Gait transition from swimming to walking: investigation of salamander locomotion control using nonlinear oscillators

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1. Introduction

This article presents a model of the salamander's locomotion controller based on nonlinear oscillators. Using numerical simulations of both the controller and of the body, we investigated different systems of coupled oscillators that can produce the typical swimming and walking gaits of the salamander. Since the exact organization of the salamander's locomotor circuits is currently unknown, we used the numerical simulations to investigate which type of coupled-oscillator configurations could best reproduce some key aspects of salamander locomotion. We were in particular interested in (1) the ability of the controller to produce a traveling wave along the body for swimming and a standing wave for walking, and (2) the role of sensory feedback in shaping the patterns.

2. Salamander locomotion

Salamander swimming is based on axial undulations in which rostrocaudal waves are propagated along the whole body with limbs folded backwards. On ground, the salamander switches to a stepping gait, with the body making S-shaped standing waves with nodes at the girdles.

3. CPG and mechanical simulation

The building block of our model of the CPGs is the following nonlinear oscillator:

$$\begin{aligned}\tau \dot{v} &= -\alpha \frac{x^2 + v^2 - E}{E} v - x \\ \tau \dot{x} &= v\end{aligned}$$

where τ, α, and E are positive constants. This oscillator has the interesting property that its limit cycle behavior is a sinusoidal signal with amplitude $\sqrt{E}$ and period $2\pi\tau$.

We constructed a complete CPG made of 80 oscillators for the body CPG and 8 oscillators for the limb CPG, and systematically tested different possible couplings between oscillators, and between the oscillators and the mechanical simulation.

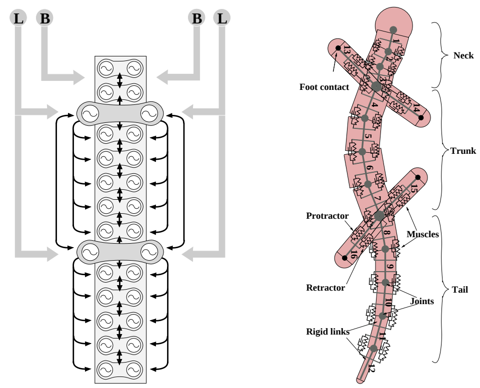

Figure 1: Left: CPG model, Right: Mechanical model.

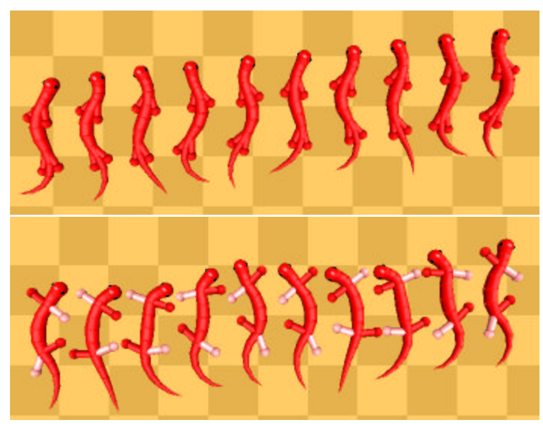

Figure 2: Top: swimming. Bottom: walking.

4. Results

A set of CPGs capable of producing stable swimming and walking gaits were found. Gait transition is obtained by activating *both* the body and the limb CPGs for walking, and *only* the body CPG for swimming. Results show that configurations which combine global couplings from limb oscillators to body oscillators, as well as interlimb couplings between fore- and hindlimbs come closest to salamander locomotion data. It is also demonstrated that sensory feedback could potentially play a significant role in the generation of standing waves during walking.