Advanced Probabilistic Models for Speech and Language-Mark Andrews

Summary: This project proposal applies to the statistical and machine learning models that are used in speech and language research. It aims to develop a more general theoretical framework for the use of state-space models in speech and language and to expand the set of models currently used in these fields. In particular, it is motivated by the belief that the use of nonlinear state-space models may lead to more powerful and more general machine learning models can improve the success and extent of speech and language technologies.

Probabilistic models used in speech and language technologies often take the form of state-space models. A state-space model is a type of stochastic generative model that describes the means by which data (i.e. a speech stream, a sequence of text, etc.) are generated. In state-space models, it is assumed that data are generated as a function of an unobserved or latent state-space, and that this state-space is evolving in time. Examples of state-space models include the Hidden Markov model (HMM) and its variants, such as factorial and hierarchical HMMs, the Kalman Filter Model (KFM) and its variants, such as extended and unscented KFMs, and hybrids of HMMs and KFMs, such as switching state-space models. While these models have been successfully applied to cases of speech and language modeling, they can suffer a lack of generality that limits success or extent of their applications. For example, HMMs have a finite number of states in their state-space. In virtue of this, they can be no more powerful than finite-automata in their generative capacity. In particular, this means that they can not model some of the recursive structures that are found across all natural languages. Kalman Filter Models, on the other hand, are based upon linear dynamical systems that evidently lack the repertoire of behaviors necessary for modeling the complex time-series data found in speech and language applications.

In light of these shortcomings, this project aims to to expand or generalize the set of models currently used in in speech and language research. In particular, it aims to investigate the use of nonlinear state-space models as alternative models in these research fields. Nonlinear state-space models are based upon nonlinear dynamical systems, and can generalize both HMMs and KFMs. The modeling potential of nonlinear state-space models has been established from the theoretical study of nonlinear dynamical systems. It has be shown that even low-dimensional and nonlinear systems, governed by smooth and continuous mappings, can simulate arbitrarily complex automata. In this respect, nonlinear state-space models generalize HMMS. Their state-spaces are continuous and can have an infinite number of distinct states. Nonlinear state-space models also generalize KFMs in that their dynamics can be arbitrarily nonlinear and complex. The challenge in the successful application of these systems is to develop tractable methods for learning and inference. Analysis of these systems is facilitated by the fact that they have the conditional independence structure of dynamical Bayesian networks. This allows efficient sequential monte-carlo methods to be employed to perform inference of state-space trajectories. In addition, given that nonlinear state-space models are governed by smooth functions, the development of learning algorithms for nonlinear systems can avail of advances in the Bayesian learning methods applied to regression and function approximation.

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