Conference paper in integration with the NRP

Bigger picture:

Towards understanding how best to use spiking models for integration with neuromrphic hardware - eventually for bio inspired low power SLAM…….

Combine spiking and none-spiking models

Working at the same time with a simulated robot

Proof of concept….????

NEST spiking HD attractor network

* Idiothetic: Estimating direction from self-motion
* Excitatory-inhibitory interactions based on reciprocal connections between the LMN and DTN
* Ring attractor with 2 conjunctive layers for driving the bump clockwise or anticlockwise around the network

Predictive coding network

* Reduce tactile and visual information into feature space
* Estimate distance between sensory scenes etc

Whiskeye robot on the NRP

* Odometry data (transform to get head movements)
  + Pass to NEST spiking network in Transfer function
  + Map velocity to current and inject into conjunctive layers
* Tactile data from whiskers at the full extent of the whisk movement
* Image from single camera at the full extent of the whisk
  + Pass both to predictive coding network in a transfer function

Intentions?

* Reduce error in HD network using the predictive coding network feature space
* Use the HD estimate to prime the predictive coding network?

**Spiking model of the head direction cell system for orientation estimation**

Why spiking?

* Want to understand how the uncertainty of the animals pose is represented in the brain

Visual and tactile data from the robot is simultaneously passed to the predictive coding network, a model of hebbian deep learning using two sensory modalities.

Produces a representation of the current view every 50Hz. We hope to find a relationship between this feature space and heading, and feed these data back onto the head direction network in order to correct for inherent drift or in the case of real world robotics, noisy odometry data.

* Generation of the HD signal in the reciprocal connections between the LMN and DTN
  + This relationship has been previously modeled as one excitatory population (LMN neurons) and two inhibitory populations (representing DTN neurons). Each of the DTN populations was connected to the excitatory population in a distance dependent manner
  + One for move left and one for move right
* Grid cells have also been modeled usign interactions between and excitatory and inhibitory population to produce an attractor network with a bump of activity representing current positon.

Separate cells with preferred firing ditrections into conjuntive layers, one for clockwise movement and one for anti clockwise movement

Dtn receives direct input from vestibular areas

These cells may reside within these two regions… as they appear just as head direction x angular velocity cells??? Not sure if these have been recorded - may be difficult as would appear very much like a head direction cell onced averaged over a whold session

The benefit of exc-inhibitory networks is fewer connections

* Also elimination of connections between HD cells within a region

Previous arrangements

Distance dependent excitatory connections between each HD cell in the ring + global inhibition + excitatory connections between the HD layer and the two conj layers - one to one

* Requires coincident AV and HD input

Distance dependent excitatory connections between each HD cell in the ring + global inhibition + inhibitory connections between the HD layer and the two conj layers in which all cells not close to the currently active HD cell are inhibited but this required many connections

Description of the head direction model

Parameters:

# population size

N\_ex = 450

N\_in = 450

N\_cj = 450

# gaussian

sigma = 0.11

mu = 0.5

# base connection weights

base\_ex = 1000.

base\_in = 100.

base\_cj = 240.

w\_ex\_cj = 560.

delay = 0.1

#bump initialisation

I\_init = 300.0 #pA

I\_init\_dur = 100.0 #ms

I\_init\_pos = N\_ex//2

Neuron model: iaf\_psc\_alpha with default parameters

For the excitatory layer, an additional parameter ‘I\_e’ was set to 450. pA to generate regular spontaneous firing.

The spiking neural network model was defined in pyNEST (cite)

Current arrangement

All leaky integrate and fire cells with the NEST default parameters except where stated otherwise

4 layers of cells

* Excitatory layer (LMN) which fires spontaneously due to an input current (I\_e = 450 pA)
* Inhibitory layer which has an equal number of cells
* Clockwise projecting layer
* Anti clockwise projecting layer

Connections

Exc -> inh distance dependant gaussian distributed connections

Inh -> exc distance dependant offset gaussian distributed connections producing a ring of inhibition which surround the bump of activity

The distance between the cells is determined by the following:

D1 =

D2 =

D = min(d1,d2)

Exc\_weight =

inh -weight =

This produces a ring attractor

Cells are connected such that the distance both ways around the ring are considered

Exc -> conj One to one excitstory conenctions

Conj -> exc One to one excitatory connections offset by one cell esther clockwise of anticlockwise around the ring

The bump is initialised using a 100 ms current injection (400 pA) into an arbitrary cell on the ring.

History of experimental work

* Types of cells and who first recorded them
* Major observations in behaviour of the cell type
* Major modelling attempts
  + Including problems

My interpretation of how we can model the HD/grid cell system

Hd cells modelled as a ring attractor network

Currently

* Connections between HD cells have a gaussian weight profile which is countered by continuous inhibition from a layer of ‘intenerurons’ leading to a stable bump of activit on the ring.
* In order to track HD of the robot, odometry data from the robot containing the measured angle is used to generate spiking input to the network. Large changes in angular velocity equate to higher firing rates.
* In order to convey this change to the HD network two underlying populations of cells ‘conjunctive cells’ drive the activity bump either clockwise or anticlockwise around the ring. Cell in the clockwise population are disinhibited by a specific HD cell and project an excitatory connection to a HD cell one position clockwise around the ring. HD cells have inhibitory connections to all other conjunctive cells

This current arrangement allows for continuous tracking of HD around the network to a fairly good accuracy

However this arrangement requires many synaptic connections between neurons

It may be possible to implement an excitatory-inhibitory network to produce an attractor bump as used in grid cell network below.

The gris cell network uses a continuous current to keep cells at an elevated excitability which maintains the bump

* This activay has been successfully synchronised with a theta pattern

This may also allow for coincident input to the conjunctive layer to produce spikes instead of using disihibition

-> alternatively a way of keeping only the cells at the position of the bump in an elevated excitable state would be preferable…. More thought can go towards this

Excitatory cells (stellate or grid cells) project to interneurons which are inhibitory cells with gaussian connectivity and inhibitory cells project back to the excitatory cells with a ring like pattern implemented by shifting the gaussian weight profile

-> find the eucledian distance between two cells on the neural sheets

Distance is always the same regardless of

The cartesian coordinates are normalised to the size of the sheet and so are always between 0 and 1

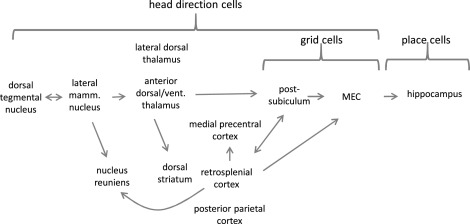
For a regular torus

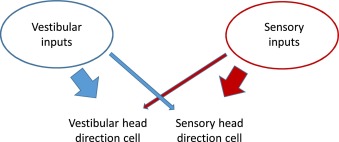
If smaller distances can be produced by subtracting or adding the 1 from either the x or y direction (equivalent to the width or height of the sheet) then this wrapped distance is used instead

Need to keep in mind our purpose

* Biologically inspired and following the biology as much as possible
* However the intention is not to contruibut potential mechanisms but to use what we do know to produce a method of tracking self motion which can be implemented using neuromorphic hardware and using in conjunction with the predictive coding network for the purpose of robot navigaiton

Dudchencko 2019





Suggests two types of head direction cells a) ‘vestibular’ head direction cells - driven primarily by internal dynamics and the [vestibular system](https://www.sciencedirect.com/topics/neuroscience/vestibular-system), and corrected by external landmarks, and b) ‘sensory’ head direction cells - driven primarily by external landmarks.

Our thoughts: May it be the case that there are actually multiple rings each responding to one information stream. Then some sort of conflict resolution occurs upstream in the HD system which produces a better estimation.



Intro

* Spatial cells
* Identifying head direction cells
* Head direction system and generation of head direction
* External inputs to head direction system
  + Rotation studies
  + Importance of landmarks

### Yoder RM, Peck JR, Taube JS. Visual landmark information gains control of the head direction signal at the lateral mammillary nuclei. J Neurosci. 2015

* Previous models of head direction
  + Rate based
  + Attractor networks
  + Exc inhibitory networks -> more like biology

Evidence for attractor networks

* Bassett et al 2018 - their absolute preferred firing directions can change (following [disorientation](https://www.sciencedirect.com/topics/neuroscience/disorientation) or manipulations of the environment), the tunings of simultaneously recorded cells retain their relative spatial offsets
  + The position of the activity peak is thought to be updated in response to head movement by the activity of upstream angular velocity-responsive cells, which have been described in the rat [midbrain](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/protocerebrum) -> conjunctive cells?
* Why spikes?
  + Want to understand how the uncertainty of the animals pose is represented in the brain
* Accounting for drift
  + Two head direction systems (allothetic and idiothetic info)
  + OR visual landmarks correct for drift directly at the point of HD signal generation (at the LMN)
  + Plasticity (learning cue reliability)
    - Knight et al 2013 (attractor network with weighted landmark input (if less reliable use background cues)
      * Cue conflict between background/ideothetic and landmark resolved by attractor dynamics
    - (goodridge et al ) longer experience of the cue resulted in more rotation (more confidence in the cue)

Model

* Network structure
* Maths behind connections

Drive conjunctive layer at equivalent HD cell in order to pull bump around the network

Does the feature space produced by the predictive coding network encode head direction? Can we find a principal component which represents HD from the visual and tactile data?

Expand to represent 2D space using grid and place cells. HD could be imported for associating specific views with positions in the environment. By dissociating similar views from different directions.

HD vs movement direction

* Raudiws et al 2015 In entorhinal cortex HD is encoded strongly and movement direction not
* This fits with HD having importance for providing a heading to visual information in order to associate a view with a place
  + However how can it do this if the HD system is also influenced by visual landmarks
  + OR maybe HD influenced backwards from view + place???? But that doesnt explain how HD cell all the way in the LMN are controlled by visual information (sensitive to cue rotations)
    - Some sort of 2 way dictionary…. Views and HD