New Challenges in Matching with Constraints

Doctoral Consortium

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ABSTRACT

In recent years, several new challenges have been observed in the application of matching theory. One important realization is that real-life matching markets are often subject to various constraints. These practical problems impose different forms of constraints on the markets which makes them different from the classical matching model. Consequently, we cannot employ classical mechanisms in these new challenges and a stable outcome, the standard solution in matching theory, is no longer guaranteed to exist. For example, one of the most pressing issues nowadays is how to allocate refugees to hosts in a safe and timely manner. The main objective of this research is to design algorithms for these new emerging problems that satisfy desirable properties while taking agents' preferences into account. Given the number of agents that participate in the market is huge, we also consider the computational efficiency to be of central importance. We are interested in designing algorithms that yield reasonable outcomes efficiently. If an algorithm could not be implemented in polynomial-time, then it is not regarded as a suitable solution.

KEYWORDS

Two-sided Matching, Mechanism Design, Distributional Constraints, Refugee Resettlement, School Choice, Regional Quotas

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1 INTRODUCTION

Matching problems involving preferences concern how to match agents from two disjoint groups while taking agents' preferences into account. The theory was established in a famous paper by Gale and Shapley [8], and it has been successfully applied to many real-life markets, including the hospital-doctor matching in the United States [19] and Japan [15], public school choice in Boston and New York city [1, 2].

Although centralized matching markets have been one of the success stories of algorithmic economics, several new challenges have been observed in the application of matching theory. For instance, in recent years one of the most pressing global issues is how to allocate refugees to hosts in a safe and timely manner. To accommodate a refugee family, a host locality needs to satisfy the multi-dimensional requirement of the family that involves different services such as housing, medical care and job opportunity.

Due to such additional constraints, we cannot employ classical mechanisms on these new challenges and a stable outcome is no longer guaranteed to exist. The main objective of this research is to design efficient algorithms for these new emerging problems that satisfy desirable properties. Given the number of agents that participate in the market is huge, we also consider the computational efficiency to be of central importance. Hence, we are interested in designing algorithms that yield reasonable outcomes efficiently. If an algorithm could not be implemented in polynomial-time, then it is not regarded as a suitable solution. In this paper, we describe several new challenges arising in the matching markets with constraints and summarize some interesting research questions that need to be explored.

2 REFUGEE RESETTLEMENT

Over the past decade, the number of refugees worldwide has risen dramatically to 25.9 million by the end of 2018[1]. Displacement has reached a record high as a result of upheavals and conflicts around the world. The large-scale refugee resettlement has become one of the most demanding global issues.

Currently, the relocation process is implemented in an ad hoc way that neither the preferences of the refugees nor the preferences of host countries are taken into consideration [21]. Once the refugees are granted asylum in some host country, little attention is paid to determine which locality should the refugees be settled [14]. However, it is important to integrate the preferences of the refugees and the hosts into the process of placement, because it matters whether the refugees will thrive in the new environment and whether the local society will welcome the refugees. This leads to the research question that how should we design a centralized matching market for the refugee allocation problem [13, 18].

One obvious feature of the refugee allocation problem that differs from the traditional two-sided matching model is the multi-dimensional requirement of families. To accommodate a refugee family, a host locality needs to provide different services such as housing, medical care and job opportunity. The multi-dimensional constraints violate the assumption of substitute condition which is sufficient for a stable outcome for two-sided matching [11, 12]. It has been shown that for the refugee allocation problem, the standard stability concept may lead to non-existence of a stable matching [6]. Aziz et al. [3] proposed a weaker stability concept capturing the idea that a refugee family that has higher priority could only replace another family with lower priority if it does not consume more resources. Aziz et al. [3] further proposed an

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[1] https://www.unhcr.org/globaltrends2018/

algorithm based on the celebrated Deferred Acceptance algorithm that yields a corresponding weaker stable outcome.

Although refugee allocation has been studied as a centralized matching problem for the past few years, there are still several important research questions that need further understanding. For instance, is there any other suitable stability concept that ensures the existence of a stable matching and leads to a reasonable outcome? How to design an efficient algorithm that is strategy-proof for refugee families while yielding a stable outcome? And what is the general condition that guarantees the existence of stable outcomes when multi-dimensional constraints are imposed?

3 CONTROLLED SCHOOL CHOICE

School choice programs aim to offer the students and their parents the opportunity to choose which public school the students will attend. Controlled school choice with affirmative action is a prevalent program adopted by numerous school districts throughout the United States, the goal of which is to promote the integration of students from diverse backgrounds. In recent years, similar centralized matching markets with diversity goals have been implemented in many other countries, including the "Mechinot" gap year program in Israel [9] and college admissions in India [5, 20].

To achieve a racial, ethnic, social and economic balance, schools typically impose minimum and maximum targets on each type [7]. For instance, schools may impose maximum quotas on majority students to limit the number of majority students that can be admitted and leave enough seats for minority students [7, 16]. Or schools may reserve some seats for students of minority types [10].

If diversity constraints are treated as hard bounds, there may not exist an outcome that fulfills all minimum quotas, and a fundamental tension between fairness and non-wastefulness arises [7]. Kojima [16] investigated the consequences of setting type-specific maximum quotas as hard bounds in terms of students' welfare and he showed that setting hard bounds can be counter-productive. There are challenges on the computational front as well: it is NP-hard to check whether there exists a feasible or stable matching for the school choice problem with diversity constraints [4]. Because of these issues with hard bounds, the recent literature on controlled school choice problems treats diversity constraints as *soft bounds* which are soft goals that schools attempt to achieve [7, 10, 17].

Most papers on controlled school choice problem assume that each student belongs to only one type. In reality, students may pertain to multiple types. For example, a student could be both female and aboriginal. The new research question is *how to design mechanisms for the controlled school choice problem where students have multiple types and diversity constraints are viewed as soft bounds?* Kurata et al. [17] first studied this question and they proposed a solution that requires students and schools to explicitly express strict preferences over types. However, students may be averse to reveal their true types, and tie-breaking over types may invite collusion or bias.

Another important issue in existing work on multiple types is the imbalance of representation for certain type combinations. For example, the existing algorithms may achieve a reasonable representation of girls as well as aboriginals but have zero representation of aboriginal girls. This violates the motivation of diversity targets, which attempts to eliminate segmentation of students from different backgrounds. Thus the goal is to design mechanisms that cater to diversity objectives while satisfying desirable properties including fairness, non-wastefulness and strategy-proofness.

4 MATCHING WITH REGIONAL QUOTAS

Another form of constraints arises in the context of Japanese residency matching program (JRMP), with a restriction on the number of doctors that are allowed to be matched to certain subsets of hospitals [15]. The JRMP program was established in 2004 to train new graduated medical students at hospitals. Due to the shortage of doctors distributed to rural areas, the Japanese government introduced "regional caps" to limit the maximum number of doctors that can be placed at each region. This form of constraints is modeled as *hospital-doctor matching with regional quotas*, in which doctors are matched to hospitals, hospitals are associated with regions, and both hospitals and regions are subject to quotas.

To ensure that the number of doctors matched to a region does not exceed its regional cap, the Japanese government also imposes a *target capacity* on each hospital which is usually smaller than its real capacity. However, such hard target capacities cause a waste of vacant positions, as pointed out by Kamada and Kojima [15]. The new research question is *how can we eliminate the waste of vacant positions with minimal modifications to the current system while assigning doctors to hospitals in a reasonable way?* The crux in the algorithm design is that when the number of applicants exceeds the regional cap, how to determine which doctors should be selected in a fair way without leading to waste.

In a recent paper, Aziz et al. [4] showed that the school choice problem with hard diversity constrains can be converted into a corresponding matching problem with hard regional quotas such that feasibility and stability are preserved under the reduction. If we apply their reduction directly, then soft diversity constraints are converted into soft regional quotas. Another research direction is to discover the connection between *soft diversity constraints* and *hard regional quotas*. Other research questions are how to weaken the stability concept to ensure the existence of stable outcomes under the general regional quotas and how to design efficient algorithms that yield stable outcomes.

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