Visualization of Stable Heteroclinic Channel-based Movement Primitives

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Key Challenges

- Employing neural dynamics for robotic control
  - Producing a functional, biologically-relevant control framework
- Introducing an adjusted movement primitive framework
  - Replacing the underlying stable equilibria of dynamic movement primitives (DMPs) with stable heteroclinic channels (SHCs)
  - Proving that this new framework is comparable to DMPs

Control Frameworks

Governing equation:

$$\tau \ddot{y} = \alpha_y(\beta_y(g - y) - \dot{y}) + f$$

DMP formulation

$$f(x) = \frac{\sum_{i=1}^{K} \psi_i w_i x}{\sum_{i=1}^{K} \psi_i}$$

$$\tau \dot{x} = \alpha_x x$$

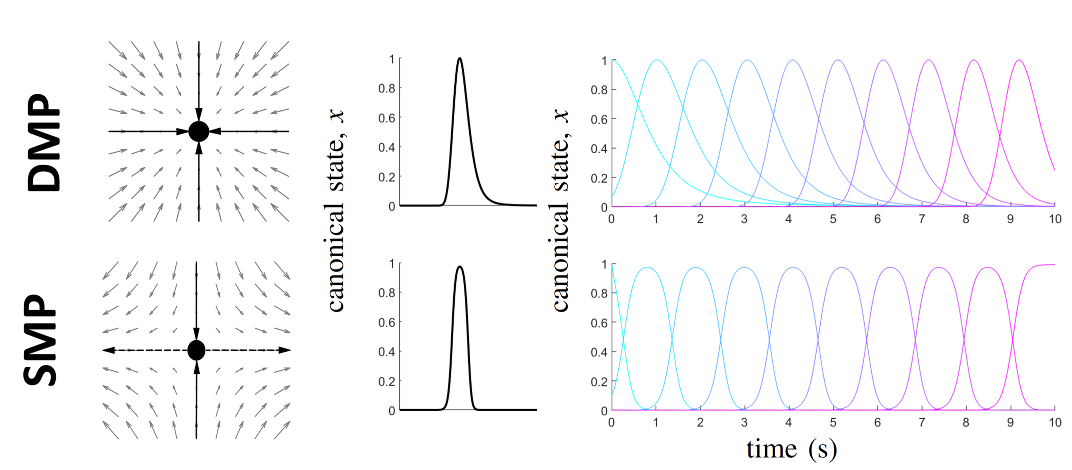
$$\psi_i = \exp\left(\frac{-1}{2\sigma_i^2}(x - c_i)^2\right)$$

SMP formulation

$$f(x_i) = \sum_{i=1}^{K} x_i w_i$$

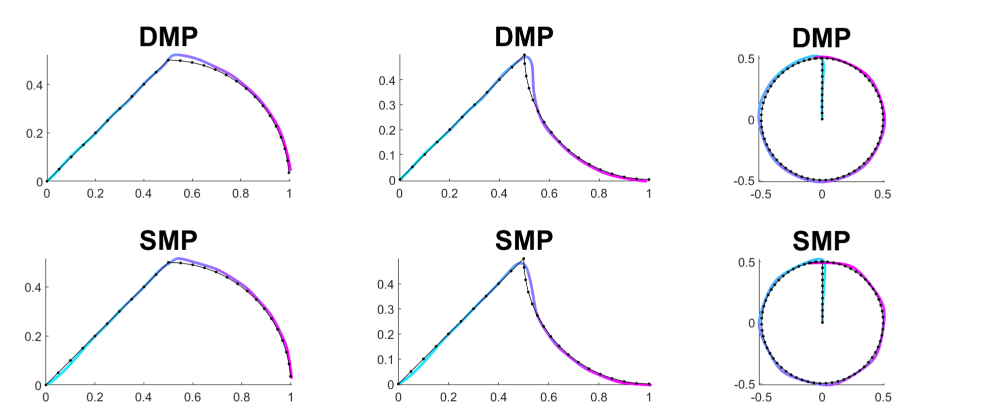
$$\tau d x_i = x_i\left(\alpha_i - \sum_{j=1}^{K} \rho_{ij} x_j\right) dt + \sum_{j=1}^{N} C_{ij} z_j$$

Graphical representations



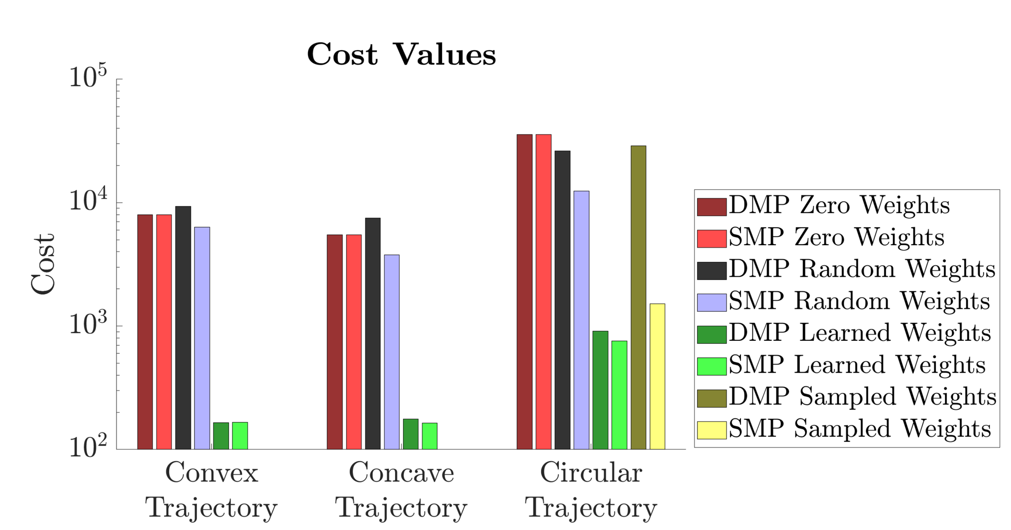
Evaluation

Trajectory-following tasks:



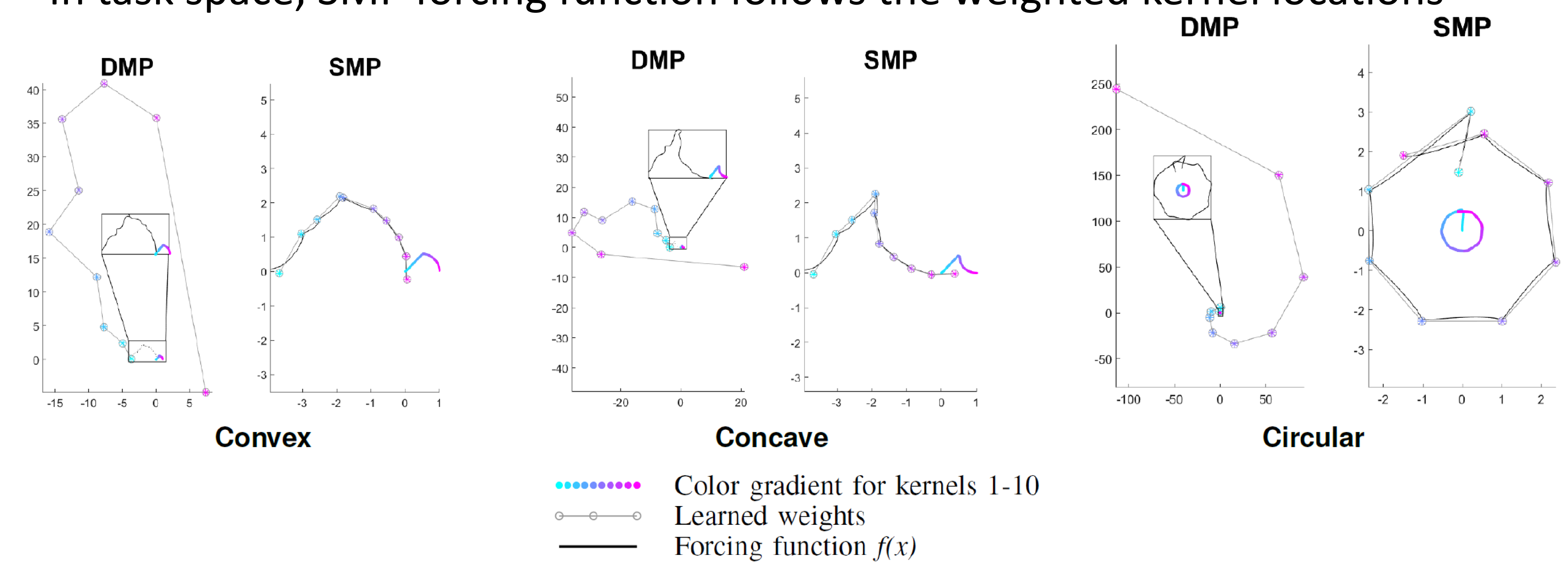
(a) Convex Trajectory (b) Concave Trajectory (c) Circular Trajectory

Comparison via kinematic cost function:



Results

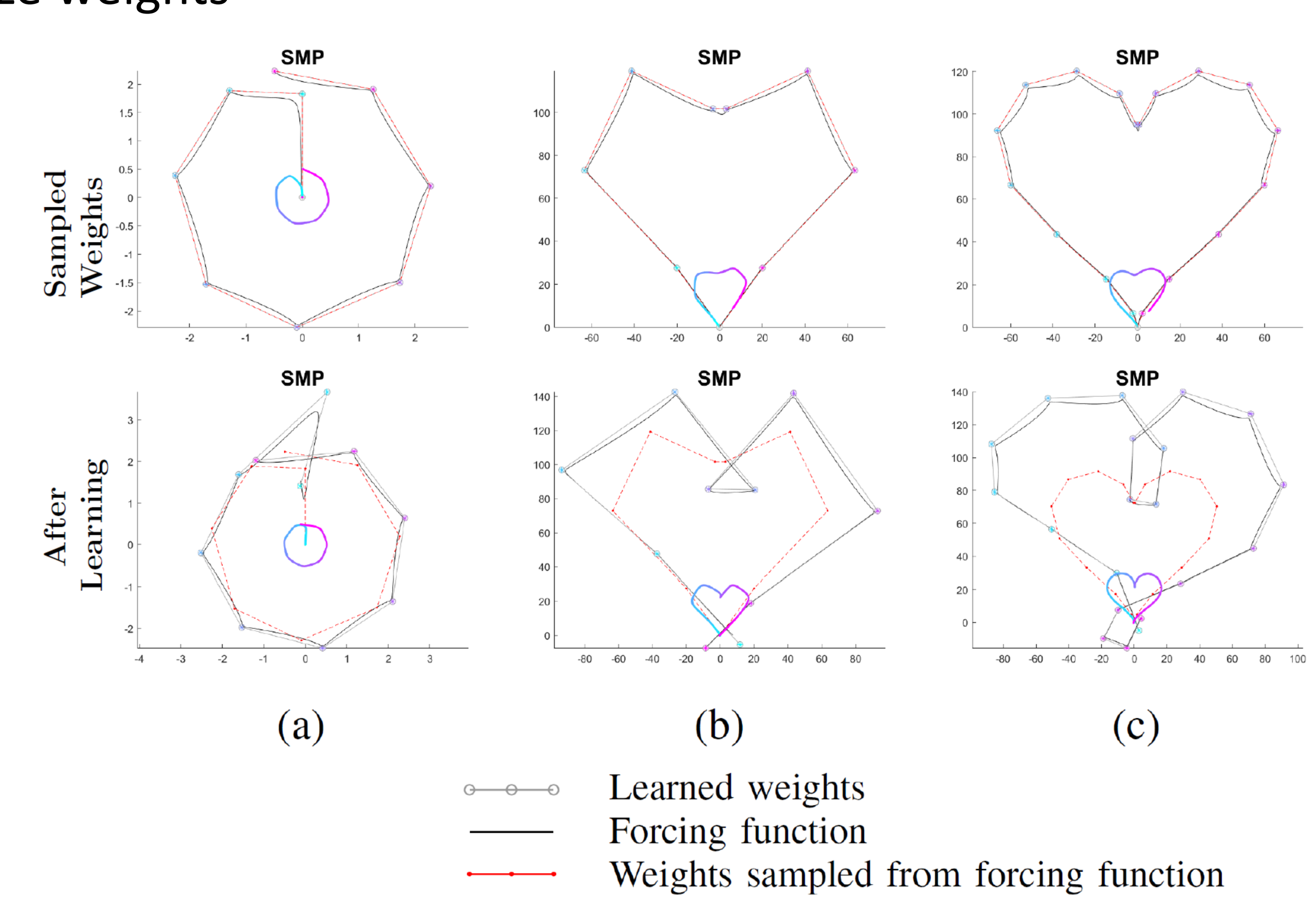
- In phase space, SMP forcing function follows the weighted kernel peaks
- In task space, SMP forcing function follows the weighted kernel locations



Weight sampling:

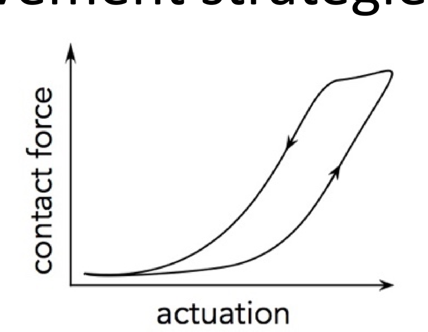
- Kernel weights for circular trajectory match the trajectory
- Sampling method to initialize weights

$$w = \left(\frac{\sqrt{(\alpha_y v)^2 + \left(\frac{\alpha_y \beta_y}{2} - \tau\left(\frac{v^2}{r}\right)\right)^2}}{r}\right)^2 * y_{desired}$$

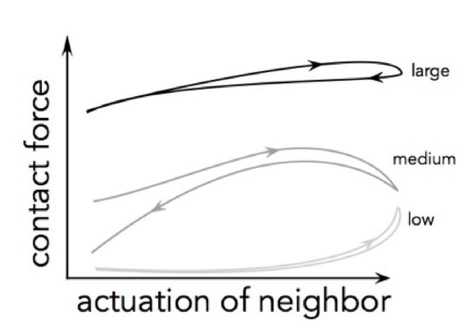


Impact

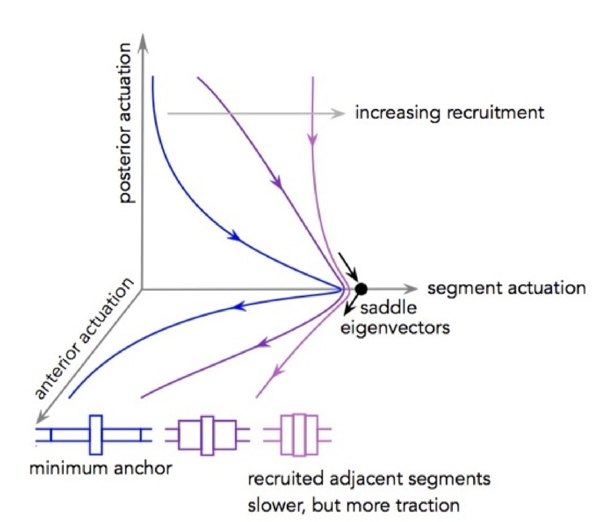
Movement strategies for worm-like robots:



(a) There is a nonlinear, hysteretic relationship between input (actuation force) and output (sensed contact).



(b) We expect actuation of neighboring segments to also affect sensed contact forces.



(c) Recruitment strategy

Reference

N. A. Rouse and K. A. Daltorio, "Visualization of Stable Heteroclinic Channel-based Movement Primitives," in IEEE Robotics and Automation Letters, doi: 10.1109/LRA.2021.3061382.