Improved Heuristics for Multi-Agent Path Finding with Conflict-Based Search

Jiaoyang Li, Ariel Felner, Eli Boyarski, Hang Ma and Sven Koenig
Macao, China
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Outlines

• Background:
  • Multi-Agent Path Finding.
  • Conflict-Based Search.
  • CG heuristics for Conflict-Based Search.

• Two more informed heuristics:
  • DG heuristics.
  • WDG heuristics.

• Experimental results.

• Summary.
Multi-Agent Path Finding (MAPF)

• Given:
  • A graph;
  • A set of agents, each with a start location and a goal location.

• Goal:
  • Find collision-free paths for all agents;
  • Minimize the sum of path costs.

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Conflict-Based Search (CBS) [Sharon et al. 2015]

Agent 1 cannot be at cell C2 at time 3.

Agent 2 cannot be at cell C2 at time 3.

Sum of path costs = 9

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Agents 1 and 2 follow paths that avoid conflict at cell C2.
Conflict-Based Search (CBS) [Sharon et al. 2015]

- CBS searches in a binary tree in a best-first manner according to the sum of path costs.

\[
g\text{-value} = \text{sum of path costs} \\
h\text{-value} = ?
\]
Conflict-Based Search (CBS) [Sharon et al. 2015]

- CBSH [Felner et al. 2018] adds admissible heuristics to CBS.
  - A conflict is **cardinal** iff all shortest paths of the both agents traverse the conflicting location at the conflicting time.
  - A cardinal conflict is an admissible h-value of 1.
CBSH [Felner et al. 2018]

- Cardinal conflict graph
- Minimum Vertex Cover

\[ h_{CG} = 3 \]

We call this CG Heuristics.
Can We Get Better Heuristics?

- Two agents are dependent iff every pair of their shortest paths has at least one conflict.
- A pair of dependent agents is an admissible $h$-value of 1.
- Two agents that have cardinal conflicts are dependent.
DG Heuristics

- Dependency graph
- Minimum Vertex Cover

$h_{DG} = 4$
Can We Get Better Heuristics?

• The **weight** for a pair of agents is the difference between the minimum sum of the costs of their conflict-free paths and the sum of their shortest path costs.

• The weight is an admissible h-value for the pair of agents.

• The weight for a pair of dependent agents is at least one.
WDG Heuristics

- Edge-weighted dependency graph
- Edge-weighted Minimum Vertex Cover

$h_{WDG} = 7$
Experiments

Empty grid

Dense grid

Large grid

20x20 empty grid

20x20 grid with 30% randomly blocked cells

192x192 grid with 51% blocked cells
Experiments

**$h$ value at the root node.**

\[ h_{WDG} \geq h_{DG} \geq h_{CG} \]

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Experiments

Runtime breakdown per expanded node.

- Yellow: Runtime for CBS
- Blue: Runtime for constructing graphs
- Red: Runtime for solving MVC

Runtime overhead of computing heuristics
Experiments

Success rate (= % solved instances) within 1 minute.

![Graph showing success rate vs. number of agents for different heuristics: WDG, DG, CG.](image)

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Summary

• Two admissible heuristics for CBS, DG and WDG, by reasoning about pairwise dependency between agents:
  • h-value: $h_{WDG} \geq h_{DG} \geq h_{CG}$.
  • Runtime overhead: relatively small.
  • Overall performance: WDG is better than DG, which in turn is better than CG.

• Future work:
  • Generalize these heuristics to groups larger than pairs of agents, e.g., to triples and quadruples.
  • Study admissible or inadmissible heuristics for sub-optimal CBS-based algorithms.