Autonomous Task Planning for Heterogeneous Multi-Agent Systems*

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Motivation

- Autonomous multi-agent operations
- High-level task description → Automatic controller synthesis
- Reactive execution
- Fault accommodation

Main Contributions

- System modeling using nondeterministic finite automata with ϵ-transitions expressing the system's behavior and combining the agent's capabilities and constraints at the individual and group level, including failure modes.
- Determination of optimal task plans that satisfy any possible task specification from any initial condition, without the need to repeat the pre-processing cycle.
- Determination of reduced complexity sub-optimal solutions to the task planning problem.
- Incorporation of failure modes on-the-fly, after building the global system model (i.e. without the need to repeat the costly pre-processing step).

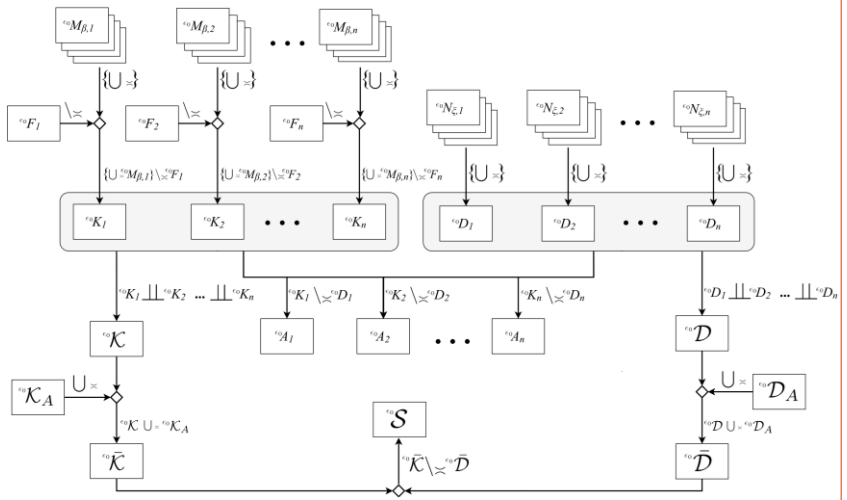
Problem Statement

"Given a set of individual and inter-agents capabilities and constraints including their failure modes, the initial state of the system and a task specification, determine a string that provides an optimal execution (in terms of total transition cost) that brings the system from any initial state to any state satisfying the task specification."

Some Important Definitions

- Definition 1: ε_0-NFAs
- Definition 5: Compatible ε_0-NFAs
- Definition 6: Union of Compatible Automata $\bigcup_{\asymp}$
- Definition 7: Subtraction of Compatible Automata $\setminus_{\asymp}$
- Definition 8: Concatenation of Compatible Automata $\amalg_{\asymp}$

Agents' & Environment Models



Problem Formulation

The **Task Specification** is a projection operation of the state space to the subspace of interest

With the **Environment Model** and the **Task Specification** we cast the problem as an instance of the Module Composition Problem

The solution to the Module Composition Problem enables us to seamlessly use the generated Module Chain as a modeled system for building Supervisory Controllers

Completeness results

Proposition 1
With the proposed construction, **the resulting environment model is complete**

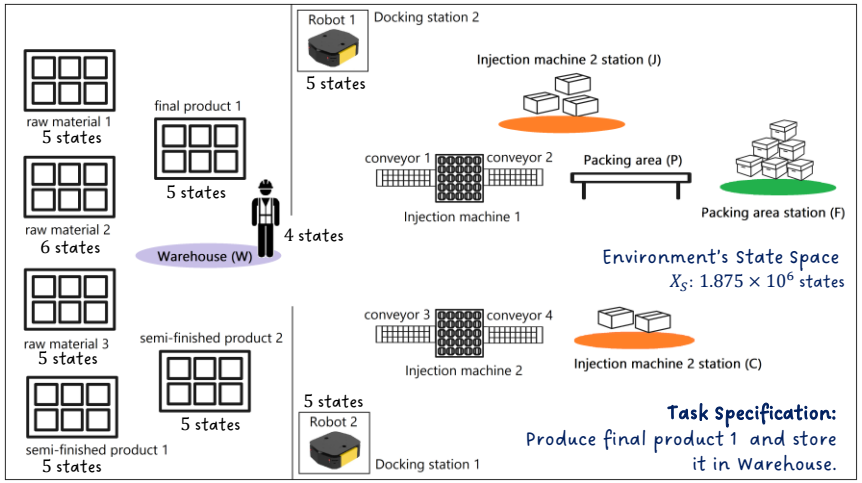
Optimality results

Proposition 2
With the proposed construction, and assuming that only one agent is allowed to operate at any time instant, the solution **produces the optimal sequence of actions** to achieve the task specification.

Analysis

- Time complexity to construct agents' models: $O(|X_{A_i}|^2)$
- Time complexity to construct environment model: $O(|X_{\mathcal{S}}|^3)$
- On-the-fly incorporation of new failure modes (worst case time complexity): $\prod_{i=1,\ i\neq\nu}^{n-1} |X_{A_i}|$
- Time complexity of complete algorithm: $\frac{\prod_{i=1}^{n-1} |X_{A_i}|}{|X_{A_\sigma}|} \times O((\mathcal{V}_{\mathcal{S}} + \mathcal{E}_{\mathcal{S}}) log \mathcal{V}_{\mathcal{S}})$
- Time complexity of heuristic algorithm: $O(\mathcal{E}_{\mathcal{S}} log \mathcal{V}_{\mathcal{S}})$

Case Study



Time Complexity	Pre-processing	Complete solution	Heuristic solution
	$3.081 \times 10^5 sec$	$10\ 720\ sec$	$165.73\ sec$

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