Our ability to understand networks is important to many applications, from the analysis and modeling of interactions between biological networks, to man-made social and infrastructure systems networks. Unveiling the network structure and dynamics allows us to make predictions and control decisions for these organisms/systems. At a higher abstraction level, the dynamic system models learnt have inspired new ideas for computation methods involving multi-agents cooperation, offering effective ways for solving information processing problems. This dissertation presents new results on the intertwined problems of networks inference (or identification) and multi-agents optimization. The presentation is divided into two parts —

The first part deals with the modeling and identification of network dynamics. We study two types of network dynamics arising from social networks and gene networks. The dynamics models are described in a generic form and their corresponding steady states are characterized. Our network identification method is akin to realizing a ‘network
RADAR’, meaning that we infer links between agents and the weights on them by injecting ‘signal’ into the network and observing the resultant steady states or reverberation. In social networks, this can be accomplished by making use of stubborn agents whose opinions do not change throughout a discussion; or in gene regulatory networks, we can suppress certain gene to create desired perturbations to the gene expression levels of other genes. Using a non-linear dynamical system model, the steady-state behaviors of the networked systems are characterized. In contrast to the common assumption of full rank input, here we work with a laxer assumption when low-rank input is used, which is more common for empirical network data. A robust sparse recovery method is then proposed to identify the network. Under the assumption that the network is sparse, we provide the first sufficient condition for which a large network can be identified even when only a small amount of data is obtained. We apply the method to both synthetic and empirical data from social networks and gene regulatory networks. The proposed methodology offers superior performance compared to state-of-the-art methods. We also discuss how to perform community detection directly on the low-rank network data.

The second part is concerned with algorithms that run on networks. In particular, we develop three new consensus-based decentralized algorithms for multi-agent optimization. First, we propose a decentralized Frank-Wolfe algorithm, called the DeFW algorithm, with convergence rate guarantees for both convex and non-convex optimizations. The main advantage of the proposed DeFW algorithm lies on its projection-free nature, where we can replace the costly Euclidean projection step in traditional algorithms with a low-cost linear optimization step, providing orders of
savings in computational complexity. The proposed algorithm is the first of its kind to perform decentralized optimization in a projection-free manner. The DeFW algorithm provides an attractive solution for handling big data via distributing the computation resources with multi-agent optimization. As shown in the numerical experiments, the DeFW algorithm offers ≈20 to 30 times speed up in computation time for tasks such as low rank matrix completion. As an extension, we have also developed an improved DeFW algorithm for low-rank regression. In addition to the DeFW algorithm, we develop two consensus-based alternating optimization (AO) algorithms — one is designed for least square problems and one is designed for general non-convex optimization problems. Compared to general algorithms like DeFW, the AO algorithms exploit the problem structure for faster convergence. We demonstrate the efficacy of these consensus-based AO algorithms on signal estimation with asynchronous measurements and decentralized dictionary learning problems. Our numerical results show that they outperform the state-of-the-art algorithms.

We conclude this dissertation by describing a few future research directions.