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A Game-theoretic Utility Network for Cooperative Multi-Agent Decisions in Adversarial Environments

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Abstract

This paper proposes a new network model called Game-theoretic Utility Tree (GUT), mimicking the multi-agent decision-making process for cooperation working in adversarial environments.

We verified the effectiveness of the GUT in the real robot application through the implementation of the Explore Game on the Robotarium hardware-simulator multi-agent testbed and compared it with the random and greedy approaches in three scenarios.

Research Questions

- How to organize complex strategies and actions in MAS/MRS to adapt uncertain and adversarial environments efficiently?
- How to optimize the global system's utility and guarantees sustainable development for each group member?
- How to help the group achieving challenging tasks with lower costs and higher winning probability?

Motivation

- Distributed Intelligence refers to systems of entities working together to reason, plan, solve problems, think abstractly, comprehend ideas and language, and learn [1].
- Especially 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 [2].
- Combining multi-agent cooperative decision-making and robotics disciplines, researchers developed the Adversarial Robotics focusing on autonomous agents operating in adversarial environments [3].

Fig 1. Illustration of the Explore Game scenario where the Aliens (opponent agents - peer adversaries) block the paths to a target of the Explorers (protagonist agents).

Background

Fig 4. The proposed Agent Needs Hierarchy inspired by Maslow's law of human needs

1. Game Theory is the science of strategy, which provides a theoretical framework to conceive social situations among competing players and produce optimal decision-making of independent and competing actors in a strategic setting.
2. In Agent Needs Hierarchy [4], the abstract needs of an agent for a given task are prioritized and distributed into multiple levels, each of them preconditioned on their lower levels. At each level, we express the needs as an expectation over its distribution of the factors/features corresponding to that level.
3. The "Explore Game" evaluates the MAS performance from the perspective of balancing the success probability of achieving tasks and system costs in adversarial environments.

Proposed Method and its Implementation

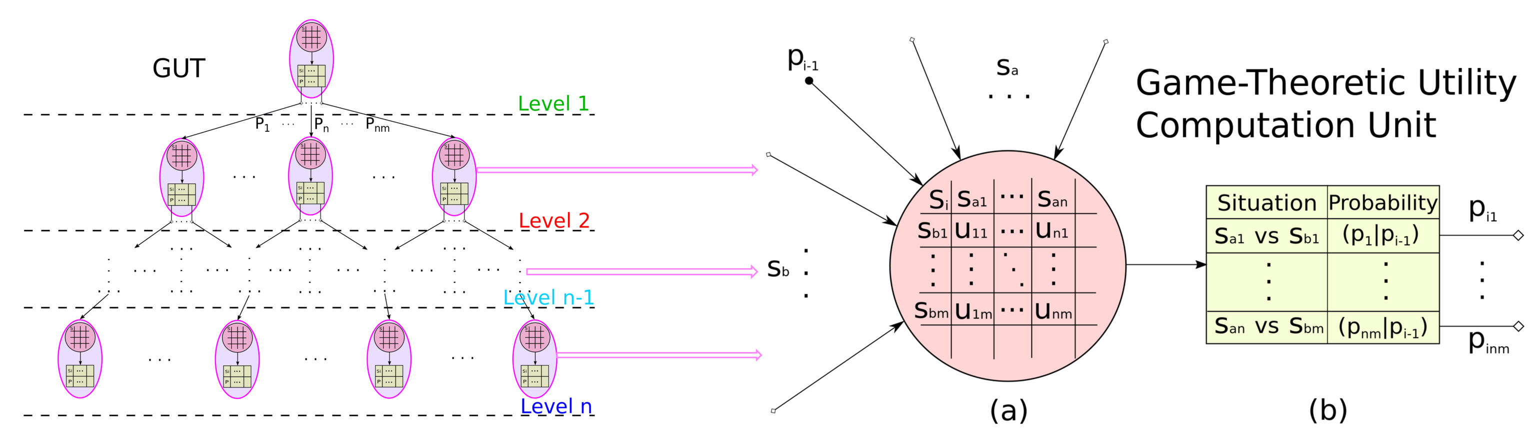

Fig 5. Illustration of General Game-theoretic Utility Tree (GUT) Model

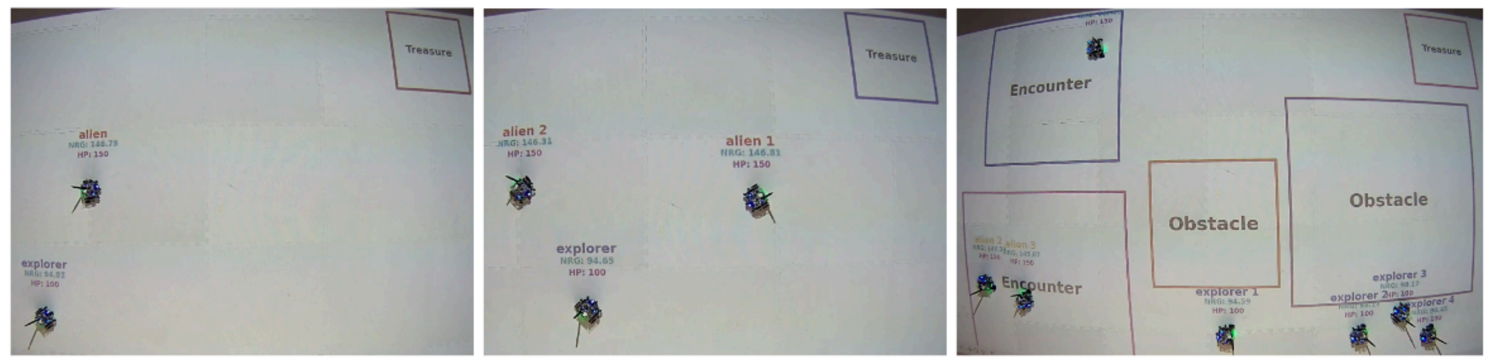

Fig 5. Three scenarios in Robotarium: 1 explorer VS 1 alien, 1 explorer VS 2 aliens, 4 explorers VS 3 aliens

- **Game-Theoretic Utility Computation Unit:** They calculates the nash equilibrium based on the utility values of corresponding situations, presenting the probability of each situation.
- **Decision-Making**: Through calculating various Nash equilibrium based on different situation utility values in each level's Game-theoretic Utility Computation Units, agents can get optimal or sub-optimal strategy sets tackling the current status.
- **Demonstration**: We consider three different propositions between the number of explorers and aliens in the Explore Game domain.

Preliminary Experiments and Results

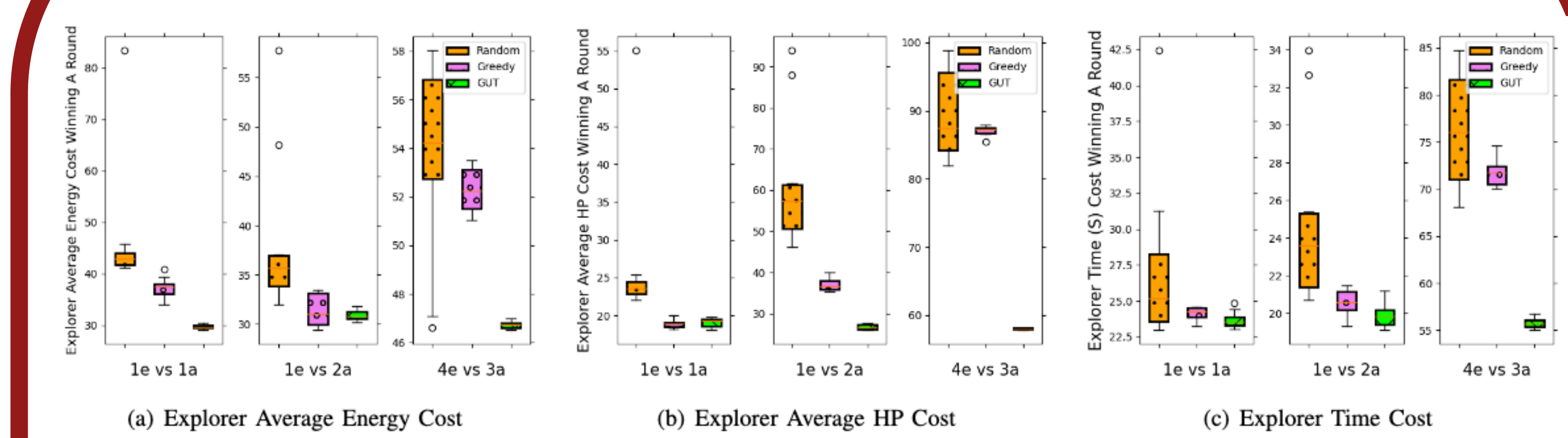

Fig 6. The Performance Results in the Robotarium Experiments with Different Proportion of the Explore Game.

PERFORMANCE RESULTS IN ROBOTARIUM EXPERIMENTS.

PRD \ APP	Winning Rate			Lost Explorers Per Round/win		
	Random	Greedy	GUT	Random	Greedy	GUT
1e vs 1a	100%	100%	100%	-	-	-
1e vs 2a	90%	100%	100%	0.1	-	-
4e vs 3a	50%	90%	100%	2.8	2.0	-

The GUT shows superior performance over other methods in all metrics, demonstrating that the GUT can help MAS organize their behaviors and select a suitable strategy adapting to complex situations.

Fig. 6 presents the results of the Robotarium experiments. The average costs of energy, HP, and the time taken to complete the mission of explorer are shown in Figs. 6(a), 6(b), and 6(c), respectively.

Conclusion

✓ In summary, the GUT could help the intelligent agent rationally analyze different situations in real-time, effectively decompose the high-level strategy into low-level tactics, and reasonably organize groups' behaviors to adapt to the current scenario.

✓ From the system perspective, through applying the GUT, the group presents more complex strategies or behaviors to solve the dynamic changing issues and optimize or sub-optimize the group utilities.

✓ From the individual perspective, GUT reduces the agent's costs and guarantees sustainable development for each group member, much like human society.

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More details available at the Paper:
https://dcslgatech.github.io/iros22-multi-agent-workshop/contributed_papers/IROS22-DMMAS_paper_6456.pdf