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

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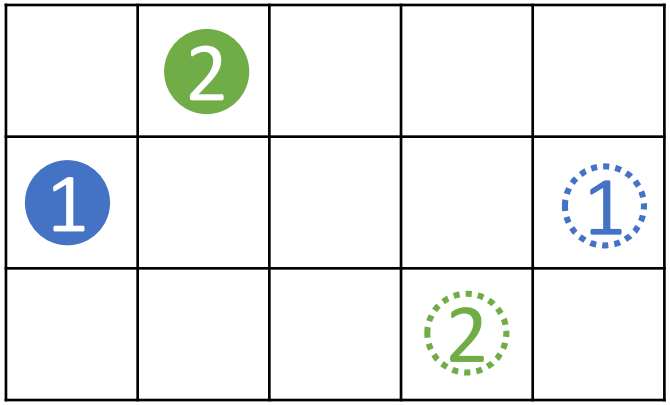
Outlines

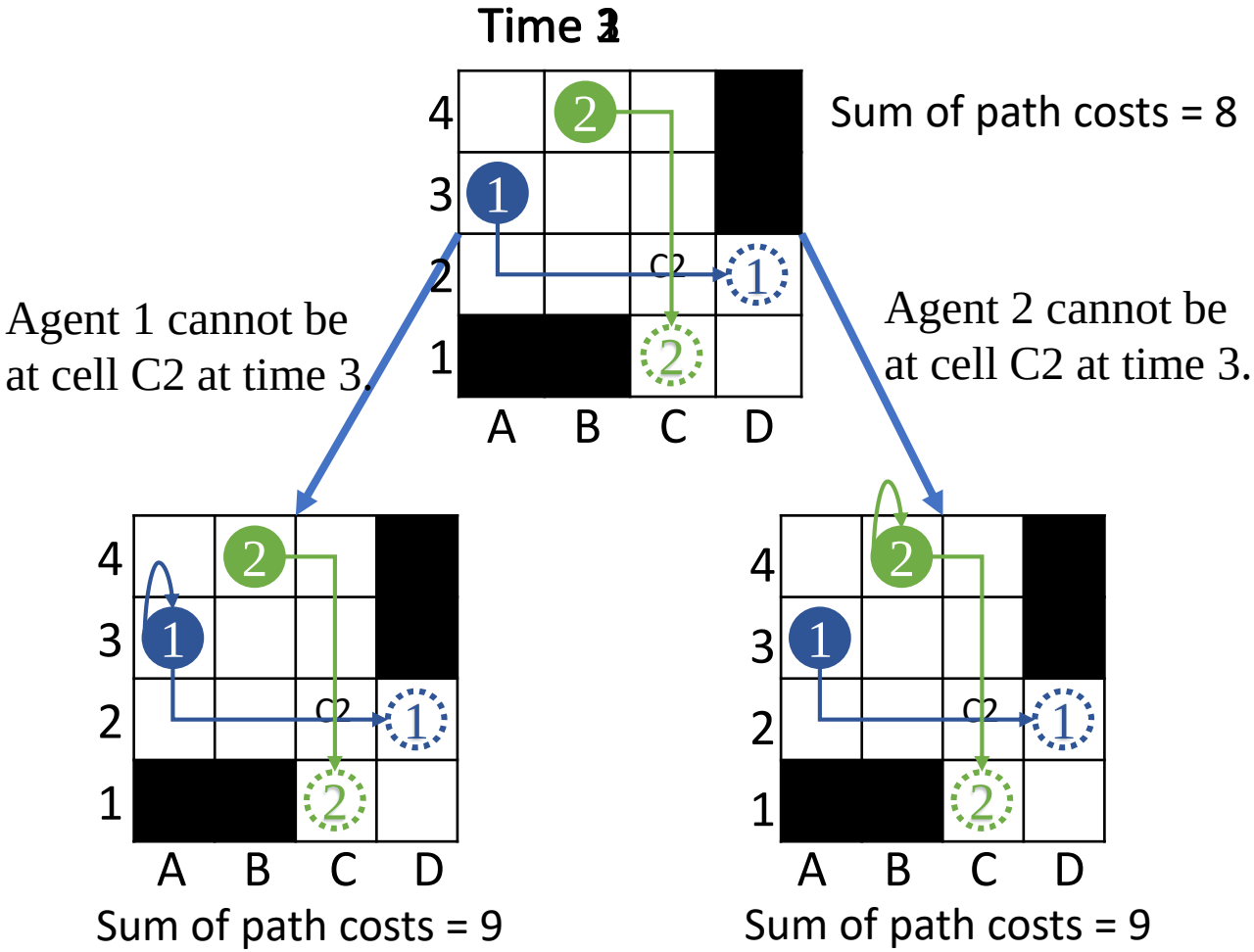
- Background:
  - Multi-Agent Path Finding.
  - Conflict-Based Search.
  - CG heuristics for Conflict-Based Search.
- Two more informed heuristics:
  - DG heuristics.
  - WDG heuristics.
- Experimental results.
- Summary.

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.

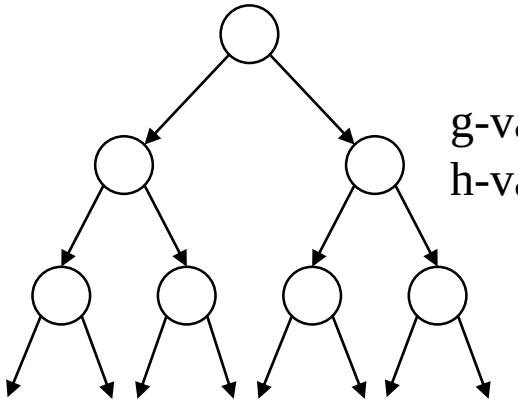


Conflict-Based Search (CBS) [Sharon et al. 2015]



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

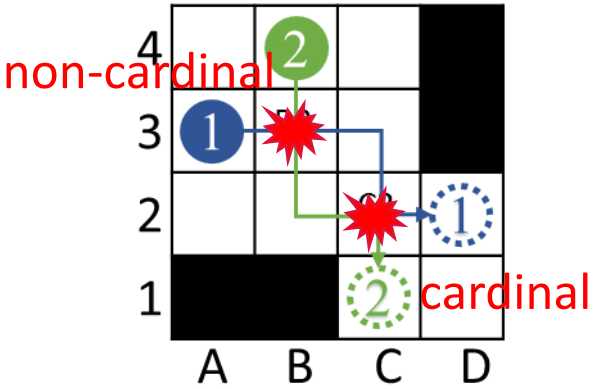
- CBS searches in a binary tree in a best-first manner according to the sum of path costs.



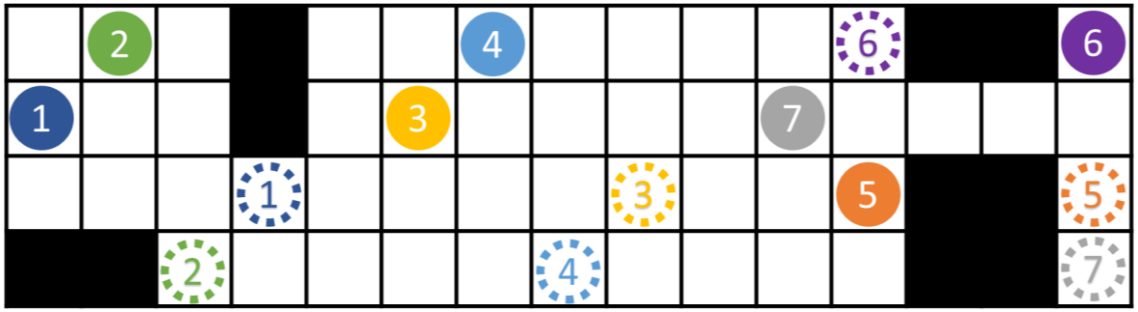
g-value = sum of path costs
h-value = ?

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

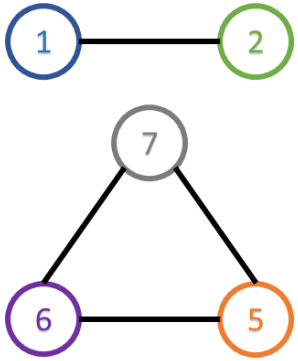
- CBSH [Felner et al. 2018] adds admissible heuristics to CBS.
  - A conflict is ***cardinal*** iff all shortest paths of the both agents traverse the conflicting location at the conflicting time.
  - A cardinal conflict is an admissible h-value of 1.

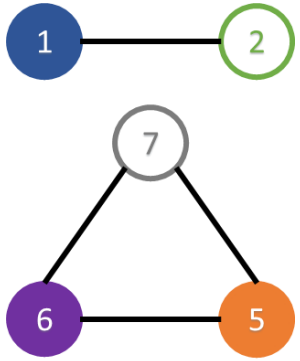


CBSH [Felner et al. 2018]



- Cardinal conflict graph
- Minimum Vertex Cover

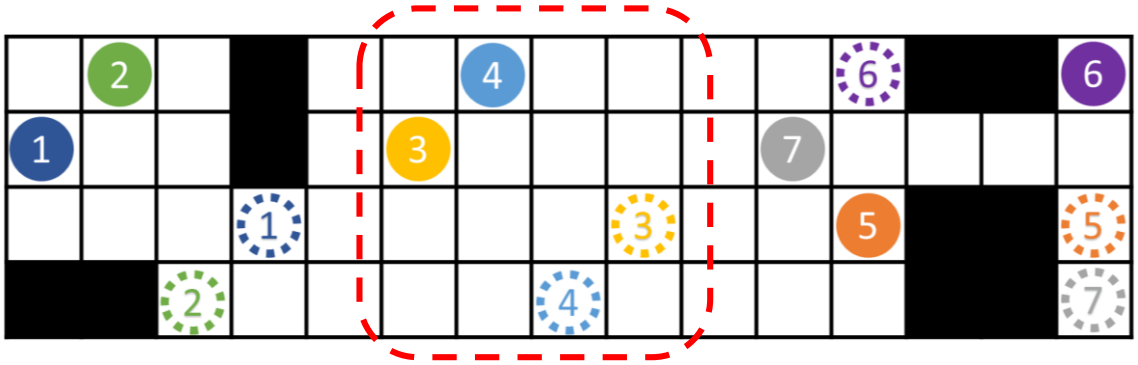


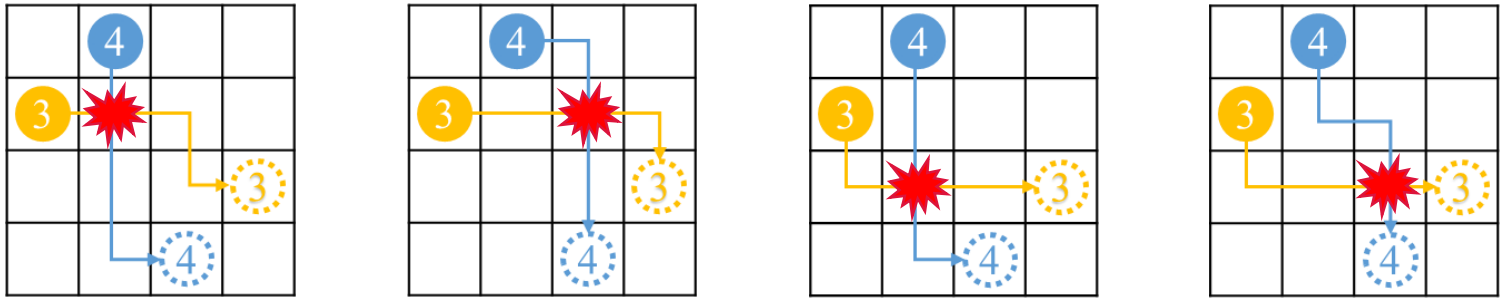


$h_{CG} = 3$

We call this CG Heuristics.

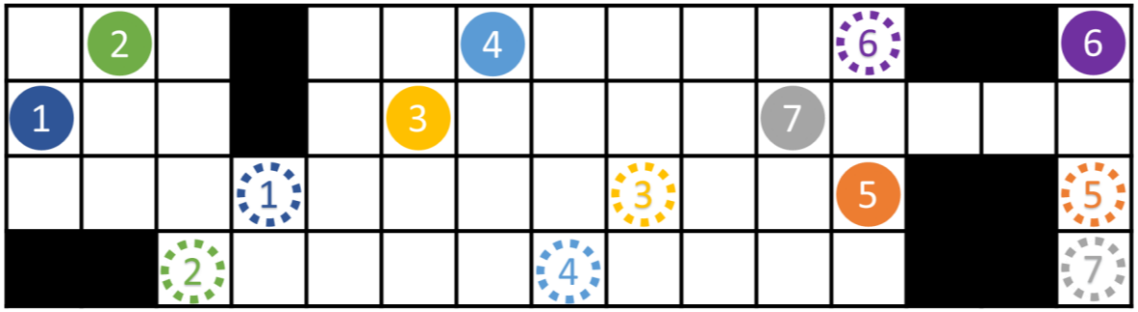
Can We Get Better Heuristics?



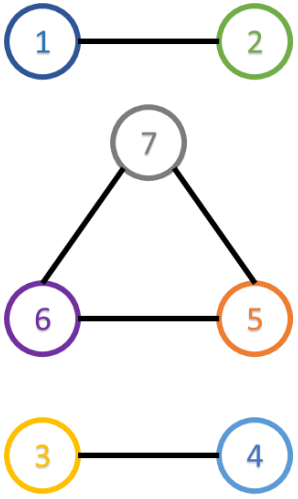


- Two agents are ***dependent*** iff every pair of their shortest paths has at least one conflict.
- A pair of dependent agents is an admissible h-value of 1.
- Two agents that have cardinal conflicts are dependent.

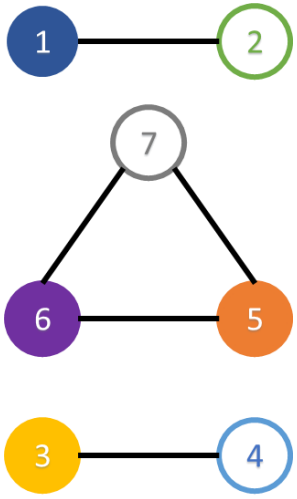
DG Heuristics



- Dependency graph

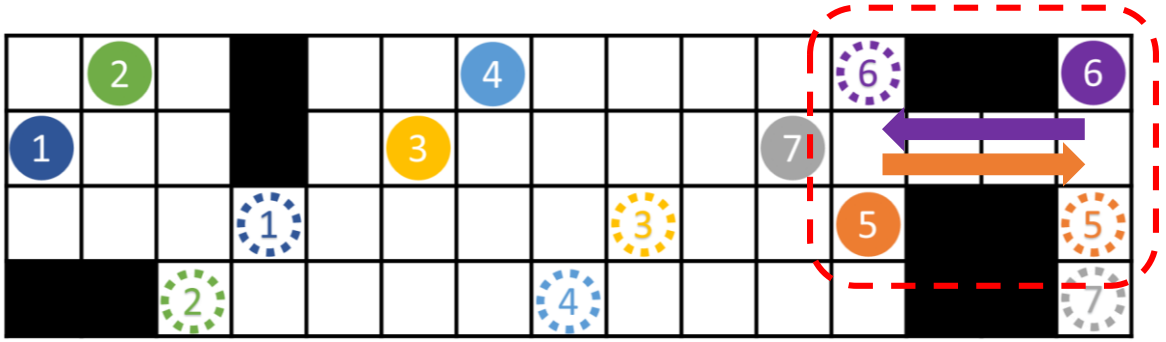


- Minimum Vertex Cover



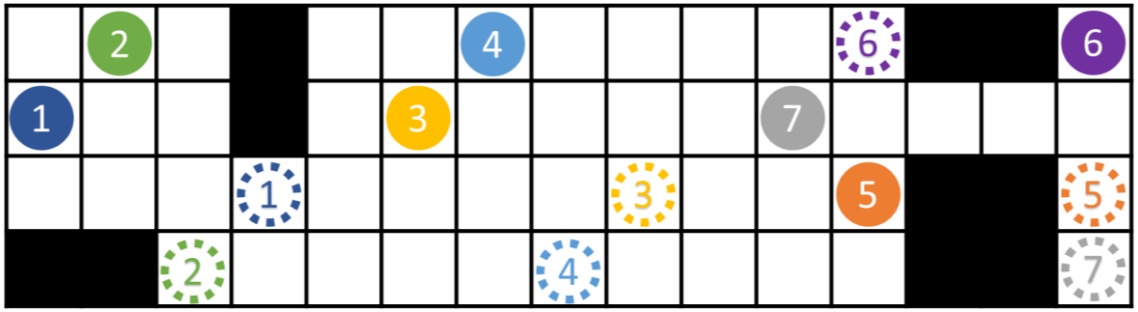
$h_{DG} = 4$

Can We Get Better Heuristics?

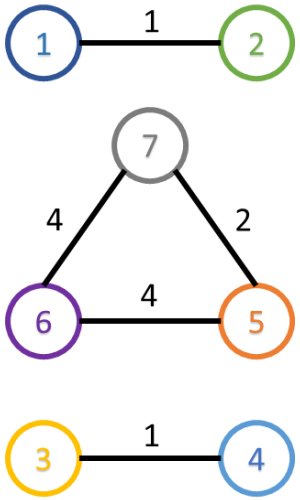


- The ***weight*** for a pair of agents is the difference between the minimum sum of the costs of their conflict-free paths and the sum of their shortest path costs.
- The weight is an admissible h-value for the pair of agents.
- The weight for a pair of dependent agents is at least one.

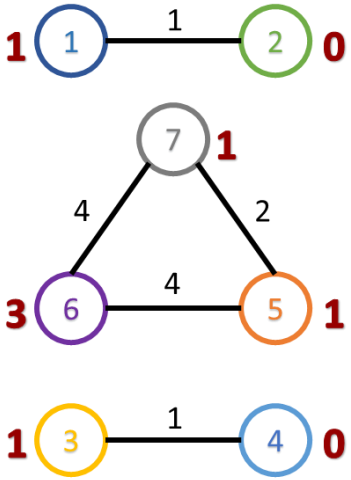
WDG Heuristics



- Edge-weighted dependency graph

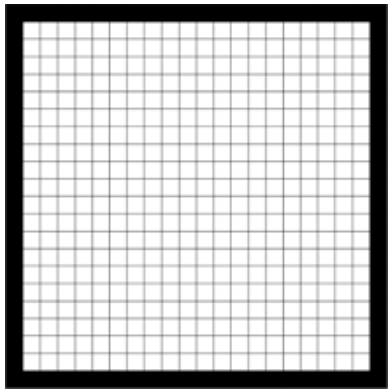
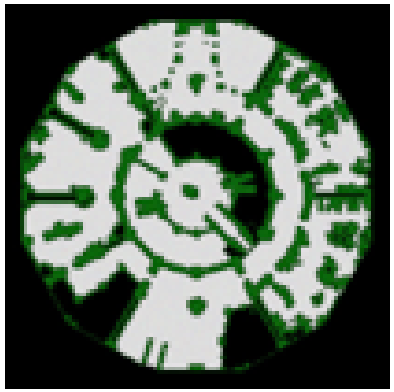


- Edge-weighted Minimum Vertex Cover



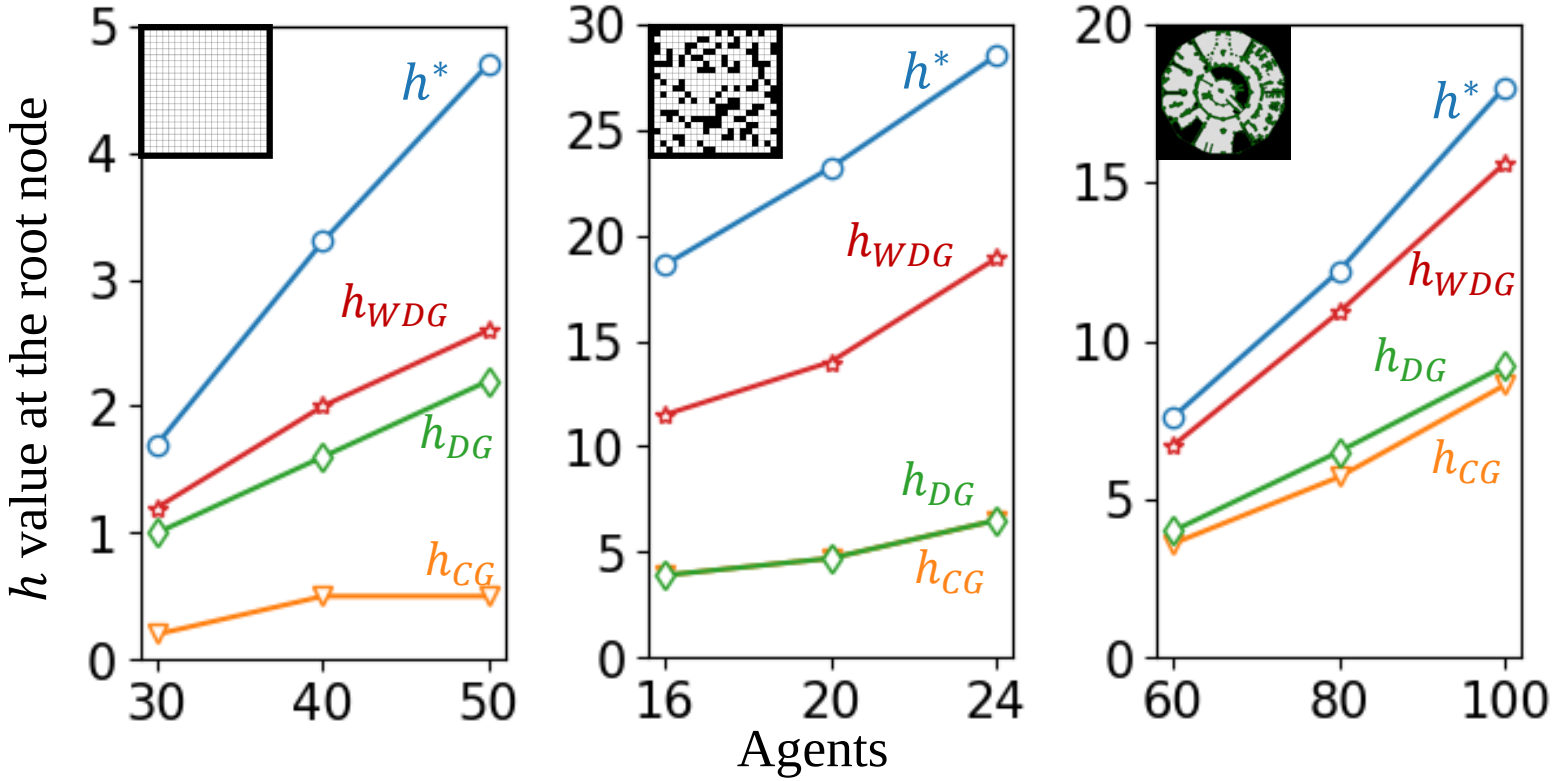
$h_{WDG} = 7$

Experiments

Empty grid	Dense grid	Large grid
		
20x20 empty grid	20x20 grid with 30% randomly blocked cells	192x192 grid with 51% blocked cells

Experiments

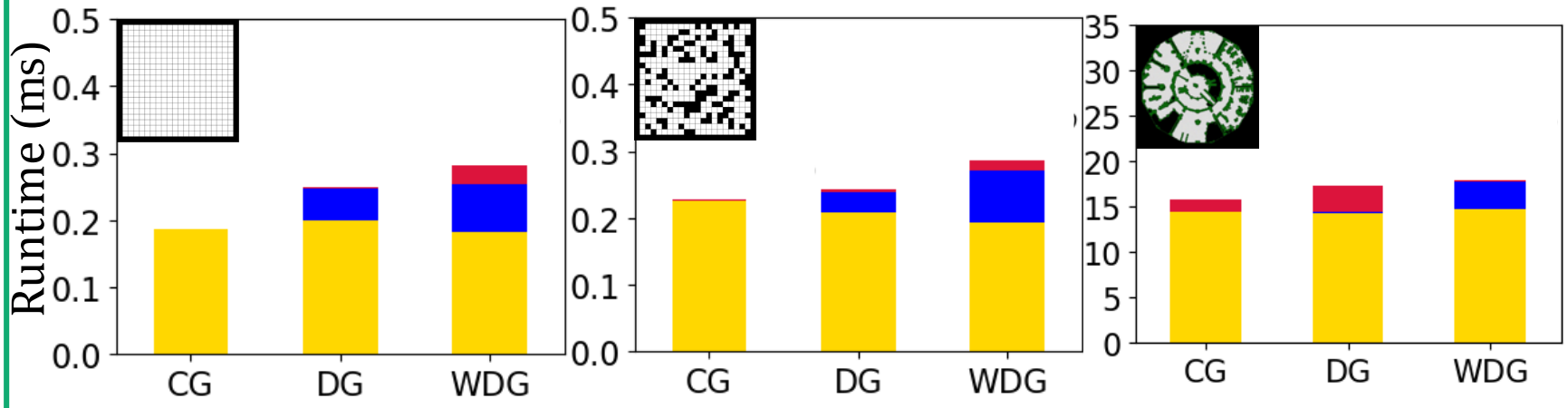
h value at the root node.



$$h_{WDG} \geq h_{DG} \geq h_{CG}$$

Experiments

Runtime breakdown per expanded node.



Runtime for CBS

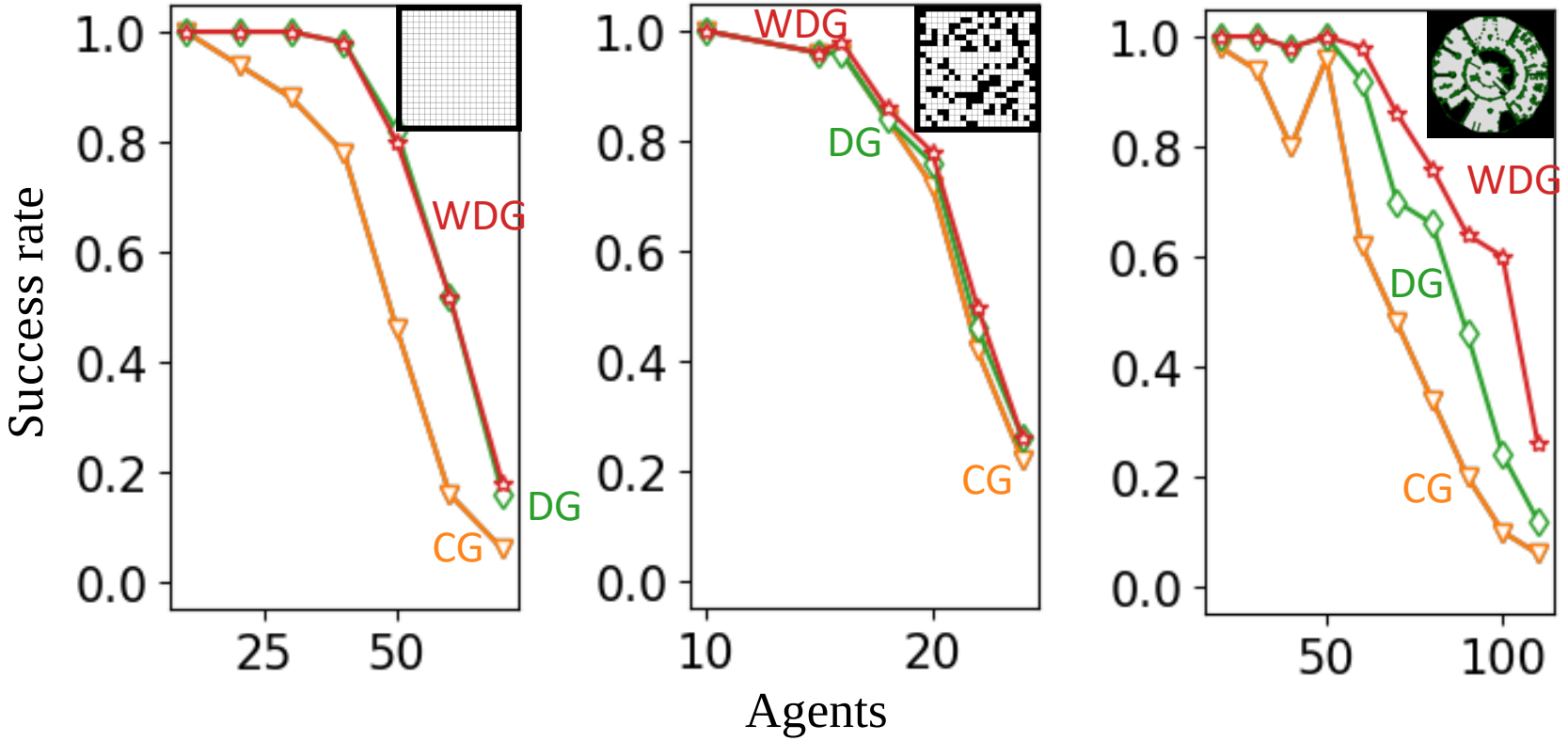
Runtime for constructing graphs

Runtime for solving MVC

Runtime overhead of computing heuristics

Experiments

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



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.