Ring Integrator Model of the Head Direction Cells

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INTRODUCTION

Head direction (HD) cells demonstrated in the post subiculum [1], [2Provide information about heading direction during spatial navigation.
Prior Models: Attractor Dynamic model [3] explains the unique firing patterns
Current Model: Ring Integrator model of the HD cells.
Benefits: Same functionality with fewer neurons and explains alignment to orienting cues.

RING INTEGRATOR MODEL

HD cells are arranged in a single ring of the HD neurons and interneurons (Fig. 1).
Each neuron is connected to two interneurons – clockwise (CW) and counter CW (CCW)

CW interneuron
- receives inputs from the neuron to its left and provides inputs to the neuron to its right.
- receive vestibular inputs

CCW interneuron
- receives inputs from the neuron to its right and provides inputs to the neuron to its left
- receive vestibular inputs

HD neurons
- feedback to themselves
- receive sensory inputs – become aligned to orienting cues

Single inhibitory interneuron
- inhibitory input to all neurons and interneurons

HD cell firing at rest
- Feeds back to itself to maintain the firing activity
- Provides excitatory input to the single inhibitory interneuron-> inhibits all neurons
- Activates both CW and CCW

Movement in clockwise direction
- the right horizontal semi-circular canal gets activated
- provides inputs to all the CW neurons

Movement in the counter-clockwise direction
- the left horizontal semi-circular canal gets activated
- provides inputs to all the CCW neurons
- Get enough excitation to activate the adjacent HD
- HD cell also starts receiving sensory input
- The previously firing HD cell stops receiving sensory inputs

Improvements over Attractor Dynamic Model
- Explains role of sensory cues
- Simpler model - a single ring of neurons for both CW and CCW movements

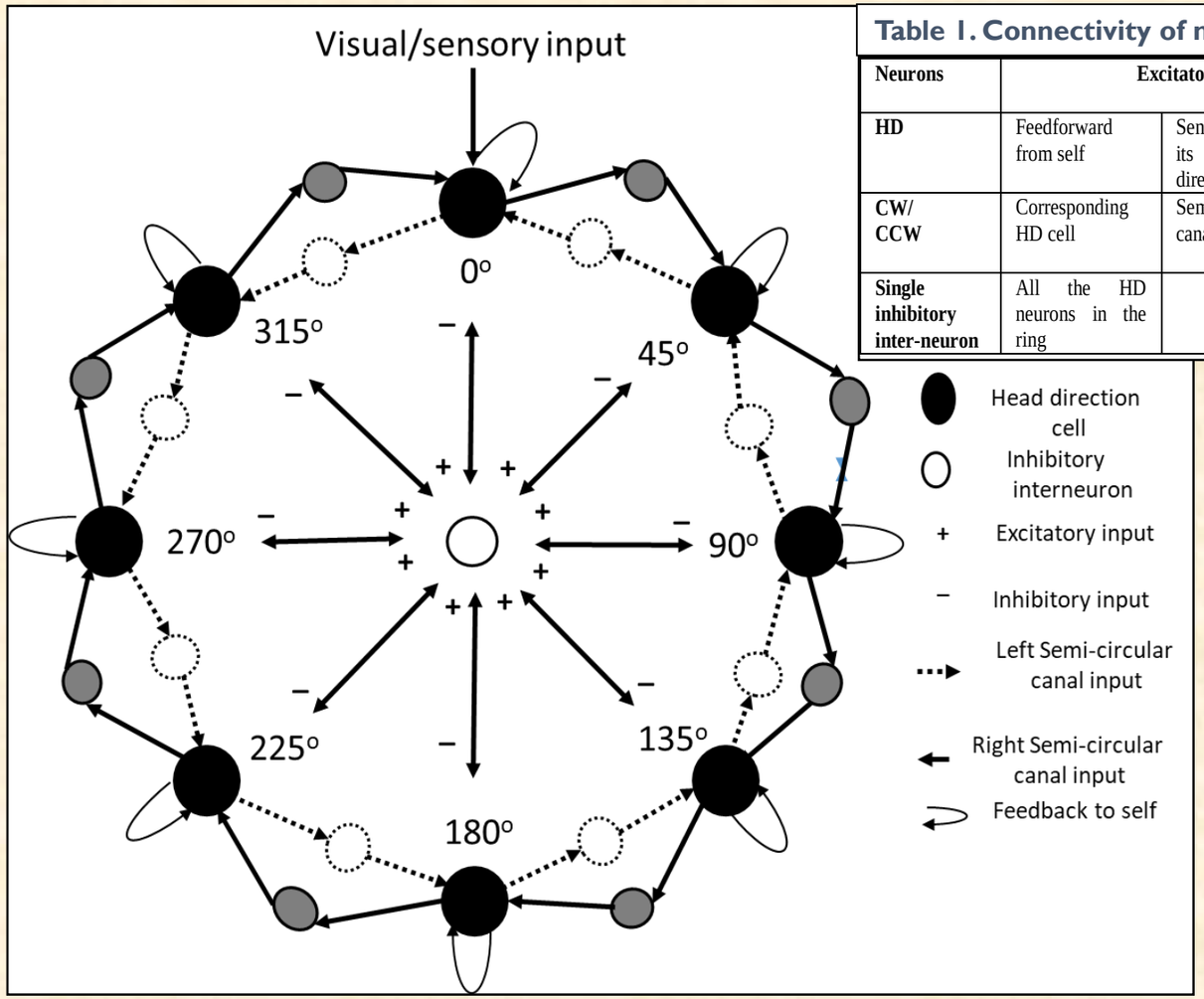

Fig. 1 Schematic of the Ring Integrator model of the Head Direction cells. With the initial visual /sensory input, the neuron in the preferred firing direction orients to the sensory orienting cue. As the animal moves its head, the vestibular inputs from the semi-circular canals are integrated at the CCW/CW to move the firing HD neuron position to the HD neuron next to it. To suppress firing in other neurons, a single inhibitory interneuron provides inhibitory inputs to all the HD neurons. Also, all the neurons also provide positive feedback to themselves that helps sustain their firing. (For simplicity, we have shown only 8 neurons that constitute the head direction cell system).

Table 1. Connectivity of neurons in the ring.

Neurons	Excitatory inputs			Inhibitory inputs
HD	Feedforward from self	Sensory- along its preferred direction	CCW/CW neurons	Single inhibitory interneuron
CW/ CCW	Corresponding HD cell	Semi-circular canals		Single inhibitory interneuron
Single inhibitory inter-neuron	All the HD neurons in the ring			

REFERENCES

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