Setup: Our implementation consists of a dual-chain CPG network structure (one chain linked to each left/right side of the plant) implemented as a controller on a 7-link snake robot with 6 actuated DoFs. The individual CPG nodes are influenced by their neighbor nodes according to a constant "phase offset", which determines the length scale of the control wave propagated through the system. It is necessary that the system be equipped with a means of applying asymmetrical friction in its contact with the ground (different values for rolling v. sliding friction), achieved here by adding passive wheels to each link. This setup is nearly identical to the system designed by Ijspeert et al in their lab's work with snake and salamander robots.

Implemented in this way, our parameter space consists of the following 4 dimensions:

1. *Frequency [0.2,1.2]:* The time frequency of one control oscillation cycle, in Hz.
2. *Phase Offset [0.125,1.0]:* The oscillation offset, in radians, between links - positive for ascending connections (from head to tail) and negative for descending.
3. *Left Amplitude [0.2,1.0]:* The amplitude coefficient of the traveling wave for the left chain of the CPG network.
4. *Right Amplitude [0.2,1.0]:* The amplitude coefficient of the traveling wave for the right chain of the CPG network.

In order to find the best CPG parameter settings for a variety of maneuvers, we collected approximately 10,000 randomly sampled parameterizations from the space described above. For each point, the following procedure is followed:

1. The system is given random initial conditions inside specified range [0,1]
2. A "zero" control is propagated for 10 seconds in order to bring the system to a zero-velocity state
3. The sampled control is propagated for 20 seconds
4. We retain as starting state the state of the system after 2 full oscillations (in order to reduce measurement of transient response), and as final state the state after 4 full oscillations.

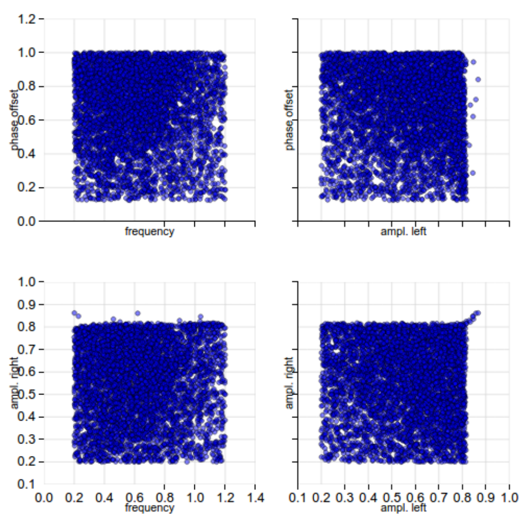
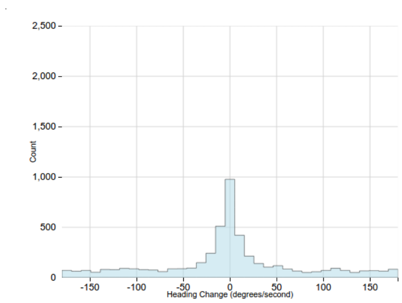


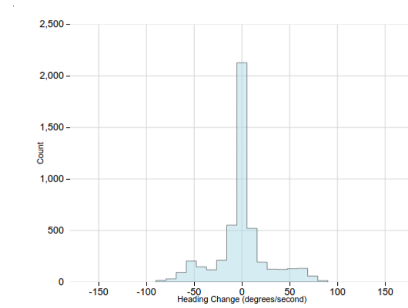
Figure 1: Parameter space coverage from randomly sampled control values

Before analyzing the resulting values, we first reject points which (1) have not achieved a minimum total displacement of the middle link, and/or (2) have angular velocity in excess of a "stable" value.

Evaluating Variety of Gaits: Because we're interested in finding gaits which can be used not only to achieve straight line locomotion but also turning in each direction to various degrees, we're first interested to see that we have sufficient variety of "heading changes" (estimated difference between starting and ending forward direction). The histograms below show [left] absolute heading change over two oscillation cycles and [right] time-normalized heading change, i.e., heading change per second at steady state.



(a) Absolute heading change for sampled points



(b) Time-normalized heading change for sampled points

Evaluating Total Displacement and Direction: Finally, in order to select which gaits we would like to use as motion primitives for planning solutions to more complex locomotion challenges, we would like to select a variety of gaits capable of different degrees of turning (heading changes) while ensuring that the displacement of the center link is also in the direction of the heading change, as this is an indicator of a stable gait. Meeting this requirement, we would like to optimize (1) total displacement, and (2) variety. In the below plots, the left shows absolute displacement terms, while the right is time-normalized.

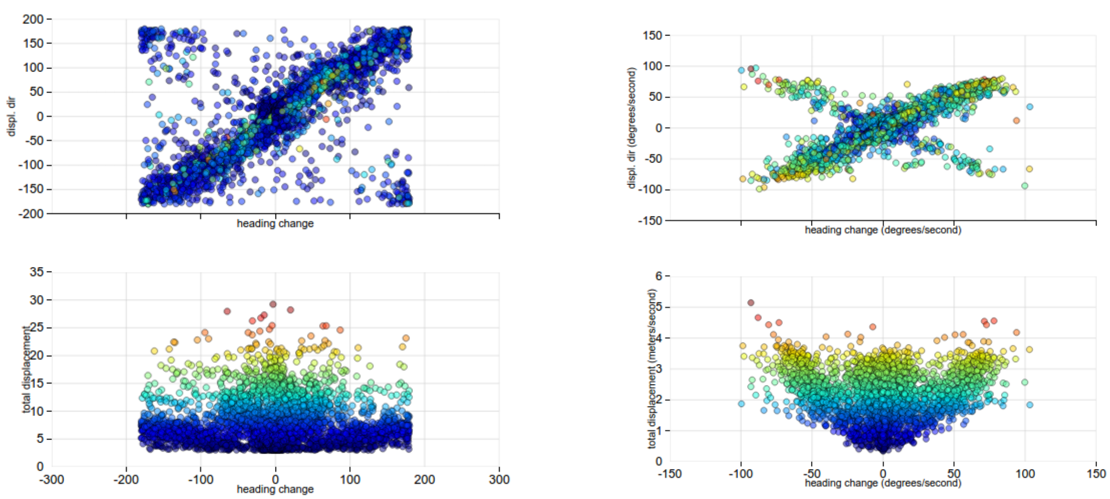


Figure 3: Top: Agreement of heading change and displacement direction of the snake. Bottom: Total displacement by heading change.