Research Statement

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

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. Multi-agent Reinforcement Learning, Planning and Scheduling
II. Algorithm Engineering via Machine/Deep Learning

I. Multi-agent Reinforcement Learning, Planning and Scheduling

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 decision making. 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 the 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,


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,


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 two 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)

**Selected Publications:**

1. **Logistics Networks**


2. **Transportation/Traffic Networks**


3. Incident Networks


b. Mobile Crowdsourcing and Crowdtasking: 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:


II. Algorithm Engineering with Machine Learning.

With exciting development in machine learning and deep (neural-network) learning, NP-hard combinatorial optimization problems (such as Traveling Salesman, Orienteering, VRP, QAP) could one day be solved efficiently and effectively by modeling them as machine learning problems and solving them using hybrid classical-quantum algorithms.

Selected Publications:


