Self-Adaptive Swarm System (SASS)

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Abstract

Distributed artificial intelligence (DAI) studies artificial intelligence entities working together to reason, plan, solve problems, organize behaviors and strategies, make collective decisions and learn. This Ph.D. research proposes a principled Multi-Agent Systems (MAS) cooperation framework, *Self-Adaptive Swarm System (SASS)*, to bridge the fourth level automation gap between perception, communication, planning, execution, decision-making, and learning.

1 Introduction

In the artificial systems, distributed artificial intelligence (DAI) has developed more than three decades as a subfield of artificial intelligence (AI). It has been divided into two sub-disciplines: Distributed Problem Solving (DPS) focuses on the information management aspects of systems with several branches working together towards a common goal; Multi-Agent Systems (MAS) deals with behavior management in collections of several independent entities, or agents [Stone and Veloso, 2000]. For cooperative MAS, the individual is aware of other group members, and actively shares and integrates its needs, goals, actions, plans, and strategies to achieve a common goal and benefit the entire group, especially building so-called *artificial social systems* [Wooldridge, 2009], such as Multi-Robot Systems (MRS).

For low-level planning and control, [Rizk *et al.*, 2019] groups the system based on the cooperative tasks' complexity as four levels of automation, and no references were found currently. For high-level MAS decision-making and learning, recent studies mainly concern partial cooperation and do not consider deeper cooperative relationships among agents representing more complex team strategies [Rizk *et al.*, 2018]. Combining the information from perceiving the environments and inferring the corresponding strategies and the world's conditional (or even causal) relations in those scenarios, a unified probabilistic framework to tightly integrate deep learning and Bayesian models adapting the environments and achieving the tasks with reasonable time complexity and efficient and effective information exchange between the perception component and the task-specific component are still challenging problems [Wang and Yeung, 2020].

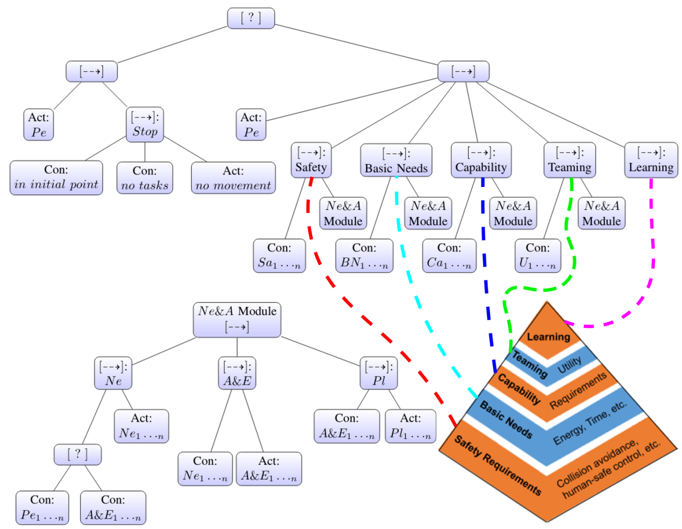

Figure 1: Behavior Tree representing *Robot Needs Hierarchy* at each agent in *SASS*. [?] - Selector Node, [- - →] - Sequence Node, Con - Conditions, Act - Actions, Pe - Perception, Sa - Safety, BN - Basic Needs, Ca - Capability, U - Utility, Pl - Plan, Ne - Negotiation, $A\&E$ - Agreement and Execution.

2 Contributions

This *Ph.D.* research proposes a principled MAS cooperation framework called *Self-Adaptive Swarm System (SASS)* [Yang *et al.*, 2019; Yang and Parasuraman, 2020b]. Fig. 1 shows *needs-driven SASS* mechanism represented as a *Behavior Tree* and we briefly introduce our contributions as follow:

Robot Needs Hierarchy To model an artificial intelligence agent's motivations and needs, we classify the *Robot Needs Hierarchy* as five different levels: *safety needs* (collision avoidance, human-safety control, etc.); *basic needs* (energy, time constraints, etc.); *capability* (heterogeneity, hardware differences, etc.); *teaming* (global utility, team performance, etc.); and *self-upgrade* (learning).

Negotiation-Agreement Mechanism We propose a *distributed Negotiation-Agreement* mechanism for selection (task assignment), formation (shape control), and routing (path planning) through automated planning of state-action sequences, helping MAS solve the conflicts in cooperation.

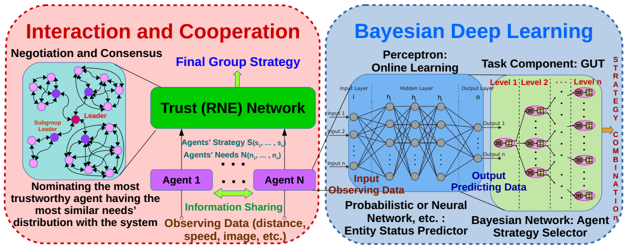

Figure 2: SASS Synthetic Framework

Atomic Operations By decomposing the complex tasks into a series of simple sub-tasks based on the *Atomic Operations*: *Selection*, *Formation*, and *Routing*, agents can recursively achieve all sub-tasks until MAS completes the mission.

Game-theoretic Utility Tree (GUT) *GUT* [Yang and Parasuraman, 2020a] is a new state-space Bayesian network model [Koller and Friedman, 2009] for artificial intelligent agent decision-making in uncertain and adversarial environments. It builds hierarchical relationships between individual behaviors and interactive entities and helps agents infer the following step strategy combination representing more complex behaviors to adapt to various scenarios through given the observations and the arriving data in real-time.

Relative Needs Entropy (RNE) Based on the *Robot Needs Hierarchy* model, *Trust* can be defined as the difference or distance of needs distribution between agents or groups in a specific scenario. Statistics regard *Relative Entropy* as the similarity of high-dimensional sample sets. Here, we call it – *Relative Needs Entropy (RNE)* [Yang and Parasuraman, 2021], which describes the reliability and stability of the relationships between agents in MAS cooperation.

GUT-Based Bayesian Adaptive Learning By designing the appropriate *Trust (RNE) Network*, building suitable perception models, estimating reasonable parameters, simplifying the corresponding *GUT* model, and implementing structure learning (Fig. 2), adaptive learning [Nikolaev and Iba, 2006] can efficiently optimize the group strategy fitting the specific scenarios in MAS interaction and cooperation.

Explore Domain From the realistic and practical perspective, *Explore Domain* [Yang and Parasuraman, 2020a] analyzes how to organize more complex relationships and behaviors in MAS cooperation, achieving tasks with higher success probability and lower costs in adversarial environments.

Urban search and rescue (USAR) Through organizing heterogeneous agents' needs for MAS cooperation in USAR, we consider the *Group's Utility* (teaming needs) as the number of victims or valuable properties rescued as much as possible in a limited time [Yang and Parasuraman, 2020c].

3 Conclusion

In the *SASS*, *Robot Needs Hierarchy* is the foundation. It surveys the system's utility from individual needs. Balancing the rewards between agents and groups for MAS through interaction and adaptation in cooperation optimizes the global system's utility and guarantees sustainable development for each group member, much like human society does.

As a novel DAI model, the planning and control govern the individual low-level *safety* and *basic* needs; *capability* and *teaming* needs are the preconditions and requirements of MAS cooperation in decision-making for achieving tasks; individuals upgrade themselves from interaction, cooperation, and adaptation in the process for the highest level needs *learning*, helping *SASS* self-evolution.

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