The University of Texas Rio Grande Valley

Center for Multidisciplinary Research Excellence in Cyber-Physical Infrastructure Systems (MECIS)

Training Adaptive Foraging Behavior for Robot Swarms with Distributed Neuroevolution of Augmented Topologies

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Abstract

This research studies NeuroEvolution of Augmented Topologies (NEAT) with a penalty-reward system to optimize swarm robotic foraging. NEAT evolves artificial neural networks (ANNs) over time, optimizing both their weights and topologies (network structures). By rewarding effective actions and penalizing inefficient ones, the system minimizes exploration time and promotes coverage. It outperforms existing foraging algorithm NeatFA and demonstrates a potential extension to a distributed, scalable, and secure model by Federated Learning (FL).

Introduction & Background

- Traditional algorithms such as Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO) demonstrate effective swarm behaviors but often struggle to adapt to changing resource availability and obstacles.
- NEAT allows for the evolution of both neural network topology and weights, enabling robots to dynamically adjust their strategies to various environmental conditions.
- Our current research utilizes an existing foraging algorithm (NeatFA) that generates a circular search pattern, which is less efficient in resource search and retrieval.
- The ultimate aim is to develop a distributed, scalable, and secure model through Federated Learning (FL) to enhance the performance of foraging robot swarms.

Methodology

- Leveraging NEAT with a penalty-reward system to develops adaptive foraging behaviors for a swarm of robots. NEAT enhances adaptability by evolving structures that respond to environmental changes, while penalizing redundant exploration or high energy usage. This shapes the fitness function to encourage strategies that maximize collective foraging efficiency.
- This study is conducted using ARGoS, a multi-robot simulation environment, modeling diverse foraging scenarios with varying resource densities and swarm sizes.
- Evolving swarm behaviors are assessed on resource collection, energy use, and adaptability to changes.
- Comparative cost results are used to evaluate performance improvements.

Results

- The cumulative rewards in each training epochs with different penalties in foraging time.

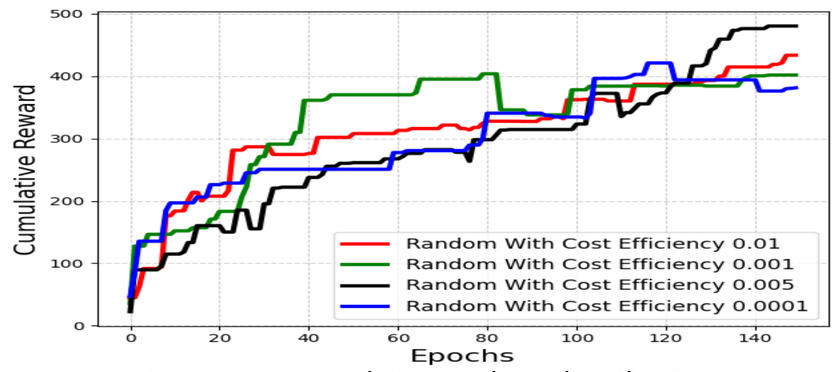

Figure 1: Rewards in random distribution

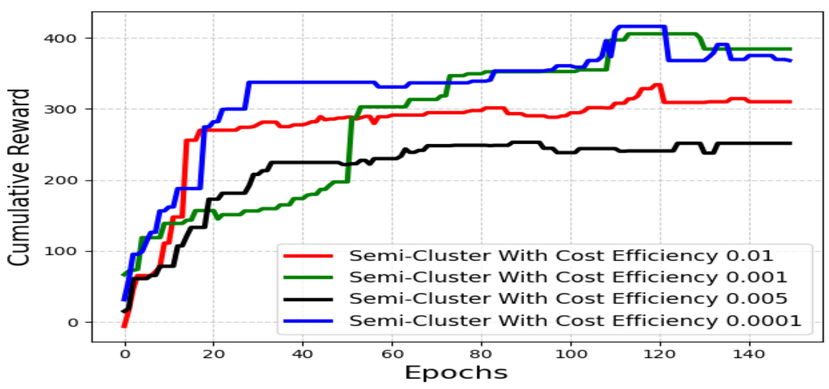

Figure 2: Rewards in semi-clustered distribution

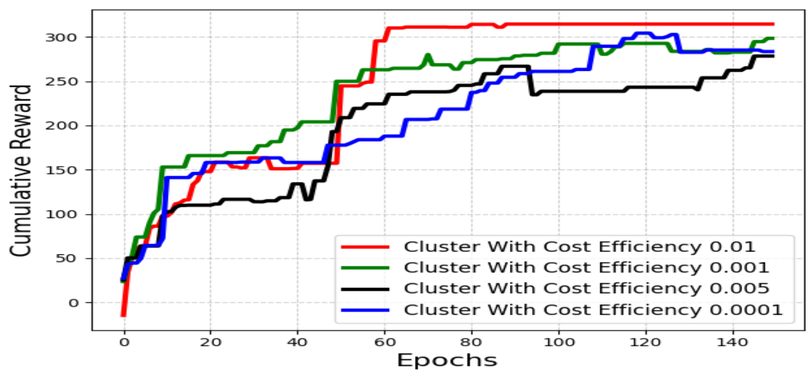

Figure 3: Rewards in clustered distribution

- The resource collections in three different resource distributions.

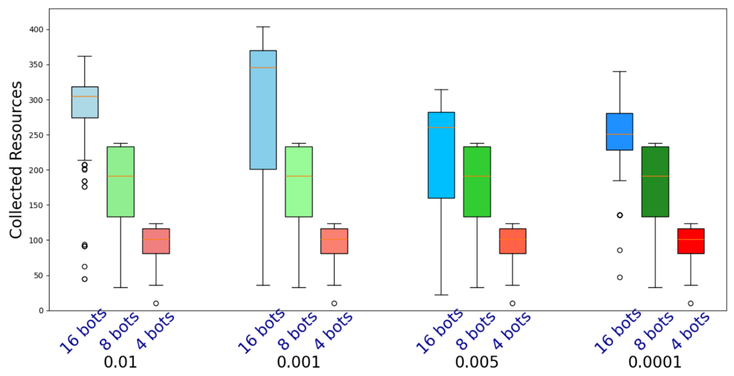

Figure 4: Resource Collected in random distribution

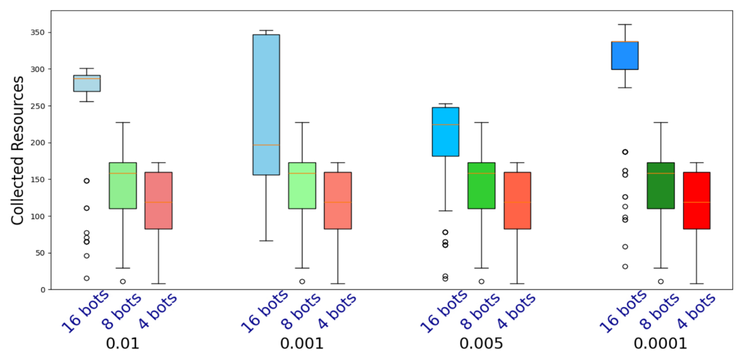

Figure 5: Resource Collected in semi-clustered distribution

Results, Cont.

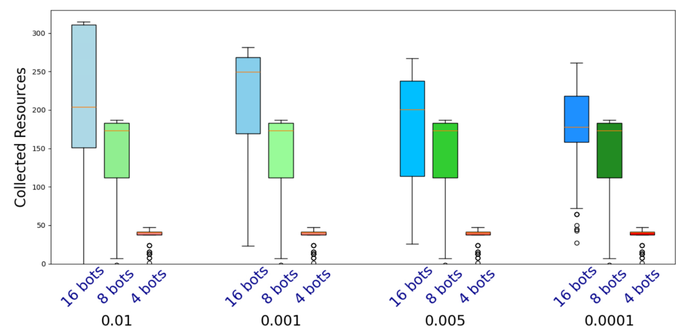

Figure 6: Resource Collected in clustered distribution

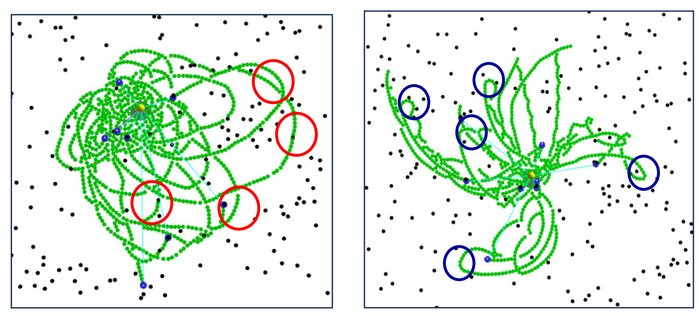

Figure 7: NeatFA generated long circular search pattern (left) and our method with penalty has more straight lines (right).

Conclusions & Future Work

- Combining NEAT with a penalty-reward system significantly enhances swarm robot foraging efficiency and adaptability.
- This approach outperforms traditional algorithms, promoting effective resource retrieval and minimizing wasted energy.
- This study highlights the potential of adaptive neuroevolutionary methods in real-world applications, such as search and rescue, where flexibility and coordination are essential.
- In the future we plan on including the variable of obstacles, for example, areas around the environment that the robots are not allowed to enter.

Acknowledgments

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References

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