A Receding Horizon Approach to Multi-Agent Planning from Local LTL Specifications

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Multi-Agent Planning from Local LTL Specifications

- Temporal, long-term missions
  - Individual
  - Possibly involving requirements on the others
Centralized Formal Methods Approach

System
Deterministic transition system

Specification
LTL Formula

Büchi automaton

Product

graph analysis

strategy

no, there is no strategy

go left, load, go straight...
service task, help, go up ....
Transition Systems

combined state of the agents
synchronized transitions
Formal Methods Approach

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Linear Temporal Logic

\[ \varphi ::= a \mid \varphi \land \varphi \mid \neg \varphi \mid \varphi U \varphi \mid X \varphi \mid F \varphi \mid G \varphi \]

- \( X \ a \)
- \( a \ U \ b \)
- \( G \ a \)
- \( F \ a \)
- \( G F \ a \)
- \( a \ U (b \ U \ c) \)
Agent 1: move around
\[ l_A, l_B, l_C, l_H \]
\[ u_A, u_B, u_C, u_H \]

Agent 2: move around
\[ t_1, t_2, t_3, t_4, t_5 \]
\[ h_H \]

\[ \phi_1 = \bigwedge_{i \in \{A, B, C\}} \text{GF}(l_i \wedge X u_i) \wedge \text{GF}(l_H \wedge h_H \wedge X u_H) \]

\[ \phi_2 = \text{GF}(t_1 \wedge X (t_2 \wedge X (t_3 \wedge X (t_4 \wedge X t_5)))) \]
Control Strategy Synthesis: Automata Based Approach

System
Deterministic transition system

Specification
LTL Formula
\( \phi_1 = GF((\text{load} \land \text{help}) \land X \text{unload}) \)
\( \phi_2 = GF\text{task} \)

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go left, load, go straight...
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Product Automaton
Product Automaton
Product Automaton

- Go right
- Load
- Go left
- Unload

- Anything
  - Go left
  - Go right

- Load
  - Go left
  - Unload

- Go right
- Load
Product Automaton

- Go right
- Load
- Go left
- Unload
- Go left
- Load

- Anything
- Go left
- Load
- Unload
- Go left
- Load
Approach Challenge

- $n$ agents, each $m$ different states = $m^n$ states of the transition system

- Computationally infeasible

- Our approach
  - Plan locally, only a few steps ahead
  - Guarantee the satisfaction of the long-term spec
  - Receding horizon approach
Receding Horizon in Single-Agent Settings

Measure progress towards satisfaction

Ding, Bela e.a., 2010
Receding Horizon in Single-Agent Settings

Ding, Belta e.a., 2010
Receding Horizon in Single-Agent Settings

Ding, Bela e.a., 2010
Receding Horizon in Single-Agent Settings

Ding, Bela e.a., 2010
Receding Horizon in Single-Agent Settings

Progressive transitions

Ding, Bela e.a., 2010
Our Approach

- Make a product for only $m$ steps
- Only with the agents that are involved/required in the following $m$ steps
Receding Horizon in Multi-Agent Settings
Receding Horizon in Multi-Agent Settings

H=2

![Diagram showing transitions between states with labels go right, go left, load, unload, help, go up, go down, task, and help.](image)
Receding Horizon in Multi-Agent Settings

- Go right
- Go left
- Load
- Unload
- Help
- Go up
- Go down
- Task
- Help
Receding Horizon in Multi-Agent Settings

H=2

Diagram showing agent movements:
- Go right
- Go left
- Load
- Unload
- Help
- Go up
- Go down
- Task
- Help
Receding Horizon in Multi-Agent Settings
Challenges

A progressive transition cannot be identified

- A transition is progressive for some, not for all of the agents
  - Choose a leader, once progress is made from its point of view, switch the leader

- A transition is not progressive for any of the agents
  - Horizon too short: extend the horizon
  - A wrong decision was made in the past: backtrack
Summary

- Address computational infeasibility of multi-agent planning from local LTL specifications
- Receding horizon approach
- Simulations: reduced number of states from millions to thousands

- **Ongoing work**
  - Decrease of synchronization needs
  - Optimality of the plans

Thank you!