Computational decision-making under uncertainty
in engineering systems: Linking UQ to the action space

Abstract: At the core of every engineering problem lies a decision-making quest, either directly or indirectly. Sophisticated UQ methods are essentially providing decision support through efficient quantification of selected metrics and quantities of interest, and sensitivity analysis. Nonetheless, despite significant progress in UQ methods and techniques, the actual decision-making process is still largely dependent on the static and rather limited traditional cost-benefit analysis framework, and dedicated rigorous computational methodologies for engineering decisions under uncertainty are practically elusive. In this talk, an approach for a seamless integration of stochastic models and data with computational decision-making, able to directly and autonomously offer optimal actions to decision-makers/agents is analyzed. As shown, challenging sequential decision-making problems in nonstationary dynamic environments can be efficiently formulated along the premises of optimal stochastic control, through Markov Decision Processes (MDPs), Partially Observable Markov Decision Processes (POMDPs), and mixed approaches thereof. In systems with relatively low dimensional state and action spaces, MDPs and POMDPs can be satisfactorily solved to global optimality through appropriate dynamic programming algorithms. However, optimal planning for large systems with multiple components is computationally hard and severely suffers from the curse of dimensionality. New developments on Deep Reinforcement Learning (DRL) methods and their capacity of addressing this problem are discussed, with emphasis on our developed DRL formulations and novel algorithmic schemes, specifically tailored to the needs of large engineering systems, able to solve otherwise intractable problems with immense state and action spaces. DRL relations to Artificial Intelligence and Machine Learning are also explained and techniques are demystified down to their fundamental mathematical attributes, underlying computational aspects and connections to engineering. The talk concludes with numerous ongoing efforts along these lines, from centralized/decentralized infrastructure management, to emergency response of cooperating agents, to autonomous robotic navigation and wildfire prevention.

Bio: Dr. Kostas Papakonstantinou is an Assistant Professor of Civil Engineering at Penn State. He obtained a five year Diploma in Civil Engineering and a M.S. in Structural Engineering from the National Technical University of Athens, and M.S. and Ph.D. degrees at the University of California, Irvine. Prior to joining Penn State, he was an Associate Research Scientist at Columbia University. Dr. Papakonstantinou's work focuses on probabilistic analysis and stochastic mechanics, decision-making under uncertainty, machine learning, optimization/inverse methods, and their integration with computational structural mechanics and engineering applications. His research has been funded by various programs and his work has received several awards, including the National Science Foundation CAREER award in 2018.