SEMINARNOTICE

Preston M. Green Department of Electrical and Systems Engineering

Information-Based Analysis and Control of Recurrent Linear Networks and Recurrent Networks with Sigmoidal Nonlinearities

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Abstract:Linear dynamical models have served as an analytically tractable approximation for a variety of natural and engineered systems. Recently, such models have been used to describe high-level diffusive interactions in the activation of complex networks, including those in the brain. In this regard, classical tools from control theory, including controllability analysis, have been used to assay the extent to which such networks might respond to their afferent inputs. However, for natural systems such as brain networks, it is not clear whether advantageous control properties necessarily correspond to useful functionality. That is, are systems that are highly controllable (according to certain metrics) also ones that are suited to computational goals such as representing, preserving and categorizing stimuli?

This dissertation will introduce analysis methods that link the systems-theoretic properties of linear systems with informational measures that describe these functional characterizations. First, we assess sensitivity of a linear system to input orientation and novelty by deriving a measure of how networks translate input orientation differences into readable state trajectories. Next, we explore the implications of this novelty-sensitivity for endpoint-based input discrimination, wherein stimuli are decoded in terms of their induced representation in the state space. We develop a theoretical framework for the exploration of how networks utilize excess input energy to enhance orientation sensitivity (and thus enhanced discrimination ability). Next, we conduct a theoretical study to reveal how the background or "default" state of a network with linear dynamics allows it to best promote discrimination over a continuum of stimuli. Specifically, we derive a measure, based on the classical notion of a Fisher discriminant, quantifying the extent to which the state of a network encodes information about its afferent inputs. This measure provides an information value quantifying the "knowablility" of an input based on its projection onto the background state. We subsequently optimize this background state, and characterize both the optimal background and the inputs giving it rise. Finally, we extend this information-based network analysis to include networks with nonlinear dynamics—specifically, ones involving sigmoidal saturating functions. We employ a quasilinear approximation technique, novel here in terms of its multidimensionality and specific application, to approximate the nonlinear dynamics by scaling a corresponding linear system and biasing by an offset term. A Fisher information-based metric is derived for the quasilinear system, with analytical and numerical results showing that Fisher information is better for the quasilinear (hence sigmoidal) system than for an "unconstrained" linear system. Interestingly, this relation reverses when the noise is placed outside the sigmoid in the model—we show analytically why this is so—supporting conclusions extant in the literature that the relative alignment of the state and noise covariance is predictive of Fisher information.

Dissertation Advisor:
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