Knowledge-Based Stable Roommates Problems

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Abstract

The PhD studies of the author focus on a human-centered and computationally-challenging interdisciplinary problem of the Stable Roommates problem and its variations. Motivated by real-world applications, and by the fact that the Stable Roommates problem does not always admit a stable solution, the goal is to develop novel computational methods to solve these problems, that are not only computationally efficient but also yield solutions that are fair, personalized, and applicable in real-world to benefit humans.

The Stable Roommates problem (SR) is a matching problem characterized by the preferences of an even number n of agents over other agents as roommates: each agent ranks all others in strict order of preference. A solution to SR is then a partition of the agents into pairs that are *acceptable* to each other (i.e., they are in the preference lists of each other), and the matching is *stable* (i.e., there exist no two agents who prefer each other to their roommates, and thus *block* the matching).

SR is studied with incomplete preference lists (SRI) (Gusfield and Irving 1989), with preference lists including ties (SRT) (Ronn 1990), and with incomplete preference lists including ties (SRTI) (Irving and Manlove 2002). While SR and SRI are tractable (Irving 1985; Gusfield and Irving 1989), SRT and SRTI are intractable under weak stability (Ronn 1990; Irving, Manlove, and O'Malley 2009). Optimization variants of SR are also studied to find more fair stable solutions, such as Egalitarian SR (Feder 1992) and Rank Maximal SRI (Cooper 2020), are NP-hard.

Unlike the Stable Marriage problem, SR does not always admit a stable solution. In such cases, variations of SR have been studied to find a good-enough solution. For instance, Almost SR aims to minimize the total number of blocking pairs; it is NP-hard (Abraham, Biró, and Manlove 2005).

Motivated by the computational challenges and real-world needs, this research aims to develop methods for personalized, fair, relaxed, and explainable solutions for SRTI, incorporating additional knowledge. To find such solutions, we introduce novel knowledge-based methods, and utilize Answer Set Programming (ASP) (Brewka, Eiter, and Truszczynski 2016) based on answer set semantics (Gelfond and Lifschitz 1988, 1991). We use the ASP solver CLINGO (Gebser et al. 2011).

Our Earlier Studies

We developed a formal framework, called SRTI-ASP (Erdem et al. 2020), that is flexible enough to provide solutions to all variations of SR mentioned above, including the intractable decision/optimization versions: SRT, SRTI, Egalitarian SRTI, Rank Maximal SRTI, Almost SRTI. For each variation of SR, given a problem instance, SRTI-ASP returns a solution if one exists; otherwise, it returns that the problem does not have a solution. We proved that SRTI-ASP is sound and complete (Erdem et al. 2020, Thm 1).

Knowledge-based SRTI. In real-world applications, preference lists are often too short or empty (e.g., for freshmen), making it difficult to find stable matchings in SRTI. When most of the preference lists are empty, Almost SRTI may not lead to good-enough solutions. To address this, we proposed a novel approach, called Knowledge-Based SRTI (Fidan and Erdem 2021), that extends the preference lists by identifying "suitable" candidates by considering domain-specific knowledge such as students' habits and desires. We introduced two methods: Personalized-SRTI and Most-SRTI.

Personalized-SRTI infers a new type of preference ordering by considering (i) the importance of each domain-specific criterion for each agent (e.g., one student may give more importance to sleeping habits whereas another student may give more importance to smoking habits), and (ii) the agents' preferred choices for each domain-specific criterion (e.g., preferring a non-smoker roommate). Then, for each agent, this new type of personalized preference list inferred from their habitual preferences are appended to the end of the preference list given by the agent.

Most-SRTI introduces a new incremental definition of a stable matching, by considering (i) the ordering of the most preferred criteria (e.g., identified by large surveys) and (ii) the agents' preferred choices for each domain-specific criterion, with the motivation that the agents with close choices are matched. Most-SRTI aims to compute such most preferred criteria based stable matchings.

Utilizing these methods, we extended SRTI-ASP to consider domain-specific knowledge about each individual's preferences about a set of criteria, and about the diversity preferences of dormitories and schools. We experimentally evaluated our methods to understand their scalability, usefulness and applicability. Surveys with students confirmed that our methods not only yield good-enough matchings but also provide personalized solutions.

Relaxed SRTI. Although our knowledge-based methods that extend the preference lists of agents by considering domain-specific knowledge are shown to be useful, it might not always be sufficient to find suitable candidates because of relevant but inaccessible knowledge about the students, due to ethical and fairness concerns. For instance, although people with similar political opinions tend to get along better, it would not be appropriate to ask questions, in a roommate questionnaire, about students' political opinions. To address this limitation, we study two different extensions to relax the problem: k-Personalized-SRTI and Sticky-SRTI.

k-Personalized-SRTI. Students often meet other students through mutual friends. Motivated by this observation, we proposed k-Personalized-SRTI (Fidan and Erdem 2025), which further extends preference lists of each agent x by including every agent y who is not already in x's preference list but "k-connected" to x (i.e., x and y are connected a chain of k PFOAF—preferred friend of a friend—relations). Also, we observed that some existing students may request not to be matched with some students (e.g., previous roommates). Based on this observation, we extended our method to consider "forbidden pairs."

We conducted experiments with both objective and subjective measures to evaluate the usefulness of the additional knowledge about the networks of the agents' preferred friends. We obtained promising results from the computational perspectives and from the users' perspectives.

Sticky-SRTI. Afacan et al. (Afacan, Aliogullari, and Barlo 2016) introduced the notion of "sticky stability" to accommodate appeal costs in school placements, and allows priority violations when the rank difference between the claimed and the received objects are less than a certain threshold. We plan to the use of sticky-stability in the context of SRTI to aid the computation of "good-enough" solutions.

Our Ongoing and Future Studies

In our interactions with the dormitory administration, they expressed interest in understanding the system's recommendations: Why does (or does not) student a match with student b? What if student a matches with student b? etc. To address such needs, we aim to make SRTI-ASP transparent and interactive enough to provide short and understandable explanations of stable roommates solution. With this motivation, we are investigating methods for generating and presenting useful explanations. Our query-based explanation generation methods utilize both knowledge-based model generation and data analysis. The proposed methods can augment explanations with formal justifications, analytical summaries, and suggestions of alternative stable or good-enough matchings, and allow interactions with the user.

We are also conducting experiments with a variety of objective and subjective measures to evaluate the computational performance, usability, usefulness, and applicability of our methods. While designing polls, surveys and interviews, we collaborate with colleagues in behavioral economics and philosophy. We plan to extend our empirical analysis with new methodologies, contributing to human-centered AI.

References

Abraham, D. J.; Biró, P.; and Manlove, D. F. 2005. "Almost stable" matchings in the roommates problem. In *International Workshop on Approximation and Online Algorithms*, 1–14. Springer.

Afacan, M. O.; Aliogullari, Z. H.; and Barlo, M. 2016. Sticky matching in school choice. *Economic Theory*, 64(3): 509–538.

Brewka, G.; Eiter, T.; and Truszczynski, M. 2016. Answer Set Programming: An Introduction to the Special Issue. *AI Magazine*, 37(3): 5–6.

Cooper, F. 2020. *Fair and large stable matchings in the Stable Marriage and Student-Project Allocation problems*. Ph.D. thesis, University of Glasgow.

Erdem, E.; Fidan, M.; Manlove, D.; and Prosser, P. 2020. A General Framework for Stable Roommates Problems using Answer Set Programming. *Theory and Practice of Logic Programming*, 20(6): 911–925.

Feder, T. 1992. A new fixed point approach for stable networks and stable marriages. *Journal of Computer and System Sciences*, 45(2): 233 – 284.

Fidan, M.; and Erdem, E. 2021. Knowledge-Based Stable Roommates Problem: A Real-World Application. *Theory and Practice of Logic Programming*, 21(6): 852–869.

Fidan, M.; and Erdem, E. 2025. Finding Personalized Good-Enough Solutions to Unsatisfiable Stable Roommates Problems. *Theory and Practice of Logic Programming*, 1–18.

Gebser, M.; Kaufmann, B.; Kaminski, R.; Ostrowski, M.; Schaub, T.; and Schneider, M. T. 2011. Potassco: The Potsdam Answer Set Solving Collection. *AI Communications*, 24(2): 107–124.

Gelfond, M.; and Lifschitz, V. 1988. The stable model semantics for logic programming. In *Proc. of ICLP*, 1070–1080. MIT Press.

Gelfond, M.; and Lifschitz, V. 1991. Classical negation in logic programs and disjunctive databases. *New Generation Computing*, 9: 365–385.

Gusfield, D.; and Irving, R. W. 1989. *The Stable Marriage Problem: Structure and Algorithms*. Cambridge, MA, USA: MIT Press.

Irving, R. W. 1985. An efficient algorithm for the "stable roommates" problem. *Journal of Algorithms*, 6(4): 577–595.

Irving, R. W.; and Manlove, D. F. 2002. The stable roommates problem with ties. *Journal of Algorithms*, 43(1): 85–105.

Irving, R. W.; Manlove, D. F.; and O'Malley, G. 2009. Stable marriage with ties and bounded length preference lists. *Journal of Discrete Algorithms*, 7(2): 213–219.

Ronn, E. 1990. NP-complete stable matching problems. *Journal of Algorithms*, 11(2): 285–304.