Anytime Heuristic for Weighted Matching Through Altruism-Inspired Behavior

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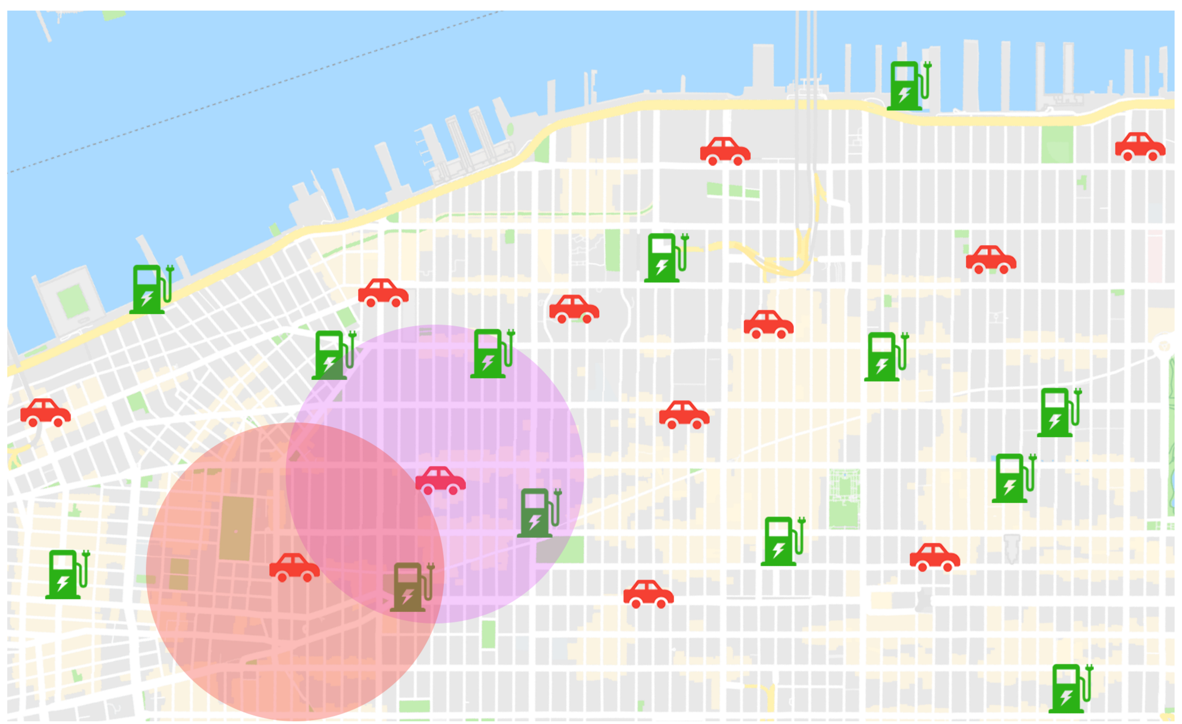
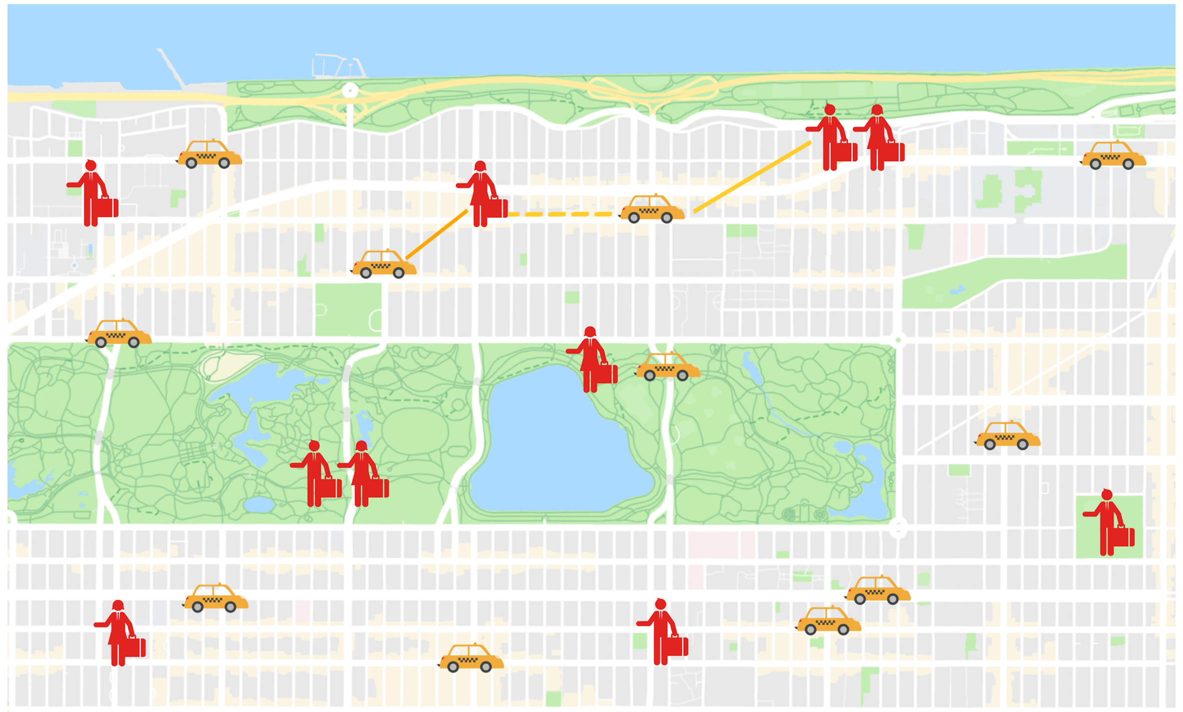
Motivation

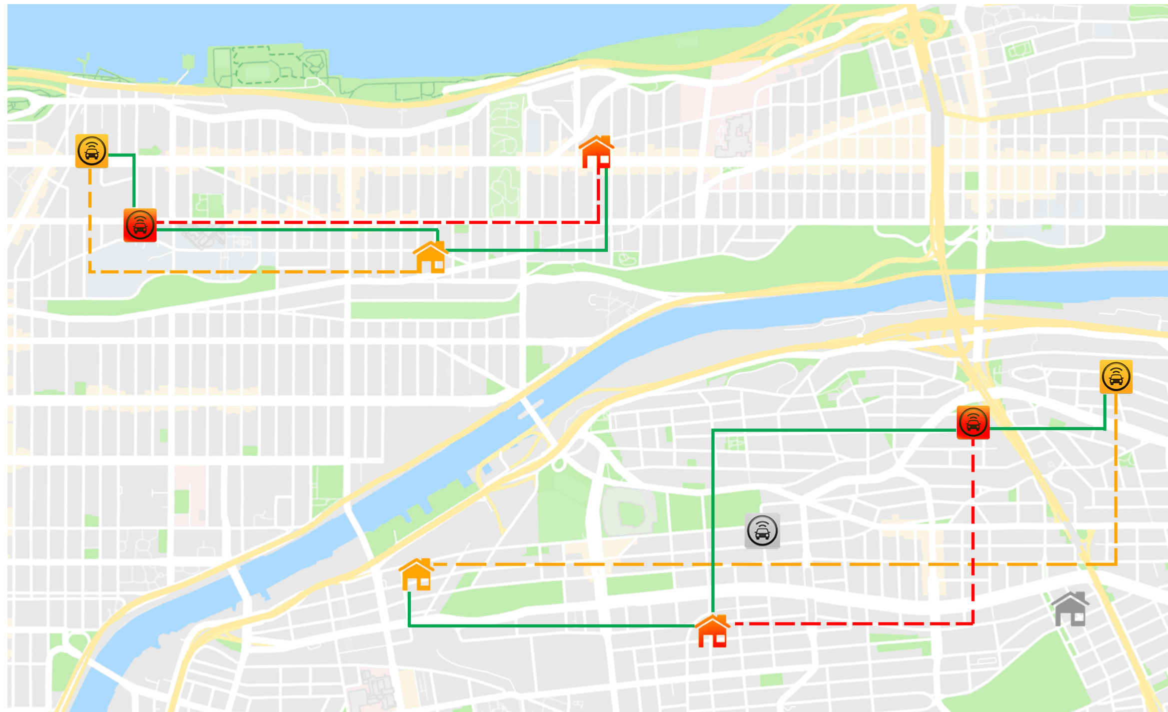
Charging / Parking Spaces:



Taxi-Passenger Matching:



Ride-Sharing:



The Assignment Problem:

- Weighted bipartite graph
- N agents compete for R resources
- Each agent is interested in a subset ($\mathcal{R}^n$) of the resources
- Goal: maximize the social welfare (sum of utilities)

Applications:

- Role allocation (e.g., robot team formation)
- Task assignment (e.g., taxi-passenger matching)
- Resource allocation (e.g., parking/charging spaces)

Challenges in Real World:

- Distributed nature
- Information restrictive (lack of communication/responsiveness, partial feedback)
- Large scale

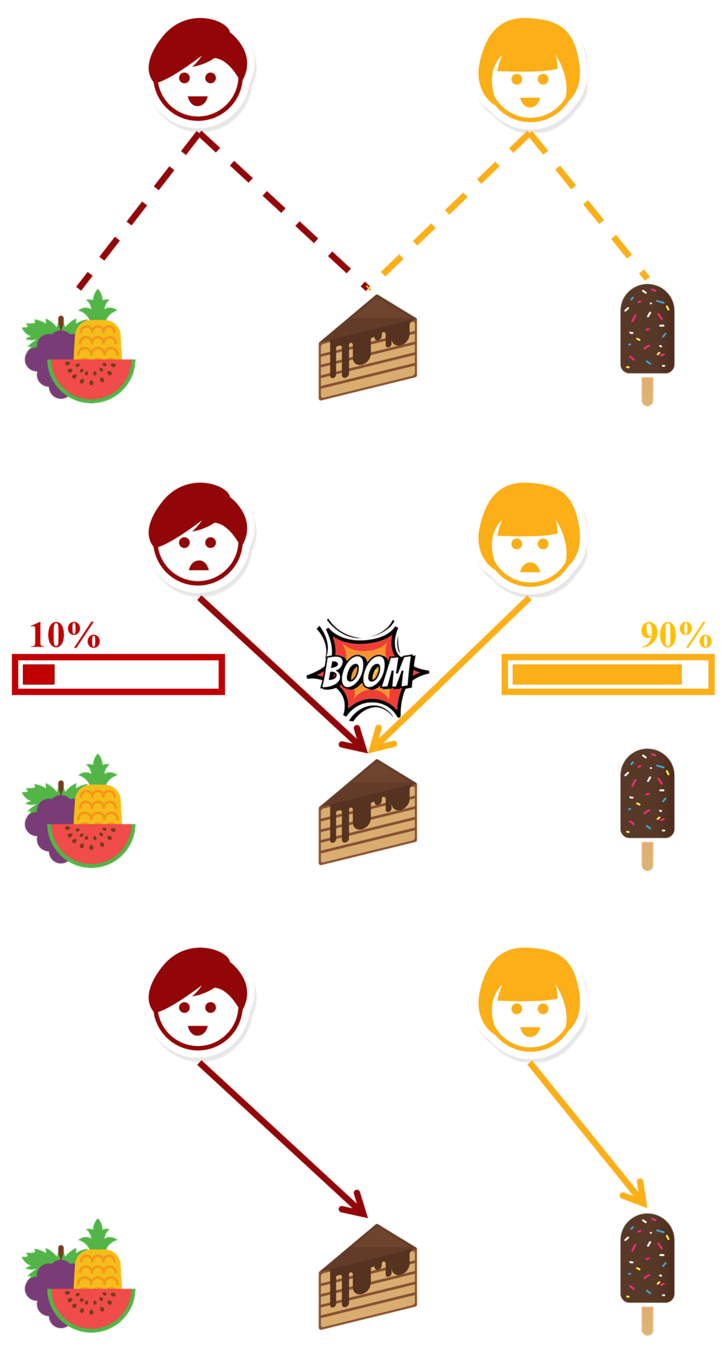
Hundreds of thousands of autonomous agents (e.g., IoT devices, intelligent infrastructure, autonomous vehicles, etc.)
Existing algorithms require: (i) runtime that increases with the total problem size, even if the agents are interested in a few resources, (ii) significant amount of inter-agent communication.

*Need for **fast convergence** to allocations of **high social welfare**.*

Humans are routinely called upon to coordinate in *large scale*, and under *dynamic* and *unpredictable* demand. Driving factor: principle of **altruism**.

ALMA: ALtruistic MAtching heuristic

Agents make decisions locally, based on (i) the contest for resources that *they* are interested in, (ii) the agents that are interested in the *same* resources. If each agent is interested in only a *subset* of the total resources, ALMA converges in *constant* time. The same is not true for other algorithms, which require time polynomial in the *total* number of agents/resources, even if the aforementioned condition holds. The condition holds by default in many real-world applications; agents have only local knowledge of the world, there is typically a cost associated with acquiring a resource, or agents are simply only interested in resources in their vicinity (e.g., urban environments).



Algorithm ALMA: Altruistic Matching Heuristic.
– Go over the set of preferred resources $\mathcal{R}^n \subseteq \mathcal{R}$ sequentially.
– If collision, back-off with probability that depends on the utility loss of switching to the remaining resources (e.g., $P(loss) = 1 - loss$).

$$loss_n^i = \frac{\sum_{j=i+1}^{k} u_n(r_i) - u_n(r_j)}{k - i}$$

$\begin{cases} \text{Good alternatives} \rightarrow \text{More likely to back-off} \\ \text{No good alternatives} \rightarrow \text{Less likely to back-off} \end{cases}$

If back-off → select an alternative resource and examine its availability.

Altruism-Inspired Behavior Give up a resource:

- To someone who values it more, to increase the social welfare
- To be nice to others; especially when there are equally good alternatives

→ Faster convergence – outweighs the loss in utility.

Theorem 1 (Convergence Speed).

$$\mathcal{O}\left(\max_{n' \in \cup_{r \in \mathcal{R}^n} \mathcal{N}^r} R^{n'} \frac{2 - p_n^*}{2(1 - p_n^*)} \left(\frac{1}{p_n^*} \log(\max_{r \in \mathcal{R}^n} N^r) + \max_{n' \in \cup_{r \in \mathcal{R}^n} \mathcal{N}^r} R^{n'}\right)\right) = constant$$

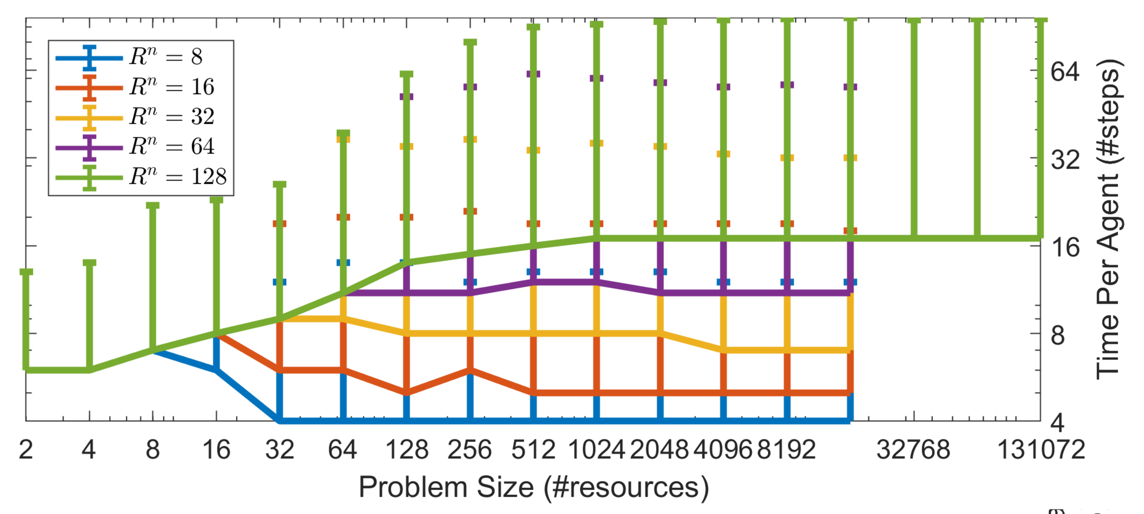
Highlights:

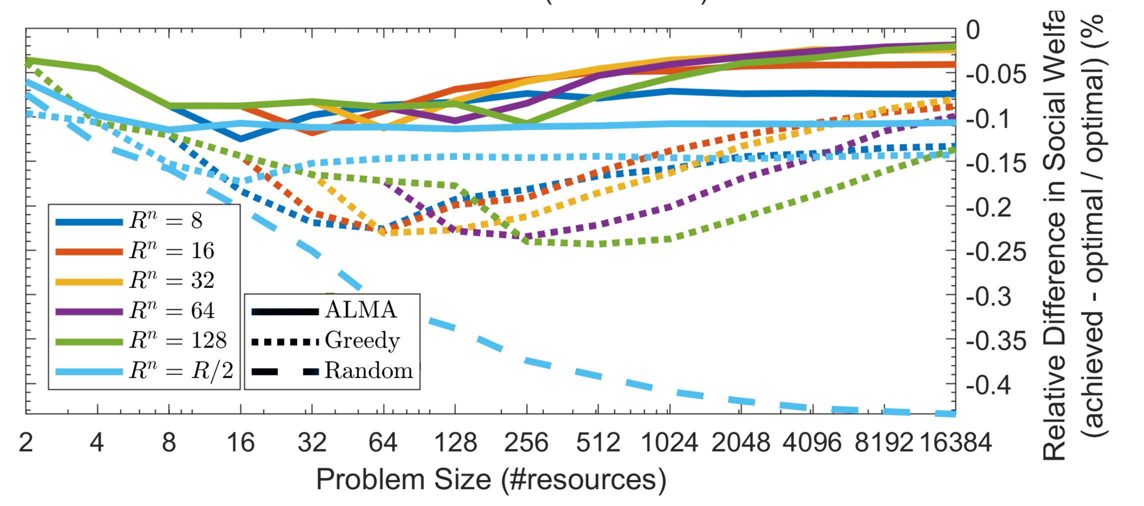
i) Decentralized, completely uncoupled, no communication, only partial feedback
ii) *Constant* in the total problem size convergence time, under reasonable assumptions on the preference domain
iii) High social welfare in a variety of scenarios: synthetic and *real* data, time constraints, on-line settings

Read the Full Paper:

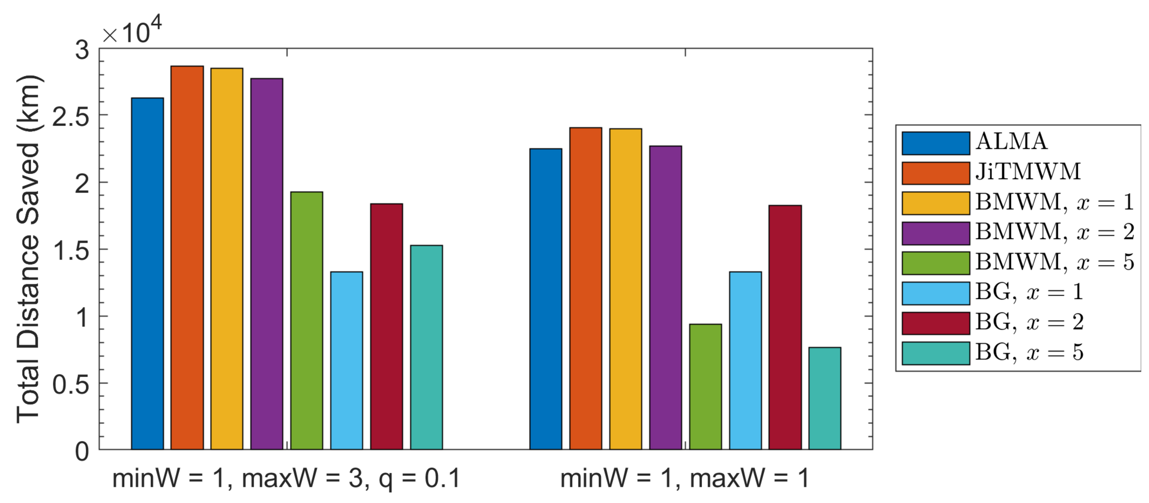
Simulation Results

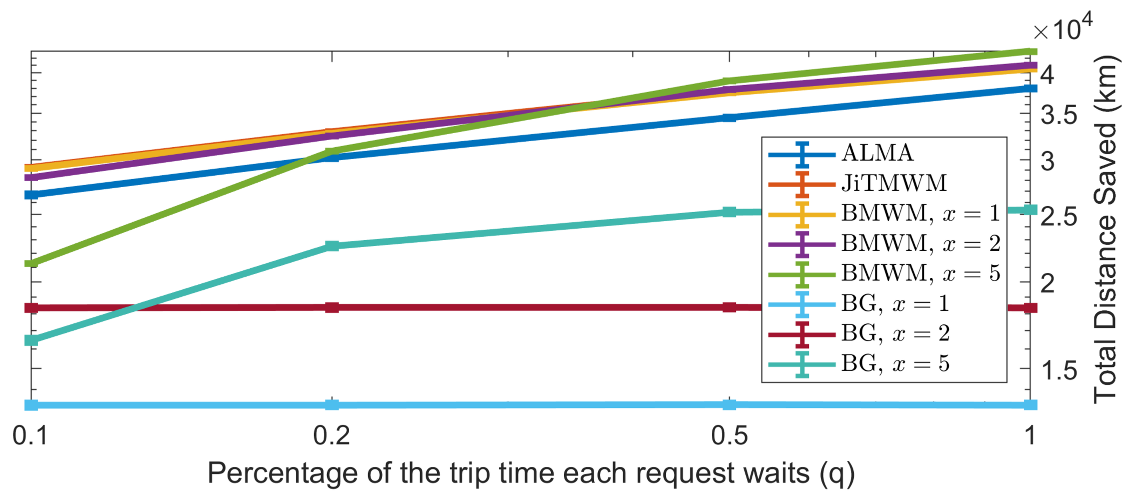
Resource Allocation in a Cartesian Map





On-line Taxi Request Match





$(1, 3, 0.1)$	$(1, 1, -)$	$(0, \infty, 0.1)$	$(0, \infty, 0.5)$	$(0, \infty, 1.0)$
0.79	0.85	0.78	0.69	0.67

Table 1: Empirical Competitive Ratio of ALMA