. *International Joint Conference on Artificial Intelligence* (IJCAI), Macau, China, August 2019.

Duc Thien Nguyen, Akshat Kumar and Hoong Chuin Lau. Credit Assignment For Collective Multiagent RL With Global Rewards. In Proc. *Neural Information Processing Systems* (NIPS), Montreal, Canada, December 2018.

Pallavi Manohar, Pradeep Varakantham and Hoong Chuin Lau. Bounded Rank Optimization for Effective and Efficient Emergency Response. In Proc. *International Conference on Automated Planning and Scheduling* (ICAPS), Delft, Netherlands, 2018.

S. Saisubramanian, P. Varakantham and H. C. Lau. Risk based Optimization for Improving Emergency Medical Systems. In Proc. *AAAI Conference on Artificial Intelligence* (AAAI), Austin, Texas, USA, January, 2015.

b. Mobile Crowdsourcing and Crowd-tasking: Mobile technology changes the way businesses engage with consumers. At the individual level, there is an increasing trend in using mobile apps to plan and manage activities. At the corporate level, customers' digital traces can be aggregated and analysed to accurately predict demand patterns and congestion. This opens many opportunities for real-time crowd flow management and coordination, which is essentially the logistics of moving *people* (rather than freight). Unlike freight however, humans are self-interested and vary in behavior. The challenge is to coordinate people flows in an uncertain environment by providing customized information/incentives so people move towards some form of system optimality. I am interested in developing computationally efficient methods to solve these complex problems where people are agents exhibiting different human behavior.

Selected Publications:

Thivya Kandappu, Archan Misra, Shih-Fen Cheng, Randy Tandriansyah, and Hoong Chuin Lau. Obfuscation At-Source: Privacy in Context-Aware Mobile Crowd-Sourcing. In Proceedings of the *ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies* (IMWUT), 2(1), March 2018.

Pradeep Varakantham, Akshat Kumar, Hoong Chuin Lau and William Yeoh. Risk-Sensitive Stochastic Orienteering Problems for Trip Optimization in Urban Environments. ACM Transactions on Intelligent Systems and Technology, 9(3), November 2017.

Shih-fen Cheng, Cen Chen, Thivya Kandappu, Hoong Chuin Lau, Archan Misra, Nikita Jaiman, Randy Tandriansyah, Desmond Koh. Scalable Urban Mobile Crowdsourcing: Handling Uncertainty in Worker Movement. *ACM Transactions on Intelligent Systems and Technology*, 9(3), November 2017.

T. Kandappu, A. Misra, S.F. Cheng, H. C. Lau, C. Chen, N. Jaiman, R. Tandriansyah, K. Dasgupta, and D. Chander. Campus-scale mobile crowd-tasking: Deployment and behavioral insights. In Proc. 19th ACM Conference on Computer-Supported Cooperative Work and Social Computing (CSCW), San Francisco, CA, USA, February 2016.

A. Gunawan, H. C. Lau and P. Vansteenwegen. Orienteering Problem: A Survey of Recent Variants, Solution Approaches and Applications. *European Journal of Operational Research*, 225:2, 315-332, 2016.

C. Chen, S. F. Cheng, H. C. Lau and A. Misra. Towards City-scale Mobile Crowdsourcing: Task Recommendations under Trajectory Uncertainties. In Proc. *International Joint Conference on Artificial Intelligence* (IJCAI-15), Buenos Aires, Argentina, 2015.

II. Algorithm Engineering with Machine and Deep Learning

With exciting development in machine learning and deep (neural-network based) learning, NP-hard combinatorial optimization problems (such as Traveling Salesman, Orienteering, VRP, QAP) may be solved more efficiently and effectively with the help of machine learning. Even though the publications below are somewhat dated, there is an emerging interest in automated algorithm configuration and selection with deep learning, as well as the use of (deep) reinforcement learning coupled with traditional OR methods to solve challenging combinatorial optimization problems.

Selected Publications:

Aldy Gunawan, Hoong Chuin Lau and Kun Lu. ADOPT: Combining Parameter Tuning and Adaptive Operator Ordering for Solving a Class of Orienteering Problems. *Computers and Industrial Engineering*, 121, 82-96, July 2018.

Teck-Hou Teng, Hoong Chuin Lau and Aldy Gunawan. Initializing Evolutionary Search using Self-Organizing Neural Network. In Proc *12th Learning and Intelligent OptimizatioN Conference* (LION), Kalamata, Greece, June 2018.

Aldy Gunawan, Hoong Chuin Lau and Pieter Vansteenwegen. Well-Tuned Algorithms for the Team Orienteering Problem with Time Windows. *Journal of Operational Research Society*, 68(8), 861-876, 2017.

Teck-Hou Teng, Stephanus Daniel Handoko and Hoong Chuin Lau. Self-Organizing

Neural Network for Adaptive Operator Selection in Evolutionary Search. In Proc *10th Learning and Intelligent OptimizatioN Conference* (LION), Naples, Italy, June 2016.

Aldy Gunawan, Hoong Chuin Lau and Misir Mustafa. Designing and comparing multiple portfolios of parameter configurations for online algorithm selection. In Proc *10th Learning and Intelligent OptimizatioN Conference* (LION), Naples, Italy, June 2016.

R. Oentaryo, D. Handoko and H. C. Lau. Algorithm Selection via Ranking. In Proc. *Twenty-Ninth AAAI Conference on Artificial Intelligence* (AAAI-15), Austin, Texas, USA, January, 2015.

M. Misir, D. Handoko and H. C. Lau. OSCAR: Online Selection of Algorithm Portfolios with Case Study on Memetic Algorithms. In Proc 9th *Learning and Intelligent OptimizatioN Conference* (LION), Lille, France, January 2015.

Z. Yuan, D. Handoko, D. T. Nguyen and H. C. Lau. An Empirical Study of Off-line Configuration and On-line Adaptation in Operator Selection. In Proc *8th Learning and Intelligent OptimizatioN Conference* (LION) (LNCS Volume 8426), Gainesville, Florida, USA January 2014.

A. Gunawan, Z. Yuan and H. C. Lau. A Mathematical Model and Metaheuristics for Time Dependent Orienteering Problem. In Proc. *International Conf. on Practice and Theory of Automated Timetabling* (PATAT), York, United Kingdom, August 2014.

Lindawati, H. C. Lau and D. Lo. Clustering of Search Trajectory and its Application to Parameter Tuning. *Journal of the Operational Research Society*, 64, 1742–1752, 2013.

A. Gunawan, H. C. Lau and E. Wong. Real-World Parameter Tuning using Factorial Design with Parameter Decomposition. In Gaspero et al. (eds) Advances in Metaheuristics (MIC 2011 post-conference volume). Springer Operations Research / Computer Science Interfaces Book Series, 37-59, 2013.

Lindawati, Z. Yuan, H. C. Lau and F. Zhu. Automated Parameter Tuning Framework for Heterogeneous and Large Instances: Case study in Quadratic Assignment Problem. In Proc *7th Learning and Intelligent OptimizatioN Conference* (LION) (LNCS volume 7997), Catania, Italy, January 2013.

Z. Yuan, M. Birattari, T. Stuetzle and H. C. Lau. An Analysis of Post-Selection in Automatic Tuning. In Proc. *Genetic and Evolutionary Computation Conference* (GECCO), Amsterdam, Netherlands, July 2013.

III. Quantum Computing for Combinatorial Optimization

Most recently, I have taken an interest in quantum computing, triggered by a project with Fujitsu on solving combinatorial optimization problems using the Digital Annealer (DA)

technology. DA is a *quantum-inspired* CMOS chip that implements bit-flip simulated annealing in parallel that allows solving quadratic unconstrained binary optimization (QUBO) problems with up to 8192 fully-connected noise-free bits. Hence, combinatorial optimization problems can be solved by formulating them as QUBO models and running these models on DA. It is a proxy for adiabatic quantum computers and quantum annealers, as they are all unified by the mathematical framework of the Ising optimization model.

More specifically, I am interested in QUBO models for constrained routing and scheduling problems that can be effectively executed on DA as well as other QUBO solvers. Specifically, they have developed hyper-parameter tuning and decomposition methods to enhance the performance of QUBO solvers. I have experimentally demonstrated that classical solvers such as CPLEX and Gurobi. These techniques could be customized and extended to Quantum Annealing and hybrid quantum-classical methods such as QAOA.

Selected Publications:

Siong Thye Goh, Jianyuan Bo, Sabrish Gopalakrishnan and Hoong Chuin Lau. Techniques to Enhance a QUBO Solver For Permutation-Based Combinatorial Optimization. *Genetic and Evolutionary Computation Conference (GECCO 2022) Workshop on Quantum Optimization*, July 2022, Boston, USA.

Whei Yeap Suen, Matthieu Parizy and Hoong Chuin Lau. Enhancing a QUBO solver via Data Driven Multi-start and its Application to Vehicle Routing Problem. *Genetic and Evolutionary Computation Conference (GECCO 2022) Workshop on Quantum Optimization*, July 2022, Boston, USA.

Siong Thye Goh, Jianyuan Bo, Matthieu Parizy and Hoong Chuin Lau. A Recommendation System Approach to Tune a QUBO Solver. *International Joint Conf. on Artificial Intelligence (IJCAI 2022) Workshop on New Architectures for Search and Optimization*, July 2022, Vienna, Austria.

Whei Yeap Suen, Chun Yat Lee and Hoong Chuin Lau. Quantum-inspired algorithm for Vehicle Sharing Problem. *IEEE Intl. Conf. on Quantum Computing and Engineering* (QCE), October, 2021.

Tian Huang, Siong Thye Goh, Sabrish Gopalakrishnan, Tao Luo, Qianxiao Li, Hoong Chuin Lau. QROSS: QUBO Relaxation Parameter Optimisation via Learning Solver Surrogates. 2021 *IEEE 41st International Conference on Distributed Computing Systems Workshops* (ICDCSW), 2021.