Designing Matching Mechanisms under Constraints: An Approach from Discrete Convex Analysis (Extended Abstract)*

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In this paper, we consider two-sided, many-to-one matching problems where agents on one side of the market (hospitals) impose some distributional constraints. The *regional maximum quotas* provide one such example, where a hospital belongs to a region, and each region has an upper bound on the number of assigned agents on the other side (doctors). Furthermore, *minimum quotas* are relevant in many markets, e.g., school districts may need at least a certain number of students in each school in order for the school to operate. Yet another type of constraints takes the form of *diversity constraints*, e.g., public schools are often required to satisfy balance on the composition of students, typically in terms of socioeconomic status. Several mechanisms have been proposed for each of these various constraints, but previous studies have focused on tailoring mechanisms to specific settings, rather than providing a general framework.

We show that when the preference of the hospitals is represented as an $\mathrm{M}^\natural$-concave function, the following desirable properties hold: (i) the *time complexity* of the generalized Deferred Acceptance (DA) mechanism is $O(|X|^3)$, where $|X|$ is the number of possible contracts, (ii) the generalized DA mechanism is *strategyproof*, (iii) the obtained matching is *stable*, and (iv) the obtained matching is *optimal* for doctors within all stable matchings. Equipped with this general result, we study conditions under which the hospitals' preferences can be represented by an $\mathrm{M}^\natural$-concave function. We start by separating the preference of hospitals into two parts, i.e., hard distributional constraints for the contracts to be feasible, and soft preferences over a family of feasible contracts. We show that if a family of hospital-feasible contracts forms a *matroid*, and the soft preferences satisfy certain easy-to-verify conditions (e.g., it can be represented as a sum of weights associated with individual contracts), then hospital preferences can be represented by an $\mathrm{M}^\natural$-concave function. These conditions are general enough to cover most of existing works, i.e., stability notions under constraints in existing works can be mapped to stability for preferences that satisfy $\mathrm{M}^\natural$-concavity, and our generalized DA mechanism corresponds to proposed solutions. These conditions provide a *recipe* for non-experts in matching theory or discrete convex analysis to develop desirable mechanisms in such settings.

* A draft full version is available at http://mpra.ub.uni-muenchen.de/56189/

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Monotonicity, Revenue Equivalence and Budgets*

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Abstract. Budget constraints are central to big business auctions. In Google's GSP keyword auction and other search engine advertising platforms, the bidders are required to specify their bids as well as their budget limits. We study multidimensional mechanism design in a common scenario where players have private information about their willingness to pay and their ability to pay. We provide a necessary and sufficient conditions for the dominant-strategy incentive-compatible implementability of direct mechanisms. Immediate applications of these results include simple characterizations for auctions with publicly-known budgets and for auctions without monetary transfers.

The celebrated revenue equivalence theorem states that the seller's revenue for a broad class of standard auction formats and settings will be the same in equilibrium. Our main application is a revenue equivalence theorem for financially constrained multidimensional bidders.

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The Price of Spite in Spot-Checking Games
(Brief Announcement)

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We introduce the class of spot-checking games (SC games). These games can be seen as the graphical counterpart of *security games*, and can be used to model problems where the goal is to distribute fare inspectors over a toll network. In an SC game, the pure strategies of network users correspond to paths in a graph, and those of the fare inspectors are subset of edges to be controlled. Mixed strategies of the network users entail a non-atomic traffic model without congestion, and can be represented using multicommodity flows. Similarly, mixed strategies of the inspector can be represented by flows in a time-extended duty graph and yield Markovian patrolling policies. With this model, best responses of the network users to a given inspector's strategy correspond to shortest paths for some weights that depends on the control intensities.

Although SC games are not zero-sum, we show that a mixed Nash equilibrium can be computed by linear programming. However, the computation of a strong Stackelberg equilibrium is more relevant – because the inspector can credibly commit to a strategy– and we give a mixed integer programming (MIP) formulation for this problem. We show that the computation of such an equilibrium is NP-hard, even in the simplest case, in which the game has a "zero-sum plus costs" structure; Consequently, it is NP-hard to compute a strong Stackelberg equilibrium in a polymatrix game, *even if the game is pairwise zero-sum.*

Then, we study the *price of spite*, which measures how the payoff of the inspector degrades when committing to a Nash equilibrium, that is, when he looses his ability to credibly commit. In fact, the Nash equilibrium is easy to compute and we regard it as an efficient heuristic for the inspector, but this is also the most harmful strategy for the network users (thus the name *spite*). We give two upper bounds for this measure. The first one depends on the detour done by the flow of users' best responses to the Nash controlling strategy, with respect to a particular metric. The second one is valid for networks with a distance-based toll: in this situation the price of spite is bounded from above by a constant which depends only on the ratio of the toll rate per kilometer to the average penalty to pay per evaded kilometer for a uniform control.

Finally, we report computational experiments on instances constructed from real data, for an application to the enforcement of a truck toll in Germany. These numerical results show the efficiency of the proposed methods, as well as the quality of the bounds derived in this article.

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Brief Announcement: A Model for Multilevel Network Games*

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Abstract Today's networks, like the Internet, do not consist of one but a mixture of several interconnected networks. Each has individual qualities and hence the performance of a network node results from the networks' interplay.

We introduce a new game theoretic model capturing the interplay between a high-speed backbone network and a low-speed general purpose network. In our model, n nodes are connected by a static network and each node can decide individually to become a gateway node. A gateway node pays a fixed price for its connection to the high-speed network, but can utilize the high-speed network to gain communication distance 0 to all other gateways. Communication distances in the low-speed network are given by the hop distances. The effective communication distance between any two nodes then is given by the shortest path, which is possibly improved by using gateways as shortcuts.

Every node v has the objective to minimize its communication costs, given by the sum (SUM-game) or maximum (MAX-game) of the effective communication distances from v to all other nodes plus a fixed price $\alpha > 0$, if it decides to be a gateway. For both games and different ranges of α, we study the existence of equilibria, the price of anarchy, and convergence properties of best-response dynamics.

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Complexity of Optimal Lobbying in Threshold Aggregation

(Brief Announcement)

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Optimal Lobbying is the problem a lobbyist or a campaign manager faces in a full-information voting scenario of a multi-issue referendum when trying to influence the result. The Lobby is faced with a profile that specifies for each voter and each issue whether the voter approves or rejects the issue, and seeks to find the smallest set of voters it must influence to change their vote, for a desired outcome to be obtained. This computational problem also describes problems arising in other scenarios of aggregating complex opinions, such as principal-agents incentives scheme in a complex combinatorial problem, and bribery and manipulation in Truth-Functional Judgement Aggregation. We study the computational complexity of Optimal Lobbying when the issues are aggregated using an anonymous monotone function and the family of desired outcomes is an upward-closed family. We analyze this problem with regard to two parameters: the minimal number of supporters needed to pass an issue, and the size of the maximal minterm of the desired set (the maximal issues set that is desired s.t. each subset of it is not desired). We show that for the extreme values of the parameters, the problem is tractable, and provide algorithms. On the other hand, we prove intractability of the problem for the non-extremal values, which are common values for the parameters.

Previous versions of this work were presented at AAMAS 2013 (Extended abstract) and at The 5th Israeli Game Theory conference.

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