Modeling and analyzing complex networks using optimal transport

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The main goal of this project is to develop and analyze methods for extracting information from complex data models. In particular we will explore directions in the intersection of the areas of optimal mass transport and graphical models for inferring information about flows and interactions in complex networks. We will consider the following two sub-projects in this direction.

1. Optimal mass transport for analyzing RNA expression networks

Concepts such as curvature and geodesics are fundamental to studying smooth surfaces and form the cornerstones of differential geometry. It has been shown that these concepts can also be extended to discrete structures such as networks by using optimal transport. This insight has recently resulted in powerful methods for analyzing complex networks in subjects such as finance and medicine [4, 5].

In this project we will use these concepts for analyzing and modelling how medicines change the RNA expression levels in a patient. Preliminary studies show that the graph curvature of the gene expression network can be used for identifying relevant genes [6]. However, further studies are needed to model dependencies and causations in the model. The project will be done in collaboration with researchers at Karolinska Institutet.

2. Information fusion and optimal transport on graphs

The second direction builds on recent computational developments of the optimal mass transport framework [3] as well as connections with Schrödinger bridge and generalizations to dynamical models [1]. Several estimation problems such as barycenter problems and tracking problems can be modelled as an optimal transport problem on a graph. This can also be viewed as a multimarginal optimal transport with cost function structured according to the information structure of the problem [2]. In this project we will develop these concepts further in terms of theory, computational algorithms, and applications.

References

[1] Y. Chen, T.T. Georgiou, and M. Pavon. Optimal transport over a linear dynamical system. *IEEE Transactions on Automatic Control*, 62(5):2137–2152, 2016.

[2] F. Elvander, I. Haasler, A. Jakobsson, and J. Karlsson. Multi-marginal optimal mass transport with partial information. *arXiv preprint arXiv:1905.03847*, 2019.

[3] G. Peyré and M. Cuturi. Computational optimal transport. *Foundations and Trends® in Machine Learning*, 11(5-6):355–607, 2019.

[4] R. Sandhu, T. Georgiou, E. Reznik, L. Zhu, I. Kolesov, Y. Senbabaoglu, and A. Tannenbaum. Graph curvature for differentiating cancer networks. *Scientific reports*, 5:12323, 2015.

[5] R.S. Sandhu, T.T. Georgiou, and A.R. Tannenbaum. Ricci curvature: An economic indicator for market fragility and systemic risk. *Science advances*, 2(5):e1501495, 2016.

[6] V. Sundström. Quantifying differences in gene networks via graph curvature, 2019.