Geometric Insights for Data-Driven Gait Analysis

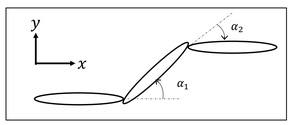
Brian Bittner, Ross Hatton, Shai Revzen

Abstract

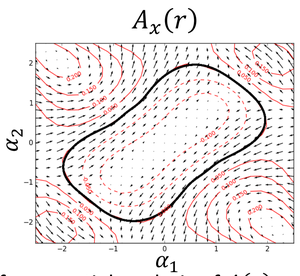
Leveraging the development of tools for geometric gait design [1] and the data driven modeling of oscillators [2], we have constructed a computational algorithm for the optimization of gaits [3]. By computing local, data-driven models about observed behaviors, we can inform iterative gait improvements, climbing the gradient of a class of goal functions. The algorithm is model-free and welcomes system noise that directly informs the local model. Initial success involves optimization of a 9 Link Purcell Swimmer, and numerical analysis of gait selection in *C. elegans*.

Geometric Gait Design

$$\xi = A(r)\dot{r}$$

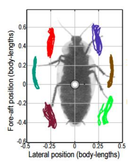


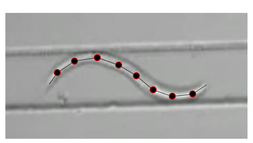
Hatton, Ross L., and Howie Choset. "Geometric swimming at low and high Reynolds numbers." *IEEE Transactions on Robotics* 29.3 (2013): 615-624.



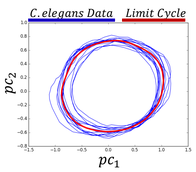
Pro : Optimal gait determined from spatial analysis of $A(r)$.
Con: Cumbersome to compute $A(r)$ in high dimensions.

Data Driven Oscillator Theory





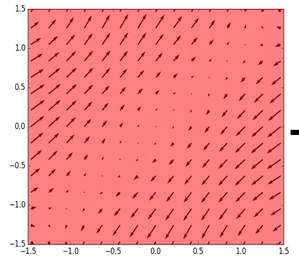
C. elegans Swimming Data: Penn Complex Fluids Lab



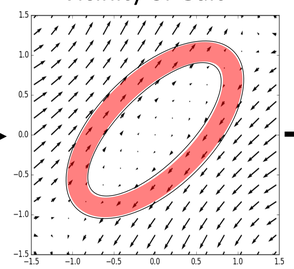
Pro : Templates are procedurally computed from noisy, high dimensional data.
Con: Solving for the dynamics locally around a cycle has proven to be a numerically challenging problem.

Modeling Connections about Gaits

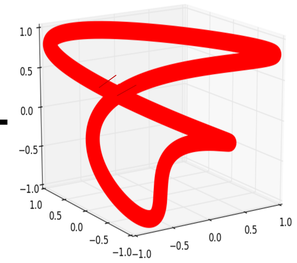
Exhaustive Empirical Approach



Build Connection in Vicinity of Gait



Bigger Win in Higher Dimensions



Given a physical system with i dof: $b_i \in \mathcal{B} \subseteq \mathbb{R}^i$
Assume we have a periodic gait:

$$\theta := \mathbb{R} \to \mathcal{B}, \text{where } \exists T > 0 \; s.t. \; \forall t \in \mathbb{R}: \theta(T + t) = \theta(t)$$

Real systems don't strictly follow θ:

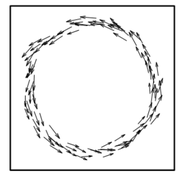
$$\delta := \mathbb{R} \to \mathcal{B}, \; \delta = r(t) - \theta(t)$$

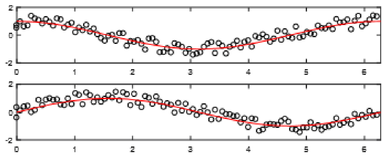
The connection written as perturbations from θ:

$$\xi^k = A_i^k(\theta + \delta)\left(\dot{\theta} + \dot{\delta}\right)^i$$

1st order Taylor Series centered on θ:

$$\xi^k \approx A_i^k(\theta)\dot{\theta}^i + A_i^k(\theta)\dot{\delta}^i + \left(\frac{\partial A_i^k}{\partial r}\right)_j(\theta)\dot{\theta}^i\delta^j + \left(\frac{\partial A_i^k}{\partial r}\right)_j(\theta)\delta^j\dot{\delta}^i$$

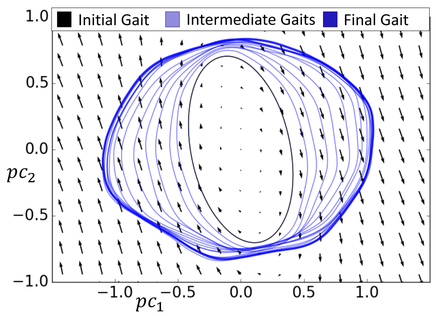


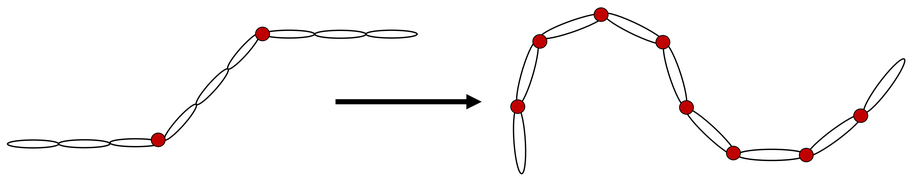


Optimizing the 9 Link Purcell Swimmer

The swimmer climbs the gradient of a minimal cost of transport gait.

- First Gait: Uses **2** motors.
- Final gait: Serpenoid of consistent waveform.
- ↑ system noise ↑ convergence rate.
- ↓ system noise ↑ articulated maneuvers.

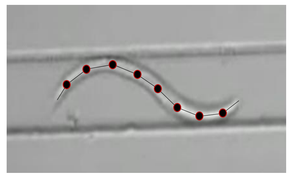




Gait Selection in C. elegans

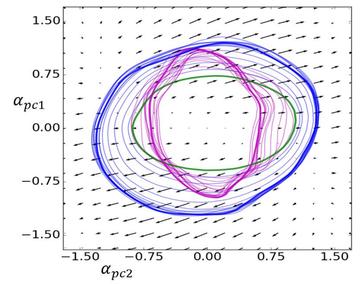
What are the prime motivators in observed organism behavior?

- We approximated high density motion capture data as a nine-link Purcell Swimmer.



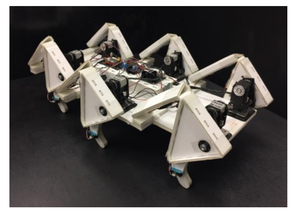
C. elegans Swimming Data: Penn Complex Fluids Lab

- Initial results show that nematode gaits more closely resemble a low cost of transport gait.



Future Work:

Our goal is to use this tool to optimize gaits on legged robots. This requires development of a geometric model of legged locomotion.



References:

[1] Hatton, Ross L., and Howie Choset. "Geometric motion planning: The local connection, Stokes' theorem, and the importance of coordinate choice." *The International Journal of Robotics Research* 30.8 (2011): 988-1014.
[2] Revzen, Shai, and Matthew Kvalheim. "Data driven models of legged locomotion." *SPIE Defense+ Security*. International Society for Optics and Photonics, 2015.
[3] Geometrically Optimal Gaits: A Data Driven Approach [under preparation]