SHORT TERM SCIENTIFIC MISSION (STSM) SCIENTIFIC REPORT

This report is submitted for approval by the STSM applicant to the STSM coordinator

Action number: CA15210 – European Network for Collaboration on Kidney Exchange Programmes
STSM title: Algorithmic research for matching problems in kidney exchanges
STSM start and end date: 18/11/2018 to 24/11/2018
Grantee name: Ioannis Caragiannis

PURPOSE OF THE STSM:

The goal of this STSM was to strengthen the collaboration between the grantee, Ioannis Caragiannis, Associate Professor at the University of Patras, and the host, Paul Duetting, Assistant Professor at London School of Economics, on algorithmic aspects of matching problems as they arise in the context of kidney exchanges. Particular emphasis was given on enhancing existing static models of stochastic matching with a temporal component, and on designing online algorithms that are provably near-optimal for this enhanced setup. The proposed research, although theoretical in nature, is likely to have a practical impact by guiding the design of novel algorithms with improved performance.

DESCRIPTION OF WORK CARRIED OUT DURING THE STSMS

The main setting that we consider assumes that a matching run of a kidney exchange program has been applied and the compatibility graph among unmatched donor-patient pairs is therefore acyclic. Our objective is to investigate how these unmatched donor-patient pairs can benefit from deceased donor transplants and be served by chains that originate from them. The problem has similarities (but also essential differences) to the, at first glance, irrelevant call admission problem. This is a nice combinatorial optimization problem that received much attention in the '90s, involves paths on directed graphs, and has been used to model important engineering problems related to the efficient use of bandwidth in high-speed communication networks. To see the relation of the problem we consider in the context of kidney exchange, imagine an acyclic graph representing compatibilities among donor-patient pairs after a maximal set of transplants have taken place, and additional nodes representing deceased donors together with their compatibilities to patients in the graph. The objective is to compute node-disjoint chains (or directed paths) that originate from the deceased donor nodes and include as many edges as possible. The number of edges is the number of patients that receive a transplant. The model is general enough and can handle altruistic (instead of deceased) donors as well as a waiting list of patients that have no associated (intended) donor and instead wait for a transplant directly from deceased donors.

DESCRIPTION OF THE MAIN RESULTS OBTAINED

Previous collaboration (in weekly skype meetings but also in an earlier STSM of Paul Duetting in Patras) between the grantee and the host had already resulted in a hardness result for the offline version of the problem when chains have a limited length (e.g., of two), a polynomial-time algorithm for computing chains of unlimited length, an analysis of the competitiveness of a greedy online algorithm and a tight lower bound on the competitiveness of any deterministic online algorithm, showing that the greedy algorithm is asymptotically optimal. Part of our previous collaboration has been the definition of a stochastic model for studying online algorithms in a more realistic context; this stochastic model has been considered extensively during this STSM.

Our first investigation considered deceased donors that belong to a small number of different types; this corresponds to the small number of different blood types in practice. In the case where the expected numbers of donors from each type is relatively large, we showed that solving the problem offline with the anticipated numbers of donors and using this solution as a guide for the online stochastic problem leads to efficient solutions. In our theoretical study, an efficient solution is one with a total number of transplants that is at most a logarithmic factor away from optimal. However, algorithms with constant competitivess are still a possibility, even though we expect that their analysis will be very challenging.

When types can be arbitrary, we have completed an analysis that makes the artificial assumption that the acyclic graph is a directed tree. Here, we exploit online algorithms for coloring inductive graphs and a nice paper by Irani in FOCS '90 that presents an analysis of a natural greedy algorithm for the problem. Our algorithm is considerably more complicated and exploits an offline linear programming solution and randomization.

We have extended the above analysis to the general case (for arbitrary types and general acyclic compatibility graphs) and we are currently completing the proof for a logarithmic upper bound on the competitive ratio of our algorithm.

En route for obtaining our new results, we have made progress in an interesting prophet inequality-type question. This captures the hardness of many online decision-making problems and could be of independent interest.

FUTURE COLLABORATIONS (if applicable)

We plan to continue our collaboration on the algorithmic aspect of kidney exchange. Our immediate next steps include the preparation of a paper with all the results obtained jointly and its submission either to the ACM Conference on Economics and Computation (EC) or to the International Joint Conference on Artificial Intelligence (IJCAI). In addition to our theoretical results, we are in contact with colleagues that work on algorithmic aspects of kidney exchange in order to collect real data and run experiments with our algorithms on them. Such experiments will be included in our forthcoming paper as well.