On Learning Symmetric Locomotion (Do symmetry constraints help?)

Farzad Abdolhosseini[1], Hung Yu Ling[1], Zhaoming Xie[1], Xue Bin Peng[2], Michiel van de Panne[1]

[1]University of British Columbia [2]University of California, Berkeley

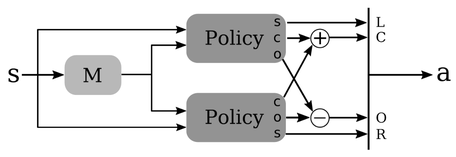
Goals and Questions

Human and animal gaits are often symmetric in nature, which points to using motion symmetry as a potentially useful structure that can be exploited for learning.

1. How can symmetry be encouraged or enforced?
2. Does enforcing symmetry benefit learning?
3. Do more efficient solutions emerge by enforcing symmetry?

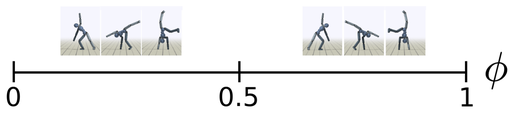
Four Unique Ways to Enforce Symmetry

NET: Network Constraint

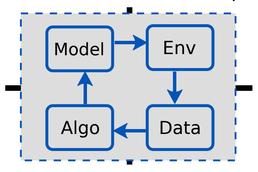


Symmetric policy by network definition.

PHASE: Time-based Constraint



Policy learns only for first half of gait cycle, then queried with mirrorred states in second half.



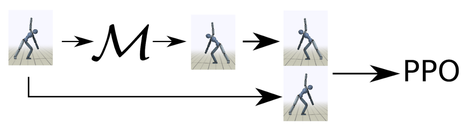
LOSS: Penalize Asymmetry

$$\left\| \pi(\text{  }) - \mathcal{M}_a(\pi(\text{  })) \right\|^2$$

$$\pi_\theta = \underset{\theta}{\operatorname{argmin}} L_{PPO}(\theta) + wL_{sym}(\theta)$$

Encourage policy to be symmetrical with additional mirroring loss term.

DUP: Duplicate Data



Append mirrored trajectories to memory for learning.

Practical Considerations

- Symmetric policy is different from symmetric gait (!)
- Symmetric policy cannot escape symmetric states (!)
- NET guarantees to produce a symmetric policy.
- LOSS allows balancing symmetry and original objective.
- DUP and PHASE are very easy to implement.
- PHASE naturally deals with symmetric states.
- PHASE is restricted to the walk cycle timing in reference motion.

Shuffle

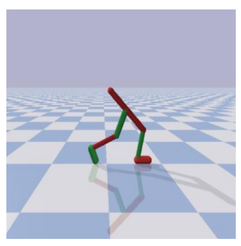
Walk

Environments

We evalute the symmetry enforcement methods in four different locomotion enviornments. The environments were chosen to represent a diverse range of locomotion tasks.

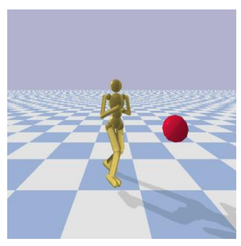
Walker2D

- Default PyBullet implementation
- Walk as far as possible forward



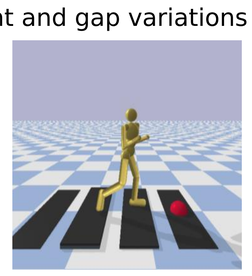
Walker3D

- Reach and stop at target
- More accurate 3D human model



Stepper

- Precision stepping locomotion
- Height and gap variations

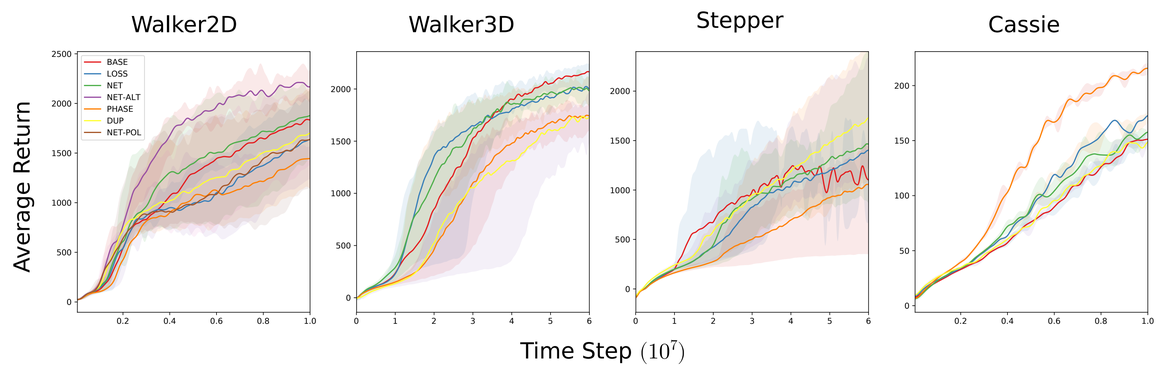


Cassie

- Imitation-guided learning task
- Validated accurate Cassie model

Impact on Learning Speed

Symmetry is a lossless abstraction that can be difficult to learn. Despite this, our experiments showed that enforcing symmetry has no consistent impact on learning speed.



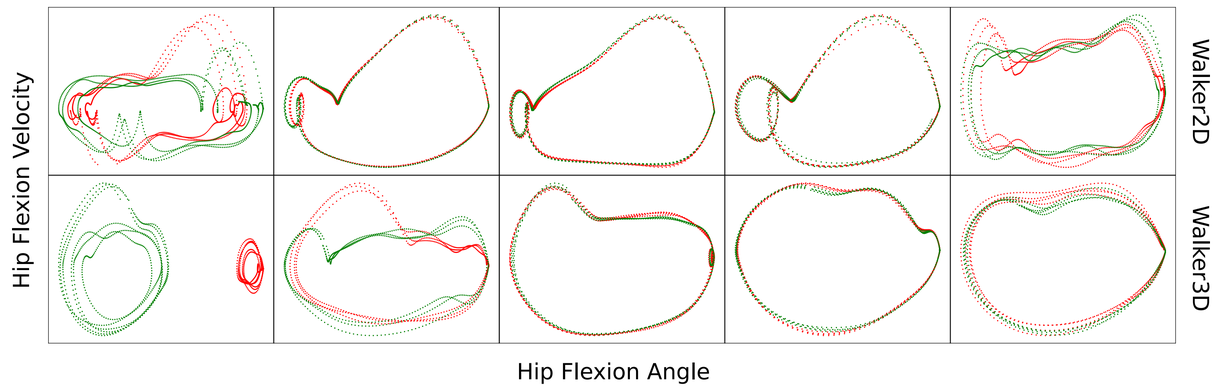
Should You Use Symmetry?

- Yes (!) Symmetry is important for better motion quality.
- Yes (!) Use PHASE when doing imitation-based learning.
- Yes (!) In some cases symmetry is necessary for solving the task.
- No, symmetry does not produce better learning curves.
- Classical control tasks may benefit even more from symmetry.
- Boardgames like Sudoku can have more than one symmetry. How to take advantage?

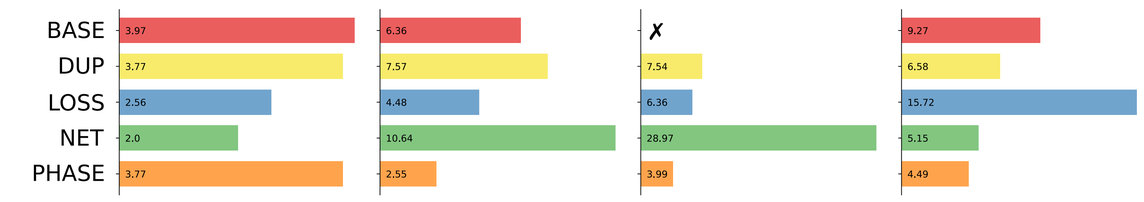
Symmetry and Motion Quality

Symmetry of a gait is clear by looking at the phase-portraits.

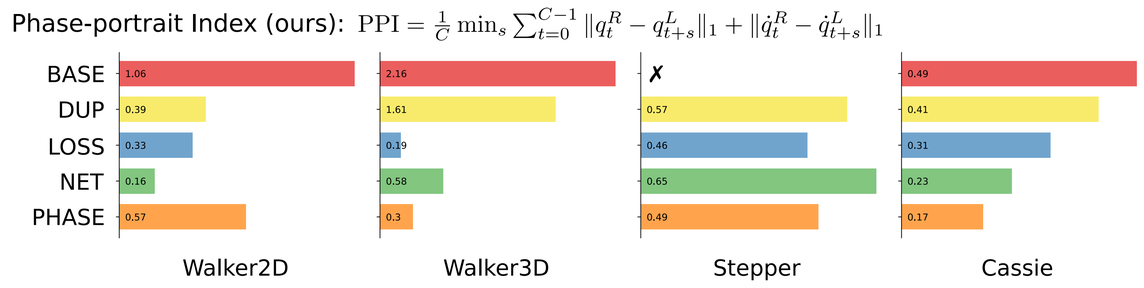
- Green (left) and red (right)



Actuation Symmetry Index: $\text{ASI} = 100 \cdot 2|X_R - X_L|/(X_R + X_L)$



Phase-portrait Index (ours): $\text{PPI} = \frac{1}{C} \min_s \sum_{t=0}^{C-1} \|q_t^R - q_{t+s}^L\|_1 + \|\dot{q}_t^R - \dot{q}_{t+s}^L\|_1$



† *Lower is better for both indexes*

Related Work

- Farzad Abdolhosseini, Hung Yu Ling, Zhaoming Xie, Xue Bin Peng, and Michiel van de Panne. (2019). On Learning Symmetric Locomotion. *MIG 2019.* **(✱)**
- Wenhao Yu, Greg Turk, and C. Karen Liu. (2018). Learning Symmetric and Low-energy Locomotion. *SIGGRAPH 2018.*
- Zhaoming Xie, Patrick Clary, Jeremy Dao, Pedro Morais, Jonathan Hurst, and Michiel van de Panne. (2019). Learning Locomotion Skills for Cassie: Iterative Design and Sim-to-Real. *CORL 2018.*
- Xue Bin Peng, Pieter Abbeel, Sergey Levine, and Michiel van de Panne. (2018). DeepMimic: Example-Guided Deep Reinforcement Learning of Physics-Based Character Skills. *SIGGRAPH 2018.*

(✱) See our paper for more detail.