Publications of Hans Gawendowicz

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Journal articles

[1] Friedrich, T., Gawendowicz, H., Lenzner, P., Melnichenko, A., Social Distancing Network Creation. In: *Algorithmica*, 2023.

During a pandemic people have to find a trade-off between meeting others and staying safely at home. While meeting others is pleasant, it also increases the risk of infection. We consider this dilemma by introducing a game-theoretic network creation model in which selfish agents can form bilateral connections. They benefit from network neighbors, but at the same time, they want to maximize their distance to all other agents. This models the inherent conflict that social distancing rules impose on the behavior of selfish agents in a social network. Besides addressing this familiar issue, our model can be seen as the inverse to the well-studied Network Creation Game by Fabrikant et al. (in: PODC 2003, pp 347–351, 2003. https://doi.org/10.1145/872035.872088), where agents aim at being as central as possible in the created network. We look at two variants of network creation governed by social distancing. Firstly, a variant without connection restrictions, where we characterize optimal and equilibrium networks, and derive asymptotically tight bounds on the Price of Anarchy and Price of Stability. The second variant allows connection restrictions. As our main result, we prove that Swap-Maximal Routing-Cost Spanning Trees, an efficiently computable weaker variant of Maximum Routing-Cost Spanning Trees, actually resemble equilibria for a significant range of the parameter space. Moreover, we give almost tight bounds on the Price of Anarchy and Price of Stability. These results imply that under social distancing the agents' selfishness has a strong impact on the quality of the equilibria.

Conference papers

[2] Angrick, S., Bals, B., Friedrich, T., Gawendowicz, H., Hastrich, N., Klodt, N., Lenzner, P., Schmidt, J., Skretas, G., Wells, A., How to Reduce Temporal Cliques to Find Sparse Spanners. In: *European Symposium on Algorithms (ESA)*, 2024.

[3] Friedrich, T., Gawendowicz, H., Lenzner, P., Zahn, A., The Impact of Cooperation in Bilateral Network Creation. In: *ACM Symposium on Principles of Distributed Computing (PODC)*, 2023.

Many real-world networks, like the Internet or social networks, are not the result of central design but instead the outcome of the interaction of local agents that selfishly optimize their individual utility. The well-known Network Creation Game by Fabrikant, Luthra, Maneva, Papadimitriou, and Shenker [PODC 2003] models this. There, agents corresponding to network nodes buy incident edges towards other agents for a price of $\alpha > 0$ and simultaneously try to minimize their buying cost and their total hop distance. Since in many real-world networks, e.g., social networks, consent from both sides is required to establish and maintain a connection, Corbo and Parkes [PODC 2005] proposed a bilateral version of the Network Creation Game, in which mutual consent and payment are required in order to create edges. It is known that this cooperative version has a significantly higher Price of Anarchy compared to the unilateral version. On the first glance this is counter-intuitive, since cooperation should help to avoid socially bad states. However, in the bilateral version only a very restrictive form of cooperation is considered. We investigate this trade-off between the amount of cooperation and the Price of Anarchy by analyzing the bilateral version with respect to various degrees of cooperation among the agents. With this, we provide insights into what kind of cooperation is needed to ensure that socially good networks are created. As a first step in this direction, we focus on tree networks and present a collection of asymptotically tight bounds on the Price of Anarchy that precisely map the impact of cooperation. Most strikingly, we find that weak forms of cooperation already yield a significantly improved Price of Anarchy. In particular, the cooperation of coalitions of size 3 is enough to achieve constant bounds. Moreover, for general networks we show that enhanced cooperation yields close to optimal networks for a wide range of edge prices. Along the way, we disprove an old conjecture by Corbo and Parkes [PODC 2005].

[4] Bilò, D., Cohen, S., Friedrich, T., Gawendowicz, H., Klodt, N., Lenzner, P., Skretas, G., Temporal Network Creation Games. In: *International Joint Conference on Artificial Intelligence (IJCAI)*, pp. 2511–2519, 2023.

Most networks are not static objects, but instead they change over time. This observation has sparked rigorous research on temporal graphs within the last years. In temporal graphs, we have a fixed set of nodes and the connections between them are only available at certain time steps. This gives rise to a plethora of algorithmic problems on such graphs, most prominently the problem of finding temporal spanners, i.e., the computation of subgraphs that guarantee all pairs reachability via temporal paths. To the best of our knowledge, only centralized approaches for the solution of this problem are known. However, many real-world networks are not shaped by a central designer but instead they emerge and evolve by the interaction of many strategic agents. This observation is the driving force of the recent intensive research on game-theoretic network formation models. In this work we bring together these two recent research directions: temporal graphs and game-theoretic network formation. As a first step into this new realm, we focus on a simplified setting where a complete temporal host graph is given and the agents, corresponding to its nodes, selfishly create incident edges to ensure that they can reach all other nodes via temporal paths in the created network. This yields temporal spanners as equilibria of our game. We prove results on the convergence to and the existence of equilibrium networks, on the complexity of finding best agent strategies, and on the quality of the equilibria. By taking these first important steps, we uncover challenging open problems that call for an in-depth exploration of the creation of temporal graphs by strategic agents.

[5] Friedrich, T., Gawendowicz, H., Lenzner, P., Melnichenko, A., Social Distancing Network Creation. In: *International Colloquium on Automata, Languages and Programming (ICALP)*, pp. 62:1–62:21, 2022.

During a pandemic people have to find a trade-off between meeting others and staying safely at home. While meeting others is pleasant, it also increases the risk of infection. We consider this dilemma by introducing a game-theoretic network creation model in which selfish agents can form bilateral connections. They benefit from network neighbors, but at the same time, they want to maximize their distance to all other agents. This models the inherent conflict that social distancing rules impose on the behavior of selfish agents in a social network. Besides addressing this familiar issue, our model can be seen as the inverse to the well-studied Network Creation Game by Fabrikant et al. [PODC 2003] where agents aim at being as central as possible in the created network. Thus, our work is in-line with studies that compare minimization problems with their maximization versions. We look at two variants of network creation governed by social distancing. In the first variant, there are no restrictions on the connections being formed. We characterize optimal and equilibrium networks, and we derive asymptotically tight bounds on the Price of Anarchy and Price of Stability. The second variant is the model's generalization that allows restrictions on the connections that can be formed. As our main result, we prove that Swap-Maximal Routing-Cost Spanning Trees, an efficiently computable weaker variant of Maximum Routing-Cost Spanning Trees, actually resemble equilibria for a significant range of the parameter space. Moreover, we give almost tight bounds on the Price of Anarchy and Price of Stability. These results imply that, compared the well-studied inverse models, under social distancing the agents' selfish behavior has a significantly stronger impact on the quality of the equilibria, i.e., allowing socially much worse stable states.

[6] Friedemann, W., Friedrich, T., Gawendowicz, H., Lenzner, P., Melnichenko, A., Peters, J., Stephan, D., Vaichenker, M., Efficiency and Stability in Euclidean Network Design. In: *Symposium on Parallelism in Algorithms and Architectures (SPAA)*, pp. 232–242, 2021.

Network Design problems typically ask for a minimum cost sub-network from a given host network. This classical point-of-view assumes a central authority enforcing the optimum solution. But how should networks be designed to cope with selfish agents that own parts of the network? In this setting, minimum cost networks may be very unstable in that agents will deviate from a proposed solution if this decreases their individual cost. Hence, designed networks should be both efficient in terms of total cost and stable in terms of the agents' willingness to accept the network. We study this novel type of Network Design problem by investigating the creation of (β, γ)-networks, that are in β-approximate Nash equilibrium and have a total cost of at most γ times the optimal cost, for the recently proposed Euclidean Generalized Network Creation Game by Bilò et al.SPAA2019. There, n agents corresponding to points in Euclidean space create costly edges among themselves to optimize their centrality in the created network. Our main result is a simple $\mathcal{O}(n^2)$-time algorithm that computes a (β, β)-network with low β for any given set of points. Moreover, on integer grid point sets or random point sets our algorithm achieves a low constant β. Besides these results for the Euclidean model, we discuss a generalization of our algorithm to instances with arbitrary, even non-metric, edge lengths. Moreover, in contrast to these algorithmic results, we show that no such positive results are possible when focusing on either optimal networks, i.e., $(\beta, 1)$-networks, or perfectly stable networks, i.e., $(1, \gamma)$-networks, as in both cases NP-hard problems arise, there exist instances with very unstable optimal networks, and there are instances for perfectly stable networks with high total cost. Along the way, we significantly improve several results from Bilò et al. and we asymptotically resolve their conjecture about the Price of Anarchy by providing a tight bound.

[7] Peters, J., Stephan, D., Amon, I., Gawendowicz, H., Lischeid, J., Salabarria, J., Umland, J., Werner, F., Krejca, M. S., Rothenberger, R., Kötzing, T., Friedrich, T., Mixed Integer Programming versus Evolutionary Computation for Optimizing a Hard Real-World Staff Assignment Problem. In: *International Conference on Automated Planning and Scheduling (ICAPS)*, pp. 541–554, 2019.

Assigning staff to engagements according to hard constraints while optimizing several objectives is a task encountered by many companies on a regular basis. Simplified versions of such assignment problems are NP-hard. Despite this, a typical approach to solving them consists of formulating them as mixed integer programming (MIP) problems and using a state-of-the-art solver to get solutions that closely approximate the optimum. In this paper, we consider a complex real-world staff assignment problem encountered by the professional service company KPMG, with the goal of finding an algorithm that solves it faster and with a better solution than a commercial MIP solver. We follow the evolutionary algorithm (EA) metaheuristic and design a search heuristic which iteratively improves a solution using domain-specific mutation operators. Furthermore, we use a flow algorithm to optimally solve a subproblem, which tremendously reduces the search space for the EA. For our real-world instance of the assignment problem, given the same total time budget of 100 hours, a parallel EA approach finds a solution that is only 1.7% away from an upper bound for the (unknown) optimum within under five hours, while the MIP solver Gurobi still has a gap of 10.5 %.