Cite the paper you found, and describe their solution in your own words (in no more than a paragraph). • Based on the results in the paper and your experience with A\*, describe your expectation of how the solution proposed in the paper would compare.

Sharon, Stern, Felner and Sturtevant propose a solution called Conflict Based Search (CBS). While A\* finds a solution by modelling the problem as a single ‘joint agent’ system, CBS does not do so, and instead employs a dual-layered approach: first, on the higher level, it searches within a ‘Conflict Tree’ that is based on the conflicts between individual agents; then, searches are performed on a per-agent basis to meet the constraints imposed by the node from the higher level Conflict Tree. If there are still conflicts between agents after running the low-level search, we continue expanding nodes with constraints that solve the new conflict. In terms of the Flatland train scheduling problem, the main conflict would be multiple trains occupying the same location at the same time.

Both CBS and A\*(with an admissible heuristic) guarantee an optimal solution.

A\* is O(bn) where b is the number of possible actions for an agent on a particular turn (i.e. the branching factor), and n is the number of agents. This exponential complexity means that using algorithms based on A\* is unfeasible for large numbers of agents due to time and memory limitations.

Furthermore, the constant time per (low-level) node of CBS is much smaller than the constant time per node of A\* for two reasons: A\* expands multi-agent nodes while CBS expands single-agent states. Second, the open list maintained by CBS is much smaller because the single agent search space is linear in the size of the input graph. By contrast the open list for A\* deals with the multi-agent state space which is exponentially larger. Consequently, insertion and extraction of nodes from the open list is faster in CBS. CBS also incurs overhead directly at the high-level nodes. Each non-goal high-level node requires validating the given solution and generating two successors. The number of high-level nodes is very small compared to the low-level nodes. Consequently, the overhead of the high-level is negligible. Sharon, Stern, Felner and Sturtevant state the worst-case complexity of , the number of states in the lower level (multiply by 2 to include higher-level nodes), is , where C\* is the cost of the optimal solution, and V represents the set of locations for the agents (i.e. the vertices of the graph).

Since the Conflict Treeg rows exponentially in the number of conflicts encountered, CBS behaves poorly when a set of agents is strongly coupled, i.e., when there is a high rate of internal conflicts between agents in the group

If there are more bottlenecks, CBS will have advantage over the A\*-based approaches as it will rule out the f-value where agents conflict in the bottleneck very quickly and then move to solutions which bypass the bottlenecks. If there are more open spaces, A\* will have the advantage over CBS as it will rule out conflicted solutions very fast.

Sharon, G., Stern, R., Felner, A. and Sturtevant, N., 2015. Conflict-based search for optimal multi-agent pathfinding. *Artificial Intelligence*, 219, pp.40-66.