Can small scale search behaviours enhance large-scale navigation?*

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Abstract. We develop a spiking neural network model of an insect-inspired CPG which is used to underpin steering behaviour for a Braitenberg-like vehicle. We show that small scale search behaviour, produced by the CPG, improves navigation by recovering useful sensory signals.

Keywords: CPG · Braitenberg · Navigation.

1 Introduction

Motor control is fundamental to the adaptive behaviour of natural and artificial systems, with one role being the production of active movement strategies to acquire and use key sensory information. A key neural component of motor systems are central pattern generators (CPGs) [1], for instance, those involved in the control of swimming movements of lamprey [2] or movement control in invertebrates [3]. CPGs have also been shown to be useful components for motor control in bio-inspired robots [4]. In insect brains, the Lateral Accessory Lobe is a key pre-motor area that has been shown to generate CPG like outputs in certain conditions. It is a conserved brain structure and is fundamental to a range of sensori-motor behaviours such as pheromone search in moths [5] and phonotaxis in crickets [6]. Computational models of the LAL have been developed to obtain a better understanding of how the LAL network can generate “flipflop” activity (Adden et al. (in prep.)) or how the LAL may contribute to pheromone plume tracking [7]. Here we develop a minimal spiking neural network model of the LAL, based on our previously developed general steering framework [8]. Our aim is to demonstrate that the model produces outputs that drive two distinct behavioural modes. Firstly, in the presence of sensory information it should output a steering signal that is proportional to that sensory information, so the location of a stimulus relative to the agent drives the steering. Secondly, in the absence of reliable sensory information, the network should produce a rhythmic output that can drive search patterns. We explore the adaptive properties of this network, by situating it in a simple Braitenberg-style animat.

* This work was funded by the EPSRC (grant EP/P006094/1).

Fig. 1. A: SNN architecture, CPG-neurons correspond to Type III neurons in the LAL, Output-neurons to Type I neurons. B: spatial familiarity function, left: one eye of the pair, right: cyclops, C: Agent configurations. Gray arrows depict direction of maximum familiarity. Left = BB, Middle = Cyclops, Right = BBCPG. D: CPG output as Spike Density Function (SDF), top: low input (resulting in large zig-zag movements), bottom: high input (resulting in small zig-zag movements). E: CPG output space showing how unilateral input results in unilateral output and bilateral input results in flip-flopping.

2 Methods

In a 2D-simulation, we implement a Braitenberg-Agent approaching a beacon. A Braitenberg-vehicle is a simplistic model agent using primitive sensors which directly control actuators, making it an ideal platform to model taxis behaviours. The agent has one of two sensor types: 1. Braitenberg version: two sensors covering 180° each with an overlap of 90° (therefore a total coverage of 270°) and 2. Cyclops version: one sensor covering 360° . The spatial transfer function imitates a typical Rotational Image Difference Function (RIDF). 100 % familiarity is sensed if the beacon is straight ahead of the agent, approaching 25% (this is the typical approximate minimum value for a 360° rotary IDF) when the target is behind the agent (Cyclops), or 0% when outside the visual range (Braitenberg). The spatial resolution is restricted to 1° . The agent is controlled by a spiking neural network (SNN) that is based on the LAL architecture as described in Steinbeck et al. 2020 [7]. The input neurons (leaky integrate & fire [LIF]) are driven by the sensor signal and excite the ipsilateral CPG- and output-neurons. The CPG neurons (adapting LIF) inhibit the contralateral CPG- and output-

neurons. The output-neurons (LIF) excite the contralateral force neurons, which translate spikes into force (integration neurons, where activity represents acceleration). An imbalance of produced force leads to rotation. The SNN is tested in three versions: Braitenberg vehicle (BB), Cyclops and Braitenberg with CPG (BBCPG). The synaptic weights are the same for the same connections in all networks. The oscillation dynamics of the CPG are such that with low symmetric input the oscillation is slow and with strong symmetric input the oscillation is fast. Unilateral input results in no oscillation.

3 Results

Fig. 2. A: one exemplary trial of Cyclops, top: familiarity, middle: Neuron spike density, bottom: heading and speed, B-D: paths and endpoints; B: Braitenberg, C: Cyclops, D: BBCPG, E: Endpoint distribution of left: BB, middle: Cyclops, right: BBCPG

Each of 300 simulations was run for 3000 timesteps, and had a random initial starting position (15 units from the beacon) and heading. The trial was stopped if the agent reached the beacon. Each vehicle version was run 300 times. The BB vehicle converged towards the beacon if one sensor detected it at the beginning. If the beacon is in the agent's blind spot, it runs off into the approximate initial heading direction (which is due to spontaneous neuron activity). The distribution of endpoints is divided into two major clusters, one beyond the starting position, the other close to the beacon. The Cyclops converges towards the beacon in most trials, with only a low percentage running away. Due to the sinuous

movements, a large area is covered. Almost all endpoints are located between the starting position and the beacon, therefore it is more successful than BB. The Braitenberg-CPG version converges towards the beacon in each trial. If it does not detect the beacon initially, the CPG driven small scale search steers the agent around (driven by Type III activity), until the stimulus becomes available and the proportional steering mode takes over (mediated by Type I neurons). The endpoints exhibit a smaller mean distance to the goal than in the other conditions.

4 Discussion

We have developed a spiking neural network model of an insect-inspired CPG which is used to underpin the steering behaviour of a Braitenberg-like vehicle. We show that a Braitenberg-only setup, or familiarity modulated CPG, have limited success navigating towards a beacon, while combining these approaches increases success. In future the system will be explored in terms of its biological plausibility to better understand the LAL network and its connection to other brain regions [10] and in more realistic scenarios we will investigate if this framework can improve navigation algorithms.

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