Karlsruhe Institute of Technology

Autonomous Learning Robots (ALR)

Prof. Gerhard Neumann

Project Type

- ☑ Master Thesis
- ☐ Bachelor Thesis
- ☑ Research Project

Supervisors

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Difficulty

Algorithmic

Math

Application

Scaling up Swarm Reinforcement Learning for Adaptive Mesh Refinement

Description

Real-world physical systems are highly non-linear, and even simple systems usually do not have analytical solutions. A common tool to simulate complex systems is the Finite Element Method, where the simulation domain is subdivided into simple elements of a mesh. Each mesh element is responsible for a small local solution of the full system. Both the quality and computational cost of the total simulation scale with the number of used elements. Especially for complex problems with multi-scale solutions, *Adaptive Mesh Refinement* (AMR) enables more efficient simulation by emphasizing interesting parts of the simulation with a locally higher resolution.

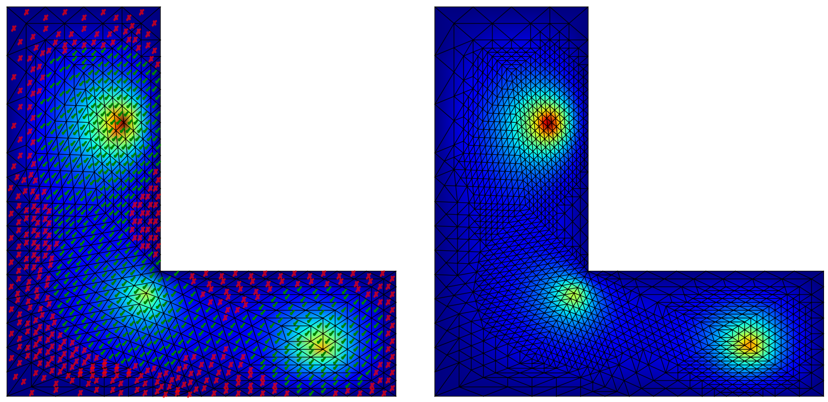

Figure 1: Left: A swarm of agents living on mesh elements decide on whether to refine or not. Right: The resulting adapted mesh.

We recently developed a novel algorithm for AMR based on *Swarm Reinforcement Learning* (RL), where each element in the mesh is viewed as one of many collaborating homogeneous agents [1]. An example can be seen in Figure 1. Coupled with *Graph Neural Networks* (GNNs) [2] for information exchange between the agents, this approach facilitates iterative local refinement decisions that, when combined, lead to an efficient global mesh. However, training our algorithm currently requires a simulation after every refinement step, and the resulting meshes are compared to an expensive ground truth. These design limitations effectively prevent deep refinements that are needed for many real-world problems.

In this thesis, we will explore different alternative training schemes to scale up RL-AMR methods to deeper and more efficient mesh refinements. To this end, we will explore different reward formulations, implicitly learning physical simulators instead of explicitly simulating in each step, and ways to augment the training process to generalize to larger problems during inference.

Tasks

- Literature Review: Get familiar with Multi-Agent/Swarm RL, AMR and GNNs.
- Algorithm Design: Develop a new reward formulation to scale existing RL-AMR methods to deeper and more efficient refined meshes.
- Evaluation: Evaluate your algorithm on different simulations and compare it to existing approaches and refinement heuristics.

References

[1] Niklas Freymuth, Philipp Dahlinger, Tobias Würth, Simon Reisch, Luise Kärger, and Gerhard Neumann. Swarm reinforcement learning for adaptive mesh refinement. *Advances in Neural Information Processing Systems*, 36, 2024.

[2] Michael M Bronstein, Joan Bruna, Taco Cohen, and Petar Veličković. Geometric deep learning: Grids, groups, graphs, geodesics, and gauges. *arXiv preprint arXiv:2104.13478*, 2021.