Symmetry-Aware Robot Design

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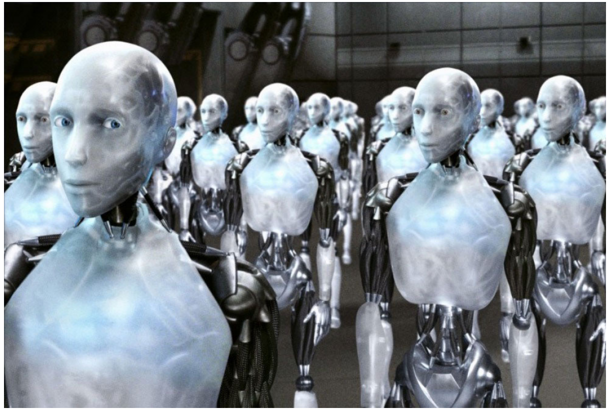
Machine Intelligence Group

清華大學 交叉信息研究院

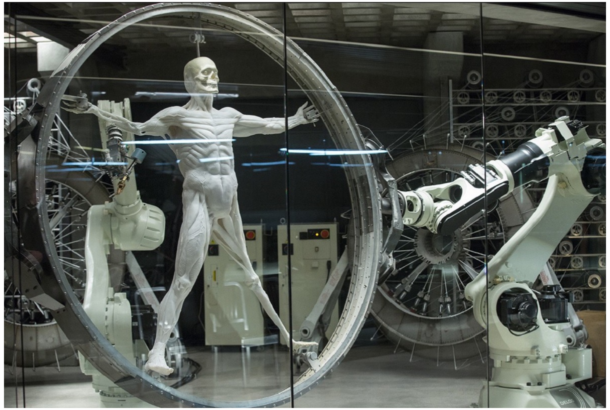
Tsinghua University Institute for Interdisciplinary Information Sciences

Creator of Robots

- Humans have been dreaming of creating creatures with embodied intelligence for decades.



Movie: I Robot



Series: Westworld

Learning to Design and Control Robots

- Learning to design and control robots can be framed as a bi-level optimization problem

performance evaluation

control policy for design D

$$D^* = \arg\max_D J(\pi_D, D)$$

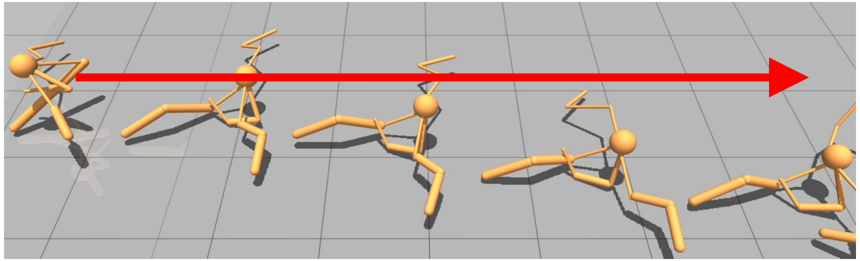
$$\text{subject to} \quad \pi_D = \arg\max_\pi J(\pi, D)$$

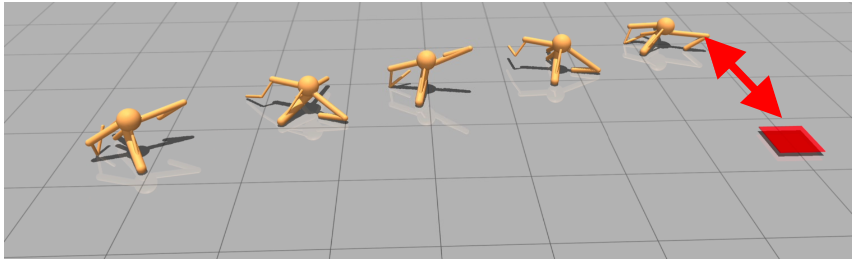
a robot design

  - Search in the immensely large design space
  - Evaluate each candidate design, which is computationally expensive

Previous Work

- The robots designed by previous SOTA Transform2Act (Yuan et al. 2021) are intuitively **abnormal**, empirically **hard to control**, and ultimately result in **poor performance**.



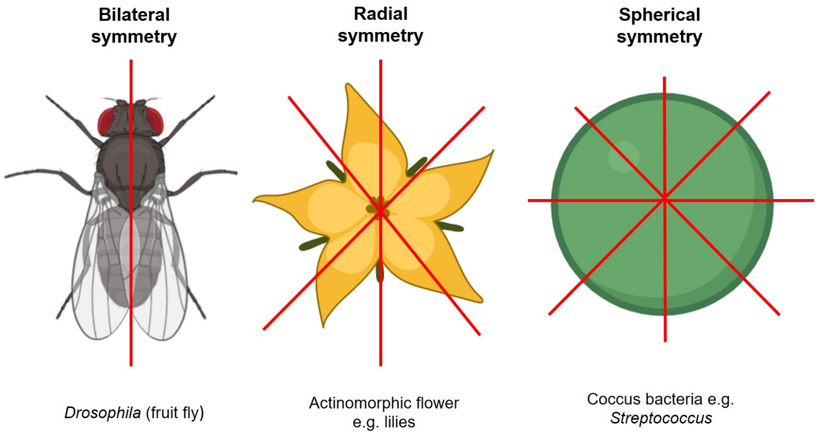


Task: running forward
Result: the robot deviated from the right direction

Task: reaching random goals
Result: the robot missed the goal

Our Idea

- We utilize **symmetry** as the key characteristic to unveil the structure of the design space and hereby reduce learning complexity.

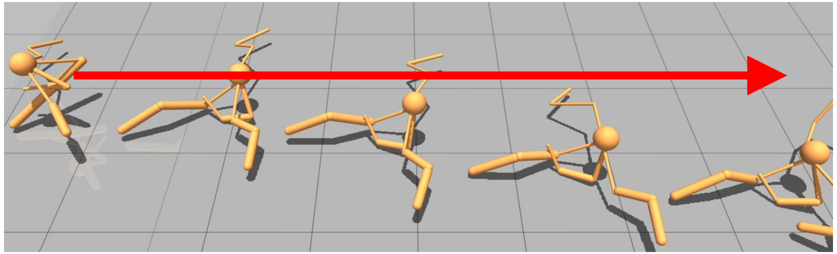


Symmetry is one structure commonly observed in biological organisms

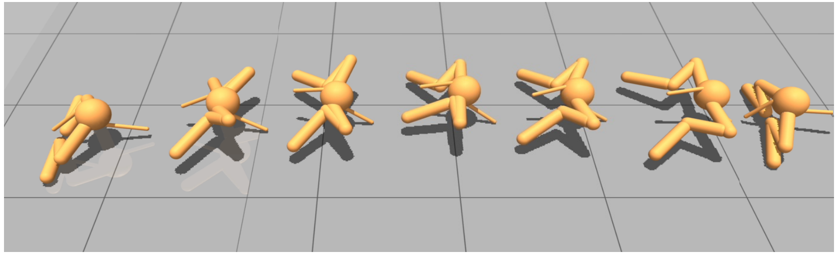
Why Symmetry? from Learning Perspective

- Searching for much fewer robot designs
  - If one design turns out to be unsuitable for the current task, other designs from **the same symmetry** can be searched less frequently as they are likely to be morphologically and functionally similar.
- Symmetric designs can reduce the degree of control required to learn balancing

Task: running forward



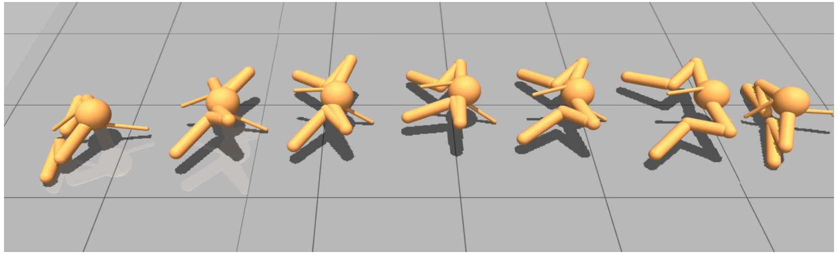
No symmetry



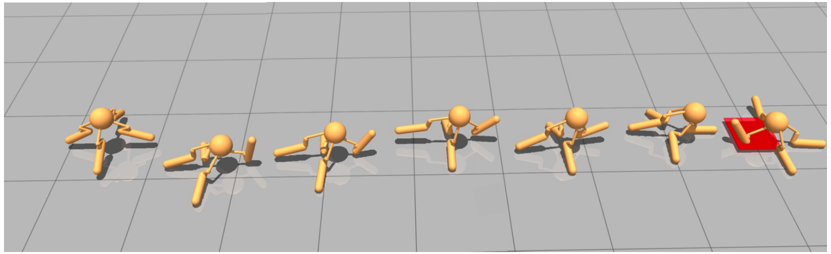
Bilateral symmetry

Is Bilateral Symmetry All You Need?

- Perhas not, different tasks may require different symmetries.



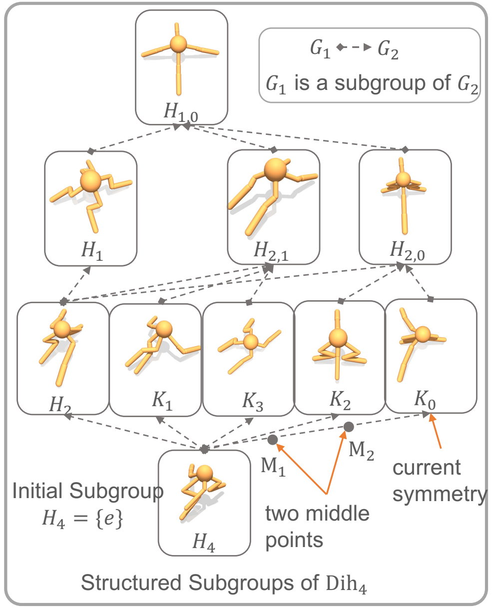
Task: running forward
bilateral symmetry



Task: reaching random goals
radial symmetry

SARD: Symmetry-Aware Robot Design

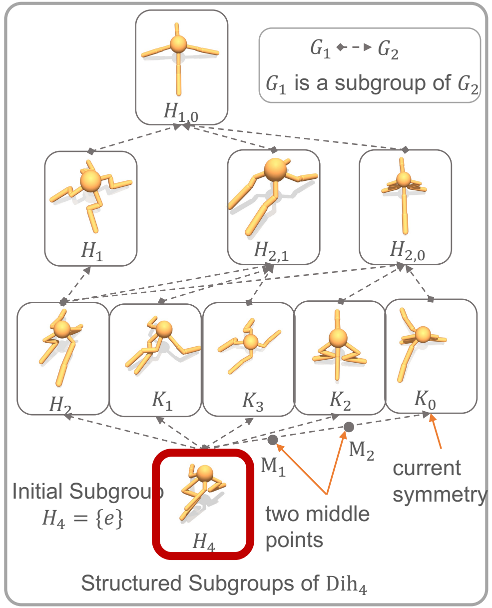
- Use the subgroups of Dihedral group ($G = \mathrm{Dih}_4$) to represent all kinds of symmetries.



(a)

Searching for the Optimal Symmetry

- Exploit the structure of subgroups by smoothly changing the symmetry



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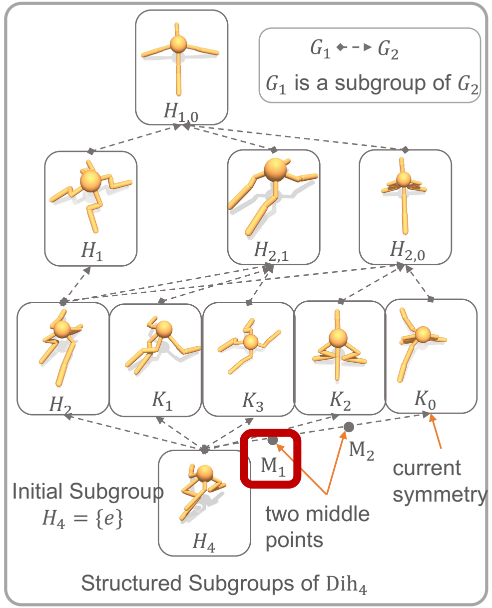

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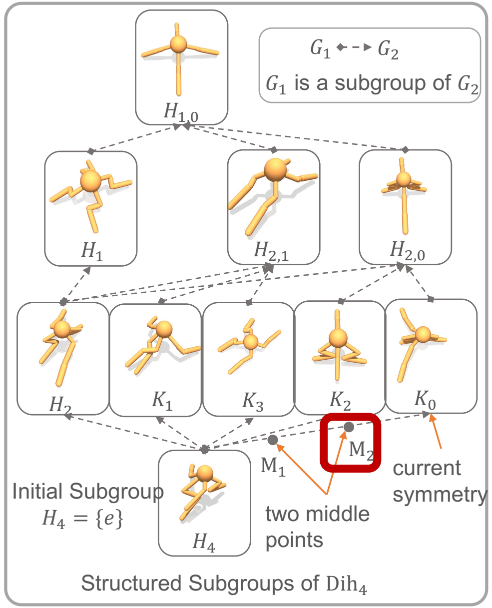

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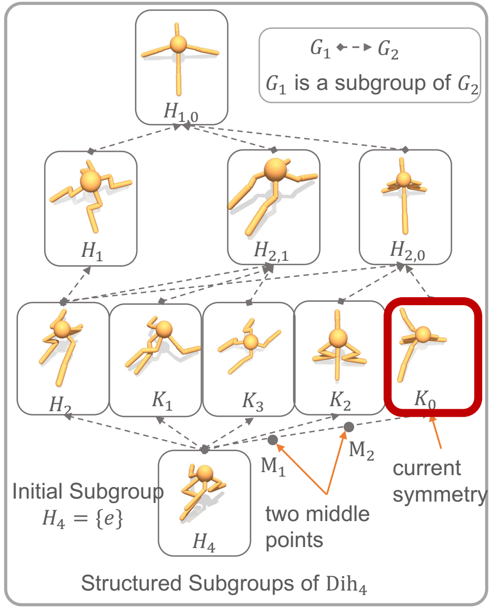

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Searching for the Optimal Symmetry

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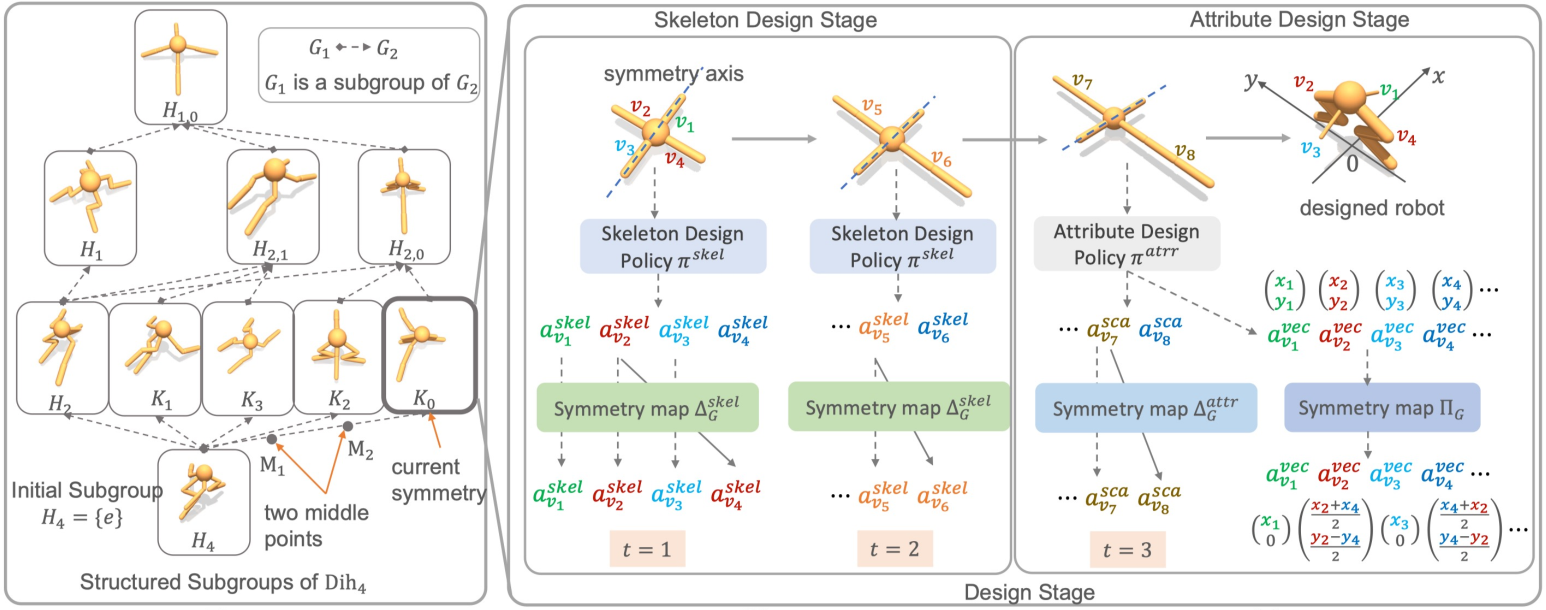
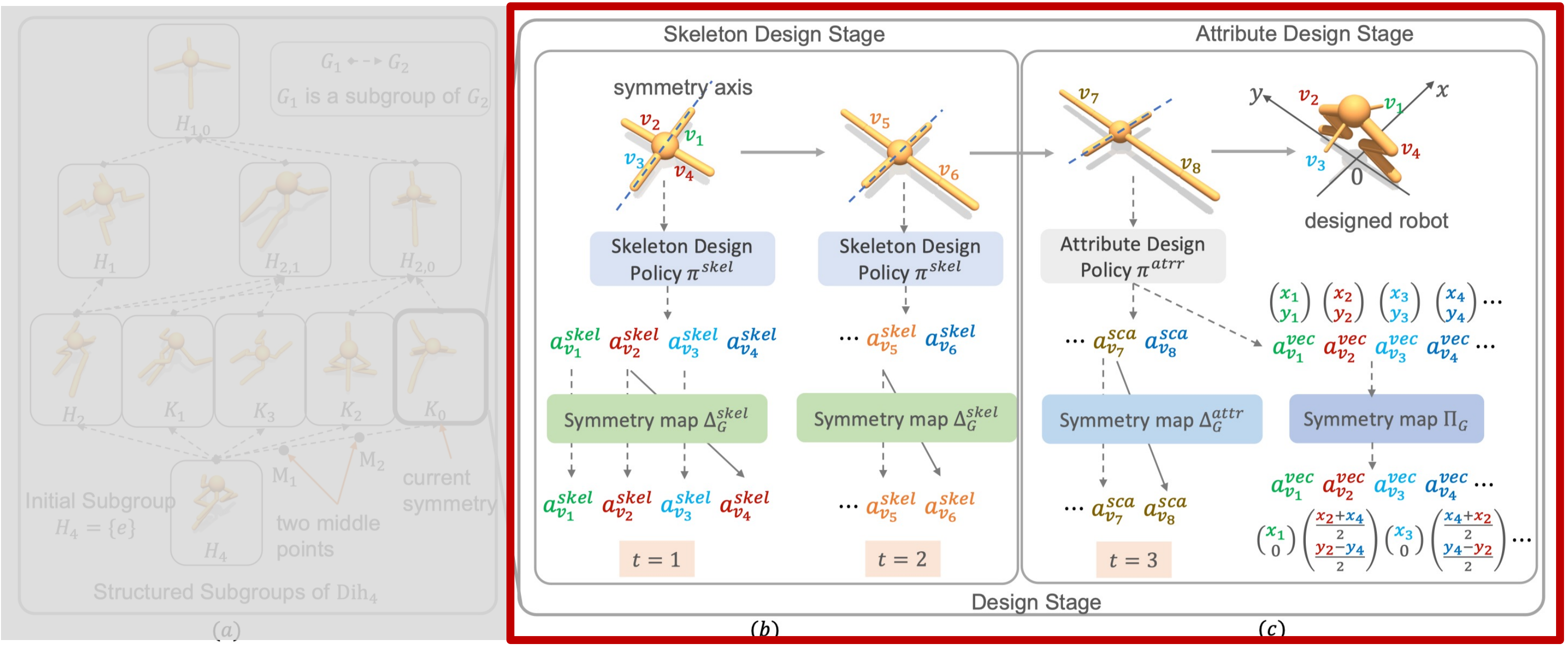


(a) (b) (c)

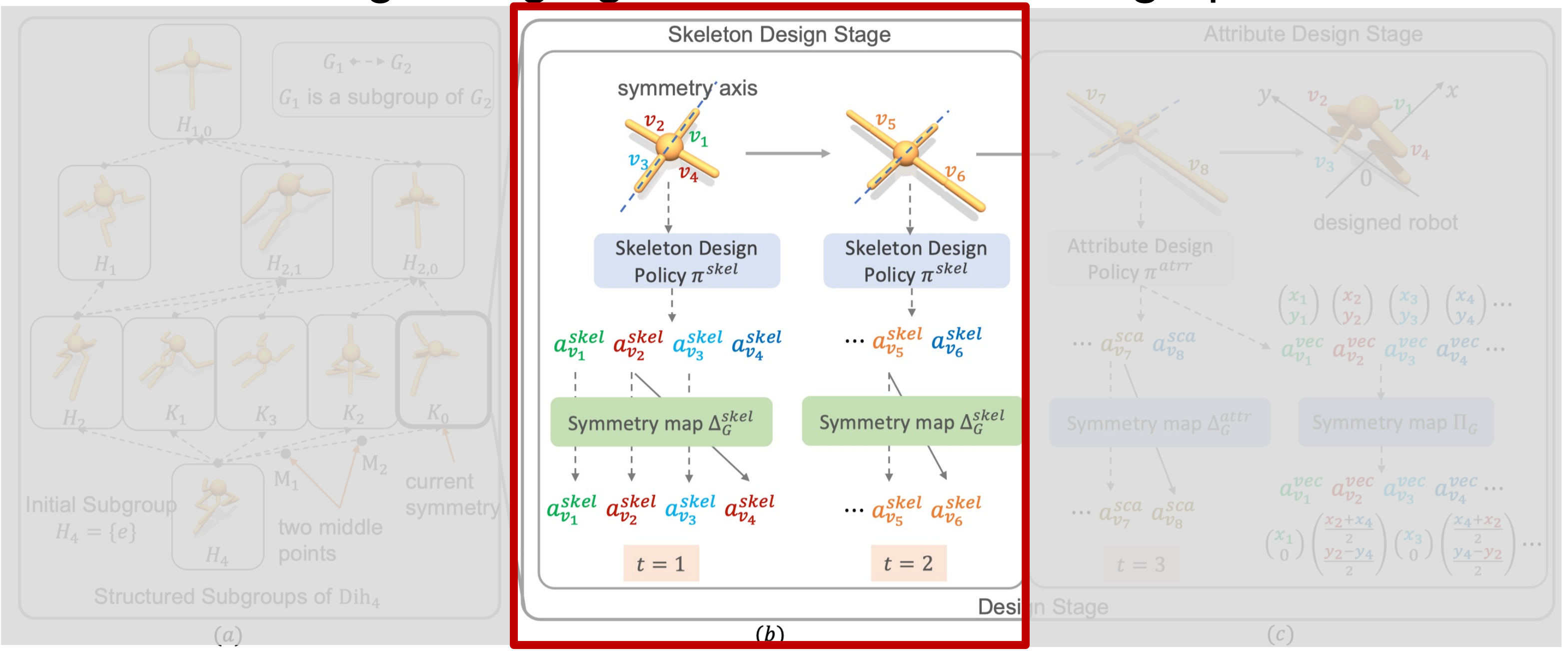
Learning Robot Design under a Given Symmetry

- The design stage is divided into two substages



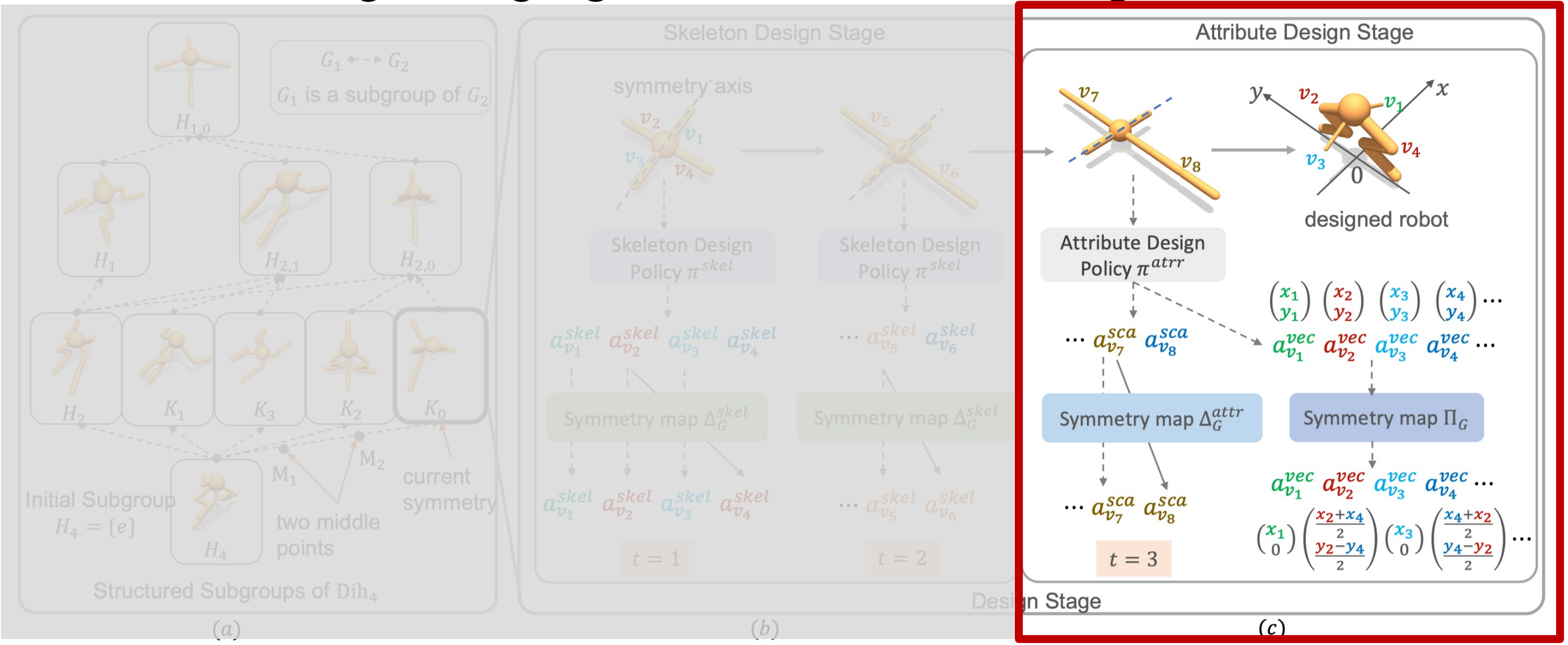
Learning Robot Design under a Given Symmetry

- The design stage is divided into two substages
  - Skeleton Design Stage generates the skeletal graph



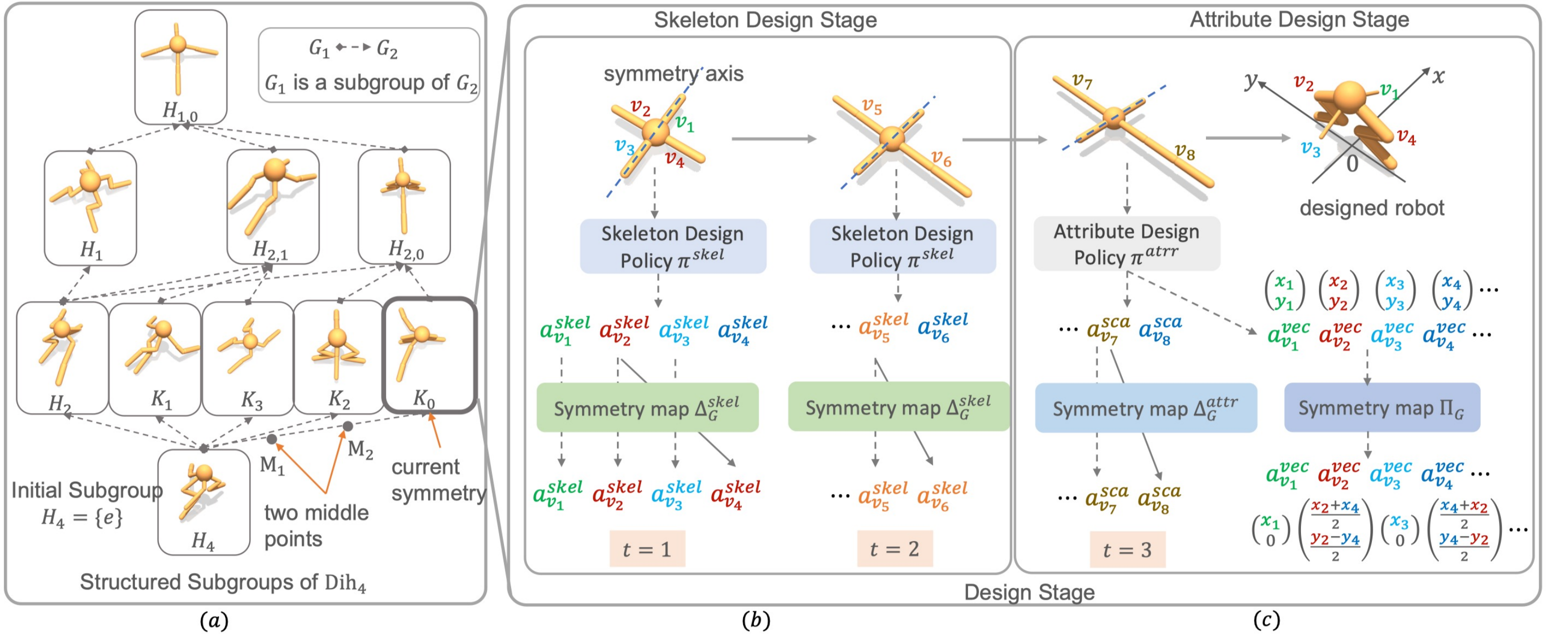
Learning Robot Design under a Given Symmetry

- The design stage is divided into two substages
  - Attribute Design Stage generates motor strength, limb size, etc.



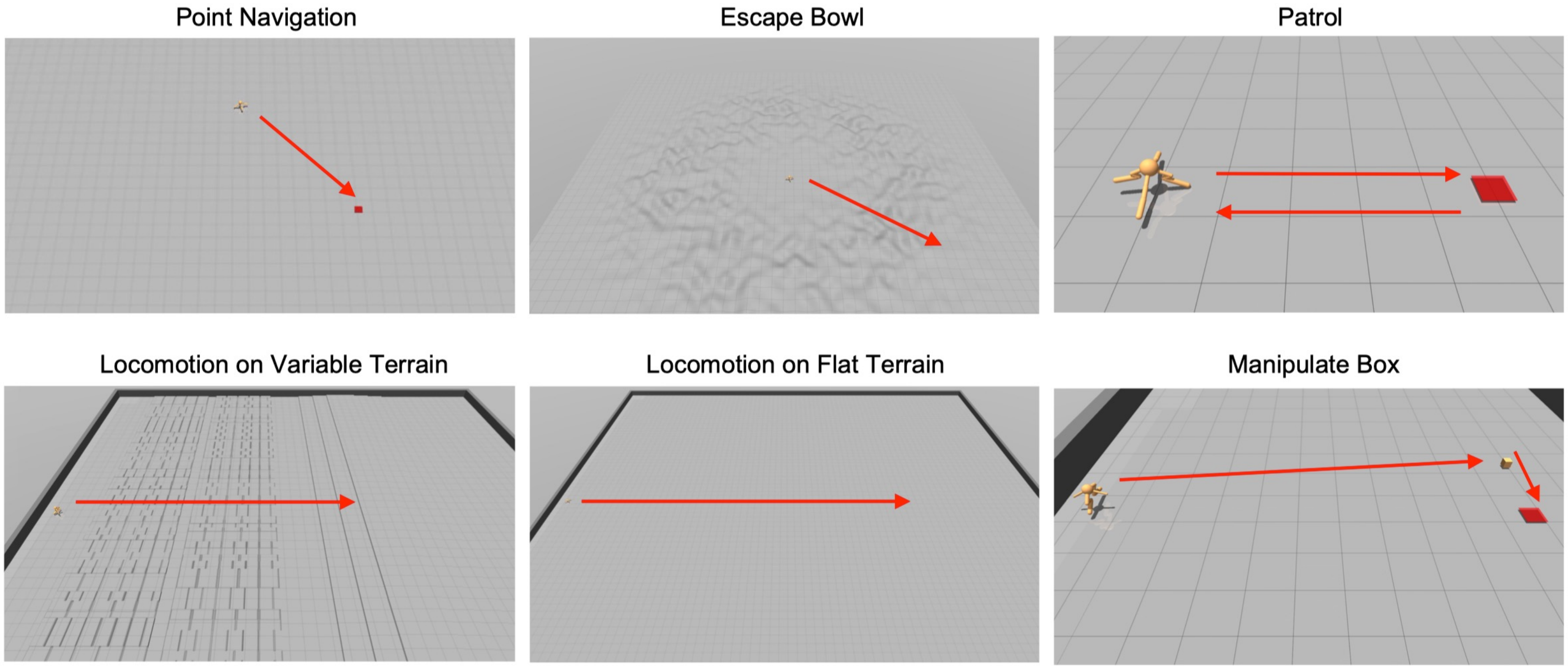
Overall Framework

- SARD: Symmetry-Aware Robot Design

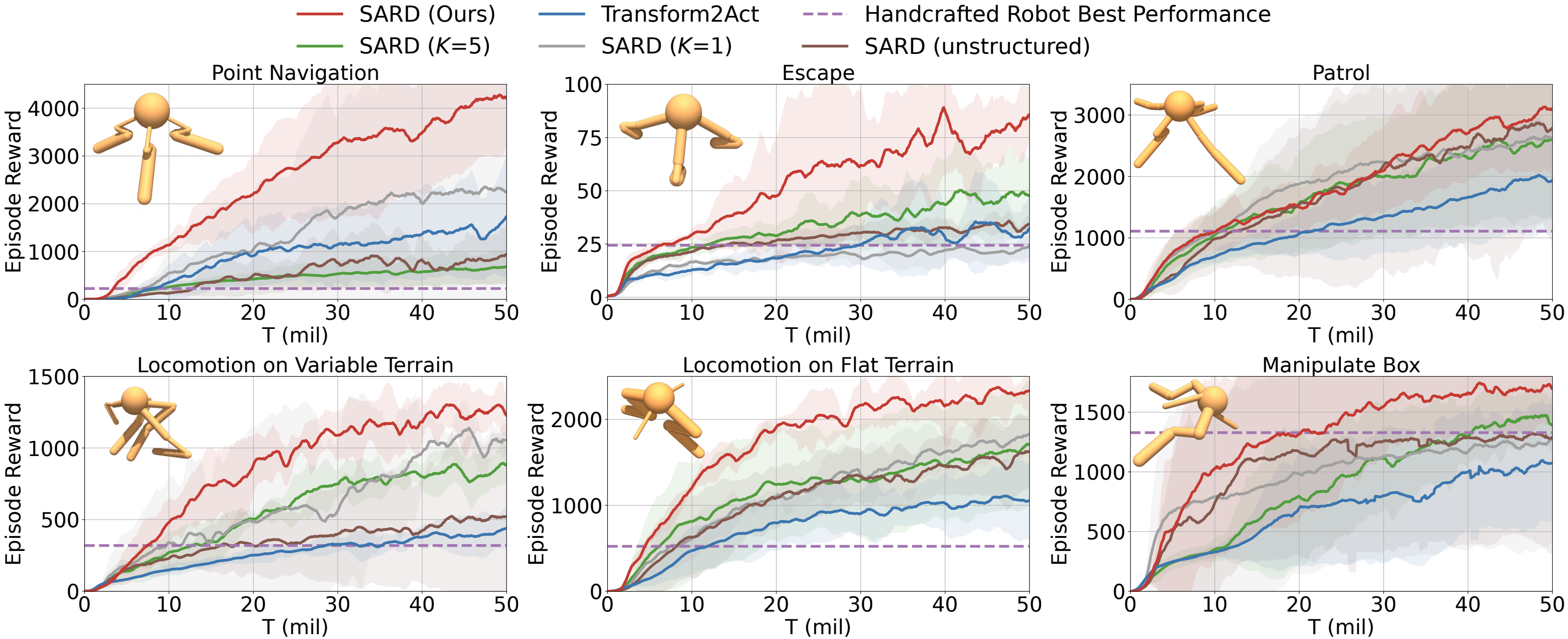


Experiments

- We test our method on all kinds of tasks

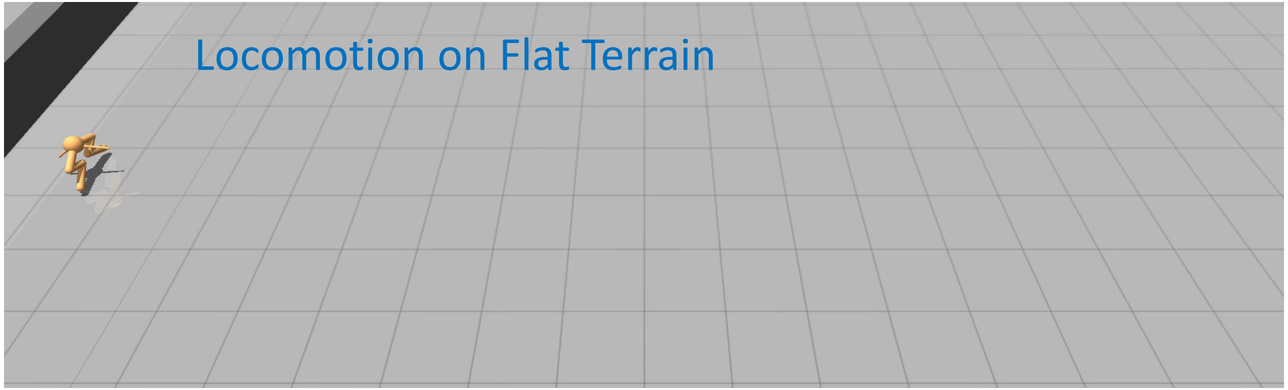


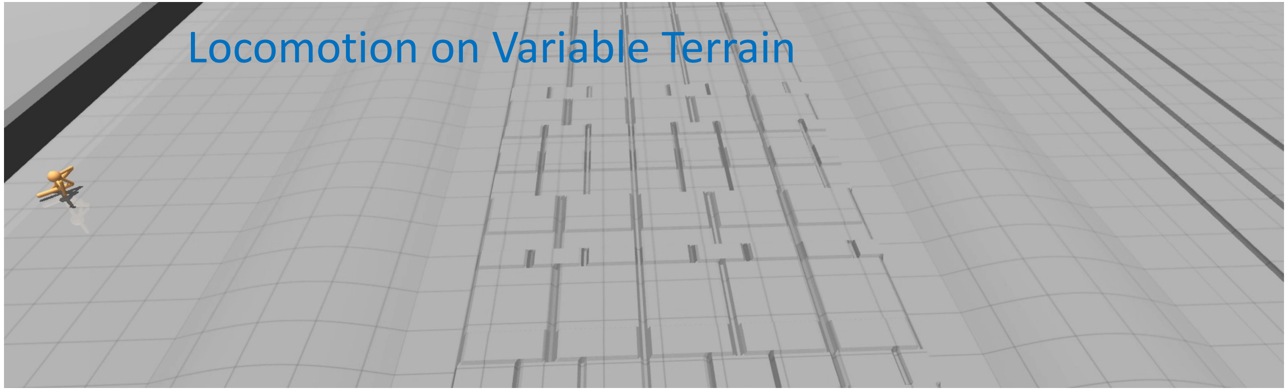
Training Performance Comparison



*upper left corner: one representative robot designed by SARD at the end of training.

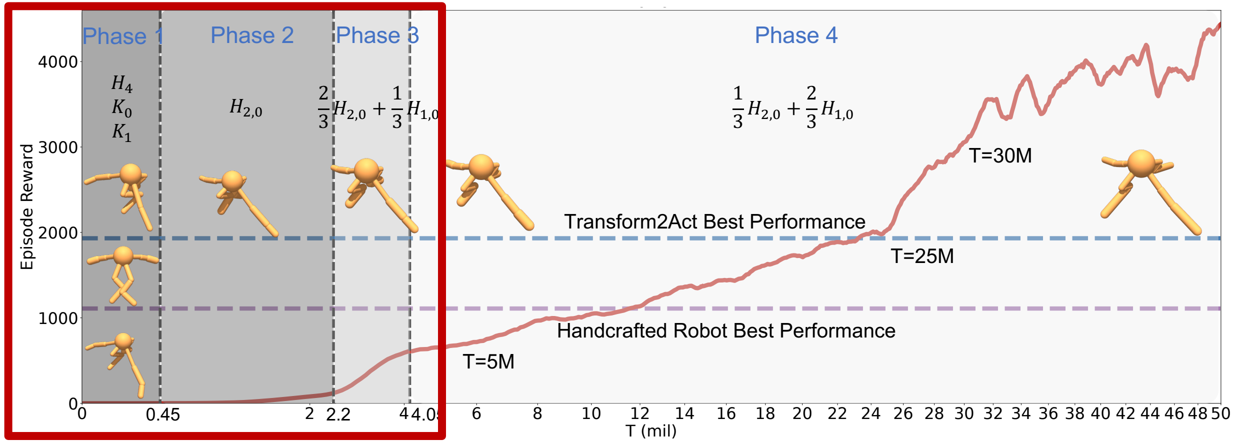
Visualization of the Learned Robots





More videos: https://sites.google.com/view/robot-design

Robot Design Analysis for Patrol Task



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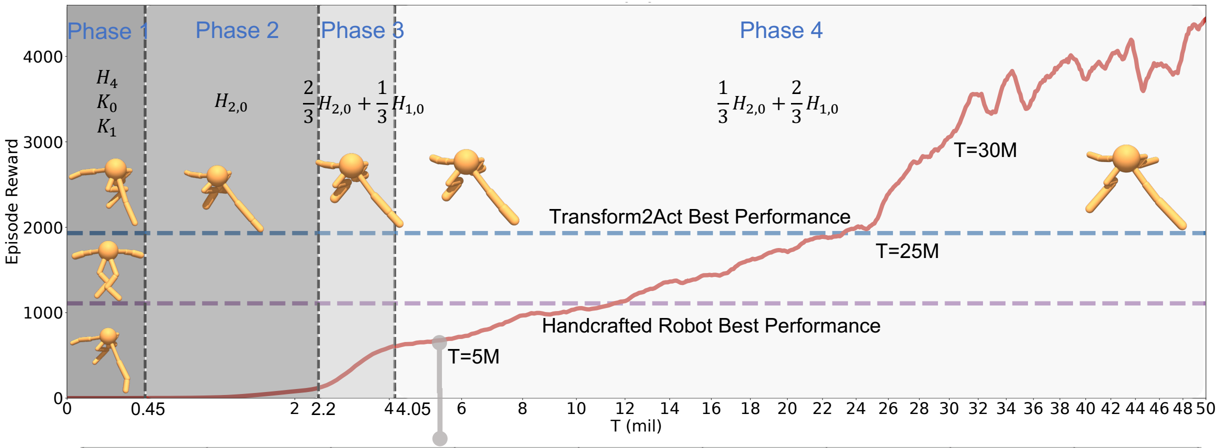

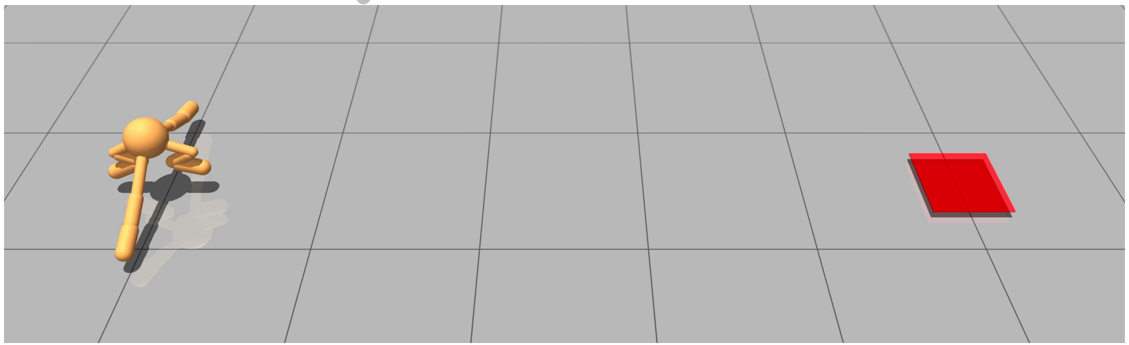

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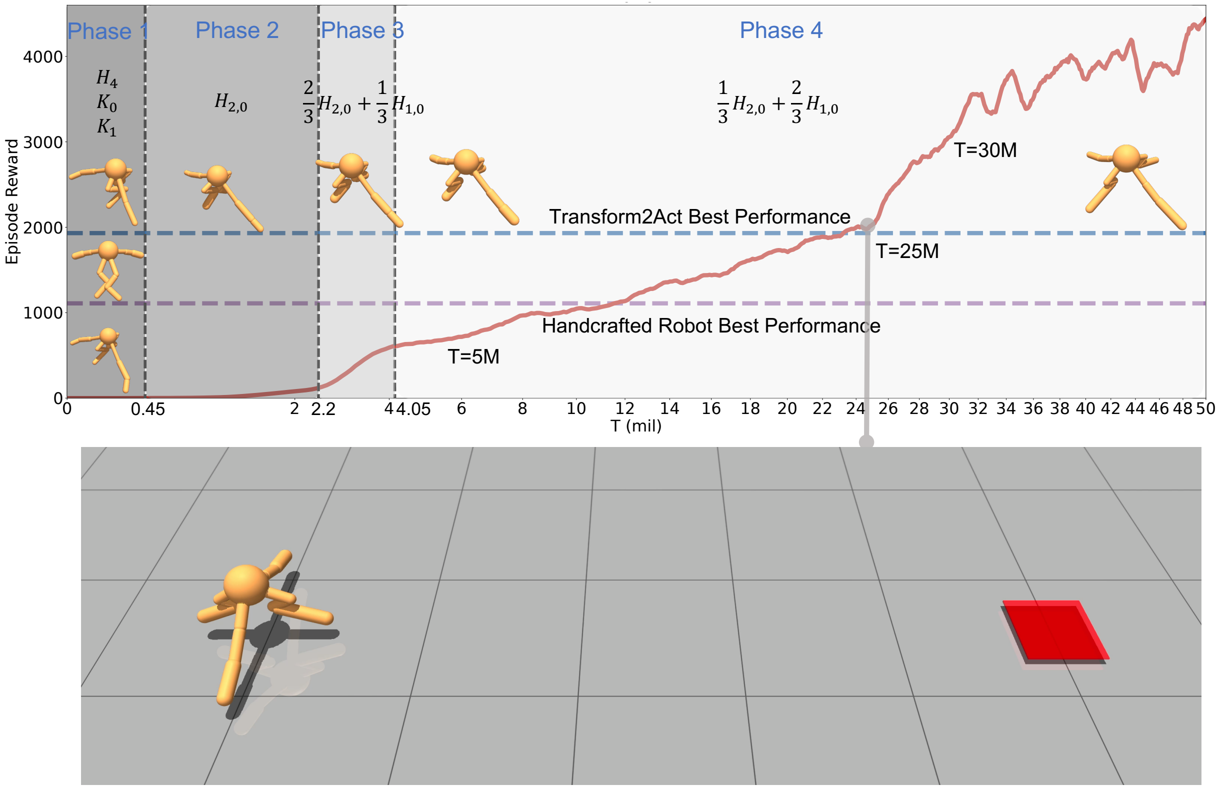

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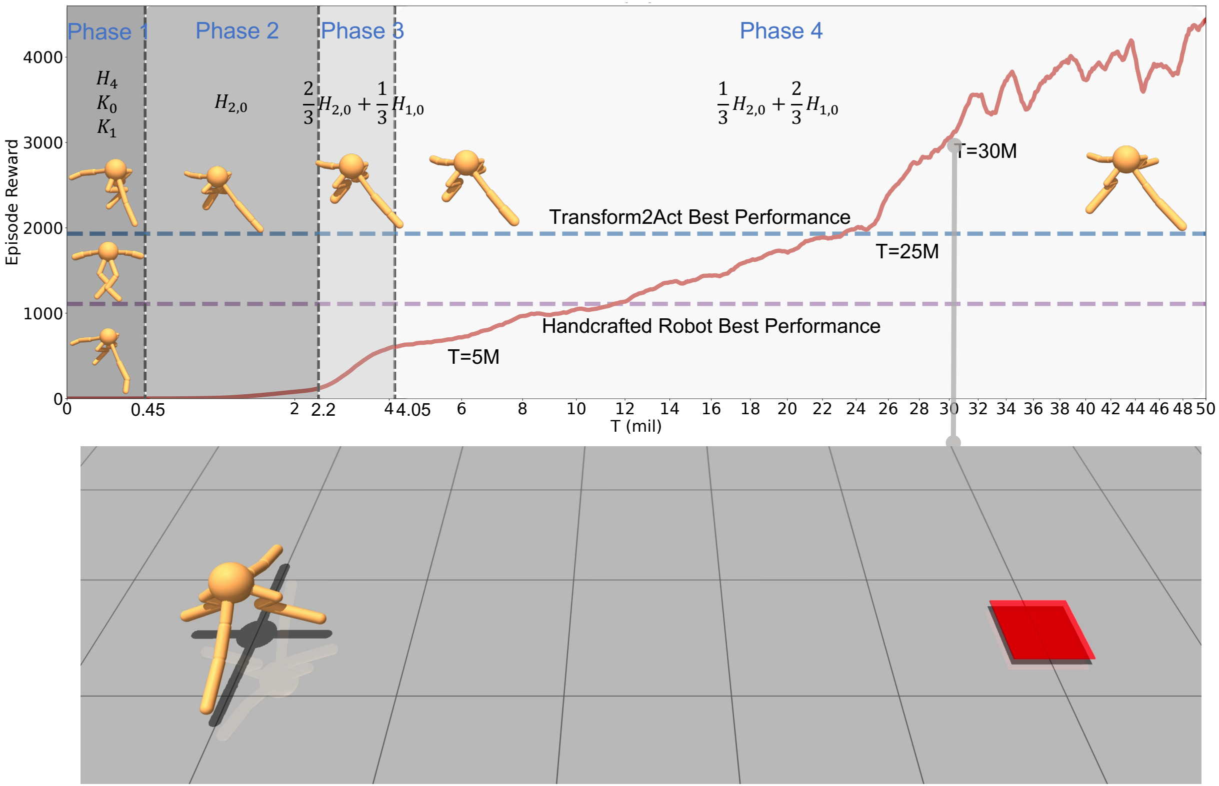
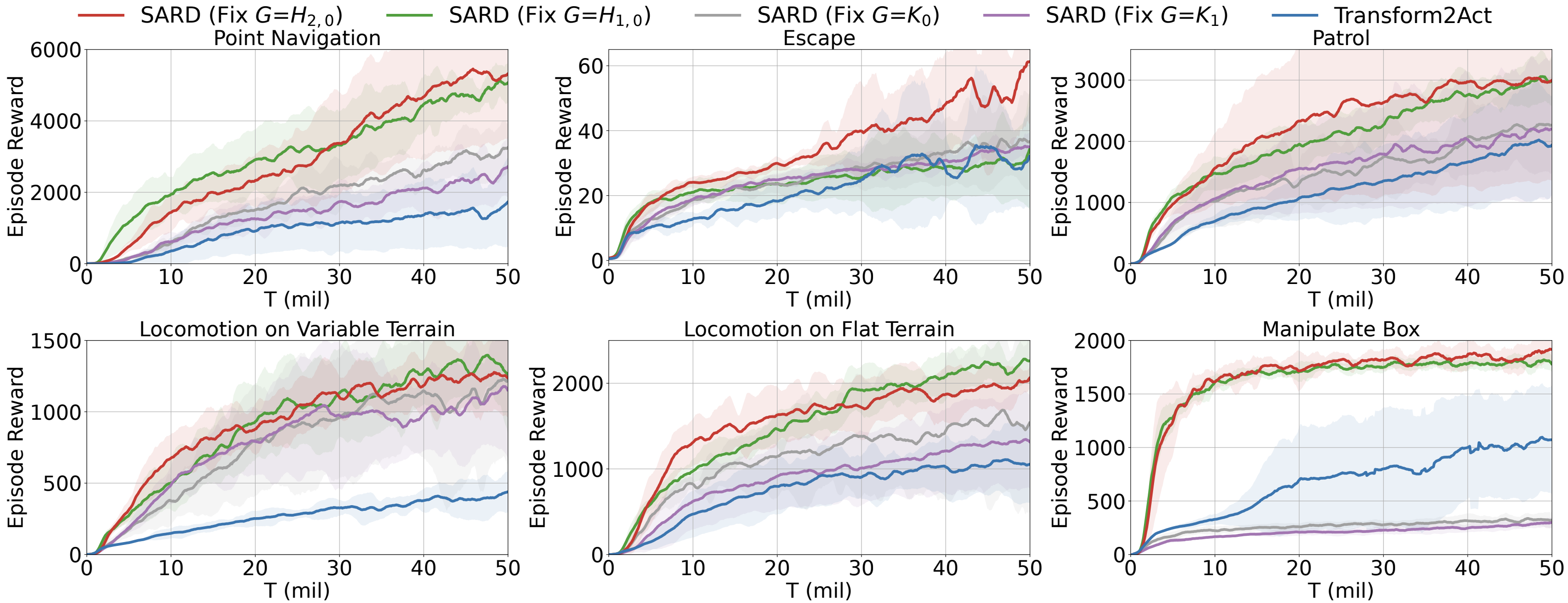


Generalization of the Learned Symmetry

- 3/4 of the experiments ended up with $H_{2,0}$ and $H_{1,0}$
  - $H_{2,0}$: 45.83%, $H_{1,0}$: 29.17%

$$H_4 < K_0 < H_{2,0} < H_{1,0}$$



Thanks for your listening