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].

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 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.
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.

References

[Koller and Friedman, 2009] Daphne Koller and Nir Friedman. Probabilistic graphical models: principles and techniques. MIT press, 2009.

[Nikolaev and Iba, 2006] Nikolay Nikolaev and Hitoshi Iba. Adaptive learning of polynomial networks: genetic programming, backpropagation and Bayesian methods. Springer Science & Business Media, 2006.

[Rizk et al., 2018] Yara Rizk, Mariette Awad, and Edward W Tunstel. Decision making in multiagent systems: A survey. IEEE Transactions on Cognitive and Developmental Systems, 10(3):514–529, 2018.

[Rizk et al., 2019] Yara Rizk, Mariette Awad, and Edward W Tunstel. Cooperative heterogeneous multi-robot systems: A survey. ACM Computing Surveys (CSUR), 52(2):1–31, 2019.

[Stone and Veloso, 2000] Peter Stone and Manuela Veloso. Multiagent systems: A survey from a machine learning perspective. Autonomous Robots, 8(3):345–383, 2000.

[Wang and Yeung, 2020] Hao Wang and Dit-Yan Yeung. A survey on bayesian deep learning. ACM Computing Surveys (CSUR), 53(5):1–37, 2020.

[Wooldridge, 2009] Michael Wooldridge. An introduction to multiagent systems. John Wiley & Sons, 2009.

[Yang and Parasuraman, 2020a] Qin Yang and Ramviyas Parasuraman. A game-theoretic utility network for cooperative multi-agent decisions in adversarial environments. arXiv preprint arXiv:2004.10950, 2020.

[Yang and Parasuraman, 2020b] Qin Yang and Ramviyas Parasuraman. Hierarchical needs based self-adaptive framework for cooperative multi-robot system. In 2020 IEEE International Conference on Systems, Man, and Cybernetics (SMC), pages 2991–2998. IEEE, 2020.

[Yang and Parasuraman, 2020c] Qin Yang and Ramviyas Parasuraman. Needs-driven heterogeneous multi-robot cooperation in rescue missions. In 2020 IEEE International Symposium on Safety, Security, and Rescue Robotics (SSRR), pages 252–259. IEEE, 2020.

[Yang and Parasuraman, 2021] Qin Yang and Ramviyas Parasuraman. How can robots trust each other? a relative needs entropy based trust assessment models. arXiv preprint arXiv:2105.07443, 2021.

[Yang et al., 2019] Qin Yang, Zhiwei Luo, Wenzhan Song, and Ramviyas Parasuraman. Self-Reactive Planning of Multi-Robots with Dynamic Task Assignments. In IEEE International Symposium on Multi-Robot and Multi-Agent Systems (MRS) 2019, 2019. Extended Abstract.