ICAPS 2021: Using Conflicts to Preserve Privacy for Decoupling Multi-Agent Plans with Uncertainty

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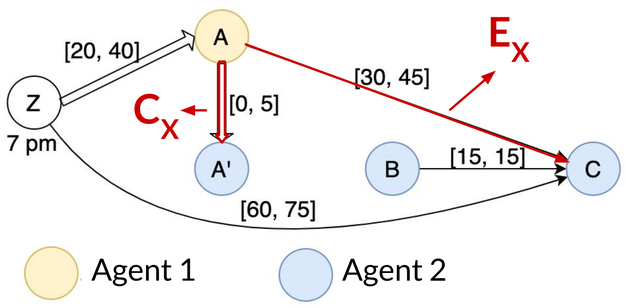
AIM OF OUR WORK

When multiple agents execute a shared task, agents have their own private events as well as inter-agent temporal constraints. We aim to develop a distributed approach to **decouple multi-agent temporal plans** such that these inter-agent constraints are guaranteed to be satisfied during execution even with limited communication, that **preserves the privacy of private events.**

KEY RESULTS

- Developed a distributed, **generate-and-test** decoupling algorithm that uses state-of-the-art $O(n^3)$ DC checker.
- For privacy, uses **privacy-preserving conflicts** for agents to communicate why a solution candidate is infeasible.
- Empirical results showed **runtime speed-up** compared to centralized algorithm for **loosely coupled** MaSTNUs.

Multi-Agent Temporal Networks with Uncertainty (MaSTNU) [1]



MaSTNU <N^A, E_X, C_X>

- N^A: local STNUs for the agents
- E_X: inter-agent requirement constraints
- C_X: inter-agent contingent constraints (representing communication)

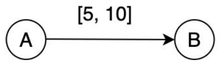
Dynamic controllable (DC) if exists execution strategy that satisfies all constraints.

Limited communication means agents cannot observe the occurrence of others' events, except for the received events of C_X

event

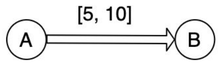
$v_A \in \mathbb{R}$

simple temporal requirement constraint



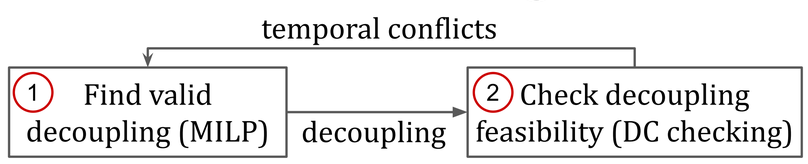
$5 \leq v_B - v_A \leq 10$

simple temporal contingent constraint

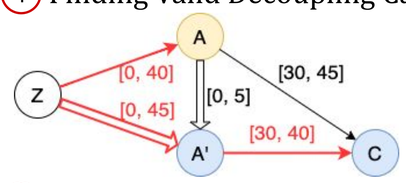


$5 \leq v_B - v_A \leq 10$

Our Distributed Algorithm



1 Finding Valid Decoupling Candidate on Shared Events

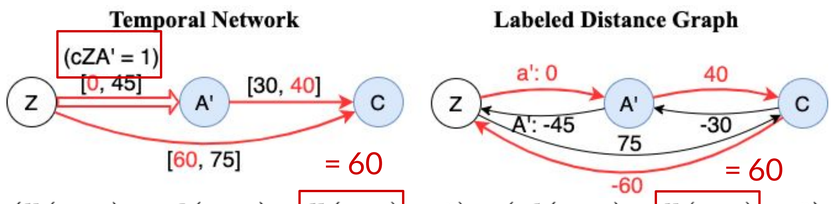


MILP encoding: valid decoupling constraints + conflict resolution

2 Each Agent Checking Feasibility of Local Network

Hybrid conflict [4]: linear inequalities + discrete supports

Preserve privacy by replacing local constraints by its values



$$(lb(e_{ZA'}) + ub(e_{A'C}) - \boxed{lb(e_{ZC})} < 0) \wedge (ub(e_{A'C}) - \boxed{lb(e_{ZC})} < 0)$$

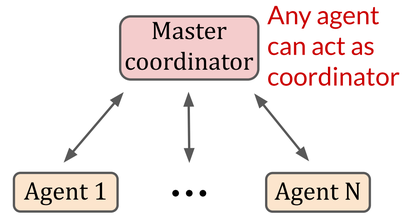
⇒ Resolve by negating it!

Privacy definition:

Shared events include ref event Z and those connected to E_X and C_X. Private events are the rest of the events for the agent's local network.

We preserve the privacy of private events and local constraints.

Distributed Architecture:

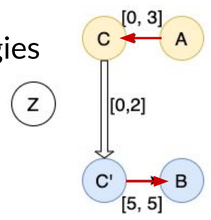


Decoupling of MaSTNU [1]

Temporal decoupling: Augment N^A with local constraints s.t.

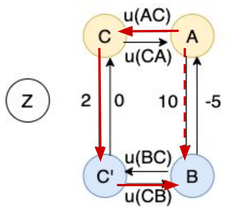
- (valid) Merging execution strategies for N^A satisfies E_X given C_X
- (feasible) N^A are DC

Impose local constraints

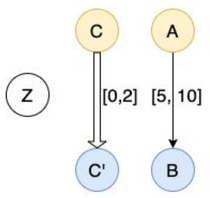


distance graph

Rationale: Creating shorter paths



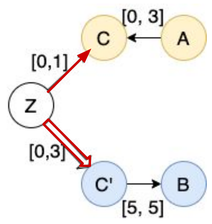
Goal: satisfy e_{AB}



$$v_B - v_A = (v_B - v_{C'}) + (v_{C'} - v_C) + (v_C - v_A)$$
$$= [5, 5] + [0, 2] + [0, 3] = [5, 10]$$

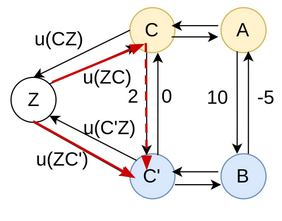
$$u_{AC} + u_{CC'} + u_{C'B} \leq u_{AB} \leq 10$$

Provide guarantee on when event C' occurs!



distance graph

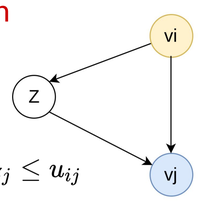
Rationale: Cover all possible time occurrences of C'



$$v_{C'} - v_Z = (v_{C'} - v_C) + (v_C - v_Z)$$
$$= [0, 2] + [0, 1] = [0, 3]$$

$$u_{ZC'} \geq u_{ZC} + u_{CC'}$$
$$0 \geq u_{C'Z} \geq u_{CZ} + u_{C'C}$$

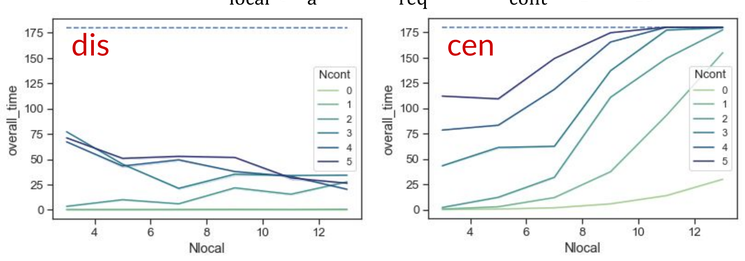
Communication Unavailable [2] (special case)



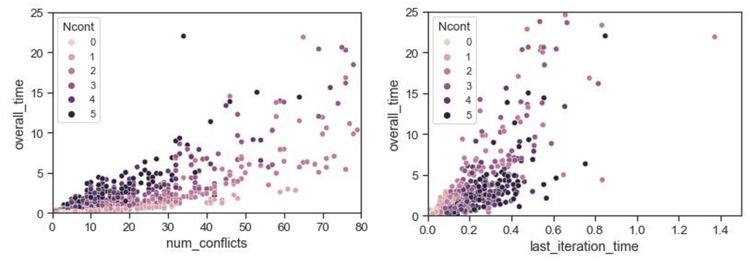
$$u_{iZ} + u_{Zj} \leq u_{ij}$$

Experiment Results

Runtime w.r.t. N_{local} (N_a = 2, N_{req} = 3, N_{cont} = [0, 5])



Runtime (dis) w.r.t. Num of conflicts & Last iteration



Distributed algorithm less effective with a larger N_{cont}, as there tend to be more hybrid conflicts discovered

Compare centralized [1] & distributed algorithm on randomly generated MaSTNUs

- N_a : number of agents
- N_{local} : size of agent local network (N_{local} contingents & N_{local} requirements)
- N_{req} : number of inter-agent requirement constraints
- N_{cont} : number of inter-agent contingent constraints

Run each case 30 times, with 3-min timeout, use average time (timed out cases counted as 3min)

References

[1] Casanova, G.; Pralet, C.; Lesire, C.; and Vidal, T. 2016. Solving dynamic controllability problem of multi-agent plans with uncertainty using mixed integer linear programming. InProceedings of the Twenty-second European Conference on Artificial Intelligence, 930–938. IOS Press.

[2] Hunsberger, L. 2002. Algorithms for a temporal decoupling problem in multi-agent planning. In AAAI/IAAI.

[3] Boerkoel Jr, J. C.; and Durfee, E. H. 2013. Distributed reasoning for multiagent simple temporal problems. Journal of Artificial Intelligence Research 47: 95–156.

[4] Yu, P.; and Williams, B. C. 2013.Continuously relaxing over-constrained conditional temporal problems through generalized conflict learning and resolution. In Twenty-Third International Joint Conference on Artificial Intelligence

Acknowledgement

This material is based upon work supported by the Defense Advanced Research Projects Agency (DARPA) under Contract No. HR001120C0035. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Defense Advanced Research Projects Agency (DARPA).