Publications of Louise Molitor

This document lists all peer-reviewed publications of Louise Molitor, Chair for Algorithm Engineering, Hasso Plattner Institute, Potsdam, Germany. This listing was automatically generated on October 23, 2021. An up-to-date version is available online at hpi.de/friedrich/docs/publist/molitor.pdf.

Conference papers

[1] Böther, M., Schiller, L., Fischbeck, P., Molitor, L., Krejca, M. S., Friedrich, T., Evolutionary Minimization of Traffic Congestion. In: *Genetic and Evolutionary Computation Conference (GECCO)*, pp. 937–945, 2021. Best Paper Award (RWA Track).

Traffic congestion is a major issue that can be solved by suggesting drivers alternative routes they are willing to take. This concept has been formalized as a strategic routing problem in which a single alternative route is suggested to an existing one. We extend this formalization and introduce the Multiple-Routes problem, which is given a start and a destination and then aims at finding up to n different routes that the drivers strategically disperse over, minimizing the overall travel time of the system. Due to the NP-hard nature of the problem, we introduce the Multiple-Routes evolutionary algorithm (MREA) as a heuristic solver. We study several mutation and crossover operators and evaluate them on real-world data of the city of Berlin, Germany. We find that a combination of all operators yields the best result, improving the overall travel time by a factor between 1.8 and 3, in the median, compared to all drivers taking the fastest route. For the base case $n = 2$, we compare our MREA to the highly tailored optimal solver by Bläsius etal. [ATMOS 2020] and show that, in the median, our approach finds solutions of quality at least 99.69% of an optimal solution while only requiring 40% of the time.

[2] Krogmann, S., Lenzner, P., Molitor, L., Skopalik, A., Two-Stage Facility Location Games with Strategic Clients and Facilities. In: *International Joint Conference on Artificial Intelligence (IJCAI)*, 2021.

We consider non-cooperative facility location games where both facilities and clients act strategically and heavily influence each other. This contrasts established game-theoretic facility location models with non-strategic clients that simply select the closest opened facility. In our model, every facility location has a set of attracted clients and each client has a set of shopping locations and a weight that corresponds to her spending capacity. Facility agents selfishly select a location for opening their facility to maximize the attracted total spending capacity, whereas clients strategically decide how to distribute their spending capacity among the opened facilities in their shopping range. We focus on a natural client behavior similar to classical load balancing: our selfish clients aim for a distribution that minimizes their maximum waiting times for getting serviced, where a facility's waiting time corresponds to its total attracted client weight. We show that subgame perfect equilibria exist and give almost tight constant bounds on the Price of Anarchy and the Price of Stability, which even hold for a broader class of games with arbitrary client behavior. Since facilities and clients influence each other, it is crucial for the facilities to anticipate the selfish clients' behavior when selecting their location. For this, we provide an efficient algorithm that also implies an efficient check for equilibrium. Finally, we show that computing a socially optimal facility placement is NP-hard and that this result holds for all feasible client weight distributions.

[3] Bläsius, T., Friedrich, T., Krejca, M., Molitor, L., The Impact of Geometry on Monochrome Regions in the Flip Schelling Process. In: *International Symposium on Algorithms and Computation (ISAAC)*, 2021.

Schelling's classical segregation model gives a coherent explanation for the wide-spread phenomenon of residential segregation. We consider an agent-based saturated open-city variant, the Flip-Schelling-Process (FSP), in which agents, placed on a graph, have one out of two types and, based on the predominant type in their neighborhood, decide whether to changes their types; similar to a new agent arriving as soon as another agent leaves the vertex. We investigate the probability that an edge u,vis monochrome, i.e., that both vertices u and v have the same type in the FSP, and we provide a general framework for analyzing the influence of the underlying graph topology on residential segregation. In particular, for two adjacent vertices, we show that a highly decisive common neighborhood, i.e., a common neighborhood where the absolute value of the difference between the number of vertices with different types is high, supports segregation and moreover, that large common neighborhoods are more decisive. As an application, we study the expected behavior of the FSP on two common random graph models with and without geometry: (1) For random geometric graphs, we show that the existence of an edge u,v makes a highly decisive common neighborhood for u and v more likely. Based on this, we prove the existence of a constant $c > 0$ such that the expected fraction of monochrome edges after the FSP is at least $1/2 + c$. (2) For Erdős–Rényi graphs we show that large common neighborhoods are unlikely and that the expected fraction of monochrome edges after the FSP is at most $1/2 + o(1)$. Our results indicate that the cluster structure of the underlying graph has a significant impact on the obtained segregation strength.

[4] Bläsius, T., Böther, M., Fischbeck, P., Friedrich, T., Gries, A., Hüffner, F., Kißig, O., Lenzner, P., Molitor, L., Schiller, L., Wells, A., Witheger, S., A Strategic Routing Framework and Algorithms for Computing Alternative Paths. In: *Algorithmic Approaches for Transportation Modelling, Optimization, and Systems (ATMOS)*, pp. 10:1–10:14, 2020.

Traditional navigation services find the fastest route for a single driver. Though always using the fastest route seems desirable for every individual, selfish behavior can have undesirable effects such as higher energy consumption and avoidable congestion, even leading to higher overall and individual travel times. In contrast, strategic routing aims at optimizing the traffic for all agents regarding a global optimization goal. We introduce a framework to formalize real-world strategic routing scenarios as algorithmic problems and study one of them, which we call Single Alternative Path (SAP), in detail. There, we are given an original route between a single

origin–destination pair. The goal is to suggest an alternative route to all agents that optimizes the overall travel time under the assumption that the agents distribute among both routes according to a psychological model, for which we introduce the concept of Pareto-conformity. We show that the SAP problem is NP-complete, even for such models. Nonetheless, assuming Pareto-conformity, we give multiple algorithms for different variants of SAP, using multi-criteria shortest path algorithms as subroutines.Moreover, we prove that several natural models are in fact Pareto-conform. The implementation and evaluation of our algorithms serve as a proof of concept, showing that SAP can be solved in reasonable time even though the algorithms have exponential running time in the worst case.

[5] Bilò, D., Friedrich, T., Lenzner, P., Melnichenko, A., Molitor, L., Fair Tree Connection Games with Topology-Dependent Edge Cost. In: *Foundations of Software Technology and Theoretical Computer Science (FSTTCS)*, pp. 15:1–15:15, 2020.

How do rational agents self-organize when trying to connect to a common target? We study this question with a simple tree formation game which is related to the well-known fair single-source connection game by Anshelevich et al.(FOCS'04) and selfish spanning tree games by Gourvès and Monnot (WINE'08). In our game agents correspond to nodes in a network that activate a single outgoing edge to connect to the common target node (possibly via other nodes). Agents pay for their path to the common target, and edge costs are shared fairly among all agents using an edge. The main novelty of our model is dynamic edge costs that depend on the in-degree of the respective endpoint. This reflects that connecting to popular nodes that have increased internal coordination costs is more expensive since they can charge higher prices for their routing service. In contrast to related models, we show that equilibria are not guaranteed to exist, but we prove the existence for infinitely many numbers of agents. Moreover, we analyze the structure of equilibrium trees and employ these insights to prove a constant upper bound on the Price of Anarchy as well as non-trivial lower bounds on both the Price of Anarchy and the Price of Stability. We also show that in comparison with the social optimum tree the overall cost of an equilibrium tree is more fairly shared among the agents. Thus, we prove that self-organization of rational agents yields on average only slightly higher cost per agent compared to the centralized optimum, and at the same time, it induces a more fair cost distribution. Moreover, equilibrium trees achieve a beneficial trade-off between a low height and low maximum degree, and hence these trees might be of independent interest from a combinatorics point-of-view. We conclude with a discussion of promising extensions of our model.

[6] Bilò, D., Bilò, V., Lenzner, P., Molitor, L., Topological Influence and Locality in Swap Schelling Games. In: *International Symposium on Mathematical Foundations of Computer Science (MFCS)*, pp. 15:1–15:15, 2020.

Residential segregation is a wide-spread phenomenon that can be observed in almost everymajor city. In these urban areas residents with different racial or socioeconomic backgroundtend to form homogeneous clusters. Schelling's famous agent-based model for residentialsegregation explains how such clusters can form even if all agents are tolerant, i.e., if they agree to live in mixed neighborhoods. For segregation to occur, all it needs is a slightbias towards agents preferring similar neighbors. Very recently, Schelling's model has beeninvestigated from a game-theoretic point of view with selfish agents that strategically select their residential location. In these games, agents can improve on their current location by performing a location swap with another agent who is willing to swap. We significantly deepen these investigations by studying the influence of the underlying topology modeling the residential area on the existence of equilibria, the Price of Anarchy and on the dynamic properties of the resulting strategic multi-agent system. Moreover, as a new conceptual contribution, we also consider the influence of locality, i.e., if the location swaps are restricted to swaps of neighboring agents. We give improved almost tight boundson the Price of Anarchy for arbitrary underlying graphs and we present (almost) tight bounds for regular graphs, paths and cycles. Moreover, we give almost tight bounds for grids, whichare commonly used in empirical studies. For grids we also show that locality has a severeimpact on the game dynamics.

[7] Feldotto, M., Lenzner, P., Molitor, L., Skopalik, A., From Hotelling to Load Balancing: Approximation and the Principle of Minimum Differentiation. In: *Autonomous Agents and Multiagent Systems (AAMAS)*, pp. 1949–1951, 2019.

Competing firms tend to select similar locations for their stores. This phenomenon, called the principle of minimum differentiation, was captured by Hotelling with a landmark model of spatial competition but is still the object of an ongoing scientific debate. Although consistently observed in practice, many more realistic variants of Hotelling's model fail to support minimum differentiation or do not have pure equilibria at all. In particular, it was recently proven for a generalized model which incorporates negative network externalities and which contains Hotelling's model and classical selfish load balancing as special cases, that the unique equilibria do not adhere to minimum differentiation. Furthermore, it was shown that for a significant parameter range pure equilibria do not exist. We derive a sharp contrast to these previous results by investigating Hotelling's model with negative network externalities from an entirely new angle: approximate pure subgame perfect equilibria. This approach allows us to prove analytically and via agent-based simulations that approximate equilibria having good approximation guarantees and that adhere to minimum differentiation exist for the full parameter range of the model. Moreover, we show that the obtained approximate equilibria have high social welfare.

[8] Echzell, H., Friedrich, T., Lenzner, P., Molitor, L., Pappik, M., Schöne, F., Sommer, F., Stangl, D., Convergence and Hardness of Strategic Schelling Segregation. In: *Web and Internet Economics (WINE)*, pp. 156–170, 2019.

The phenomenon of residential segregation was captured by Schelling's famous segregation model where two types of agents are placed on a grid and an agent is content with her location if the fraction of her neighbors which have the same type as her is at least τ, for some $0 < \tau < 1$. Discontent agents simply swap their location with a randomly chosen other discontent agent or jump to a random empty cell. We analyze a generalized game-theoretic model of Schelling segregation which allows more than two agent types and more general underlying graphs modeling the residential area. For this we show that both aspects heavily influence the dynamic properties and the tractability of finding an optimal placement. We map the boundary of when improving response dynamics (IRD), i.e., the natural approach for finding equilibrium states, are guaranteed to converge. For this we prove several sharp threshold results where guaranteed IRD convergence suddenly turns into the strongest possible non-convergence result: a violation of weak acyclicity. In particular, we show such threshold results also for Schelling's original model, which is in contrast to the standard assumption in many empirical papers. Furthermore, we show that in case of convergence, IRD find an equilibrium in $O(m)$ steps, where m is the number of edges in the underlying graph and show that this bound is met in empirical simulations starting from random initial agent placements.

[9] Chauhan, A., Lenzner, P., Molitor, L., Schelling Segregation with Strategic Agents. In: *Symposium on Algorithmic Game Theory (SAGT)*, 2018.

Schelling's segregation model is a landmark model in sociology. It shows the counter-intuitive phenomenon that residential segregation between individuals of different groups can emerge even when all involved individuals are tolerant. Although the model is widely studied, no pure game-theoretic version where rational agents strategically choose their location exists. We close this gap by introducing and analyzing generalized game-theoretic models of Schelling segregation, where the agents can also have individual location preferences. For our models we investigate the convergence behavior and the efficiency of their equilibria. In particular, we prove guaranteed convergence to an equilibrium in the version which is closest to Schelling's original model. Moreover, we provide tight bounds on the Price of Anarchy.

[10] Chauhan, A., Lenzner, P., Melnichenko, A., Molitor, L., Selfish Network Creation with Non-Uniform Edge Cost. In: *Symposium on Algorithmic Game Theory (SAGT)*, pp. 160–172, 2017.

Network creation games investigate complex networks from a game-theoretic point of view. Based on the original model by Fabrikant et al. [PODC'03] many variants have been introduced. However, almost all versions have the drawback that edges are treated uniformly, i.e. every edge has the same cost and that this common parameter heavily influences the outcomes and the analysis of these games. We propose and analyze simple and natural parameter-free network creation games with non-uniform edge cost. Our models are inspired by social networks where the cost of forming a link is proportional to the popularity of the targeted node. Besides results on the complexity of computing a best response and on various properties of the sequential versions, we show that the most general version of our model has con- stant Price of Anarchy. To the best of our knowledge, this is the first proof of a constant Price of Anarchy for any network creation game.