Abstract: Robust and sensorless manipulation of large populations of dynamical systems is prevalent in numerous research areas of science and engineering. Prominent examples range from excitations of spin ensembles in nuclear magnetic resonance (NMR) spectroscopy and imaging (MRI), and desynchronization of neuron ensembles for the treatment of neurological disorders, to approximate steering of robot swarm under bounded model perturbation. However, investigating fundamental properties of such ensemble systems remains a significant challenge, as it is beyond the scope of classical control theory. In this thesis, we study fundamental control problems associated with ensemble systems, including controllability analysis and control input design. In particular, we introduce the notion of ensemble controllability for populations of control systems and then focus on the investigation of ensemble controllability for linear and bilinear populations. Specifically, we exploit techniques from functional analysis, differential geometry, Lie theory, and symmetric group theory to establish necessary and sufficient conditions for ensemble controllability of linear and bilinear ensemble systems. Furthermore, such controllability analyses also inspire the design of control inputs for ensemble systems. In particular, we present a systematic method to construct optimal selective pulses for spin ensembles in MRI and also devise control laws to create synchronization patterns for noisy oscillatory networks.

Date: Thursday, August 15, 2019
Time: 2:30 p.m.
Location: Green Hall, Room 0120

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