HIERARCHY OF ROBOTS

Vaishnava Hari
June 12, 2025, *v0*

1 Objective

Transfer knowledge learnt by a primitive robot morphology to a more complex robot morphology. Additionally, such a technique would allow the transfer of knowledge of solving a task from one morphology to another.

2 Background

The current approaches setup the problem as multi-task RL objective or Emboidiment aware architecutes. In the former case, the policy cannot be easily extrapolated to unseen emboidiments. [1] In the latter case, controllers or action knowledge is not carried over to the new morphology. [2]

A general pattern in the previous works is to use a fixed architecture and pass the morphology information as an additional input to the architecture. [3] [4] [5]

3 Approach

Instead of passing the morphology information to a fixed architecture to meet a diversity of morphologies, an alternative approach could be to let the architecture grow with the complexity of the morphology. There have been several similar approaches in the past, [6] [7] attempt to couple the growing complexity of the morphology with the complexity of the controller. The resulting architecture from the above works does not extrapolate well, a requirement well defined by [1].

To mitigate this issue, the relationship between differnt emboidiments and morphologies need to be utilized. This can be achieved by building a hierarchy of robot emboidiments/mechanisms, where each level of the hierarchy corresponds to a different level of complexity. Such a knowledge graph would allow us to learn the function responsible for the relationship between the morphology and the controller, rather than directly learning the controller for each morphology.

4 Knowledge Graph

The objective is to arrange the different robot emboidiments and morphologies in a increasing order of complexity. It starts with a single link and graudally divereses by adding more links and types of joints. TODO: Memory strategy and how to sample from this tree

5 Engineering Design

First step of the process is to define the robot configurtion, in other words, determining the number of link, type of joints, and other parameters. Later one can decide to either buy a robot that closely matches the requirements or design a new robot from scratch. Both these options further require several decision steps, such as selecting the actuators, materials, gripper and so on. The traditional engineering design process is too iterative and time consuming and knowledge is not easily transferable.

Trying to address this problem, there have been attempts like *kinematic automatic*, *modular joints* and *Text-to-CAD*.

5.1 Linkage Synthesis

Challenge: Too data intensive, only 1 DoF and 2D acheived.

5.2 Text-to-CAD

Text-to-CAD models generates 3D CAD geometry from text description

References

[1] M. Parakh, A. Kirchmeyer, B. Han, and J. Deng, "AnyBody: A Benchmark Suite for Cross-Embodiment Manipulation," May 2025.

[2] M. Naya-Varela, A. Faíña, and R. J. Duro, "Morphological Development in Robotic Learning: A Survey," *IEEE Transactions on Cognitive and Developmental Systems*, vol. 13, no. 4, pp. 750–768, Dec. 2021.

[3] S. Beaussant, "Transfer learning between robots with state abstraction," Ph.D. dissertation, Université Clermont Auvergne, Sep. 2023.

[4] S. Hong, D. Yoon, and K.-E. Kim, "Structure-Aware Transformer Policy for Inhomogeneous Multi-Task Reinforcement Learning," in *International Conference on Learning Representations*, Oct. 2021.

[5] N. Bohlinger, G. Czechmanowski, M. Krupka, P. Kicki, K. Walas, J. Peters, and D. Tateo, "Learning Robot Locomotion for Multiple Embodiments."

[6] A. M. Deshpande, E. Hurd, A. A. Minai, and M. Kumar, "DeepCPG Policies for Robot Locomotion," *IEEE Transactions on Cognitive and Developmental Systems*, vol. 15, no. 4, pp. 2108–2121, Dec. 2023.

[7] J. Whitman, M. Travers, and H. Choset, "Learning Modular Robot Control Policies," *IEEE Transactions on Robotics*, vol. 39, no. 5, pp. 4095–4113, Oct. 2023.