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Research statement

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My research interests fall in the intersection of economics and optimization and deal chiefly with topics in discrete optimization, computational social choice and fair division.

Over the past decade, optimization techniques, algorithms and machine learning have revolutionized many parts of our everyday life. However, when the time comes to make a decision together, as a society, the process looks much as it did thirty years ago. Algorithmic game theory and computational social choice give us the tools to improve deliberation, sift through masses of opinions to detect the truth and enhance the way in which large-scale decisions are made.

For example, we leverage the so-called 'wisdom of the crowds' in our paper *'Making right decisions with wrong opinions'*, by trying to approximate some unknown objective ground truth from voter opinions. Previous work typically assumed that voter opinions are distorted by some noise model, or gave guarantees that rely on having large numbers of voters. In contrast, we make no assumptions about specific noise models or the number of votes — only that, on average, voter opinions are within some bounded distance from the ground truth. This allows us to extract benefit from crowd-sourcing opinions even in situations where we have only a small number of voters who share the same biases.

'Preference elicitation for participatory budgeting' considers perhaps one of the most exciting contemporary applications for computational social choice. Under this framework, a city allows its citizens to vote for various potential infrastructure upgrades, then aggregates these votes to form a final budget. In 2016, Paris allocated more than €100M via participatory budgets and Madrid €34M, and adoption is rising worldwide. The fundamental difficulty with the process is that it is not reasonable to ask each voter to provide their full utility function when casting a vote. Instead, a vote should be easy to cast and place a low cognitive burden on voters, thereby necessarily only capturing partial information about voters' true utilities. We study how, under this uncertainty, theoretical performance guarantees depend on the voting format that is used and find that a novel input format, which we call threshold-approval votes, theoretically provides the most useful information about voter preferences. After fixing an input format, it remains to somehow aggregate the votes into a budget. Our proposal is to do this with a two-stage mathematical programming model, and we observe that threshold approval votes also lead to the most efficient outcomes in experiments using real world data. This theoretical work is complemented by an extensive user study in *'Efficiency and usability of participatory budgeting methods,'* where we evaluate how the cognitive burden associated with different types of votes impacts efficiency. We find that aggregating approval votes leads to the most efficient outcomes, while also being easy to understand and imposing a relatively low cognitive burden on voters. This may guide administrators of participatory budgeting elections towards using voting formats that are efficient and encourage participation.

Our work in *'Fair division approaches to districting'* (working title) concern another part of politics, the drawing and redrawing of political districts. This is a controversial issue, since it is often possible for parties to manipulate the drawing of districts for political gain. We ask whether there are natural fairness properties that equitable districtings should satisfy, while taking into account each party's support and existing geographical constraints. We demonstrate that it is reasonable for every party to expect to win a number of districts equal to the midpoint between the least and most districts that the party can win in any districting. Surprisingly, it is always possible to guarantee this target number of districts to each party (up to rounding). This suggests new computational approaches to the problem of finding fair districtings, for example, an equitability constraint may be added to existing formulations which optimize some measure of compactness.

Fair division problems ask you to fairly divide some resources or goods among agents with possibly heterogenous utility functions. We investigate a dynamic variant of this problem in *'Making envy vanish over time'*, where indivisible goods arrive over time. Future arrivals are unknown and agents' utility functions are chosen by an adaptive adversary. The objective is to minimize envy, or how strongly any agent prefers the allocation of another. This models donations arriving at a food bank, or shared computing resources becoming available over time. We establish that envy vanishes (grows sublinearly in the number of goods allocated), and provide optimal algorithms for making such online assignments.

My work in discrete optimization is slightly more abstract. In *'Optimization bounds from the branching dual'* we present a general method for finding strong bounds for discrete optimization problems which can be applied even when the problem has no useful linear/convex relaxation. Partial branching trees are treated as dual solutions. We propose an algorithm for solving this dual and characterize for which problem classes the algorithm is optimal.

The allure of academia, for me, is producing theoretical research that is relevant to society. I intend to continue studying discrete optimization problems related to decision diagrams, as well as the theoretical and practical aspects of designing decision-making processes and finding responsible outcomes in dynamic environments while balancing efficiency, uncertainty and fairness. As society becomes ever more connected and large-scale collaboration more common, optimization will play a crucial role in making computational social choice theory a practical reality. I believe my training and research experience has prepared me to thrive at this intersection.

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