Cooperative Electric Vehicles Planning

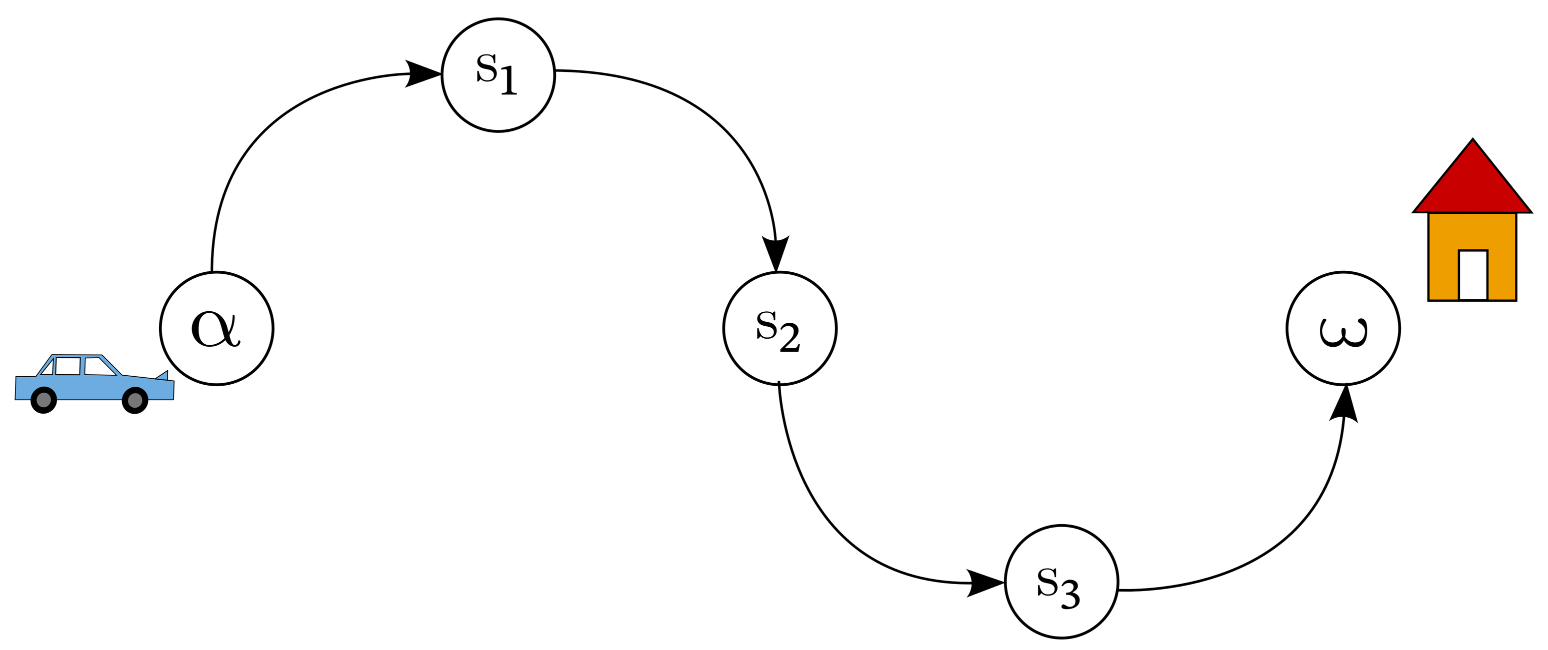
Jaël Champagne Gareau, Marc-André Lavoie, Guillaume Gosset, Éric Beaudry

Centre de Recherche en Intelligence Artificielle (CRIA), Département d'informatique, Université du Québec à Montréal (UQAM)

UQÀM

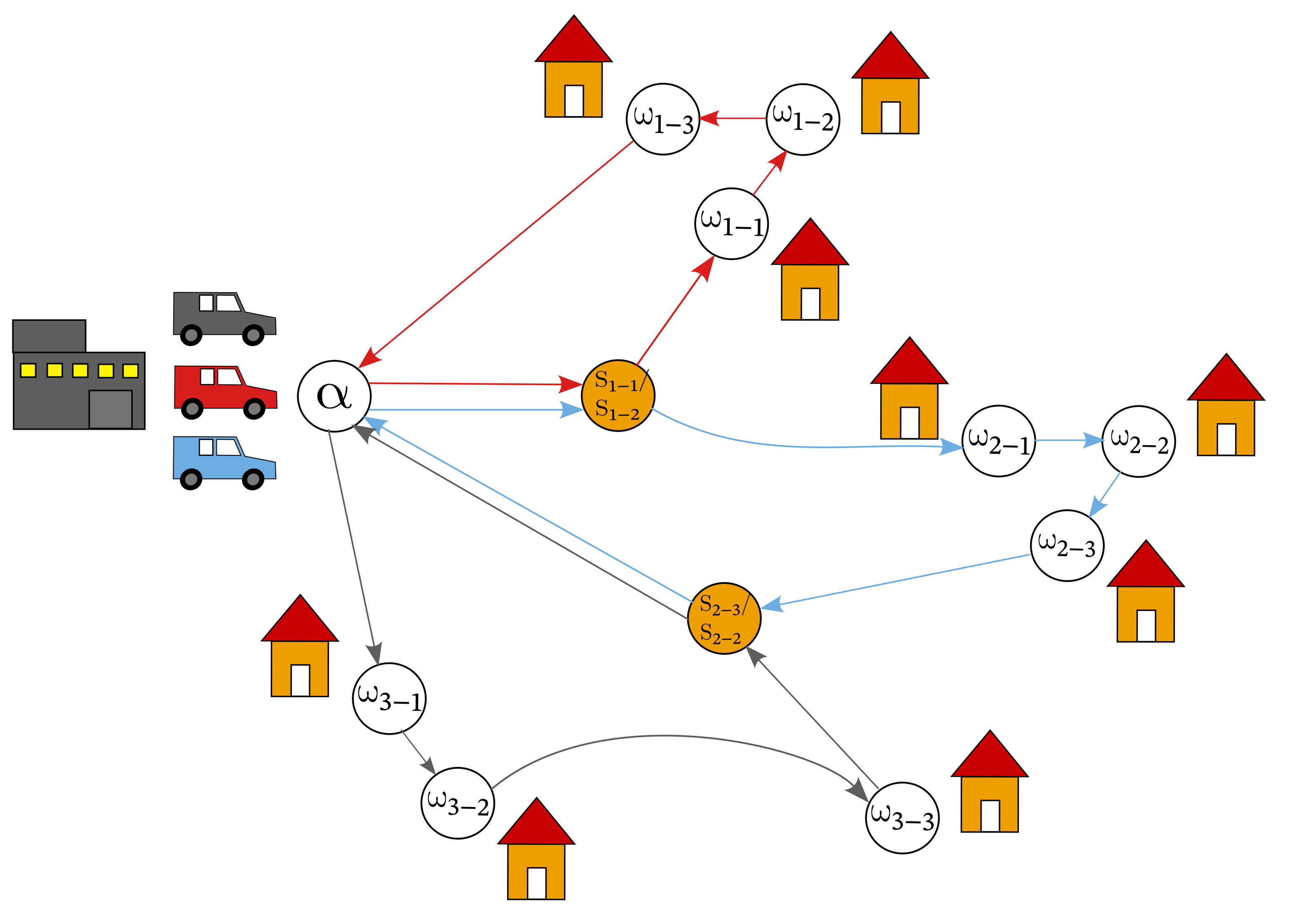
Electric Vehicles Path-Planning (EVPP)

- Single EV path-planning from α to ω;
- The EV has a range ρ and must hop from stations to stations;
- Many variants (consideration of regenerative braking, waiting times, etc.)



Electric Vehicles Routing Problem (EVRP)

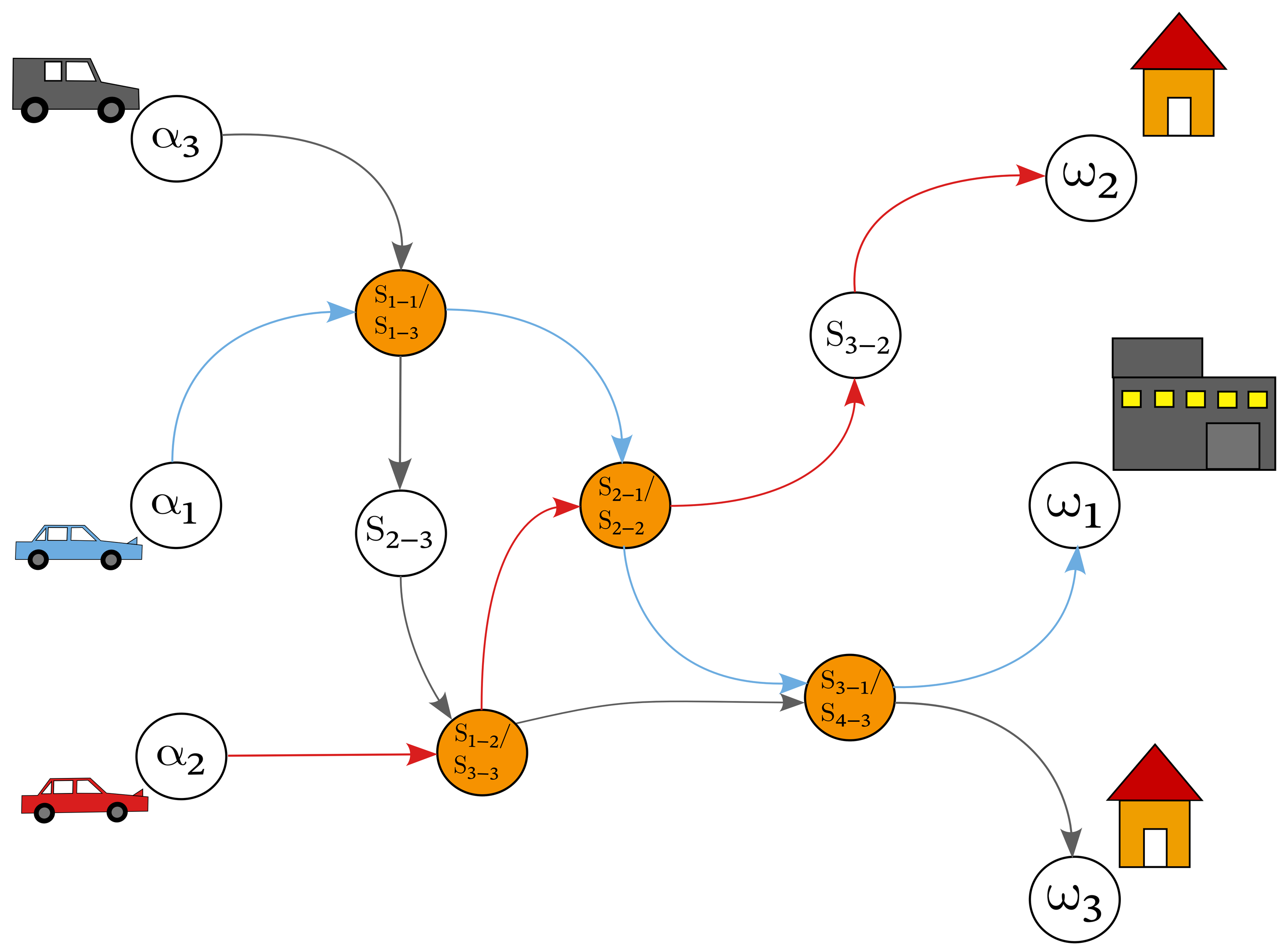
- A fleet of EVs controlled by the same entity and sharing the same objective;
  - E.g., deliver packages from a warehouse to a set of locations;
- Goal: find a min-set of EVs able to complete all tasks with minimal cost;



Cooperative Electric Vehicles Planning Problem (CEVPP)

"An open challenge is to devise algorithms for socially optimal real-time routing with a reasonable response time for a large number of vehicles." [1]

- Many EVs, controlled by different end-users, each with their own goal.
- It is desirable to plan their routes collectively to reduce waiting times.
- Each EV has an associated request, i.e., a tuple $(\alpha, \omega, \rho, \tau)$, where:
  - α is the departure node; ω is the arrival node;
  - ρ is the range of the EV; τ is the time of departure.
- A CEVPP instance is a road network M along with a set of EV requests R.
- Objective: minimize total (travel + charge + wait) time of the batch of EVs.
- $\pi^\star = \arg\min_{\pi\in\Pi} P(\pi) := \arg\min_{\pi\in\Pi} \left[\frac{1}{k}\sum_{i=1}^{k}\left(C(\pi_i) - C^\star(\pi_i)\right)^2\right]$.
- $C^\star(\pi_i)$ is the cost of the shortest-path when the EV is alone in M.



Algorithms

- **Baseline** (ncEVP): plan each EV separately as a distinct EVPP problem.
- **Optimal** (escEVP): search in a state-space where states are array:
  - $\sigma = [(\sigma_1^s, \sigma_1^t), (\sigma_2^s, \sigma_2^t), \dots, (\sigma_k^s, \sigma_k^t)]$, where:
    - σ_i^s is the charging station currently used by the EV i;
    - σ_i^t is the planned departure time of EV i from station σ_i^s.
  - Uses an heuristic function to prune parts of the state-space.
  - Algorithm has worst-case time complexity $\Omega(|S|^k)$.
- **Permutations** (pcEVP): inspired by the Cooperative-A* algorithm.
  - Computes a plan one EV at a time, considering other EVs already commited to a station.
  - The order in which EVs are considered can produce different solutions.
  - The algorithm test a subset of permutations of EVs and keep the best solution.
  - Time complexity: $\Theta(|\mathcal{P}| \cdot |S|^2)$, where $\mathcal{P}$ is the set of considered permutations.

Results

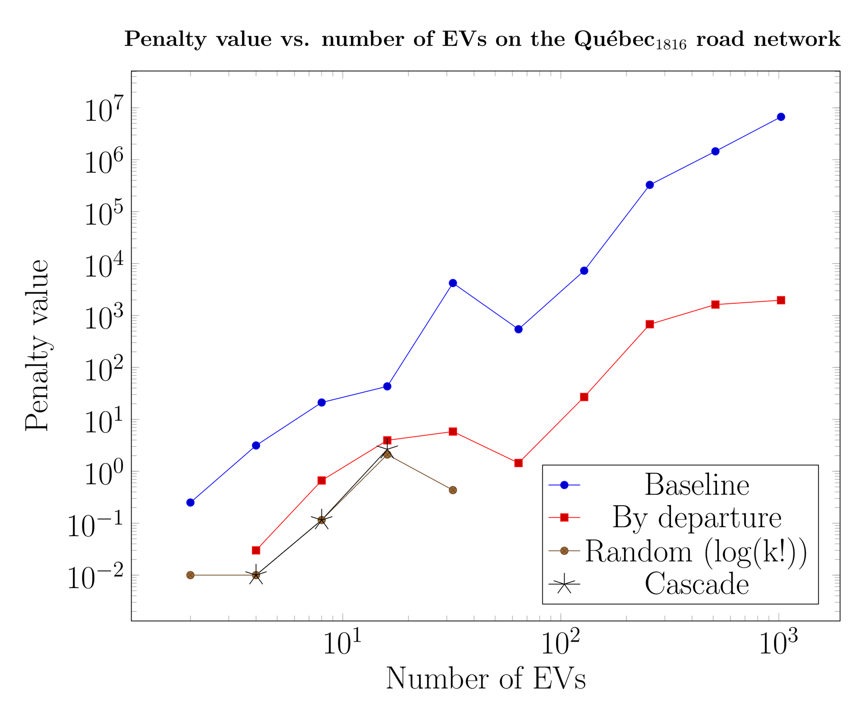
- We compared the baseline planner to three different instances of pcEVP:
  - only one permutation, where EVs are ordered by time of departure τ ($\Theta(S^2)$);
  - random $\log(k!)$ permutations ($\Theta(k \log k \cdot S^2)$);
  - cascade permutations ($\Theta(k^2 \cdot S^2)$).
- Empirical evaluation is done on two regions (Québec and Maritimes).
- We used real charging stations data from Circuit-Électrique.

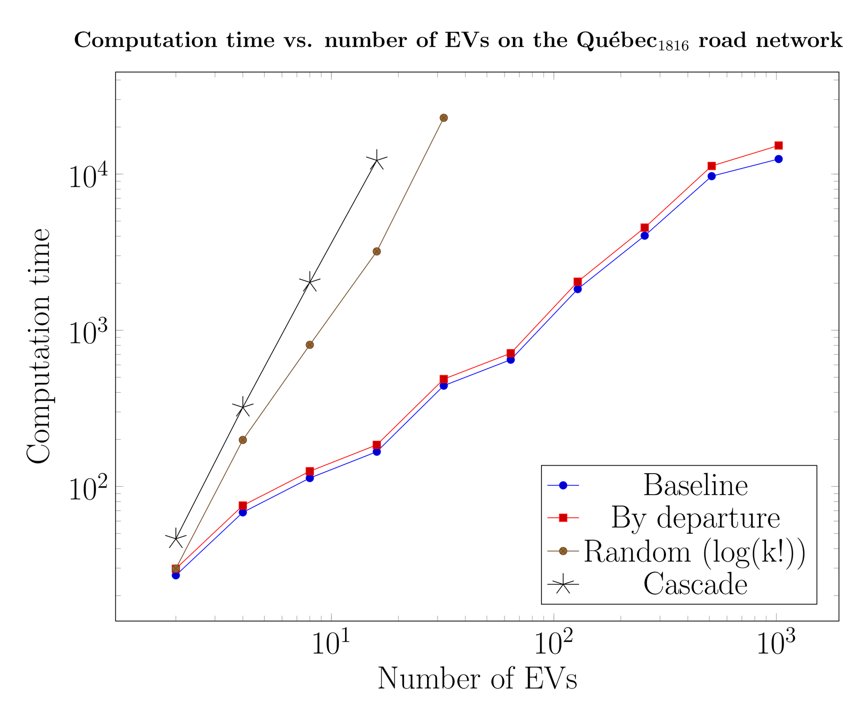
Table 1: Average running times (ms)

Network	Baseline	By departure	Random $\log(k!)$	Cascade
Maritimes_{50}	0.09	0.19	95.35	1459.2
Quebec_{347}	2.272	2.70	99.27	558.86
Quebec_{1816}	93.84	103.76	1058.18	3656.6
Average	32.07	35.55	417.60	1891.55

Table 2: Average reduction (%) in penalty $P(\pi)$ (min) compared to baseline

Network	By departure	Random $\log(k!)$	Cascade
Maritimes_{50}	93.06	93.07	95.22
Quebec_{347}	86.33	86.73	89.35
Quebec_{1816}	96.69	97.57	98.25
Average	92.03	92.46	94.27





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Online Material

The paper, presentation slides, C++ code, test instance generators and supplementary materials are available by scanning the following QR code:

Acknowledgments

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