**Slide 2**

1: approach; 2: problem; 3: progress

Big picture – I am attempting to model circuitry identified in the cortex and superior colliculi of rats which allows them to keep track of shelter; and I am modelling this with recurrent neural networks

**Slide 4**

Approach: largely informed by Cueva and colleagues’ work on modelling head direction

Circuitry found in many organisms, keeping track of its heading

Cueva modelled with a standard continuous-time RNN (some variations exist so happy to discuss particulars)

Model was given an initial heading, and angular velocity at each time step, and integrated to keep track of current heading continuously

Figure: the model learned the task

**Slide 5**

Looking at how the model solves the task

Generates two classes of units

Compass units – active at a certain HD, indifferent to AV; keeps track of heading

Shifters – active at a certain HD, but in a specific AV band; shifts heading

These functional types are also seen in experimental data

**Slide 6**

Classifying every unit in this way allows comprehension of recurrent connectivity

Pattern of lateral inhibition (sombrero pattern) between compass units

Out-of-phase pattern between shifters

**Slide 7**

Dynamics of network can be captured with two PCs

Network initialises to some point on ring

Integrates by shifting along the ring

**Slide 8**

Not going to get too into neurophysiology, other than to say these circuits exist

**Slide 9**

Put rats in a pen with a shelter on the edge

When startled, they vector straight to the shelter

**Slide 10**

Tracked the head-to-shelter angle

**Slide 11**

Neurons in the RSP and SC are tuned to this head-to-shelter angle

RSP: angular velocity and direction of the head

SC: egocentric mappings

Escape vectoring is expediated by a ‘motor read-out’

**Slide 12**

How does a network do this?

**Slide 13**

Cueva’s model

Inputs: AV, two components of initial HD (transient)

Outputs: two components of integrated HD, at every timestep

Equations: CTRNN, ReTanh activation, linear readout

**Slide 14**

Current model

Additional inputs (transient): two components of allocentric shelter angle (shelter coordinates; used to encourage mapping, not just doing two simultaneous integrations)

Additional outputs: two components of integrated head-to-shelter angle

**Slide 15**

Modelled situation

Zero-dimensional case

Allocentric shelter coordinates

Head direction and head-to-shelter angle allow reconstruction of where model believes shelter is

Define: head direction, head-to-shelter, allocentric shelter

**Slide 16**

Informative inputs are transient

Model learns task

Initialisation period

Drift at long times – analagous to memory drift

**Slide 17**

X: Angle (Head Direction, Head-to-Shelter, Allocentric Shelter)

Y: Average activity of unit at that angle

Units tuned just to each of the task variables

But also joint tuning

**Slide 18**

X: Angular Velocity (randomly sampled at each timestep so spans a range: here plus/minus 3 STDs)

Y: Average activity of unit at that AV

Units are more broadly tuned to angular velocity than in Cueva’s task

Will see: the distinction between a shifter and a compass unit becomes murky

**Slide 19**

X: Head Direction

Y: Angular Velocity

Colour: Average activity at that combination

Still see compass units

Still see shifters

But also: something inbetween, and something opposite, and some untuned

**Slide 22**

X: Head-Shelter Angle

Y: Angular velocity

Compass units, shifters seen again

How do these units map onto HD compass/shifters?

**Slide 24**

X: Allocentric Shelter Angle

Y: Angular velocity

Compass units, shifters seen yet again

But compass units are scarce, and borderline

**Slide 26**

X: Head Direction

Y: Head-Shelter Angle

Univariate Compass units

Joint shifters (in general, correspond to shifters in both variables, but not always cleanly)

Inverse shifters?

**Slide 28**

X: Head Direction

Y: Allocentric Shelter Angle

Univariate compass units (look like maps between HD and HSA)

i.e. not ASA specific compass unit (looks more like a diffuse shifter)

Joint shifters (again, generally match others)

**Slide 32**

Find same units as Cueva’s

**Slide 33**

But also new compass units for our two new task variables

shifter units which appear to shift all the compass units

And inverse shifters

(will get back to connectivity)

So there is some clear cut classing, and some less clear – this makes grouping neurons and analysing connectivity within and between difficult

**Slide 34**

Turning to dynamics -

PCA – generate several thousand trials, and decompose activity of network

Left: Activity is low-dimensional

Right: look at angle between a principal component and a given weight vector as a measure of their similarity (cosine, so 0 indicates dissimilarity)

PCs 1/2: related to the initial and ongoing HD

PCs 3/4: related to the ongoing, but not initial shelter angle (i.e. HSA, not ASA)

PC 5/7: related to the initial, but not ongoing, shelter angle (i.e. ASA, not HAS)

PC 6: AV

**Slide 35:**

Empirical Fixed/slow point analysis on network dynamics

(Assuming familiarity)

**Slide 36:**

70,000 FPs generated

Looking at combinations of PCs (ignoring that 6th AV one)

We find the three rings we expected

Slightly off axis from PCs contributes to ‘messiness’

**Slide 38**:

To help understand, I’m going to perform a visual manipulation

Top: parametrisation of torus surface

Middle: let these ring attractors be for some slightly offset head direction angle and head-shelter angle

Bottom: then we can take our princpal components as the sines and cosines of these new angles, and plug them back into our torus equations

(R and r simply describe the aspect ratio of this torus; purely visual parameters)

**Slide 39**:

This gives a torus

Donut-bite cross section – head-direction ring

Bagel-slice cross section – head-shelter angle ring

A given allocentric shelter angle should be an oblique slice running around the torus

**Slide 40:**

So here’s how those rings interact

Bottom left: model tracking a shelter at due north, as it rotates anti-clockwise

HD ring: rotates with rat

HSA ring: rotates with rat, out of phase

ASA ring: stable (memory analogy)

Bottom right: activity of the network follows these oblique contours around the torus

**Slide 41:**

The activity can be described by three ring attractors – but are these trivial

Take the PC loadings and cluster

Assign clusters to one of three rings (i.e. pairs of PCs)

**Slide 42:**

Order by preferred angle

And we can regain the sombrero-like connectivity of compass units

Does not account for shifters

**Slide 43**

Non-linear dimensions

* Can these rings be better extracted with non-linear dim reduction techniques

1/2D Cases

* Expect place-cell behaviour
* Drastically increases complexity of relationship between HD and HAS

Task formulations

* Landmark model
* FOV model

Cell-types

* Dale’s law

Network constraints

* Low-rank (already seems R5 is insufficient, R7 is possible, R10 is sufficient)
* Mixture of Guassian populations (not obvious what a population might correspond to)

Learning regimes

* Reinforcement learning (shelter is learned as something which reduces aversive stimulus)

Experimental data

* Present data only tested two shelter locations, not a continuum