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Efficient and Fair Decentralized Task Allocation Algorithms for Autonomous Vehicles

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14. ABSTRACT This project produced four papers: 1) "Achieving Envy-freeness and Equitability with Monetary Transfers" addresses one of the original aims of allocating tasks and giving payments to ensure that all parties feel that the outcome was fair. Fairness can incentivize different groups of robots to cooperate; 2) "Multi-Robot Task Allocation-Complexity and Approximation" develops approximation algorithms to process the most number of tasks when there lower caps on robots requires for finish a task. It achieves a key goal of the research project of designing new algorithms for important robot-task allocation problems; 3) "A General Approximation Algorithm for Ordered Allocations" develops mathematical insights on how well CBBA type algorithms can approximate maximum welfare under submodular domains even under complex feasibility constraints. The result is central to our understanding of the welfare approximations achieved by CBBA-type algorithms. We focus on a class of algorithms that is more general than CBBA; 4) "Auction-based Allocation of Location-Specific Tasks" develops understanding of decentralized auction-based methods where the goal is minimize total distance travelled.			
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Efficient and Fair Decentralized Task Allocation Algorithms for Autonomous Vehicles

- BAA Name: FA9550-19-S-0003
- Proposal Title: Efficient and Fair Decentralized Task Allocation Algorithms for Autonomous Vehicles
- Principle Investigator: Qinru Qiu (USA)¹ and Haris Aziz (Australia)²
- Key Researcher(s) involved in the Proposed Project: Qinru Qiu and Haris Aziz
- Affiliation of each Researcher(s): ¹Syracuse University, ²UNSW Sydney
- Proposed Period-of-Performance: September 1st, 2020 ~ August 31st, 2021
- Proposed Total Cost (for one year): \$68,000 USD (UNSW Sydney)
- UNSW Grant number: RG202947
- Start date: 04 Sep 2020
- Funder reference number: FA2386-20-1-4063

Annotated List of published, submitted, and in-work papers (ACM or IEEE reference format)

Haris Aziz, Achieving Envy-freeness and Equitability with Monetary Transfers. AAAI 2021: 5102 - 5109

Synopsis:

This work addresses one of the original aims of allocating tasks and giving payments to ensure that all parties feel that the outcome was fair. Fairness can incentivize different groups of robots to cooperate.

Abstract:

When allocating indivisible resources or tasks, an envy-free allocation or equitable allocation may not exist. We present a sufficient condition and an algorithm to achieve envy-freeness and equitability when monetary transfers are allowed. The approach works for any agent valuation functions (positive or negative) as long as they satisfy superadditivity. For the case of additive utilities, we present a characterization of allocations that can simultaneously be made equitable and envy-free via payments. Our study shows that superadditive valuations constitute the largest class of valuations for which an envy-free and equitable outcome exists for all instances. We then present a distributed algorithm to compute an approximately envy-free outcome for any class of valuations.

Haris Aziz, Hau Chan, Ágnes Cseh, Bo Li, Fahimeh Ramezani, Chenhao Wang: Multi-Robot Task Allocation-Complexity and Approximation. AAMAS 2021: 133-141

Synopsis:

This work develops approximation algorithms to process the most number of tasks when there are lower caps on robots required to finish a task. It achieves a key goal of the research project of designing new algorithms for important robot-task allocation problems.

Abstract:

Multi-robot task allocation is one of the most fundamental classes of problems in robotics and is crucial for various real-world robotic applications such as search, rescue and area exploration. We consider the Single-Task robots and Multi-Robot tasks Instantaneous Assignment (ST-MR-IA) setting where each task requires at least a certain number of robots and each robot can work on at most one task and incurs an operational cost for each task. Our aim is to consider a natural computational problem of allocating robots to complete the maximum number of tasks subject to budget constraints. We consider budget constraints of three different kinds: (1) total budget, (2) task budget, and (3) robot budget. We provide a detailed complexity analysis including results on approximations as well as polynomial-time algorithms for the general setting and important restricted settings.

Haris Aziz, A General Approximation Algorithm for Ordered Allocations, Working Paper 2021

Synopsis: In this paper, we develop mathematical insights on how well CBBA type algorithms can approximate maximum welfare under submodular domains even under complex feasibility constraints. The result is central to our understanding of the welfare approximations achieved by CBBA-type algorithms. We focus on a class of algorithms that is more general than CBBA.

Abstract:

We consider a general allocation problem in which each agent has valuations over permutations of subsets of tasks. The outcome is a partitioning of a subset of the tasks into ordered bundles allocated to agents. The goal is to maximize social welfare. We present the Careful Insertion Greedy algorithm that is more general than some prominent deployed algorithms for autonomous routing and allocation problems. It takes into account feasibility constraints and allows for various particular ways to make allocation decisions. We show that when agent valuations satisfy a natural diminishing marginal gain property, then the algorithm gives a 2-approximation guarantee of the maximum welfare even if we impose a very general family of feasibility constraints.

Fahimeh Ramezeani, Brendan Sims, Haris Aziz

Auction-based Allocation of Location-Specific Tasks, Unpublished Working Paper.

Synopsis:

This work develops understanding of decentralized auction-based methods where the goal is minimize total distance travelled.

Abstract:

We consider a task allocation problem in which agents and tasks have locations, and the goal is to allocate the tasks among agents so as to minimize the distance travelled. We analyse two important algorithms under a generalised setting that puts additional feasibility constraints on the allocations. We provide matching lower and upper bounds on the approximation guarantees achieved by the algorithms. We then conduct a detailed experimental analysis of the relative performance of the algorithms. Our results indicate the relative performance of the algorithms as well as the effect of feasibility constraints on the guarantees of the algorithms.

USAF/USSF/DoD/Academia/Industry Relationship or Collaboration Highlights

- Fortnightly meetings between UNSW, DSTG members, and Syracuse University members. The meetings allows for joint training and sharing of resources and papers on task allocation algorithms.
- Brendan Sims and Syracuse University members were also collaborating on streamlining their code for CBBA and related algorithms.

Follow-on awards or research milestones enabled by this grant

- Further collaboration between DSTG Australia and UNSW Sydney and commitment to continue ongoing collaboration.

Students involved at all levels (undergrad, MS, PhD, post-doc)

Fahimeh Ramezani, postdoc UNSW Sydney
Ali Pourmiri, postdoc UNSW Sydney
Alexander Lam, PhD student UNSW Sydney
Ayda Orang, PhD student UNSW Sydney
Aditya Ganguly, Undergrad USNW Sydney