Research Statement

Guni Sharon

November 24, 2017

I am a researcher with a strong theoretical basis in combinatorial search, multiagent route assignment, game theory, flow and convex optimization, and multiagent modeling and simulation. I gained vast knowledge and experience in utilizing my theoretical foundations towards traffic management and traffic optimization application. Nonetheless, I view myself as part of the AI community where my work is highly cited. I strive to further the impact of my applicable expertise for solving real-life problems while simultaneously continuing to make theoretical advances that justify the proposed solutions.

1 Past Research

As a PhD. student, I was involved in the development of general, domain independent, search algorithms such as Enhanced-Partial Expansion A* [1, 2], Exponential deepening A* [3] and Meet in the Middle [4, 5, 6]. Yet my personal main research passion, and the focus of my own research, always remained the multiagent pathfinding problem (MAPF) where, given a graph and a set of agents, each agent must be assigned a path leading from its initial location to its destination such that it will not collide with obstacles or other moving agents.

During my graduate studies, I developed two algorithms for optimally solving the MAPF problem:

- Increasing Cost Tree Search (ICTS) [7, 8] - ICTS provides a novel formalization for MAPF which includes a search tree called the increasing cost tree (ICT) and a corresponding search algorithm that finds optimal solutions. I provided theoretical and empirical analysis presenting the benefits of ICTS over the previous state-of-the-art A*-based approach.

- Conflict Based Search (CBS) [9, 10] - CBS is a two-level algorithm. At the high level, a search is performed on a tree based on conflicts between agents. At the low level, a search is performed only for a single agent at a time. In many cases this reformulation enables CBS to examine fewer states than both ICTS and A*-based approaches while still maintaining optimality.

Both ICTS and CBS provided an entirely new approach to solving MAPF rather than incrementally improving on existing methods. As such, both have become benchmark MAPF solvers, and there is a large body of work that bases itself on and expands these algorithms. Prominent examples include: enhancements that reduce computational time [11][12][13][14], MAPF with kinematic constraints [15, 16, 17], sub-optimal variants [18, 19, 20], an incentive-compatible MAPF solver [21], and extensions to other problems [22, 23, 24, 25, 26].

Though my research interests have now broadened considerably, I am still contributing as a collaborator to several projects that involve MAPF and general heuristic search [6, 27, 28, 29, 5].
2 Current Research

My choice in research problems is always guided by a desire to eventually help solve real-world problems. In the context of MAPF, one such application is that of centralized route assignment for vehicles. The Autonomous Intersection Management protocol [30] is a prominent example of such an application. Similar centralized traffic management protocols are becoming more relevant as connected and autonomous vehicle technology advances. Developing such protocols, however, is very challenging as it requires broad knowledge and synergy between several kinds of expertise including game theory, human computer interaction, behavioral science, flow and convex optimization, and multiagent modeling and simulation.

As part of my current position I am heading a research team spanning the computer science and civil engineer departments. Our team was assembled with the purpose of developing novel AI-based traffic management techniques for the time when connected and autonomous vehicles will become common. The team is supported and funded by the Texas Department of Transportation under a project entitled “Bringing smart transport to Texans: ensuring the benefits of a connected and autonomous transport system in Texas”.

As part of this project, I have developed a novel micro-tolling scheme, denoted \(\Delta\)-tolling [31, 32]. Similar to ICTS and CBS in MAPF, \(\Delta\)-tolling presents an entirely new micro-tolling approach that was overlooked by researchers for nearly a century. I theoretically established that, when assuming that all vehicles route selfishly, the tolls imposed by \(\Delta\)-tolling result in a user equilibrium that maximizes social welfare. Using traffic simulators, our team has shown a potential increase of 33\% in social welfare and a 32\% reduction in average travel time when \(\Delta\)-tolling is applied to downtown Austin during the morning rush hour. Given such compelling empirical results along with strong theoretical foundation, and the fact that \(\Delta\)-tolling is model free (i.e., it does not assume a specific traffic model), I anticipate that \(\Delta\)-tolling will be commonly applied in the future and will have a significant impact on transportation networks.

Unfortunately, political factors may deter public officials from allowing such a micro-tolling scheme to be realized in the near future. Road pricing is known to cause a great deal of public unrest and is thus opposed by governmental institutes [33]. To tackle this issue, we directed our efforts to introduce an opt-in micro-tolling system where, given some monetary incentive, drivers choose to opt-in to the system and be charged for each journey they take based on their chosen route. The vehicles belonging to such drivers will need to be equipped with a GPS device as well as a computerized navigation system. Given the toll values and driver’s value of time, the navigation system will suggest a minimal cost route where the cost is some function of the travel time and sum of tolls.

While addressing the issue of political acceptance, an opt-in system would result in traffic that is composed of a mixture of self-interested and compliant agents (compliant in the sense that the system manager can influence their route choice). Such a scenario raises some interesting theoretical and practical questions which are the focus of my current research. For example, it is known that if all users are charged a toll equivalent to the damage they inflict on others (marginal-cost toll), then the system will settle at a social optimum equilibrium. Following this fact, I examined and have been able to formulate what minimum percentage of users need to be compliant with such tolls in order to achieve a system optimal performance [34].

As part of the same project I am also developing an intersection management protocol for a mixture of autonomous and human-operated vehicles called Hybrid-AIM (H-AIM) [35, 36]. H-AIM builds on top of the AIM protocol [30] that was shown to have little or no advantage over traditional traffic signals when less than 90\% of the vehicles are fully autonomous. For a demonstration of H-AIM please visit: http://www.cs.utexas.edu/~aim/.

\footnote{A micro-tolling scheme allows assigning a unique toll value for each link in a road network.}
3 Research Vision

Communication and computation capabilities are becoming increasingly common on board vehicles. Such capabilities present opportunities for developing AI-based techniques that result in safer, cleaner, and more efficient road networks. My research plan will keep ahead of such developments and enable me to lead the way towards a more sustainable transportation network. My research will continue developing mechanisms for optimizing traffic flow while making fundamental contributions to the field of AI, in the sub-areas of multiagent systems, multiagent route assignment, game theory, and mechanism design. In general, my objective is to increase the impact of my research by generalizing my findings beyond specific domains. As such, my research will eventually branch from transportation application towards other domains.

3.1 Funding and students

A large portion of my current and planned research intersects with real-life applications that are of interest to private companies and governmental agencies. Part of my current research, for instance, is funded by the Texas Department of Transportation and Toyota, InfoTechnology Center. I will continue seeking for private sources of funding from companies that have commercial interest in my research. For instance, my research on multiagent pathfinding is relevant to automated warehouse management where goods must simultaneously be delivered from specific locations in the warehouse to specific packing stations. Due to the high relevancy of my research to this domain, I was invited by Amazon Robotics (formerly Kiva Systems) to their headquarters to give a talk entitled "Multiagent Pathfinding: computational feasible approaches with solution quality guarantees".

On a different topic, my current research on traffic flow optimization is appealing to governmental agencies seeking to reduce road congestion through influencing drivers’ route choice and departure time, or through improved intersection management techniques. Finally, my research regarding shared vehicle fleet management, is relevant to companies such as Uber and Lyft.

Artificial intelligence, in general, and multiagent applications specifically, are drawing increased interest in recent years. As a result, I am certain that many graduate students will be attracted to my line of research. One way that I intend to recruit graduate students is through a graduate course. My proposed course will focus on autonomous multiagent systems and will cover topics such as: agent architectures, inter-agent communication, teamwork, distributed rational decision making, agent modeling, multiagent learning, and bidding agents.

3.2 Research topics

When looking further into the future, fully autonomous vehicles will dramatically change the way we commute. Given the rapid advancements in autonomous driving technology, it is safe to say that our world is on the brink of a massive revolution. This revolution presents endless opportunities for high impact research. AI-based technology, in particular, offer many such opportunities.

One topic that inspires my research agenda is management of shared autonomous vehicle fleets [37]. In such a scenario, passengers are continually appearing at different locations and must be commuted to different destinations. The fleet manager must assign each of its available vehicles a route such that the maximum number of passengers will be served while ensuring quality of service (minimizing the passengers’ wait and travel time). My research will focus on two variants of this problem:

• **Private ride assignment**, where each vehicle is assigned no more than a single passenger at any given time.
- **Shared ride assignment**, where the same vehicle can be assigned to more than one passenger.

I will explore solutions that are based on planning and scheduling algorithms for these, high dimensional, problems. Specifically, I will explore domain-dependent heuristics that allow dramatic speedups in computation time when used within search-based planning algorithms. By generalizing my solutions beyond the shared fleet domain, this line of research will contribute to the general field of automated planning and scheduling as well as the field heuristic search.

Another topic that I intend to explore is optimizing traffic flow by influencing the route assignment of some or all vehicles. I will address questions such as:

- Given a road network as a directed graph $G(V, E)$, a set of latency functions $\forall e \in E, l_e(f_e)$, a set of flow demand $r_{i,j}$ mapping any pair of nodes $i, j \in V^2$ to a non-negative flow value, and while assuming the ability to influence the path assignment of a compliant subset of the demand, I will address the following question; what is the optimal way to assign paths to the compliant subset assuming the rest of the flow follows Wardrop’s user equilibrium [38]. This problem is often viewed as a Stackelberg routing game [39] where the compliant portion of the flow is controlled by the Stackelberg leader and the rest of the flow by a follower.

- Building on the previous problem, assume a limited ability to choose which portion of the demand is compliant. For example in a scenario where the government can incentivize a limited amount of drivers to change their route. Such an ability raises the question of which drivers, if re-routed, would yield the largest system benefit.

This line of work will later be generalized to cover different types of congestion games and different agent modeling paradigms.

I will also explore the topic of adaptive road pricing as a mechanism for influencing vehicle’s route assignment. In this scenario the price affiliated with each road segment dynamically changes according to observed traffic. Specifically, I will investigate empirical and algorithmic questions such as:

- How do different price update intervals affect the system performance when risk averse users are assumed. On the one hand, shorter update intervals allow the system to be more adaptive to observed congestion, but on the other hand, shorter update intervals result in higher variance in toll values which negatively affect risk averse users.

- How can traffic prediction be used to set values in a pro-active, congestion pricing mechanism. Assuming a bounded error for traffic prediction, what performance guarantees can be given.

This line of work will later be generalized to apply to other pricing mechanisms within multiagent systems e.g., in combinatorial resource allocation when demand and supply are dynamically changing.

As an expert in combinatorial search, multiagent route assignment, game theory, flow and convex optimization, and multiagent modeling and simulation, I am confident in my ability to be a leading researcher on this front. The above topics will also require knowledge beyond my expertise. Hence, I will collaborate with faculty members from within and without the CS department, including departments such as economics, finance, civil engineering, and psychology, which all have wide application to automated traffic management.

---

1 A latency function returns the latency on a link $e$ as a function of the flow assigned to it $f_e$. 

---

2 A latency function returns the latency on a link $e$ as a function of the flow assigned to it $f_e$. 

---
References


[24] B. Banerjee, C. Davis, Multi-agent path finding with persistence conflicts, IEEE Transactions on Computational Intelligence and AI in Games.


[38] J. Wardrop, Some theoretical aspects of road traffic research, Proceedings of the Institute of Civil Engineers, Part II (1952) 325–378.