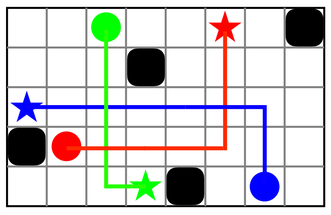
Conflict-Based Search for Explainable Multi-Agent Path Finding

Justin Kottinger[1], Shaull Almagor[2], Morteza Lahijanian[1]

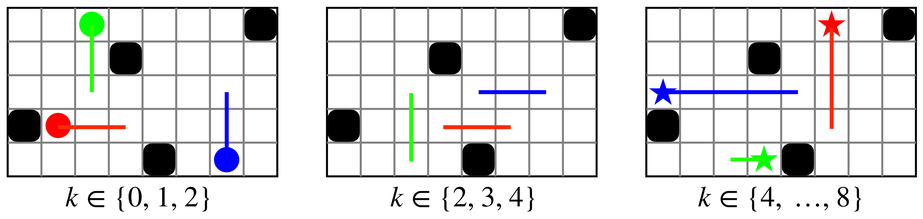
[1] University of Colorado Boulder, USA [2] Technion, Israel

Motivation

- MAPF algorithms are provably correct
- Not trusted in safety critical applications
- Currently use trained humans
  - Less efficient; more prone to mistakes



Goal: Allow MAPF solvers to explain correctness of solution to human user

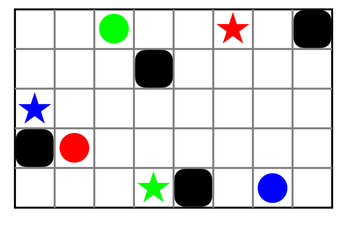


An MAPF explanation consisting of 3 segments as defined in[1]

Problem Formulation

Given:

- n agents operating in a graph $G = \langle V, E \rangle$
- List $s_1, \ldots, s_n$ if start vertices
- List $g_1, \ldots, g_n$ of goal vertices
- Explanation bound $r \in \mathbb{N}$



Compute:

- Non-colliding paths for all agents
- Plan is decomposed into at most r segments

This Work: Find a solution using Conflict-Based Search

Explanation-Guided CBS

Explanation-Guided CBS

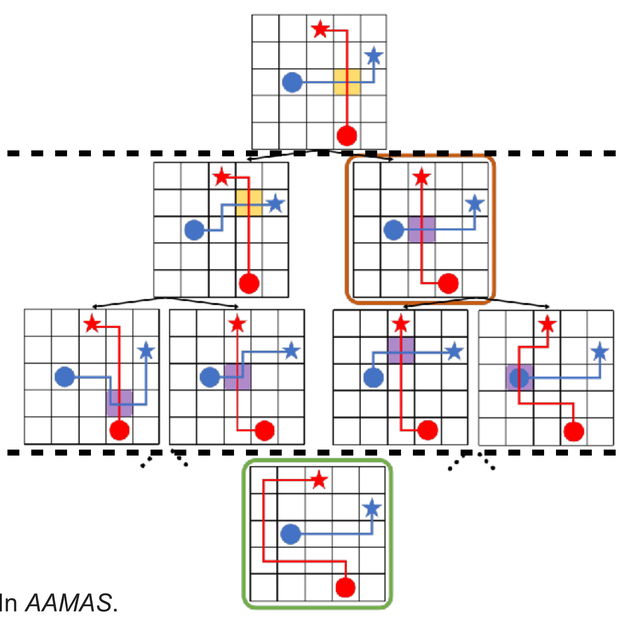
- CBS appended with Segmentation Conflicts
- Returns correct plan with satisfiable decomposition

Segmentation Conflicts

- Occur when plan explanation has over r segments
- Identified using minimal disjoint-segmentation from[1]

Collision Conflicts

Segmentation Conflicts



Step 1: Use low-level search to create initial plan

Step 2: Simulate plan to find conflicts

Step 3: Resolve conflicts by adding constraints

Step 4: Repeat until solution is found

[1]Almagor, S., & Lahijanian, M. (2020, May). Explainable multi agent path finding. In *AAMAS*.

Low-Level Search

1. Explanation-Guided A* (XG-A*)

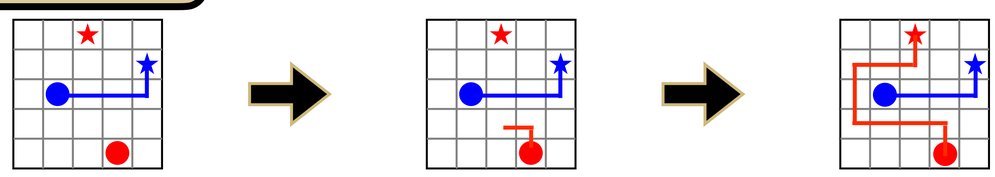
- Cost function $f_{XG-A*}(q) =$ number of segments within explanation
- Optimizes over number of segments within explanation
- Complete; Very slow and inefficient

2. Weighted XG-A* (WXG-A*)

- Combine A* with XG-A* by balancing between $f_{A*}(q)$ and $f_{XG-A*}(q)$
- Cost function $f_{WXG-A*}(q) = w f_{XG-A*}(q) + (1 - w) f_{A*}(q)$ where $w \in (0,1)$
- Complete; Difficult to find good value for w

3. Segment-Respecting A* (SR-A*)

- Plan around existing segmentation
- Treat explanation as a set of time-dependent obstacles
- Incomplete; works very well in practice

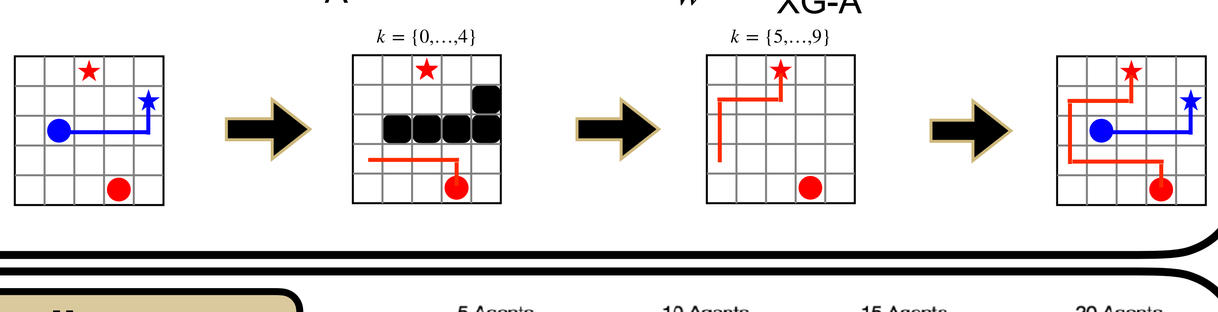


Shorter paths
longer explanations
Quicker search

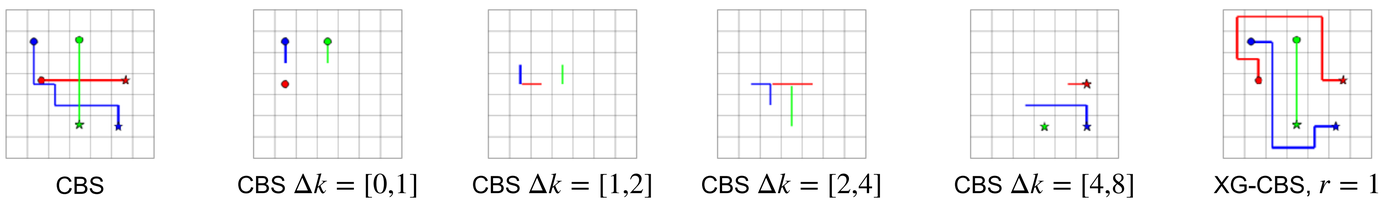
Increased Explanation-Guiding

A* — w — XG-A*

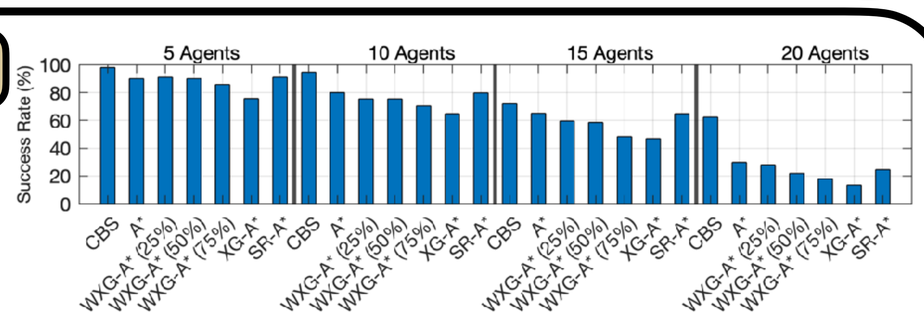
Longer paths
Shorter explanations
Slower search

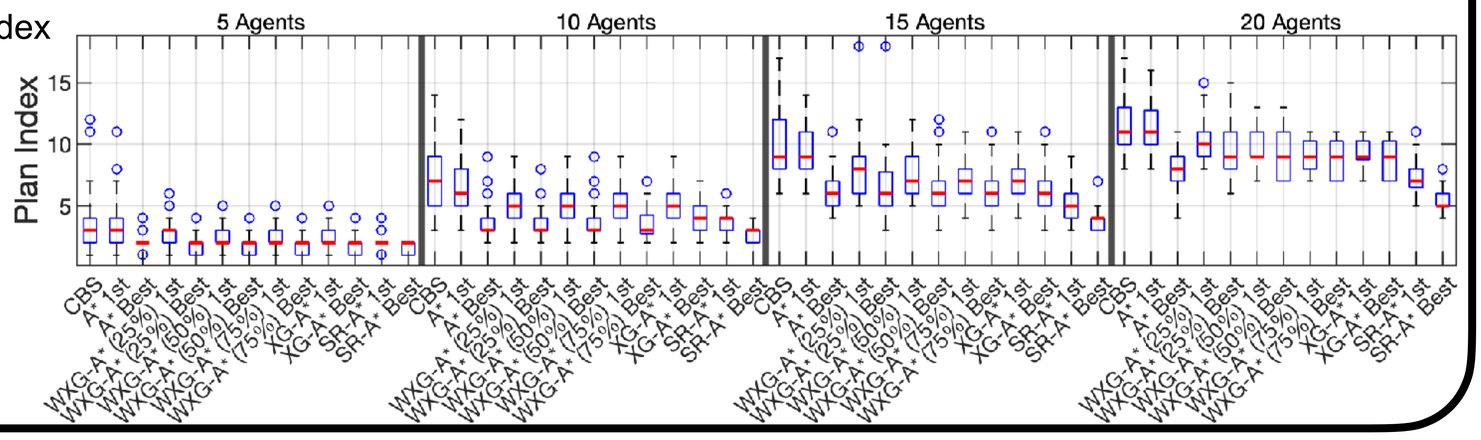


Case Studies



Apparent Collision in short plan vs. optimal index





Key Results

- CBS outputs lengthy explanations
- XG-CBS-A* excel when minor changes are required
- XG-CBS-XG-A*and XG-CBS-WXG-A* excel in small, congested environments
- XG-CBS-SR-A* clear choice in most realistic problems