Multi-Agent Terraforming
Efficient Multi-Agent Path Finding via Environment Manipulation
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Motivation
Multi-Agent Path Finding (MAPF) is used to model smart warehouses, such as those of Amazon. Agents are tasked with carrying shelves to their destination.

The MAPF Problem

Given a graph $G = (V, E)$ with static obstacles, find collision-free paths $\pi = (\pi_1, ..., \pi_n)$ for agents $A = (a_1, ..., a_k)$.

Optimal & complete algorithm:
- Convert movable obstacles (new)
- Initialize root node $R$
- Detect conflicts $(u_i, v_j, t_i) \text{ or } (v_j, u_i, t_j)$
- Compute flowtime $f_{\text{flowtime}}$
- Exact best-first search
- Constrain child node & replan

Solution quality is determined by:
- The flowtime as the sum of individual path costs $\sum_{i=1}^{n} |\pi_i|$.
- Agent-to-agent interactions → Congestion, delays and detours.

The total task delay as the latency $= \sum_{i=1}^{n} |\pi_i|$, where $\pi_i$ is the optimal path of agent $a_i$ if all collisions are ignored.

Key Insight
Agents that carry shelves can create shortcuts for efficiency. A shortcut can serve multiple agents, lowering flowtime and reducing latency.

Terraforming

Given a MAPF problem for graph $G$, agents $A$, and movable obstacles $\mathcal{O} = \{o_1, ..., o_k\}$, find the optimal plan $\pi$.

Displacing an obstacle incurs a cost that accounts towards the total cost and the obstacle must be returned to its original location. Idle obstacles do not accrue a cost.

Dynamic shortcut

Contribution
Terraforming the environment → enhance efficiency:
- Lowering flowtime and reducing latency.
  - A novel formulation that can attain negative latency with shortcuts that cut through obstructed regions.
  - We present TF-CBS, a complete and optimal algorithm for solving the Terraforming problem.

Figure 1: MAPF task for agents $a_1, a_2$.

Figure 2: (a) Obstacles block the shortcut paths. (b) Optimal solution (static obstacles). (c) Solution $a_1, a_2$ with candidate shortcut.

Figure 3: (a) Solution $a_1, a_2$ without shortcut.

Figure 4: MAPF task with 54 agents.

See it in action!