Multi-agent Plan Reconfiguration under Local LTL Specifications

Meng Guo

ACCESS Linnaeus Center, EES
Royal Institute of Technology, KTH, Sweden

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Agent Model: FTS

- Abstraction as finite transition systems (FTS):

\[ T_k^t = (\Pi, \rightarrow_k, \Pi_{k,0}, AP_k, L_k, W_k), \]

- \( \Pi_k \), regions or places. \( \Pi_{k,0} \), initial states.
- \( \rightarrow_k \subseteq \Pi_k \times \Pi_k \) transition relation.
- \( AP_k \), set of properties. addresses or general properties.
- \( L_k : \Pi \rightarrow 2^{AP_k} \), labelling function.
- \( W_k : \rightarrow_k \rightarrow \mathbb{R}^+ \), transition cost.

- Example:
Local Task Specifications

- Agent $k$’s local task specification $\varphi_k$, over $AP_k$ as Linear Temporal Logic (LTL), syntax:

$$\varphi ::= \text{true} \mid a \mid \varphi_1 \land \varphi_2 \mid \neg \varphi \mid \Box \varphi \mid \varphi_1 \cup \varphi_2.$$ 

- To specify control tasks:
  - Safety: $\Box \neg \varphi_1$. Order: $\varphi_1 \cup (\varphi_2 \cup \varphi_3)$.
  - Response: $\varphi_1 \Rightarrow \varphi_2$. Liveness: $\Box \Diamond \varphi_1$.

- $\varphi_k = \varphi_k^{\text{soft}} \land \varphi_k^{\text{hard}}$, where $\varphi_k^{\text{hard}}$ for safety. $\varphi_k^{\text{soft}}$ for performance.

- Ex1: pass by ‘shop1’, ‘shop2’ and ‘shop3’, avoid toll and policeman as possible, then back home.

- Ex2: go to ‘room1’ and pickup a ball, then go to ‘room2’ and drop it.
Motivation

- $\mathcal{T}_k^t$, incomplete model of the actual workspace.
  - $\mathcal{T}_k^t$ and $\mathcal{W}_k$ may change, due to dynamic constraints or congestion.
  - $L_k$ may change, due to partial or incorrect initial model.

- Agents are normally distributed at various locations within the workspace, with real-time/accurate observations.

- How could they ‘talk’ to each other and improve their own plan?
Model-checking-based motion and task planning:

- **Inputs:** $\varphi_k$, $T^0_k$;
- **Outputs:** initial plan $\tau^0_k$.
- **Fully-automated process.**
- Nested-Dijkstra graph search.
- **Complexity:** $O(|\tilde{A}^t_{p,k}| \cdot \log |\tilde{A}^t_{p,k}| \cdot (|Q'_0| + |F'|))$.

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Plan Structure

- Motion and task plan $\tau_k^t$ with **prefix-suffix** structure:
  
  $$\tau_k^t = \tau_{k,\text{pre}}^t \left( \tau_{k,\text{suf}}^t \right)^\omega$$

- an infinite sequence of **regions to visit**, and **actions to perform**.

- **Guarantee**: always $\tau_k^0 \models \varphi_k^{\text{hard}}$ for **safety**, and $\tau_k^0$ satisfies $\varphi_k^{\text{soft}}$ as much as possible under $\mathcal{T}_k^0$.

- **Ex1**: go to ‘shop1’ via ‘road1’, to ‘shop2’ via ‘road2-road3’, to ‘shop3’ via ‘road4’, **back home** via ‘road5’.

- **Ex2**: go to ‘room1’ via ‘room2-cor1’, **pickup** a ball, go to ‘room2’ via ‘cor2-cor3’, **drop** it.
Knowledge Update and Transfer

- **Knowledge Update** by means of
  - own sensing ability,
  - communication with others.

- Communication Network: $\mathcal{N}_k \in \mathcal{N}$. Static or dynamic.

- Protocol:
  - Request once: $\text{Request}_{k,g}^t = (k, \varphi_k|_{AP_k})$.
  - Sensing info.: $\text{Sense}_{k}^t = \{ (\pi, S, S_\neg), E, E_\neg \}$.
  - Event-based Reply: $\text{Reply}_{h,k}^t = (\pi, S', S'_\neg)$, where $S' = S \cap (\varphi_h|_{AP_h})$ and $S'_\neg = S_\neg \cap (\varphi_h|_{AP_h})$.

- Note: 1. reply only based on own actual sensing; 2. always contain useful info.
Plan Verification and Revising

- Update $\mathcal{T}_k^t$ based on $\text{Sense}_k^t$ and $\text{Reply}_{g,k}^t$.

- Given $\mathcal{T}_k^{t^+}$ and $\tau_k^t$, two questions:
  
  - is $\tau_k^t$ still valid or safe for $\mathcal{T}_k^{t^+}$? (valid for $\rightarrow_k^t$ and safe for $\varphi_k^{\text{safe}}$).
    
    > by verifying all transitions along $\tau_k^t$, using $\mathcal{T}_k^{t^+}$.
  
  - if not, how to revise it?
    
    > full synthesis — slow, safe and cost optimal
    > local revising — fast, safe and not optimal
    > any-time solution — middle, safe and long-term optimal
Conclusion and Future Work

- Conclusion
  - cooperative motion and task planning.
  - de-centralized.
  - partially-known workspace.
  - guarantee safety.

- Future Work
  - dependent tasks.