Symmetry-Aware Robot Design with Structured Subgroups

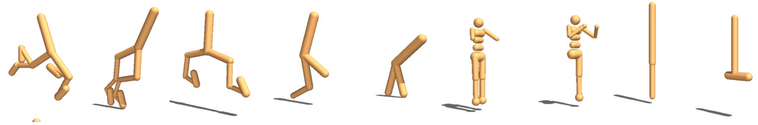
Heng Dong[1], Junyu Zhang[2], Tonghan Wang[3], Chongjie Zhang[1]
[1]IIIS, Tsinghua University, [2]Huazhong University of Science and Technology, [3]Harvard University

清華大學 交叉信息研究院
Institute for Interdisciplinary Information Sciences, Tsinghua University

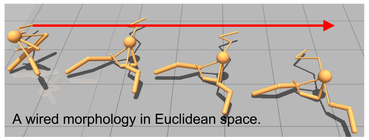
ICML International Conference On Machine Learning

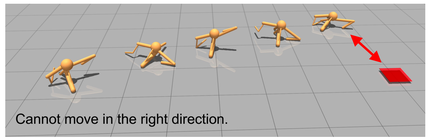
Introduction

Previous work on robotic learning



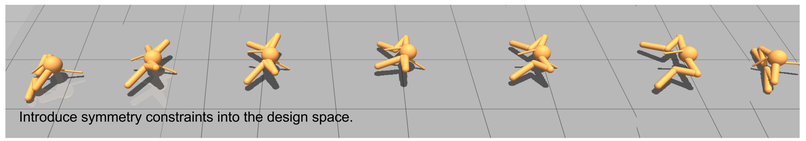
Design robot morphology by hand and then learn control policies by RL. Here we show some commonly used robot morphologies, presented in the Mujuco benchmark. It is hard to guarantee the effectiveness of a morphology.

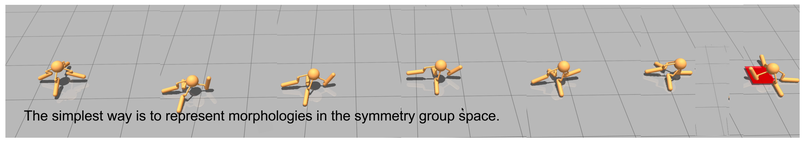




Search robot morphology in the Euclidean space. For example, add a joint at some coordinates. The search space is large, and the generated morphology is wired, not suitable for the task.

idea





Search robot morphology in a non-Euclidean space: A space represented by symmetry group.

Background and Notation

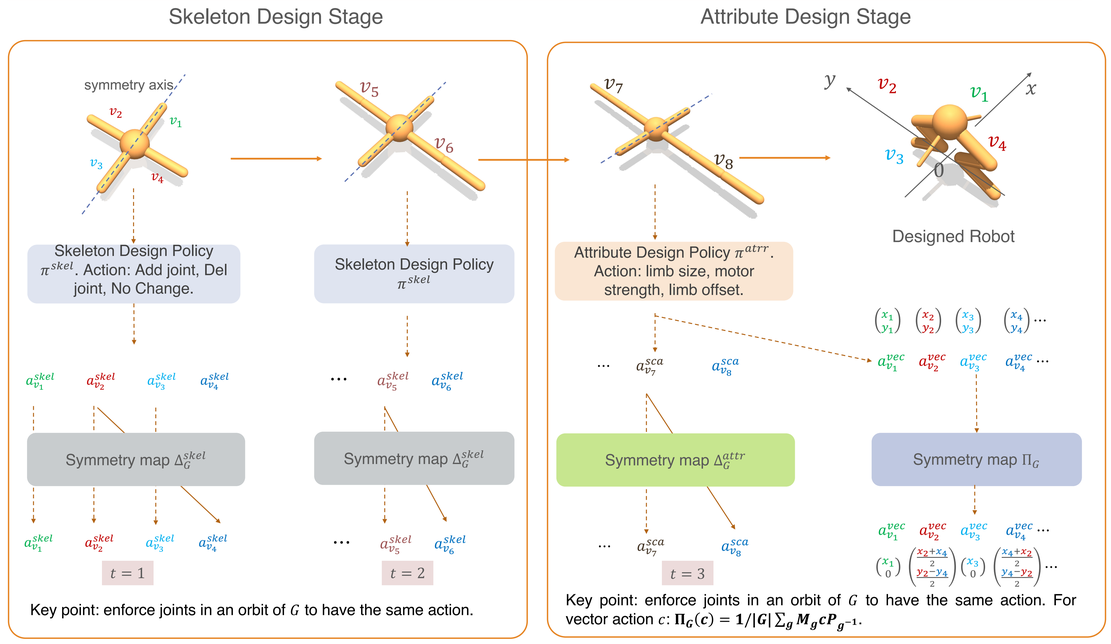
Dihedral group (containing rotation and reflection transformations):
For $n \geq 3$, $\mathrm{Dih}_n = \{\rho_k, \pi_{k-1} | k = 1,2,\dots,n\}$. ρ_k: counterclockwise rotate by $360°/k$. π_{k-1}: first ρ_k, then reflect along x-axis.

Subgroups of the Dihedral group:
$H_d = \langle \rho_d \rangle$, where $1 \leq d < n$, and n is divisible by d
$K_i = \langle \pi_i \rangle$, where $1 \leq i < n-1$
$H_{k,l} = \langle \rho_k, \pi_l \rangle$, where $1 \leq l < k \leq n-1$, and n is divisible by k

Orbit:
The *orbit* of a point $x \in X$ is the set of all its transformation under G.

Approach

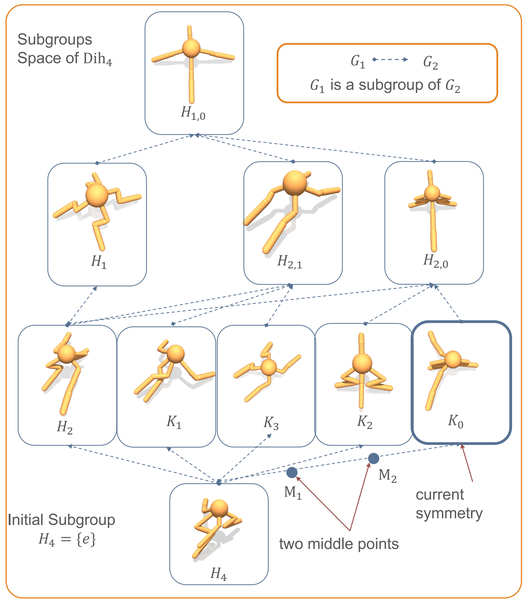
Morphology learning phase 1: Given a symmetry G, search for a morphology.



Key point: enforce joints in an orbit of G to have the same action.

Key point: enforce joints in an orbit of G to have the same action. For vector action c: $\mathbf{\Pi_G}(\boldsymbol{c}) = \mathbf{1}/|\boldsymbol{G}| \sum_g \boldsymbol{M_g c P_{g^{-1}}}$.

Morphology learning phase 2: Search G over the symmetry group space



Result