Optimal Multi-Agent Multi-Task Planning

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Problem Statement

- **Objective** - to find an optimal team solution for an unordered set of independent motion tasks using a team of heterogeneous robots
- **Motion Task** - task of moving one or more objects between locations in an environment
- Tasks can be completed in **any order** and have varying start and goal locations
- Robots may have **spatial constraints** that prevent them from traversing certain areas of an environment
- Task Conflict-Based Search (TCBS) is an adaptation of Conflict-Based Search to task space.
  - Conflict-Based Search is a multi-agent pathfinding algorithm

Task Conflict-Based Search (TCBS) Tree

Root

Conflicts	Cost
T_1: T_2:	12

Plan

T_1:	R_1: 2 – 4, $S_1 \rightarrow B$	R_3: 4 – 9, $B \rightarrow E$	R_4: 9 – 12, $E \rightarrow G_1$
T_2:	R_1: 2 – 4, $S_2 \rightarrow B$	R_3: 4 – 9, $B \rightarrow E$	R_4: 9 – 12, $E \rightarrow G_2$

Left child

Conflicts	Cost
T_1: {R_1: 2-4, $S_2 \rightarrow B$} T_2:	13

Plan

T_1:	R_2: 3 – 5, $S_1 \rightarrow B$	R_3: 5 – 10, $B \rightarrow E$	R_4: 10 – 13, $E \rightarrow G_1$
T_2:	R_1: 2 – 4, $S_2 \rightarrow B$	R_3: 4 – 9, $B \rightarrow E$	R_4: 9 – 12, $E \rightarrow G_2$

Right child

Conflicts	Cost
T_1: T_2: {R_1: 2-4, $S_1 \rightarrow B$}	13

Plan

T_1:	R_1: 2 – 4, $S_1 \rightarrow B$	R_3: 4 – 9, $B \rightarrow E$	R_4: 9 – 12, $E \rightarrow G_1$
T_2:	R_2: 3 – 5, $S_2 \rightarrow B$	R_3: 5 – 10, $B \rightarrow E$	R_4: 10 – 13, $E \rightarrow G_2$

Left-left child

Conflicts	Cost
T_1: {R_1: 2-4, $S_2 \rightarrow B$} T_2: {R_3: 5-10, $B \rightarrow E$}	14

Plan

T_1:	R_2: 3 – 5, $S_1 \rightarrow B$	R_3: 5 – 10, $B \rightarrow E$	R_4: 10 – 13, $E \rightarrow G_1$
T_2:	R_1: 2 – 14, $S_2 \rightarrow G_2$		

Left-right child

Conflicts	Cost
T_1: {R_1: 2-4, $S_2 \rightarrow B$} {R_3: 4-9, $B \rightarrow E$} T_2:	19

Plan

T_1:	R_2: 3 – 19, $S_1 \rightarrow G_1$		
T_2:	R_1: 2 – 4, $S_2 \rightarrow B$	R_3: 4 – 9, $B \rightarrow E$	R_4: 9 – 12, $E \rightarrow G_2$

Right-left child

Conflicts	Cost
T_1: T_2: {R_1: 2-4, $S_1 \rightarrow B$} {R_3: 4-9, $B \rightarrow E$}	15

Plan

T_1:	R_1: 2 – 4, $S_1 \rightarrow B$	R_3: 4 – 9, $B \rightarrow E$	R_4: 9 – 12, $E \rightarrow G_1$
T_2:	R_2: 4 – 15, $S_2 \rightarrow G_2$		

Right-right child

Conflicts	Cost
T_1: {R_3: 5-10, $B \rightarrow E$} T_2: {R_1: 2-4, $S_1 \rightarrow B$}	18

Plan

T_1:	R_1: 2 – 18, $S_1 \rightarrow G_1$		
T_2:	R_2: 3 – 5, $S_2 \rightarrow B$	R_3: 5 – 10, $B \rightarrow E$	R_4: 10 – 13, $E \rightarrow G_2$

Method

Low-Level Search

- **Search Space** – subtask starts/ends × agents × available intervals
- **Available Interval** – time during which an agent is available to complete a subtask
- **Path** – a sequence of subtasks and agents

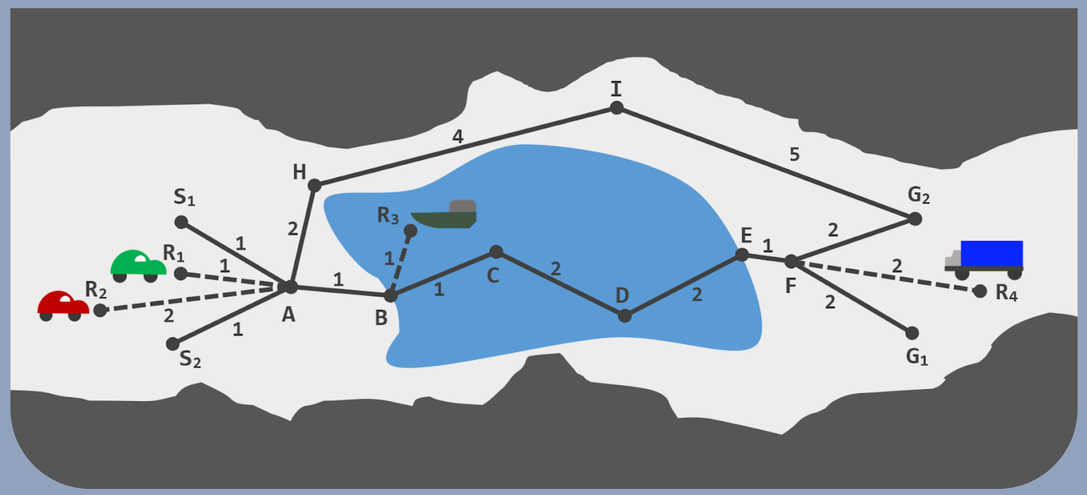
High-Level Search

- **TCBS Tree Node** – holds individual task plans, a conflict map, and a team plan cost
- **Task Conflict** – time intervals where an agent allocation conflict exists between tasks
- **Conflict Map** – a set of interval constraints that are placed on individual tasks

Experiments

- Thirty trials were run on a team of four robots with varying numbers of randomly generated tasks

	Tasks		
	1	2	3
Task Evaluation Time (s)	0.06	0.10	20.86
Total Nodes	1.00	2.94	135.86
Max Depth	1.00	1.52	5.86



Conclusion

- TCBS produces **optimal solutions**
- Creating a team plan can be expensive because it is an NP-hard problem
  - State space **grows exponentially** with the number of tasks

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