BSc project proposals

in

Computational Complexity and Game Theory

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The following pages contain potential topics for BSc projects, but other projects are also possible. The final topic and direction of the project is settled under guidance by the advisor. In particular the weightening between theory and practical implementations is done on an individual basis, and is often adjusted during the BSc project process. Please do not hesitate to pass by our offices on or send us an e-mail for setting up a meeting to discuss potential BSc projects.

Gradient Descent: Theory and Practice

The aim of this project is to study first-order methods in convex optimization. The project should be a mix of theory and practice. The theoretical part of the project consists presenting the mathematical foundations and of analyzing convergence rates and complexity of several of the main methods used for solving large-scale problems. The practical part of the project consists of implementing and comparing these methods.

References

- To be determined based upon scope of project in terms of theory and practice.

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The Multiplicative Weights Update Method in Game Theory

The idea of the multiplicative weights update method is an important online learning method with applications to many areas, including machine learning and optimization. The goal of this project is to explore the method in the context of game theory. Classic work of Freund and Schapire show that the averages of the strategies produced by the method converge to optimal strategies of zero-sum games. Recent work of Bailey and Pilioras show that while the averages converge to optimal strategies, the sequence may in fact be repelled by optimal strategies. The goal of the project is to present the theoretical background of the multiplicative update method and perform experiments with the method on concrete games.

References

- *Adaptive game playing using multiplicative weights*. Yoav Freund and Robert E Schapire. Games and Economic Behavior, 29(1-2), 79–103, 1999. DOI: 10.1006/game.1999.0738.

- *Multiplicative Weights Update in Zero-Sum Games*. James P. Bailey and Georgios Piliouras. Proceedings 2018 ACM Conference on Economics and Computation (EC), 321–338, 2018. DOI: 10.1145/3219166.3219235.

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Fair Division Algorithms for Indivisible Items

Fair division is the task of allocating items to agents so that some fairness criterion is satisfied. The problem finds applications in every setting where some kind of allocation of resources is required. In the very popular variations with indivisible items, problem instances consist of a set of n agents and a collection of m items. Agents have valuations for the items: agent i has a valuation $v_i(j)$ for item j. Valuations for sets (or bundles) of items are then additive, with the valuation of agent i for the bundle of items S being $v_i(S) = \sum_{j \in S} v_i(j)$. An allocation of items to agents is simply a partition $A = (A_1, A_2, ..., A_n)$ of the items to the agents so that agent i gets the bundle of items A_i.

An important fairness criterion is envy-freeness. We say that an allocation A is envy-free if for every pair of agents i and j, it holds that $v_i(A_i) \geq v_i(A_j)$. In words, every agent is happy with his/her bundle of items and does not envy the bundle allocated to some other agent. It can be easily seen that envy-freeness is rarely feasible. Indeed, consider an instance with two agents, who have positive valuations for a single item. Then, any allocation that gives the item to one of the agents is not envy-free. For this reason, several relaxations of envy-freeness have been considered in the literature.

Among them, the notion of envy-freeness up to any item (or EFX) is the most appealing. An allocation A is EFX, if for every pair of agents i and j, it holds that $v_i(A_i) \geq v_i(A_j \setminus \{g\})$, for any item $g \in A_j$. In words, an allocation is EFX if the possible envy of an agent for another is eliminated by removing any item from the bundle of items allocated to the latter. Unfortunately, until now, it is not known whether all instances have EFX instances or not. Fortunately, there are polynomial-time algorithms to compute partial EFX allocations (i.e., by discarding some of the items), simultaneously providing additional efficiency guarantees (e.g., they make sure that all agents get a bundle of items, for which they have a high value). The objective of this project is to study the recent literature on fair division of indivisible items, with a particular focus on the proposed algorithms for computing partial EFX allocations. Part of the work will include the implementation of these algorithms (and of variations of them) and their testing on real and synthetic instances.

References

- *A Little Charity Guarantees Almost Envy-Freeness.* Bhaskar Ray Chaudhury, Telikepalli Kavitha, Kurt Mehlhorn, and Alkmini Sgouritsa. In *Proceedings of the 31st ACM-SIAM Annual Symposium on Discrete Algorithms (SODA)*, 2658–2672, 2020. DOI: 10.1137/1.9781611975994.162.
- *Envy-Freeness Up to Any Item with High Nash Welfare: The Virtue of Donating Items.* Ioannis Caragiannis, Nick Gravin, and Xin Huang. In *Proceedings of the 20th ACM Conference on Economics and Computation (EC)*, 527–545, 2019. DOI: 10.1145/3328526.3329574.
- *Spliddit: Unleashing Fair Division Algorithms.* Jonathan R. Goldman and Ariel D. Procaccia. SIGecom Exchanges, 13(2), 41–46, 2014. DOI: 10.1145/2728732.2728738.

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Algorithmic Aspects of Participatory Budgeting

Participatory budgeting is a relatively recent trend used by municipalities and regional governments worldwide to decide the distribution of funding to public projects. The main idea is to let the citizens express their opinion through voting over spending priorities and then implement the outcome of the vote as a public decision.

The details of voting are rather complicated (compared to a typical government election) and include a series of steps and features. We briefly present three components that are interesting from an algorithmic viewpoint. The first is the selection of the available alternatives and their nature. For example, alternatives could be discrete such as the construction of a bridge or continuous such as the length of bicycle paths. Second, how are the actual preferences of the citizens will be structured in the ballots? This step may result in a loss of information. Third, how should the votes be aggregated into a collective decision? This part is the most crucial algorithmically but strongly depends and interplays with the previous two.

The interdisciplinary field of computational social choice (lying at the intersection of social choice theory and theoretical computer science), which traditionally studies the computational complexity of voting rules, has extensively considered participatory budgeting recently, together with other modern trends of participatory democracy. The focus has been on axiomatic properties, and on quantifying the lack of efficiency of the voting process, due to the loss of information when expressing preferences.

The aim of the project is to survey the recent approaches in participatory budgeting, focusing on theoretical developments and analysis, case studies from its application to municipalities around the world, and available online tools. The project will involve the implementation of representative aggregation methods and experiments/simulations with synthetic voting scenarios.

References

- Web: www.participatorybudgeting.org, pbstanford.org.

- *Participatory Budgeting: Models and Approaches.* Haris Aziz and Nisarg Shah. In *Pathways Between Social Science and Computational Social Science: Theories, Methods, and Interpretations*, Springer, 2021. Forthcoming (available from Nisarg Shah's homepage).

- *Interactive Democracy.* Markus Brill. In *Proceedings of the 17th International Conference on Autonomous Agents and Multi-Agent Systems (AAMAS)*, 1183–1187, 2018. dl.acm.org/doi/10.5555/3237383.3237873.

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