Guest Editorial

In-Network Computation: Exploring the Fundamental Limits

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Computing functions of distributed data has held a sustained interest in both electrical engineering and computer science research communities. Several new applications, e.g., sensor and social networks, are being built around this paradigm of distributed computation of functions of distributed data over a network. The network could be formed from wireless or wireline links; it could even be an overlay network like in a social network setting. The general problem is very complex in its full generality when all possible model variations are to be considered. Hence quite a bit of the research is concentrated on various simplified forms by researchers from various fields. An important aspect of this body of research is that problem formulations, and the solution techniques, intersect different disciplines—source coding and network coding, random networks, and algorithms and associated complexity theory of time, space and communication.

Some of the early work on in-network computation, a term that is being applied to this class of problems, was on the asymptotic analysis of the number of transmissions needed to compute specific functions in noisy broadcast networks. The development of geometric random graph theory and its applicability to wireless networks led to an extending of the analysis to large, multihop wireless networks. A typical problem formulation in this latter category assumes that the node locations are from a realization of a suitable random point process; hence the resulting communication graph of the network is a geometric random graph. While there are many preliminary results, there is scope for significantly advancing the state of the art.

A second approach, which in some sense predate s the preceding class of problems, considers simple, we may even say simplistic, networks with a small number of correlated sources. Much of this body of work takes the information theoretic perspective in which the objective is to find encoding rate regions for reliably communicating the desired function of the source data to one or more destination nodes. This class of work allows block coding to achieve better rates. This problem is natural in the network coding literature that consider larger and more complex networks with independent sources and the interest is in designing optimal coding schemes and obtaining the capacity for different functions and different networks.

A third approach is to analyze the communication complexity of computing functions. Early research in this framework concentrated on two-party protocols and has been followed by quite a bit of work on multi-party protocols over broadcast networks. Renewed focus considers communication over a graph rather than over a broadcast medium. A recent work in this genre considers the communication complexity of computing the equality function over a small fully connected network. Increasingly, the interest is the case where either the network or a subset of the nodes, or both are not trustworthy.

Taking yet another view, multicommodity flow formulations are being used to devise algorithms to optimally schedule computations and communication to compute a given (arbitrary) function over a given (arbitrary). The objective is to maximise the rate of delivering the function at the terminal node.

Note that in the above, both the “in-network computation” (in which a given network, possibly random, is utilized to perform the computation) and “networks for computation” (in which the network may be designed for the specific computation) have been explored.

The preceding is of course a sample of the extant literature and we launched this special issue with the hope of consolidating the area and also provide a launch-pad for new problem formulations and applications. We are happy to note that we have been reasonably successful on both counts and this special issue contains papers that advance our understanding of the fundamental limits and also develop several interesting new strands of research. And there are also papers that analyze the performance of in-network computation in specific application environments.

Zhan et al establish a duality relation between wired networks and broadcast networks and apply nested-lattice codes to reduce the wireless network problem to a wired network problem. They then use the duality relation to compute functions of discrete sources over linear deterministic networks.

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The distortion for sending a linear function of Gaussian sources across a class of relay networks is characterized. Kowshik and Kumar first consider the worst case computation of threshold functions, delta functions and interval functions of Boolean data over a collocated network with a finite number of nodes. They determine optimal transmission strategies for these functions. They then consider the case when the data values are drawn from Bernoulli distributions. Ramamoorthy and Langberg consider the problem of communicating the sum of independent sources to more than one destination in directed acyclic networks with error-free, capacity-constrained links. Karamchandani, Niesen, and Diggavi consider computing of a function of two sources over a multiple access channel when the channel computes a function of the variables that is not the same as the target function. Lalitha et al consider a subspace computation problem in which a receiver needs to losslessly obtain a set of $s$ linear combinations of the $m$ sources. The sources could be statistically dependent. Three linear encoders are described and their sum rates characterized.

Tyagi considers secure computation in which $m$ trustworthy nodes observe correlated data and compute different functions by communicating over a noiseless untrusted network. Conditions in which the functions are securely computable are derived.

Kannan and Viswanath consider computation of multiple functions specified by computation trees over an undirected capacitated network. Achievable rates are characterized by connecting approximation algorithms for Steiner cuts to the function computation problem. Shah, Dey and Manjunath also consider optimal computation of a function of multiple sources over an undirected capacitated network. The capacity to be allocated to different overlays of the function graph on the network graph are obtained and that is then used to determine communication and computation schemes to achieve the optimal computation rate. Sappidi, Rosenberg and Girard consider the problem of computing moments of the data over a given capacitated network. Linear programs to characterize the computation rate are determined. Lu et al also consider computation of a function specified by a computation tree but consider one overlay and optimal placement of computational operations to minimize computation costs.

Kanoria and Tamuz consider a social network that is a tree and have the agents receive independent private signals from their neighbors and can also see the actions of their neighbors. Algorithms to learn the ‘state of the world’ are developed.

Leblanc et al consider the problem of achieving consensus in a network in which some of the nodes may misbehave. They characterize network topologies where local information based algorithms can succeed. Both time invariant and time varying networks are considered. They also examine properties of robust digraphs and describe a construction method for such robust networks.

There are three papers on applications of in-network computation. Takine and Sasabe consider the interesting problem of achieving consensus for clock synchronization when the network has nodes that are mobile. Pajic et al study a wireless control network that uses in-network computation to stabilize a dynamical system. Finally, Wei et al consider the problem of target tracking using in-network computation. Specifically, they characterize the mean square error in the location estimated when the network performs in-network aggregation.

We have enjoyed putting together this issue. We owe a debt of gratitude to several people that helped along the way. Firstly, we thank all the authors that submitted their work for consideration to this special issue and have made this a memorable issue for us. We also thank the reviewers for the comprehensive reviews. We are grateful to Martha Steenstrup, Laurel Greenidge and the JSAC editorial board for efficient handling of our proposal. We are also very grateful to Sue Lange for the excellent support during the final submissions. Finally, thanks to Santhana Krishnan for help with EDAS and the associated support.

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