Department of Mathematical Sciences

NTNU

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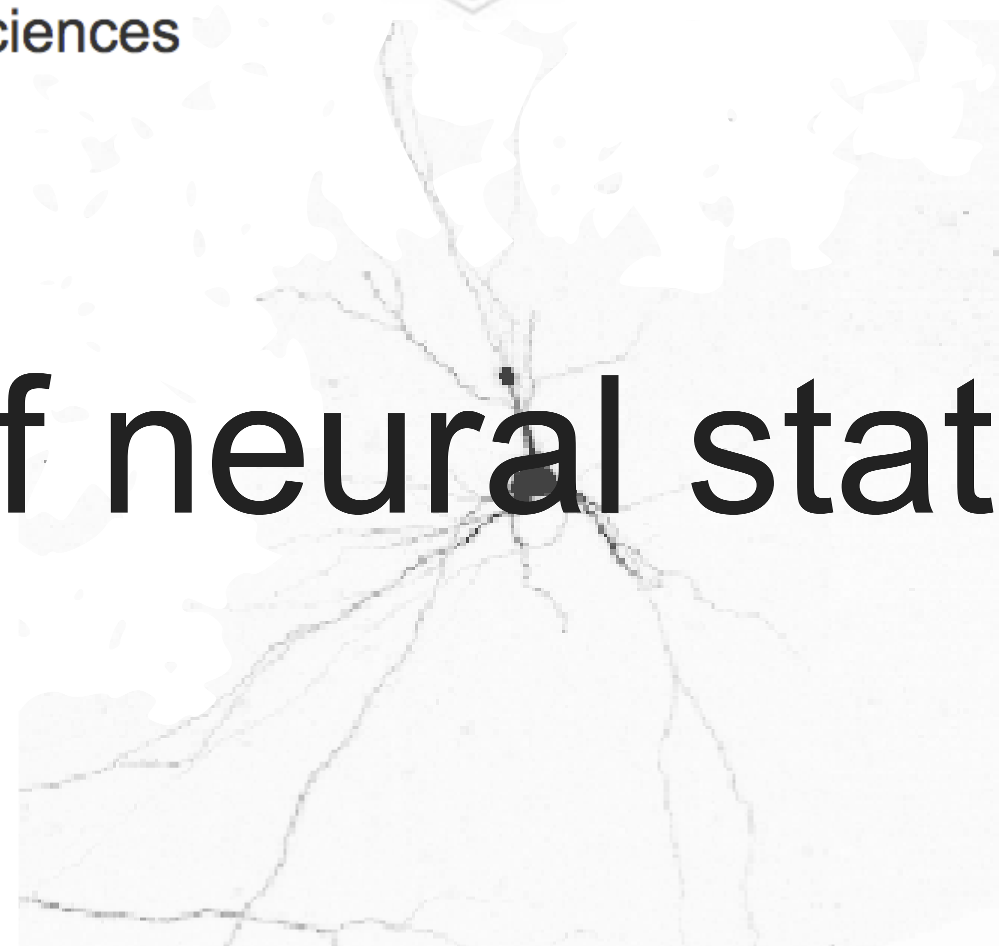
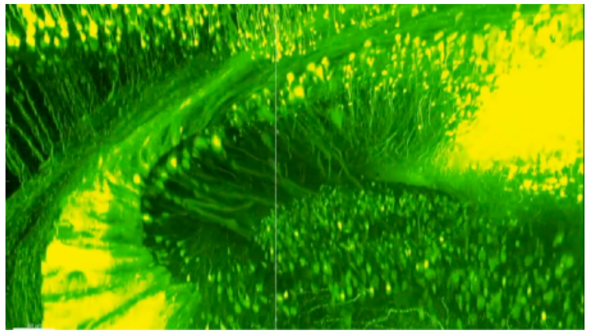
Kavli Institute for Systems Neuroscience
Centre for Neural Computation



Shape of neural state space

Work largely based on:
Gard Spreemann et al., 2015/2018
Erik Rybakken et al., 2017
And **Nils Baas**

Neuroscience

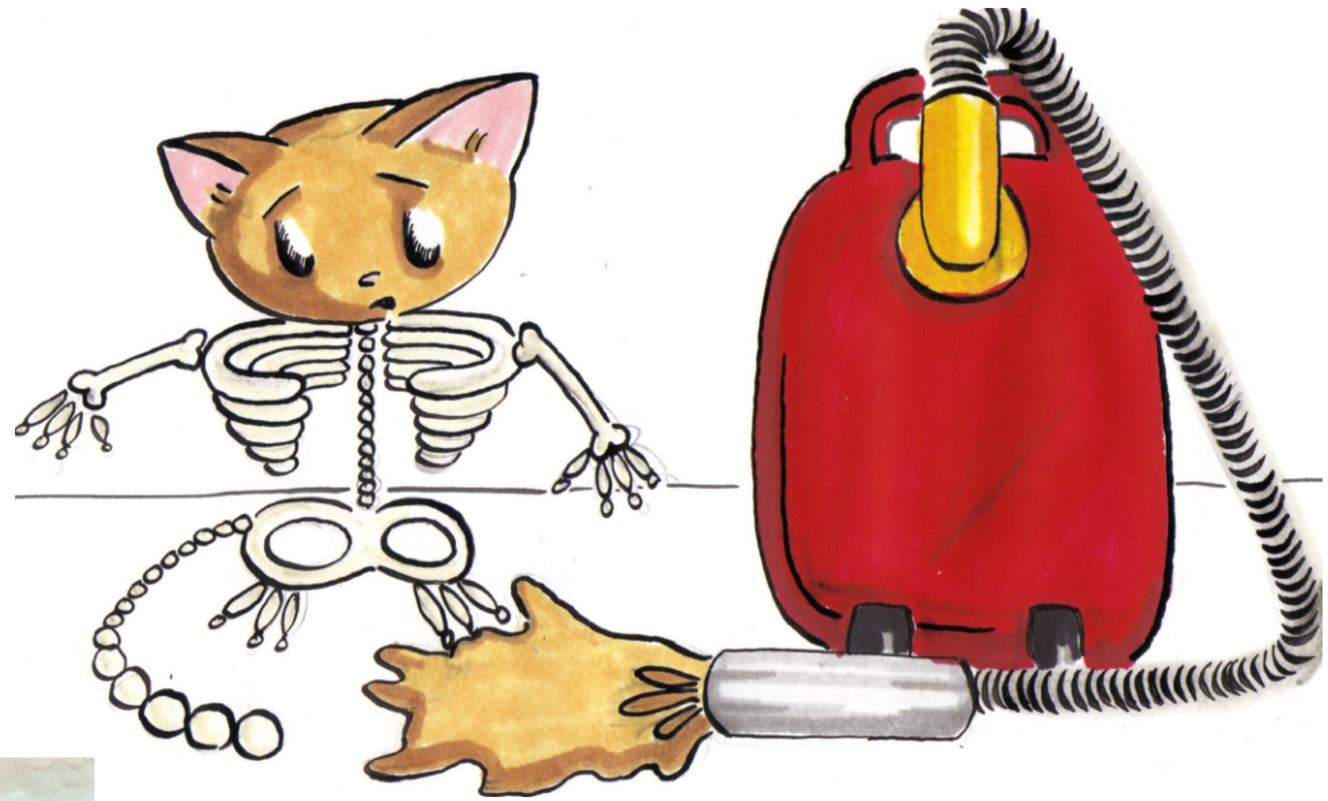


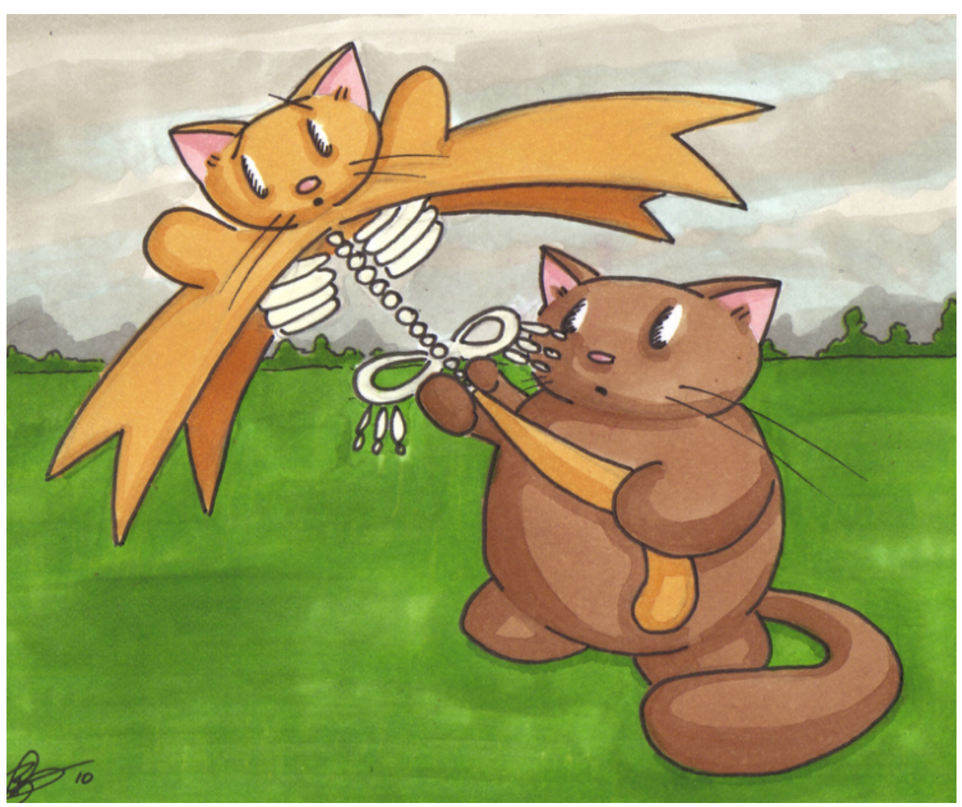
Cheung et al., 2013

how do these enable us to do interesting things?

How to figure out how the brain works:

- Perturb it
- Take it apart
- **Observe it**
- Model it
- etc.



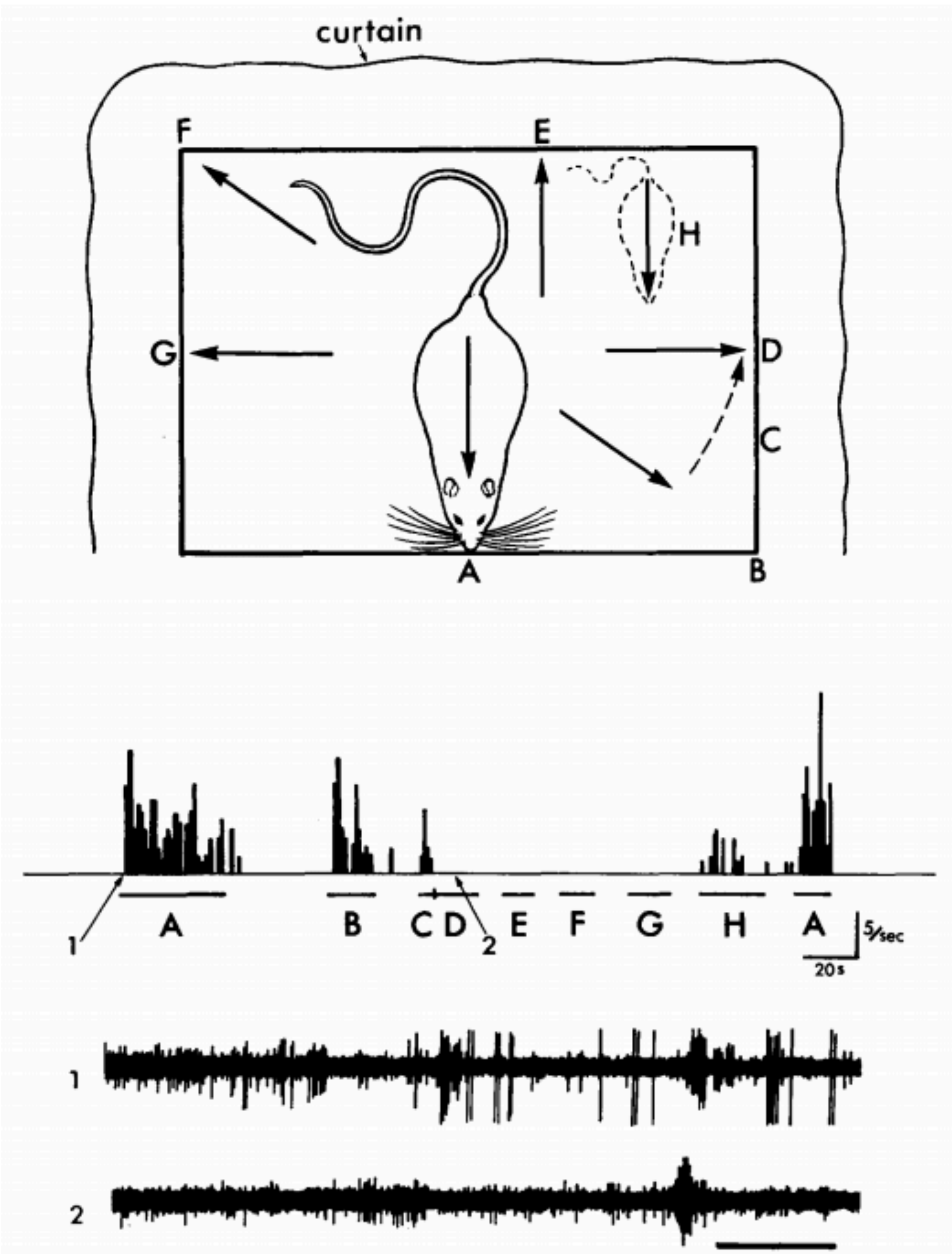


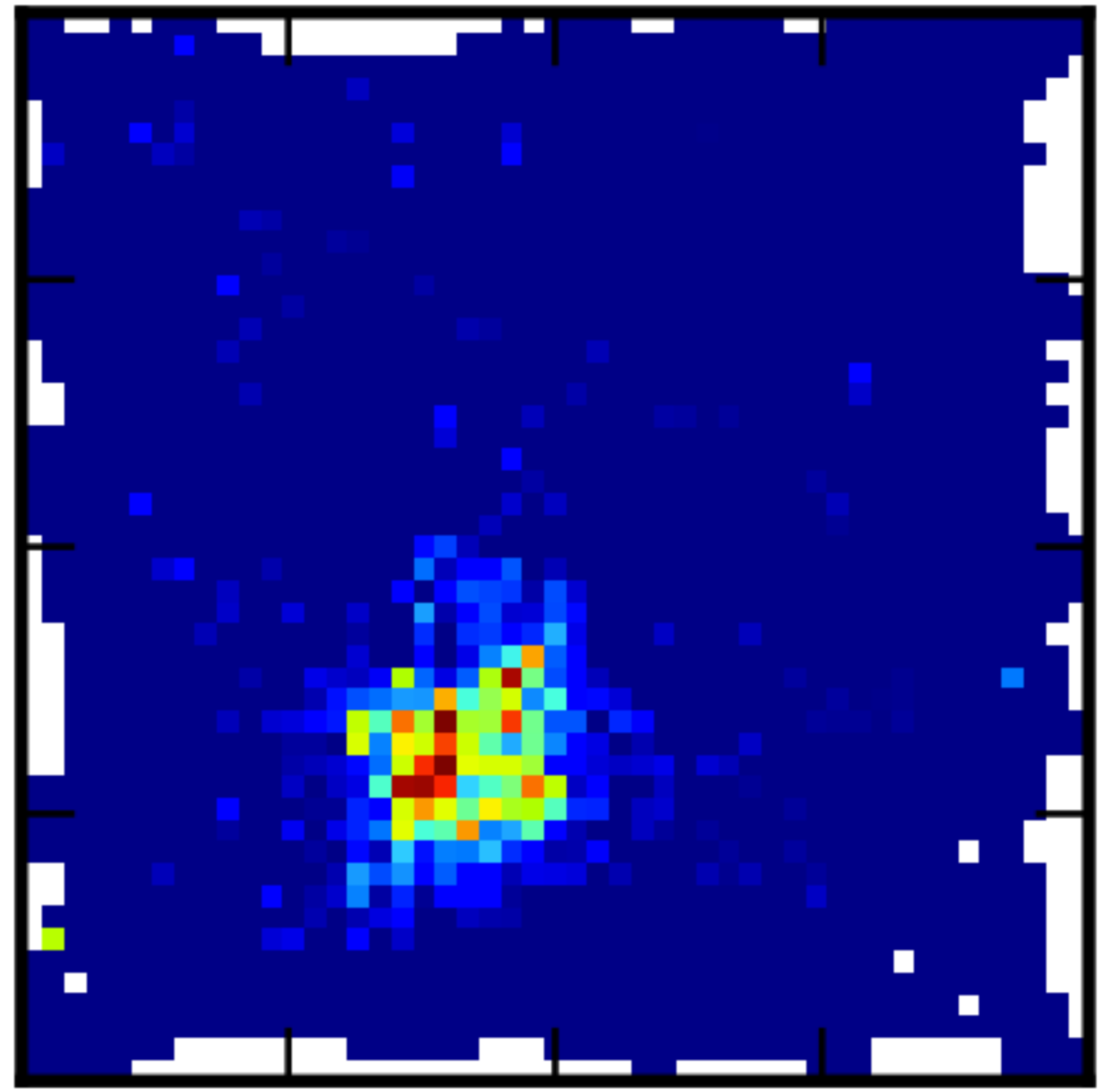
Example - place cell

"Unit activity was monitored during spontaneous behaviours such as **walking, eating, drinking, grooming, and sleeping**, and during elicited behaviours such as **orienting, sniffing at cotton wool or various odours, biting at a polyethylene tube, and in some instances, bar-pressing for food**. Responses to simple **auditory (clicks, whistles, scratching noises), visual (moving light, hand, black and white striped board), olfactory (various odours, rat feces), and tactile (touch and pressure over the body surface) stimuli were also tested**... This preliminary paper will concentrate on the response properties of **8 of the 76 units** obtained in 36 electrode penetrations through the dorsal hippocampus (fields CA1 and 4) and the dentate gyrus in 23 rats. Of the remaining 68 units, **14 were classified as 'arousal' or 'attentional' units** and resemble those reported by Vinogradova et al.; **21 'movement' units** had patterns of activity directly related, to the animal's behaviour, firing briskly during some but not necessarily all of the following behaviours: orienting, sniffing, bar-pressing, and walking, and firing infrequently or not at all, during eating, drinking, grooming, quiet sitting, and slow wave sleep*; **two units** had interesting properties relating to the **animal's expectations**; and for the remaining **31, either no adequate stimulus or behaviour could be found** or their responses were inconsistent and uninterpretable. This last group includes **15 units which**, apart from an occasional spike in conjunction with a burst of spikes in several smaller units, **remained silent in spite of considerable**, **and sometimes drastic, attempts to fire them.** "

O'Keefe and Dostrovsky, 1971

Example - place cell

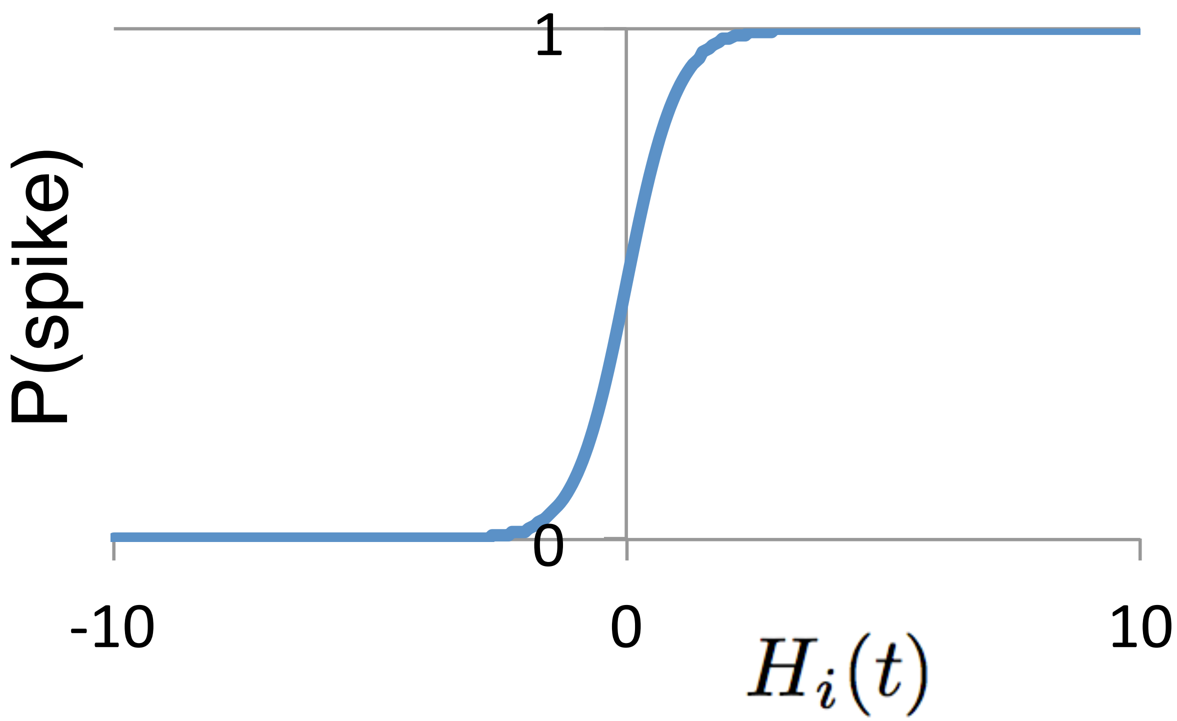




O’Keefe and Dostrovsky, 1971

Model selection with GLMs

$$P(S_i(t+1)|\mathbf{S}(t)) = \frac{\exp[S_i(t+1)H_i(t)]}{2\cosh H_i(t)}$$



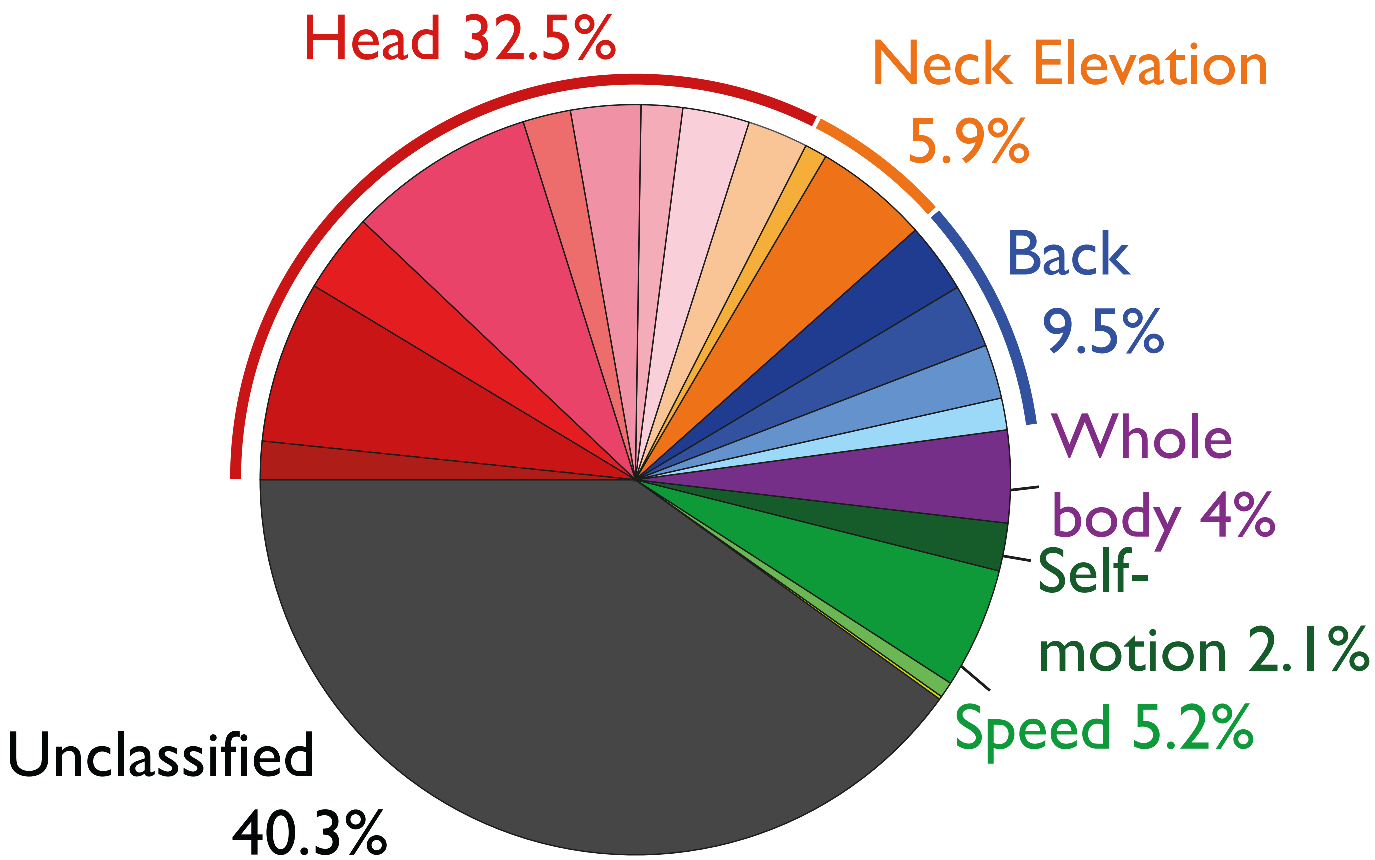
H(t) can include may things:

- input from other cells
- cues in the environment
- aspects of the experiment (e.g. head direction)
- motor things …. etc.

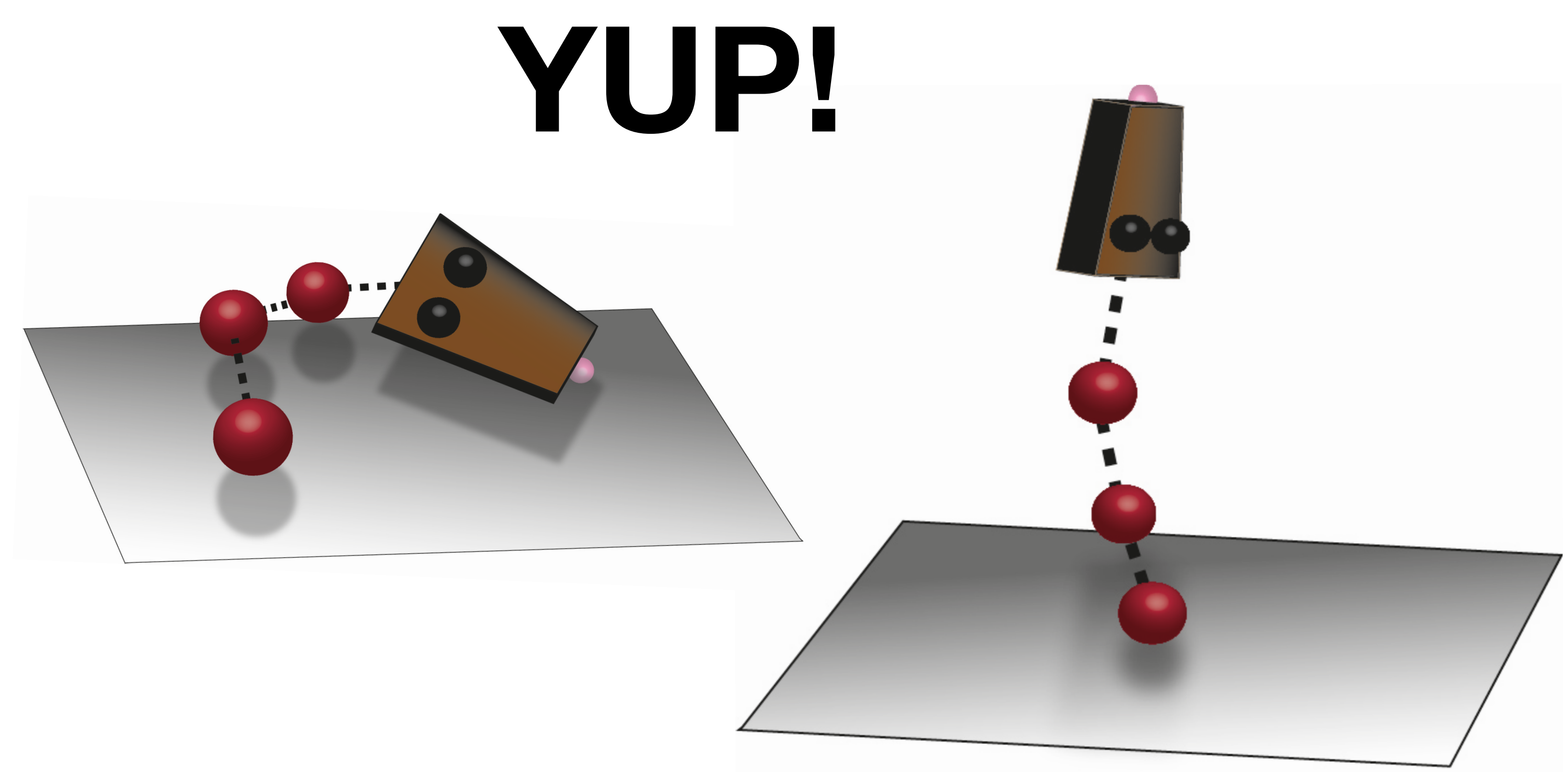
$$H_i(t) = h_i + \sum_j J_{ij} S_j(t)$$

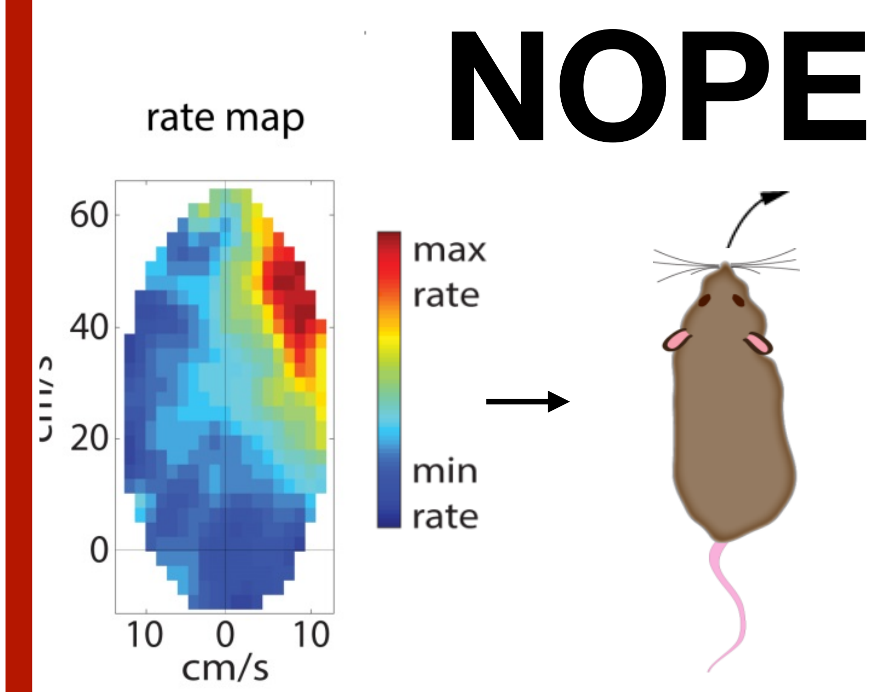
Truccolo et al., 2005,
Nelder & Wedderburn, 1972,
McCullagh & Nelder, 1989,
Roudi et al., 2015

Model selection: tedious but important



Parietal cortex

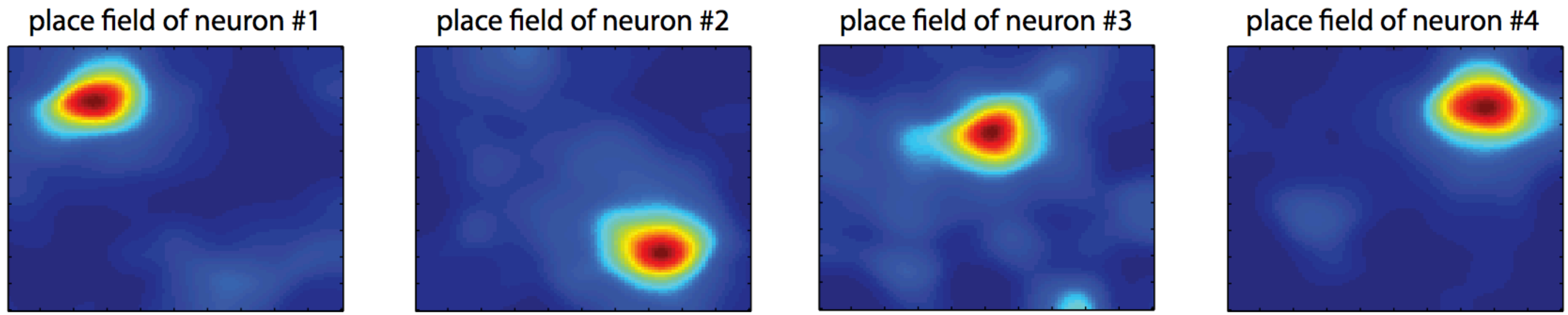


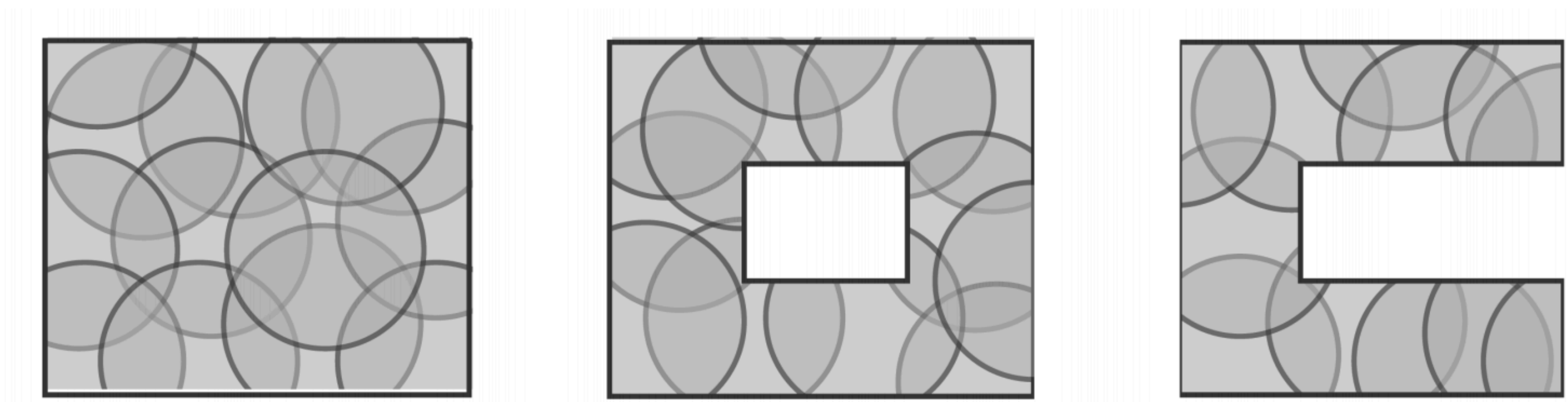


Mimica et al., 2018

This typical way of doing model selection can be:

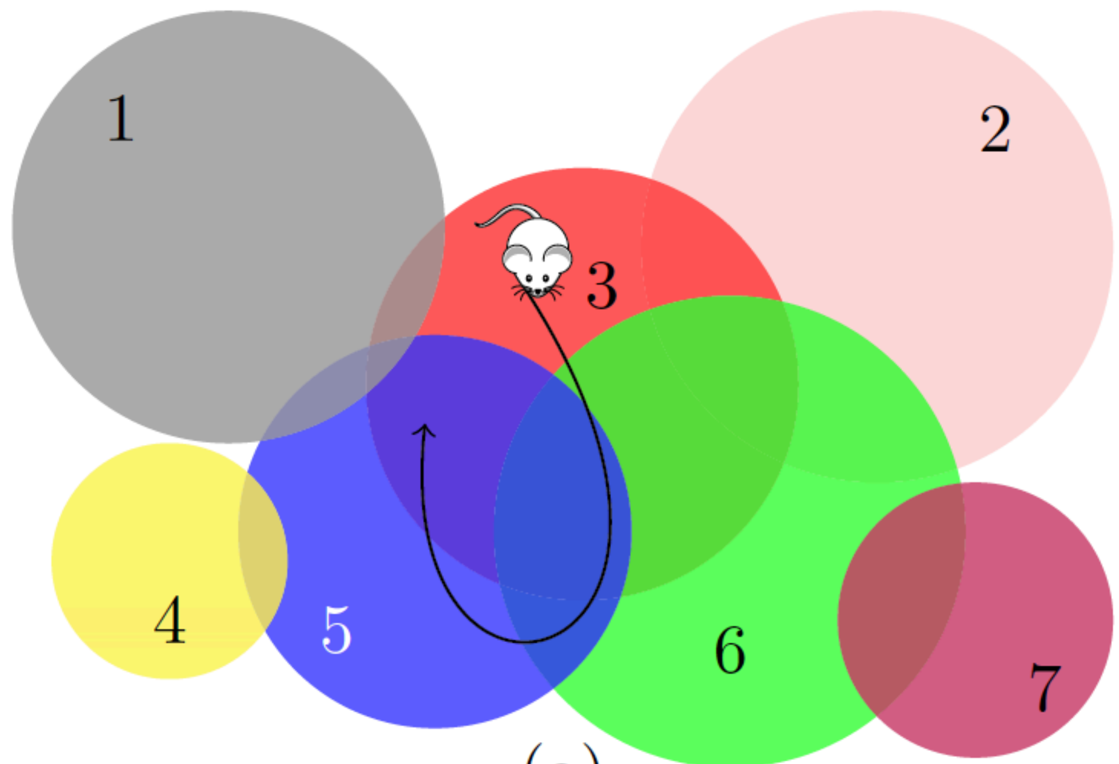
- Boring
- Time consuming
- Trying everything is impossible
- Easily “tampered”



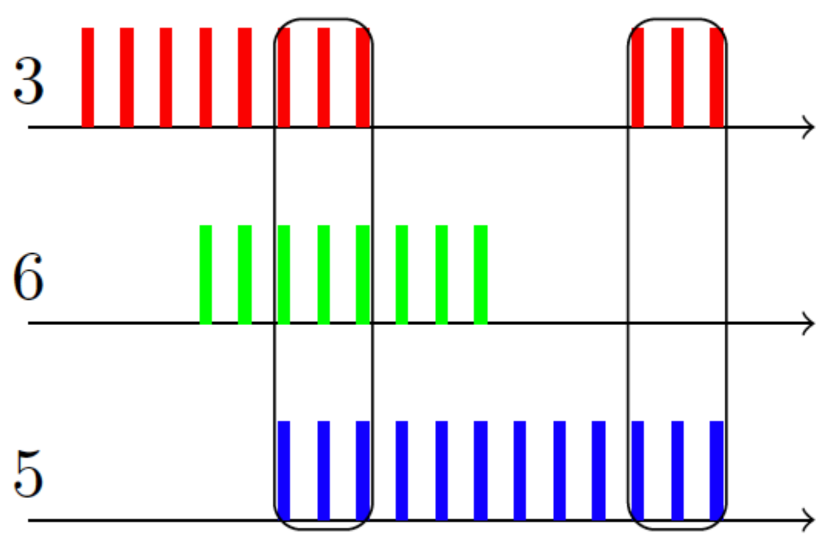


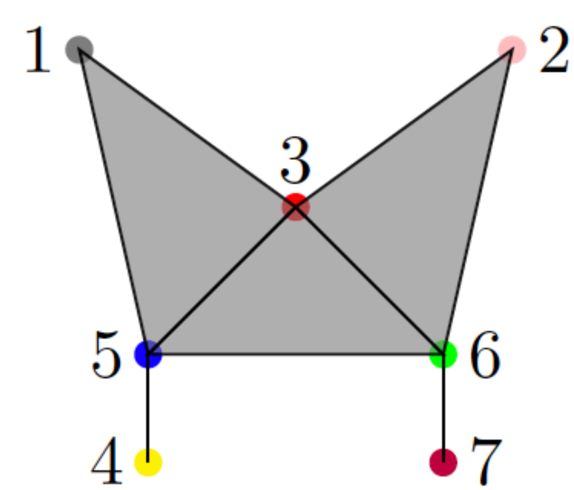
Singh et al., 2008
Curto and Itskov, 2008
Curto, 2016

From data to space



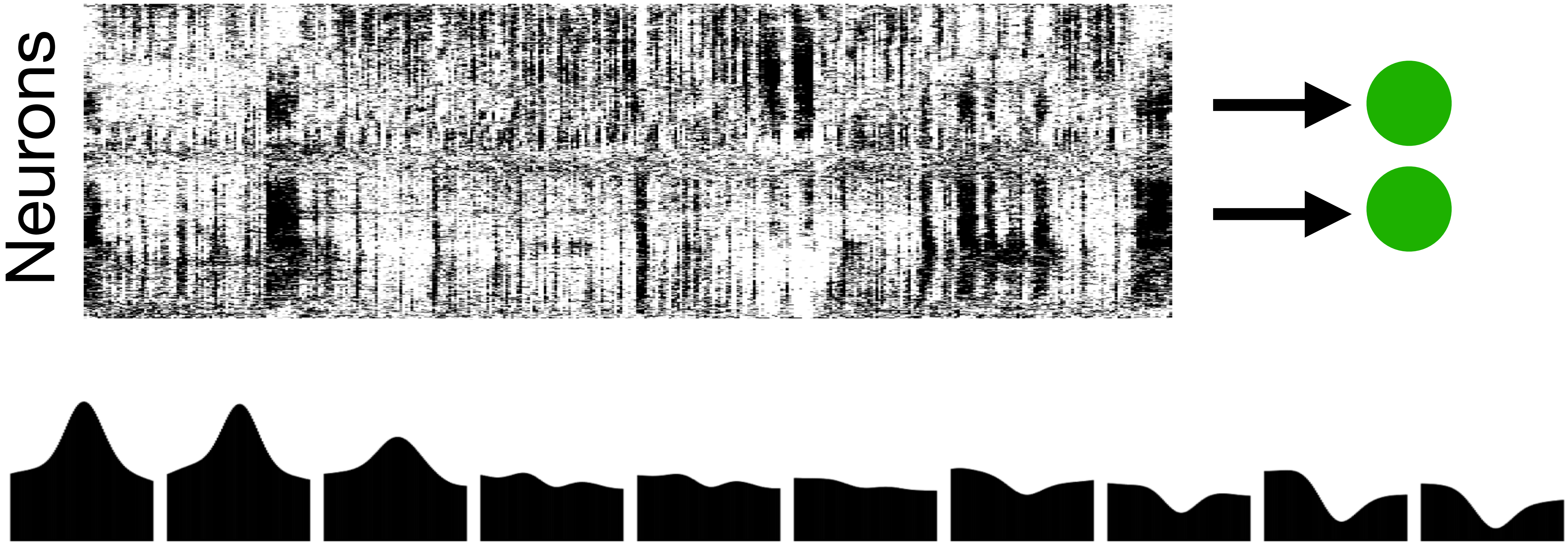
(a)





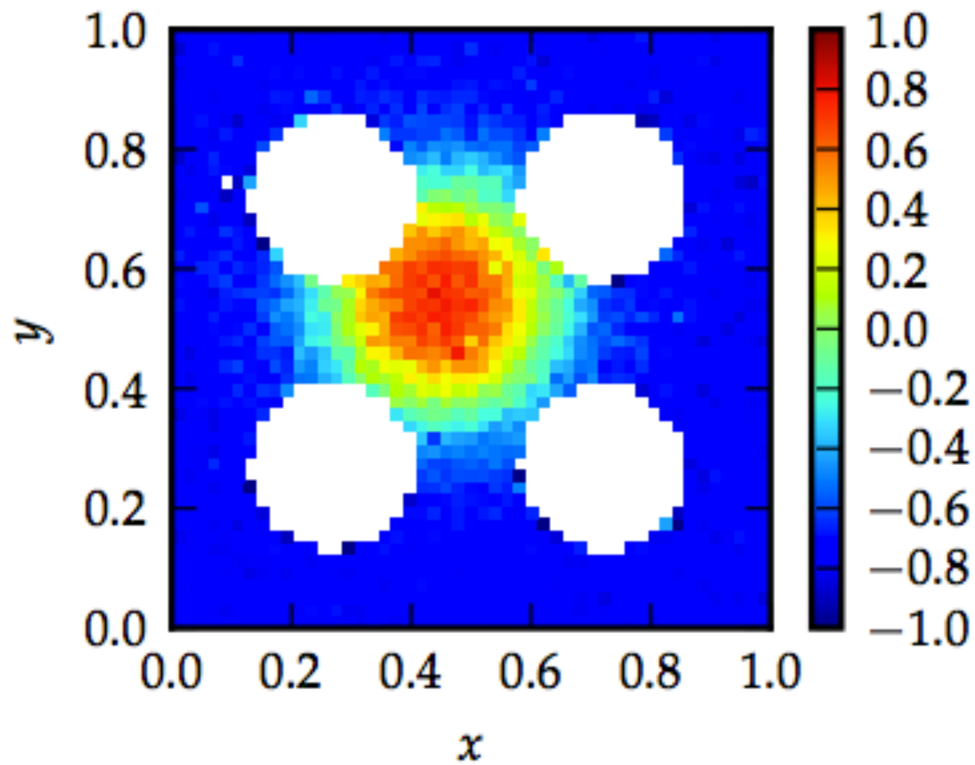
Singh et al., 2008
Curto and Itskov, 2008
Spreeman et al., 2015/18

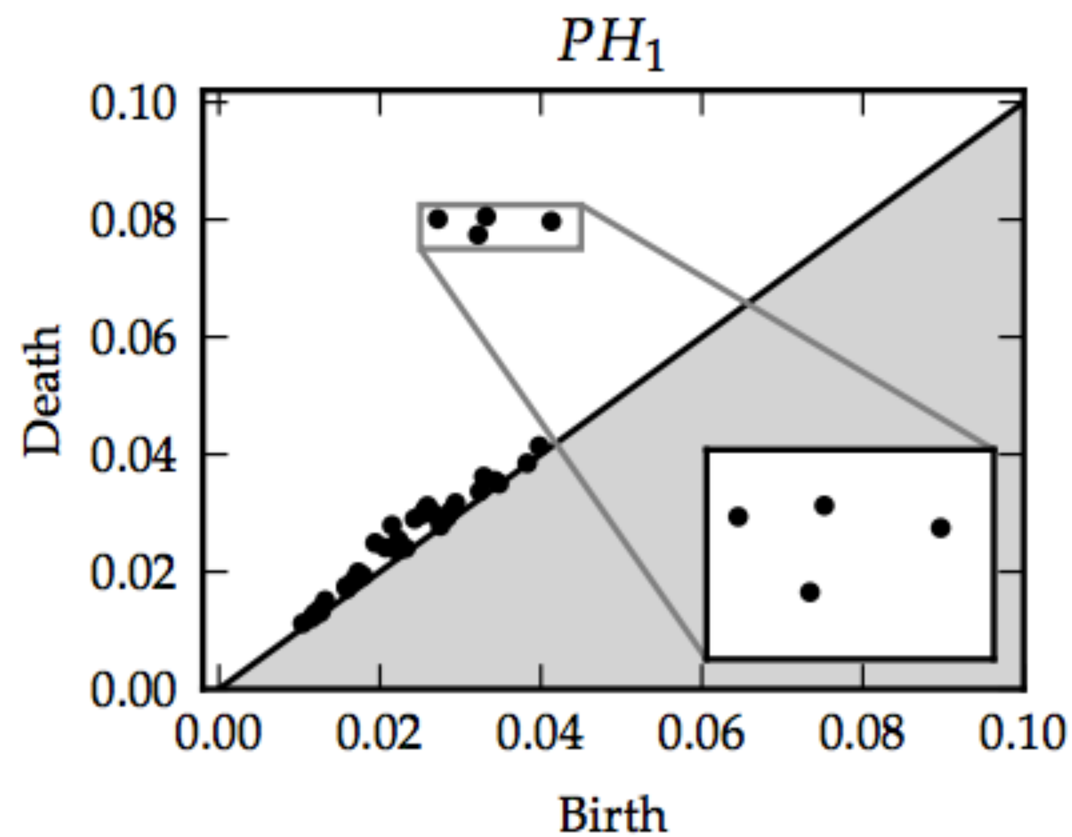
Neurons as vertices

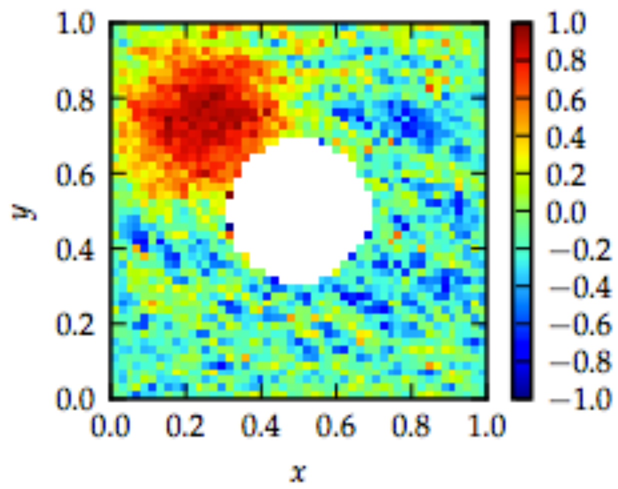


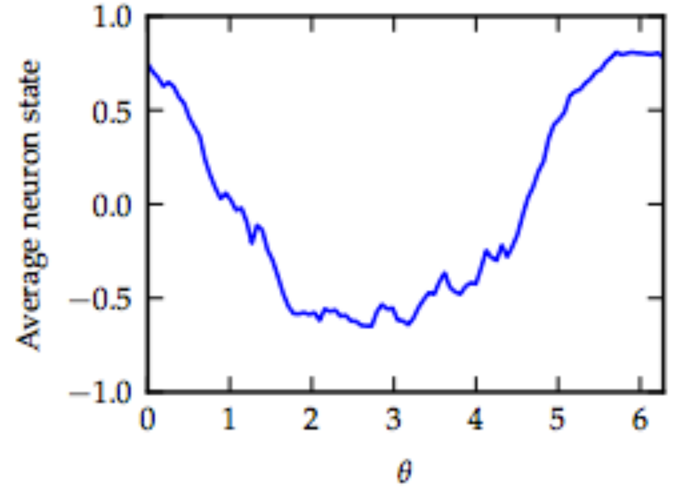
1 - Pearson correlation seemed reasonable

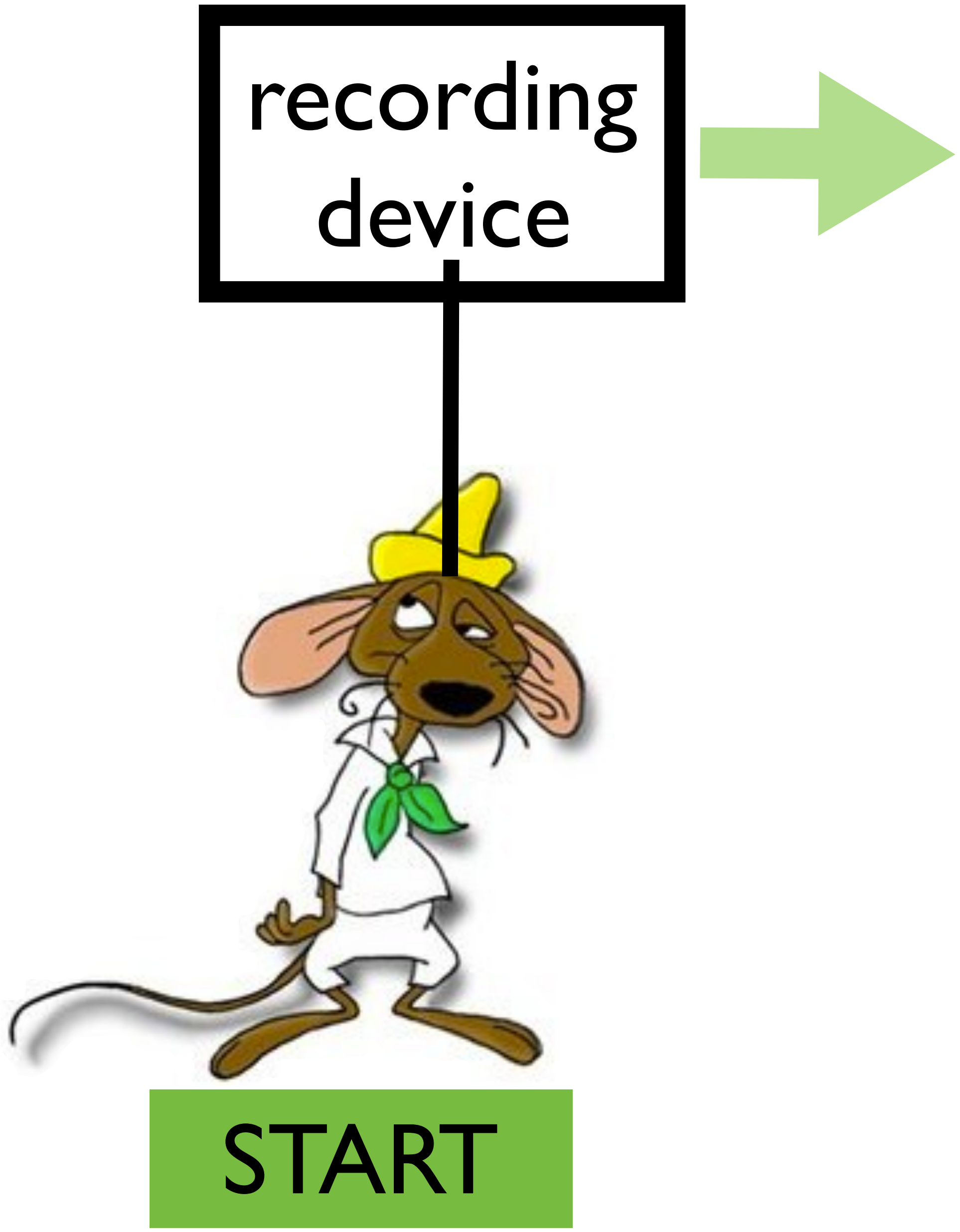
Example with four holes

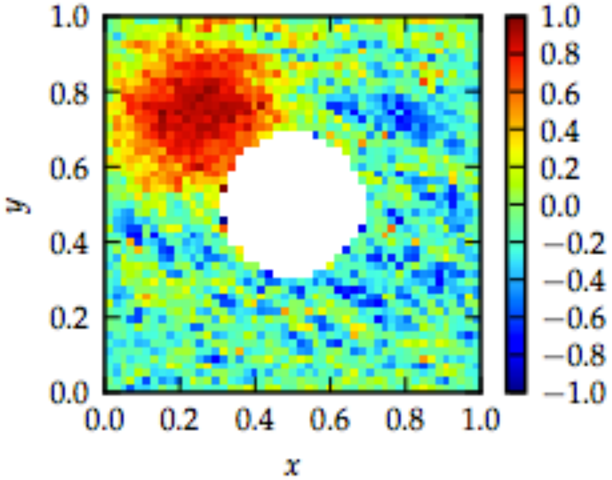


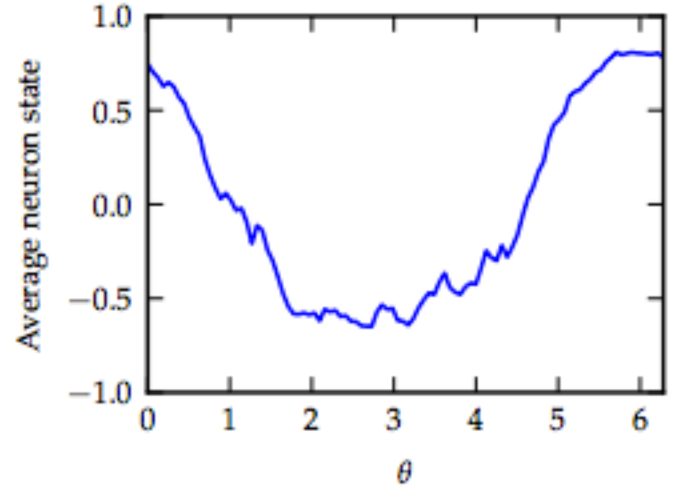


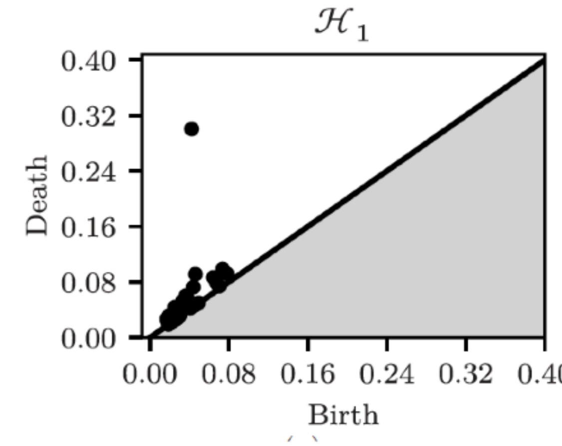

y
x

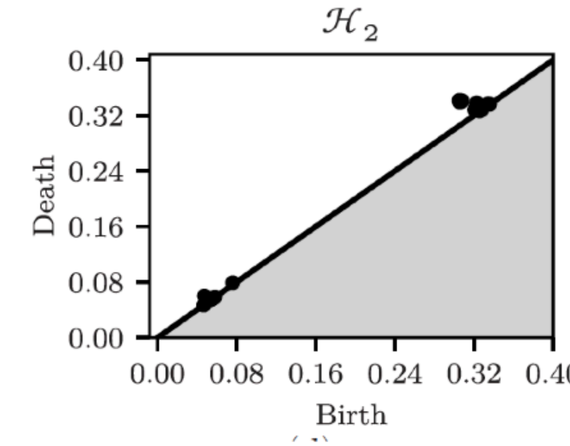

Average neuron state
θ


recording device
START







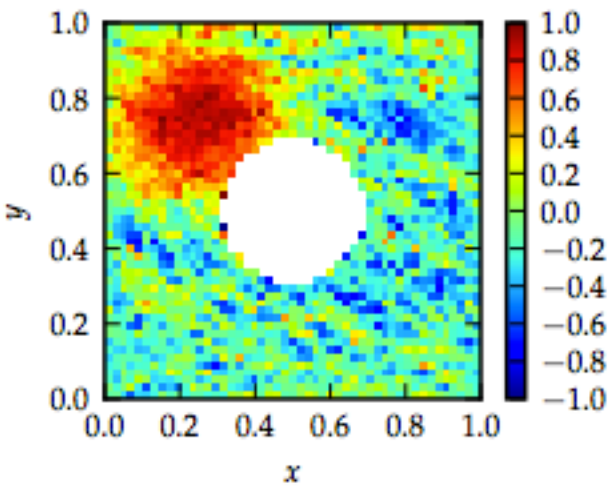


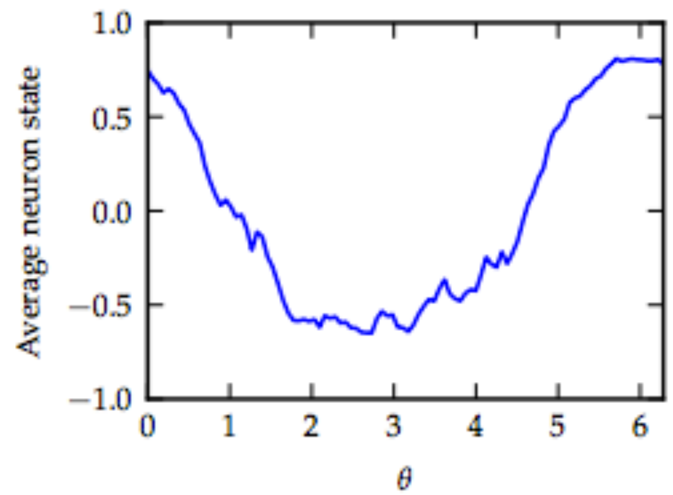
recording device

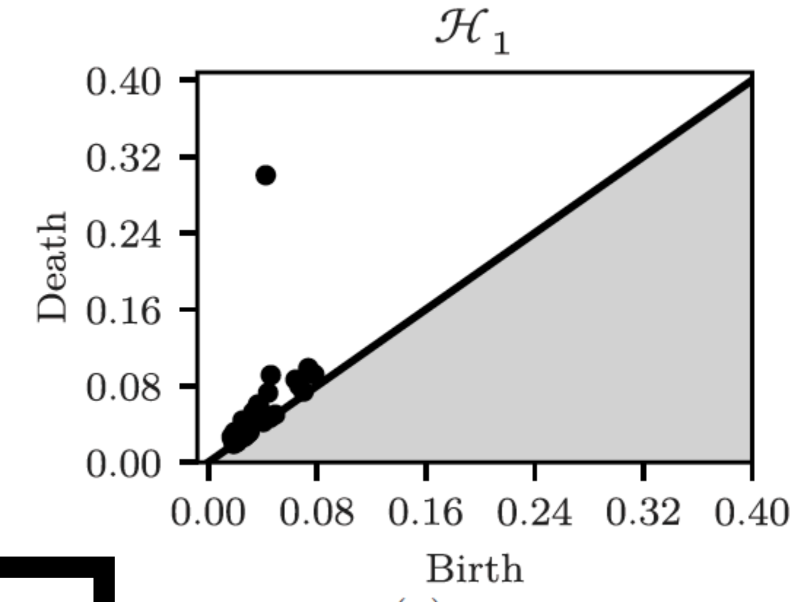
is there a code? If so, does it have a detectable shape?

yup

START







recording device

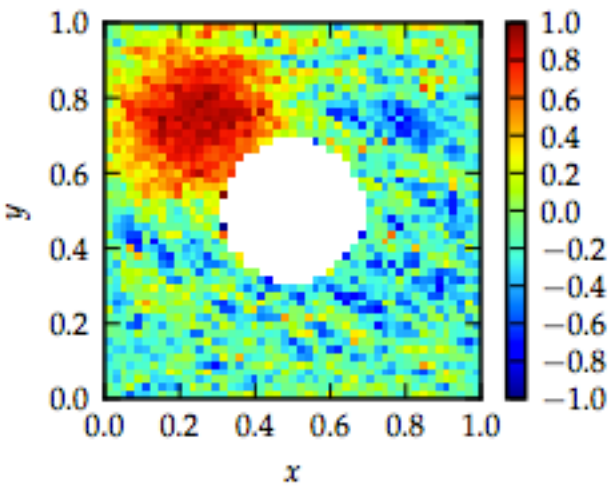
is there a code? If so, does it have a detectable shape?

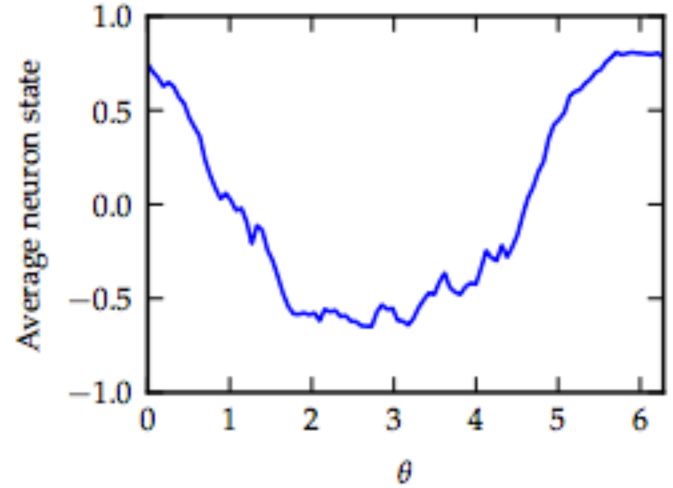
yup

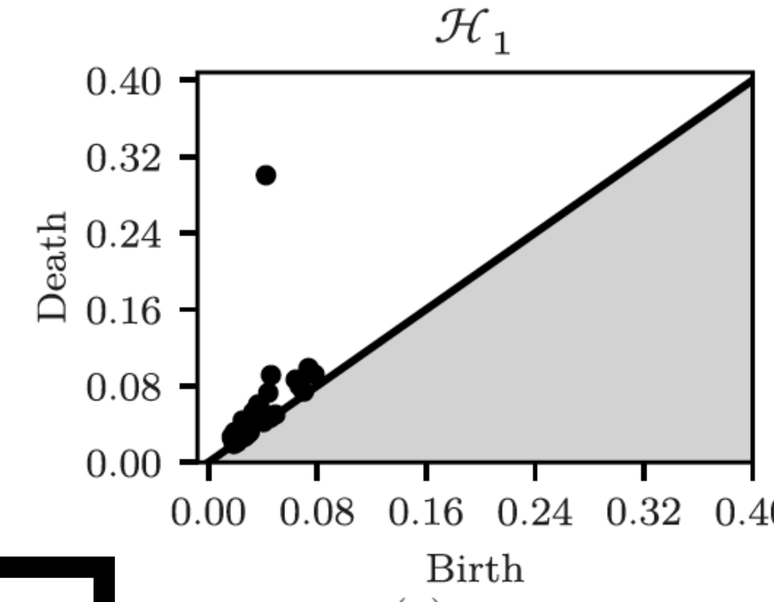
SPACE

Find most likely feature

START

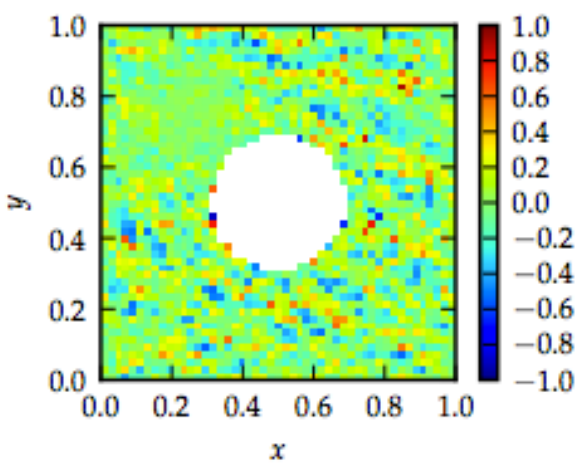


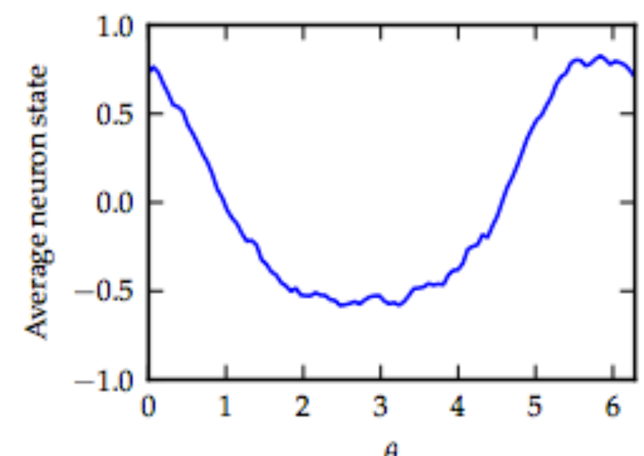




recording device

is there a code? If so, does it have a





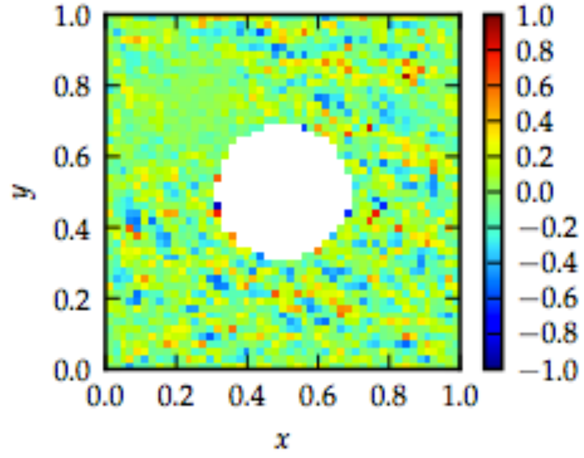
yup

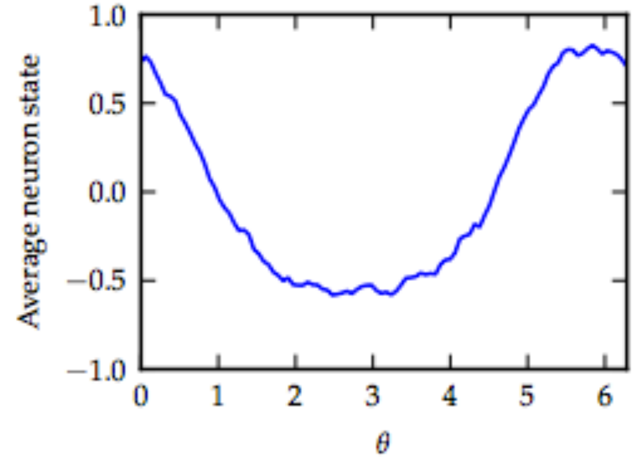
SPACE

START

found something! make "new" data without feature

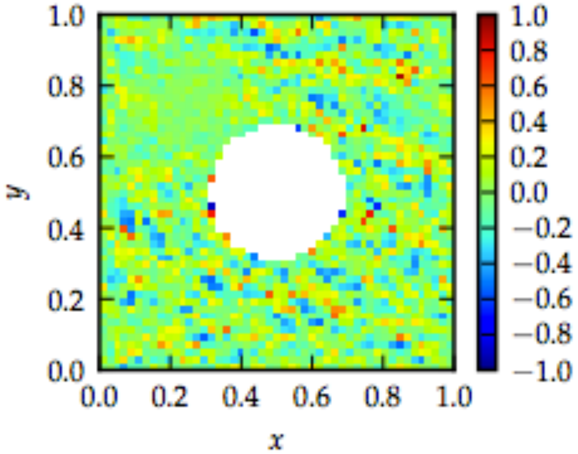
Find most likely feature

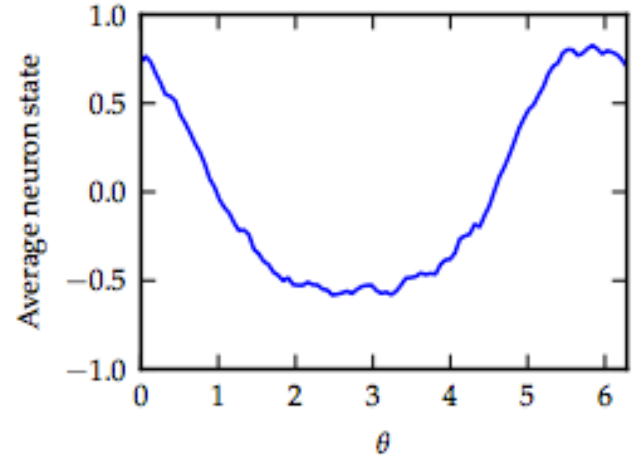


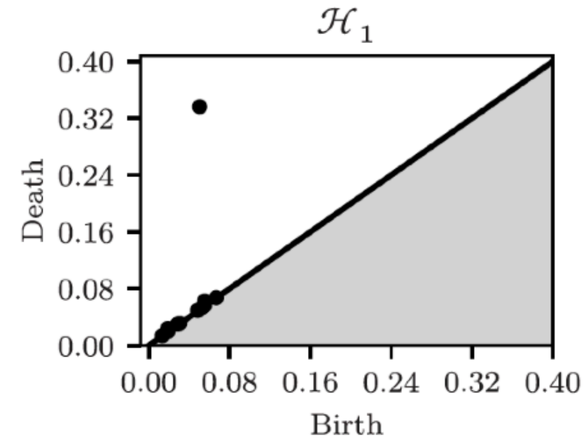


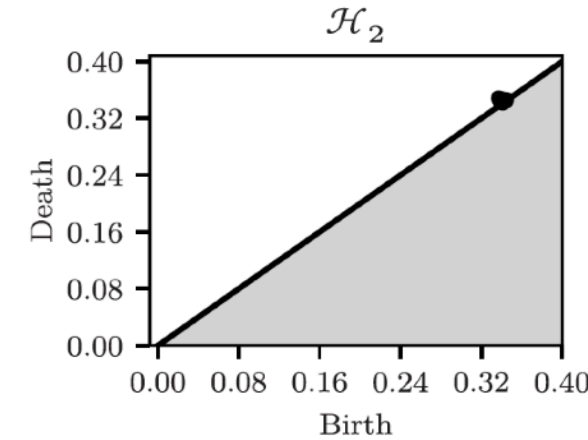
Residual data

is there a code? If so, does it have a detectable shape?





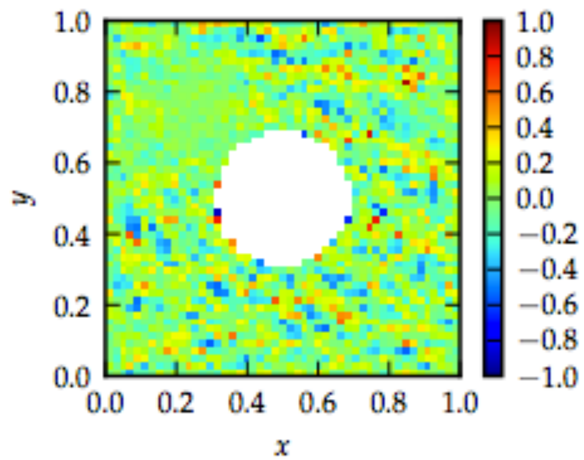


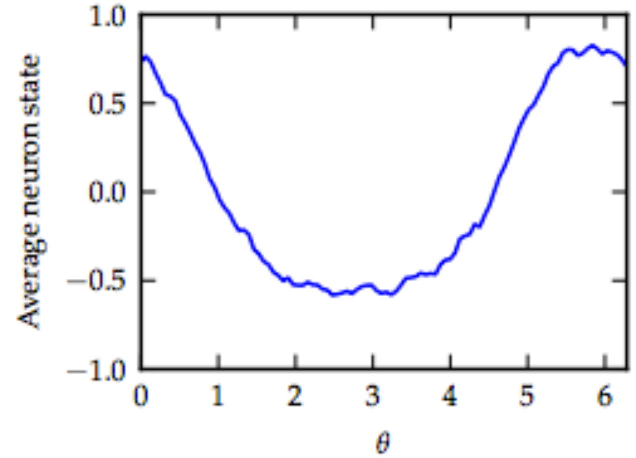


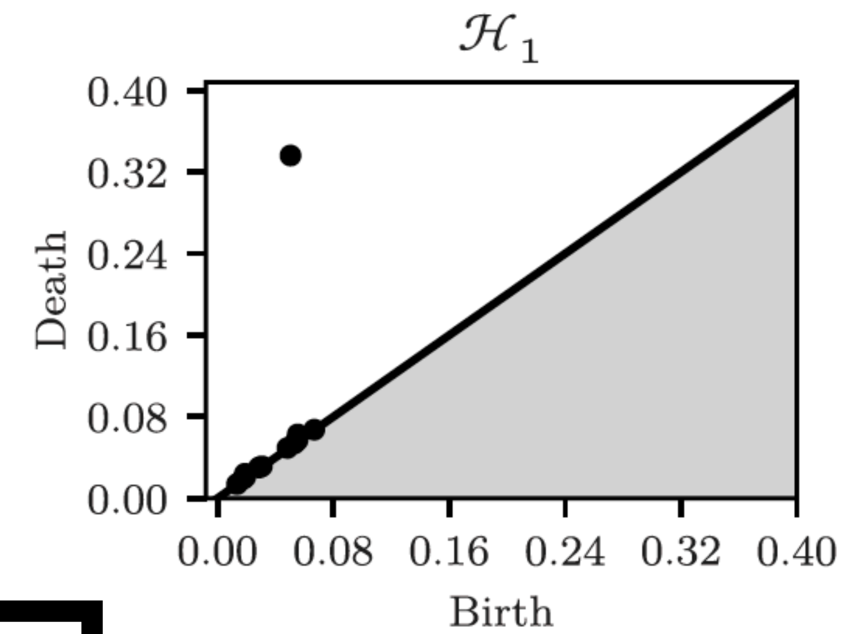
Residual data

is there a code? If so, does it have a detectable shape?

yup







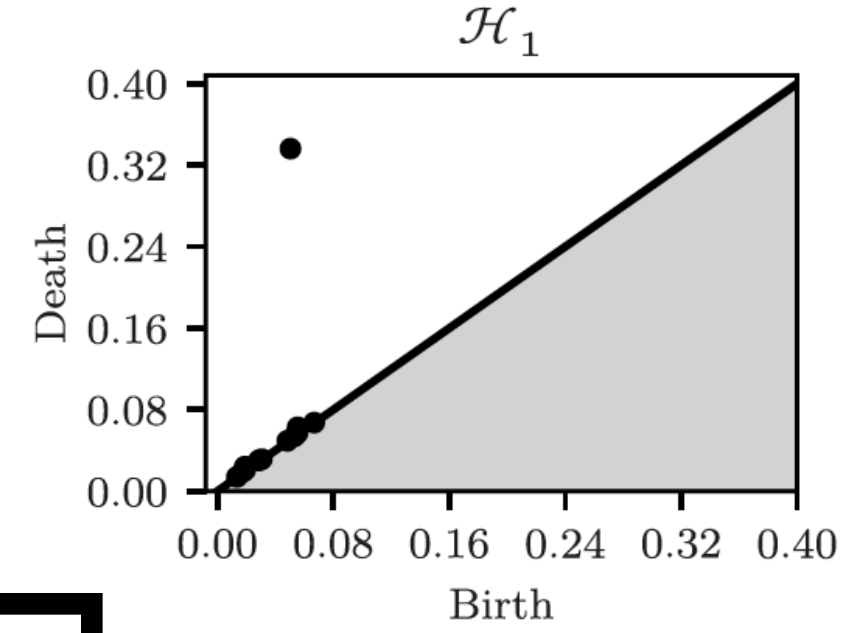
Residual data

is there a code? If so, does it have a detectable shape?

yup

Head direction

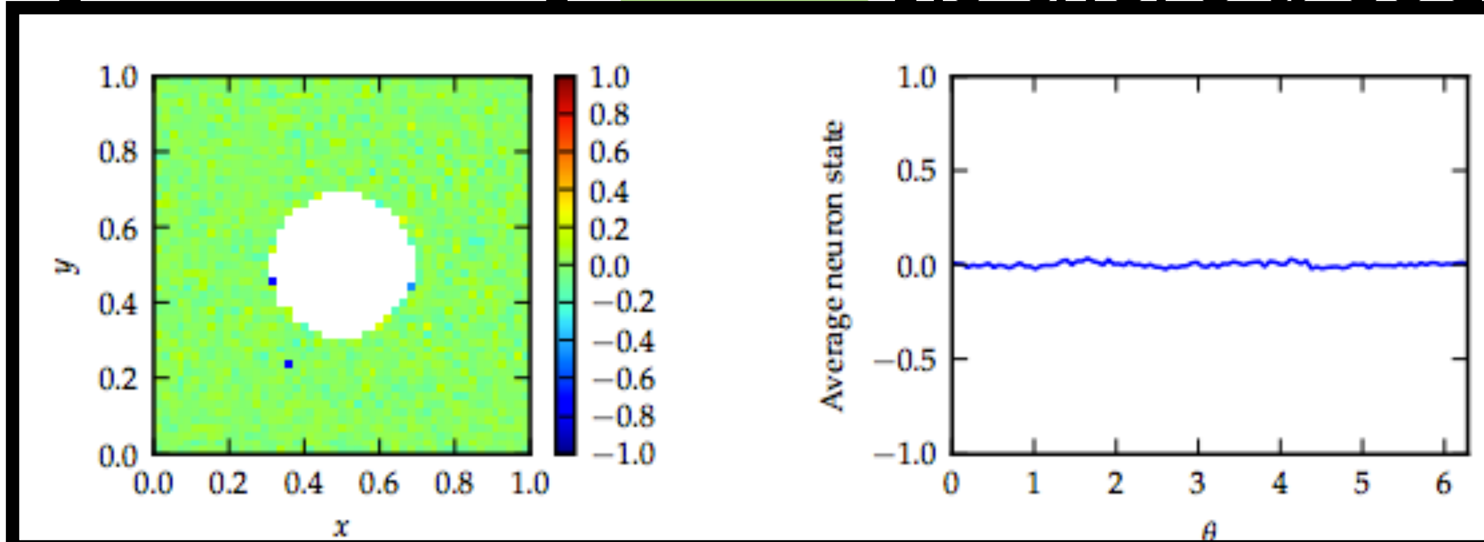
Find most likely feature



Residual

is there a code? If so,

pe?

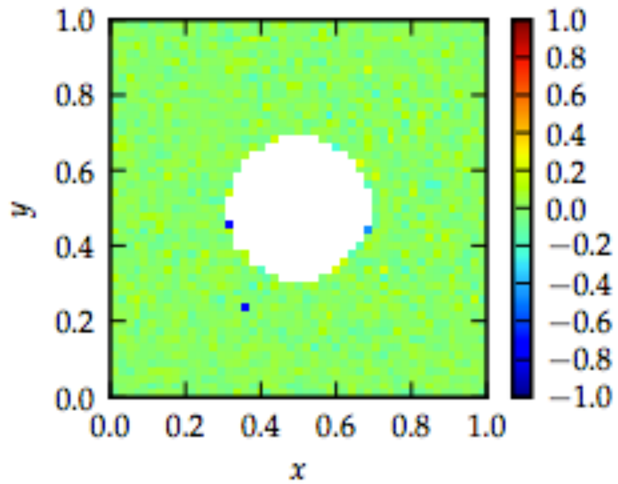


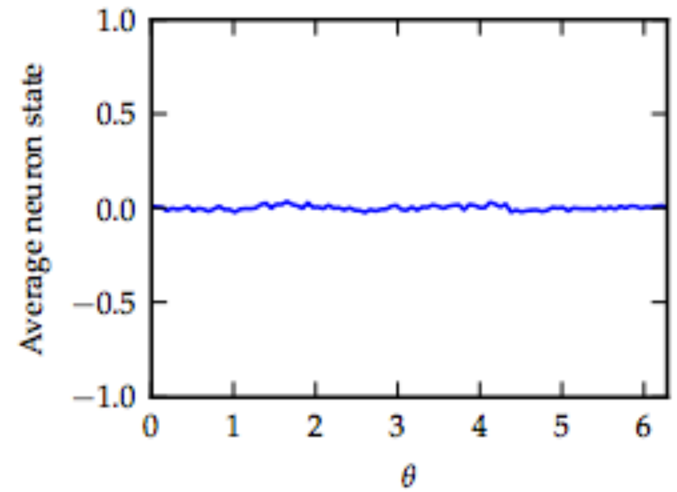
yup

Head direction

Find most likely feature

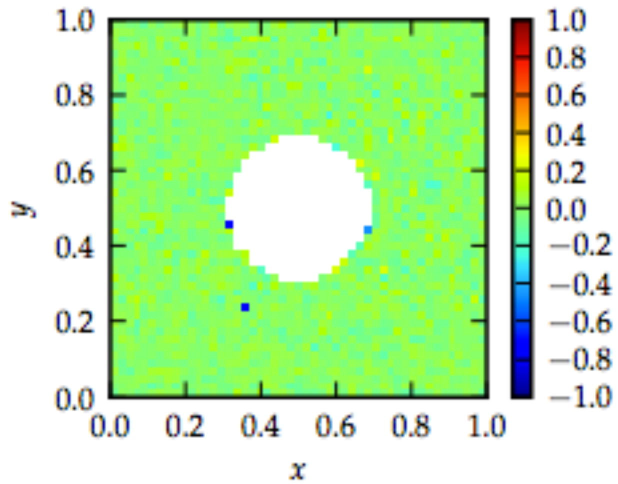
found something!
make “new” data
without feature

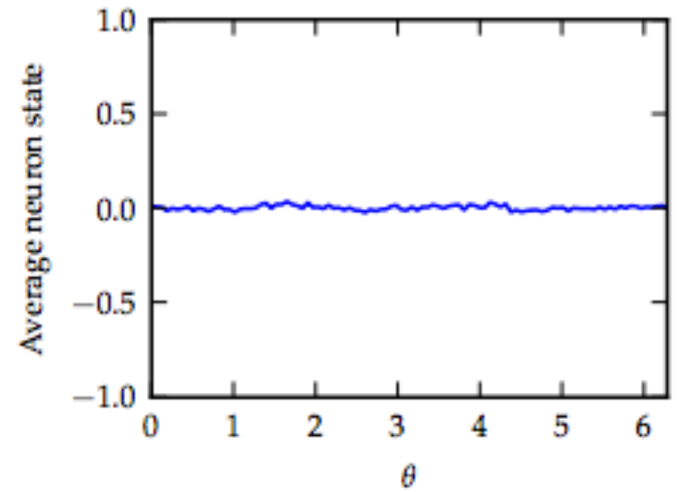




Residual data

is there a code? If so, does it have a detectable topology?

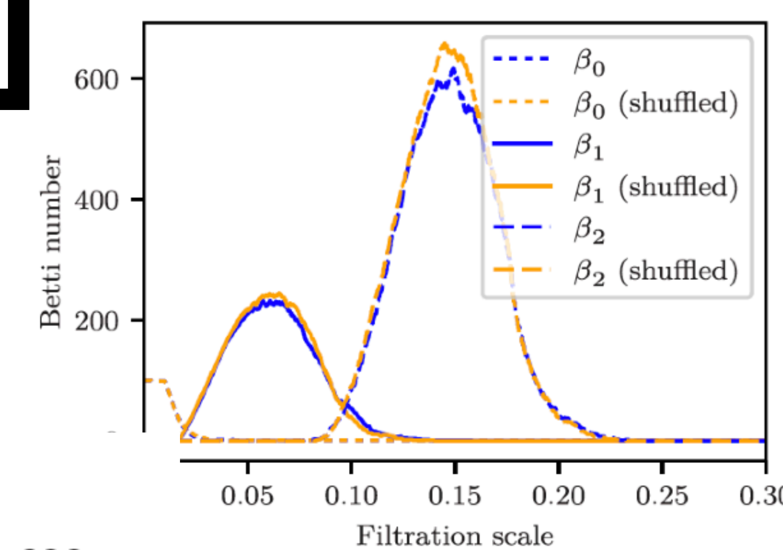


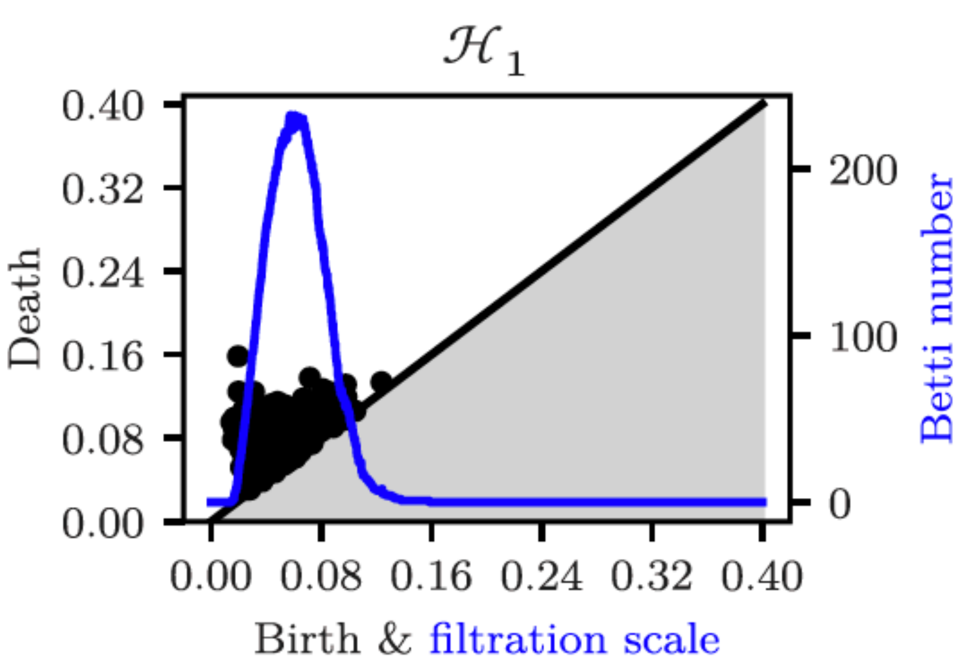


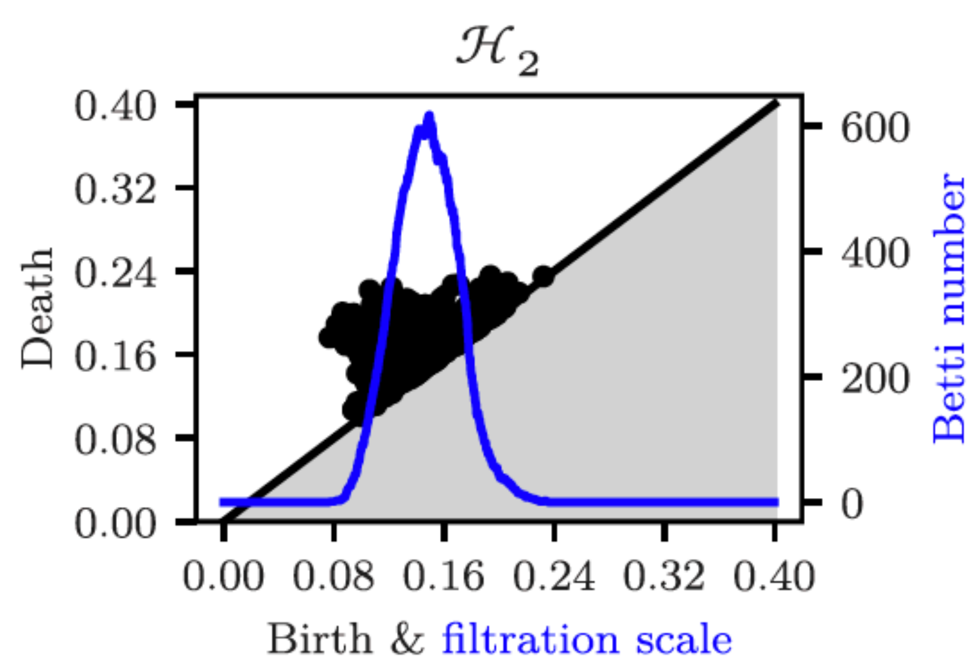
Residual data

is there a code? If so, does it have a detectable topology?

nope (all done)







So, this approach let’s us ask

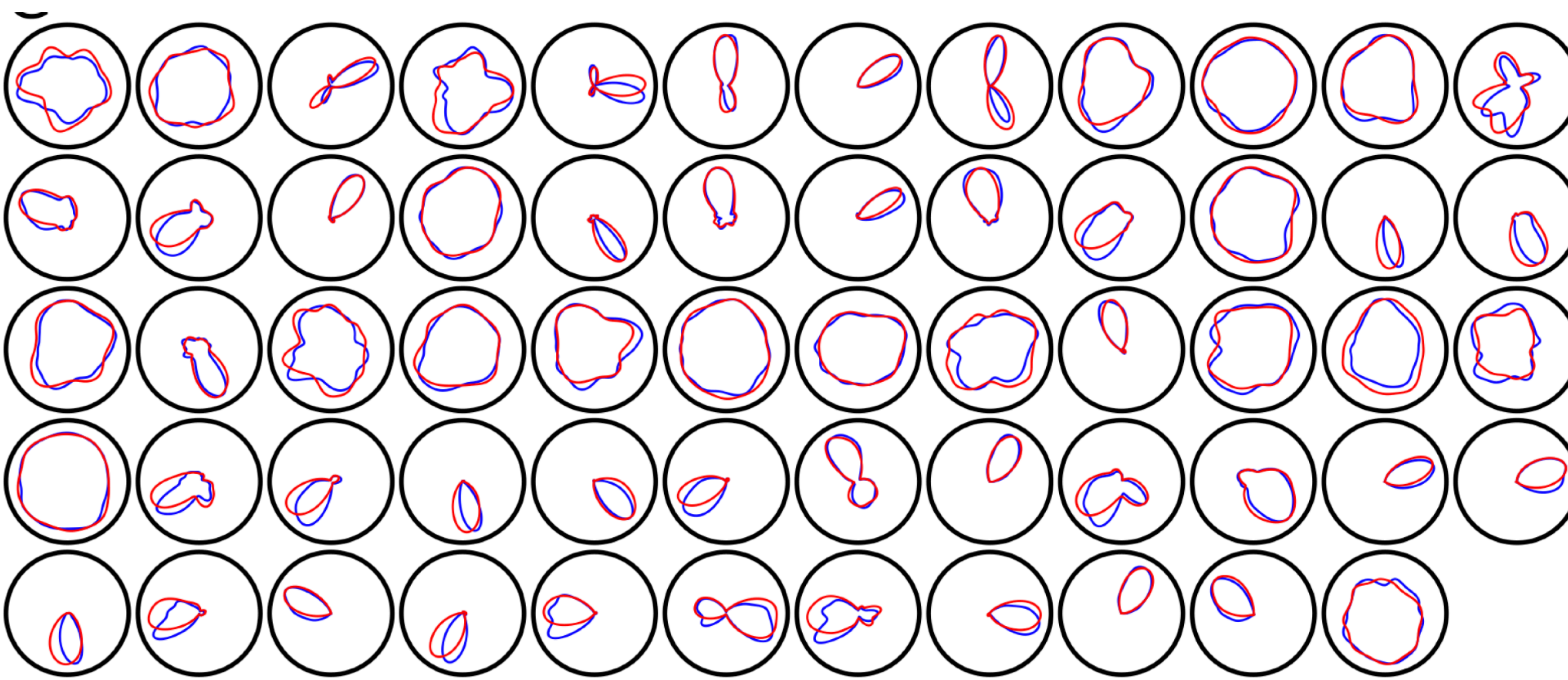
1) is there anything interesting here?

2) does it have a shape?

3) is there anything else?

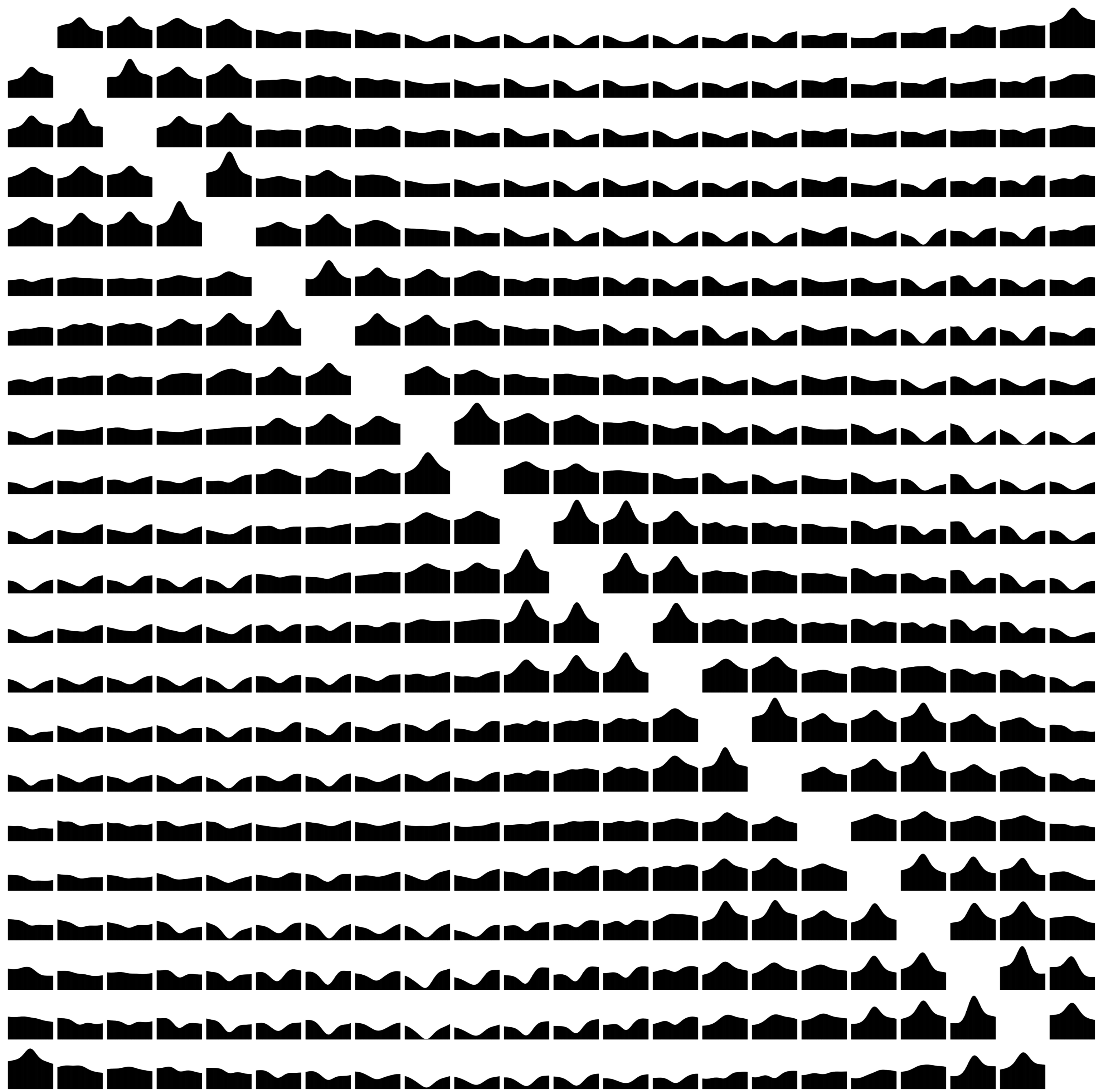
Great, so now for real data

Head direction neurons

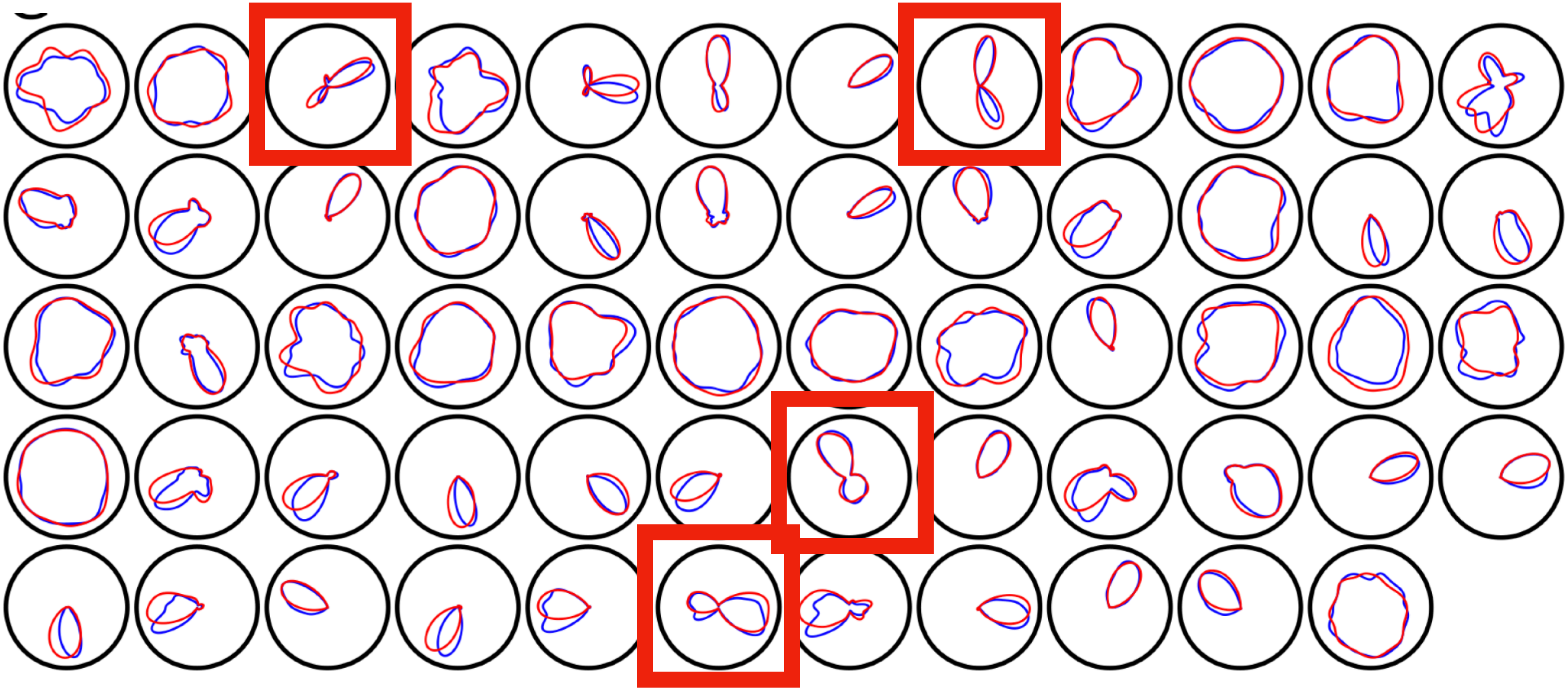


Data from Peyrache et al., 2015

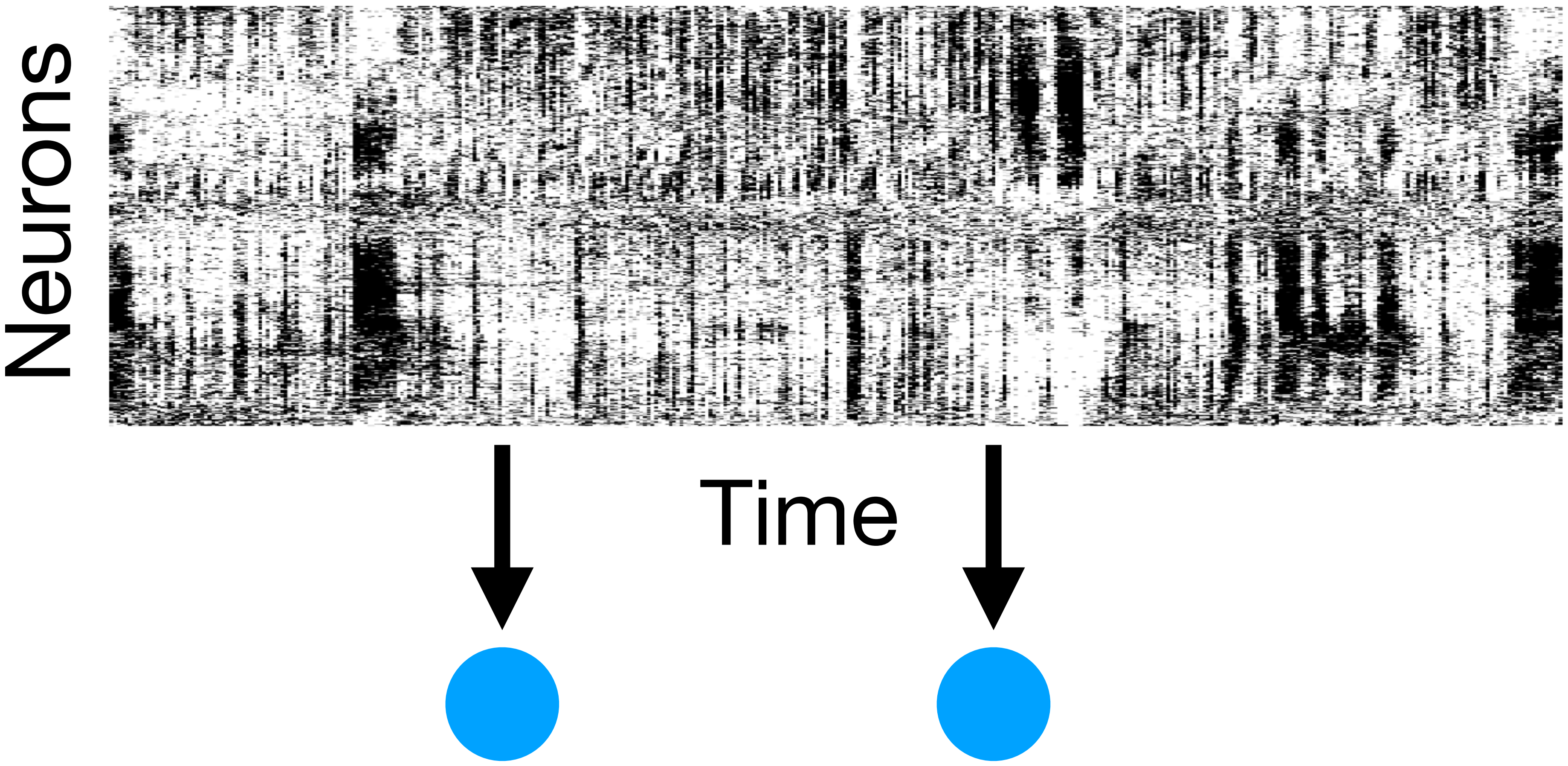
If we choose the neurons properly the circle is very obvious using same as before

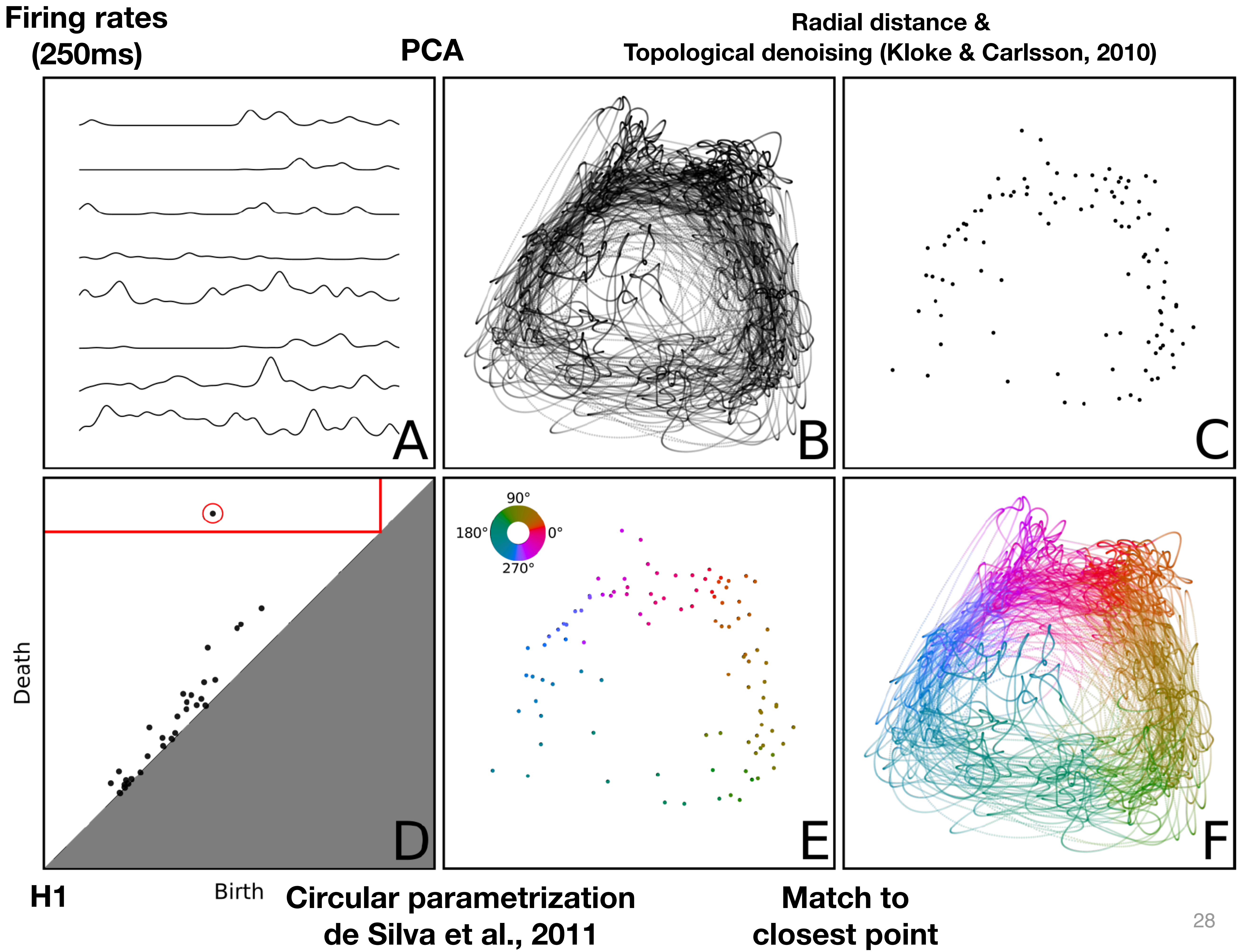


But some complicate things

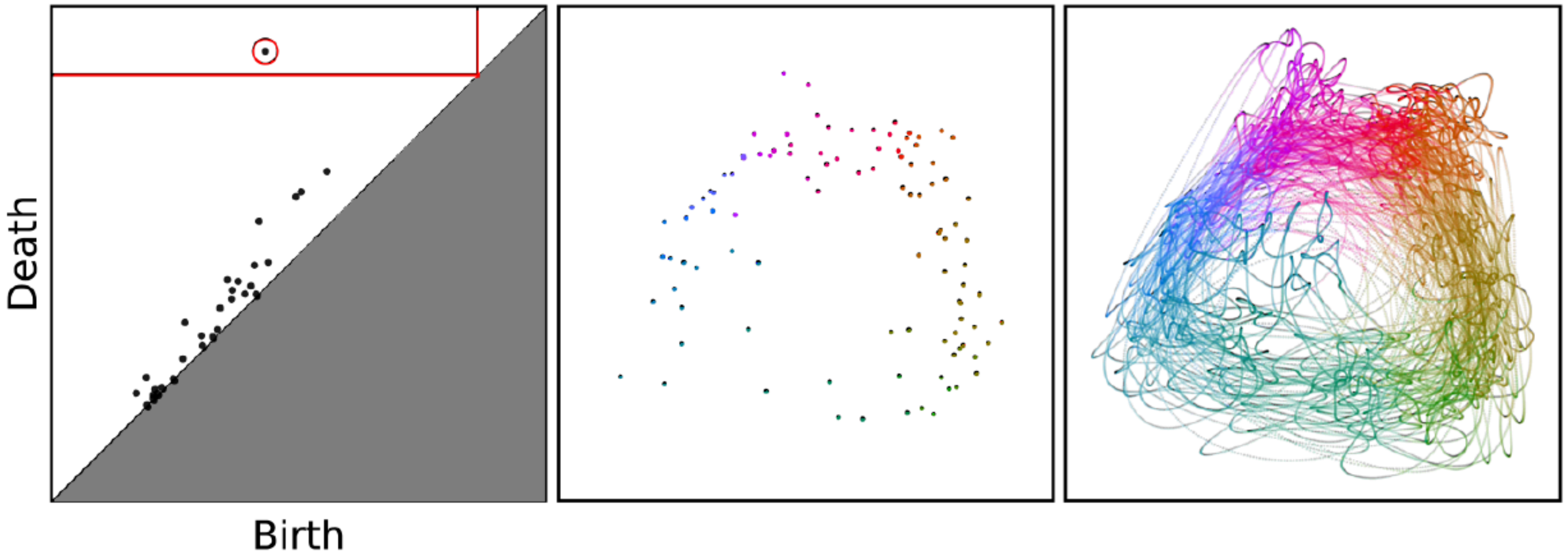


Population states

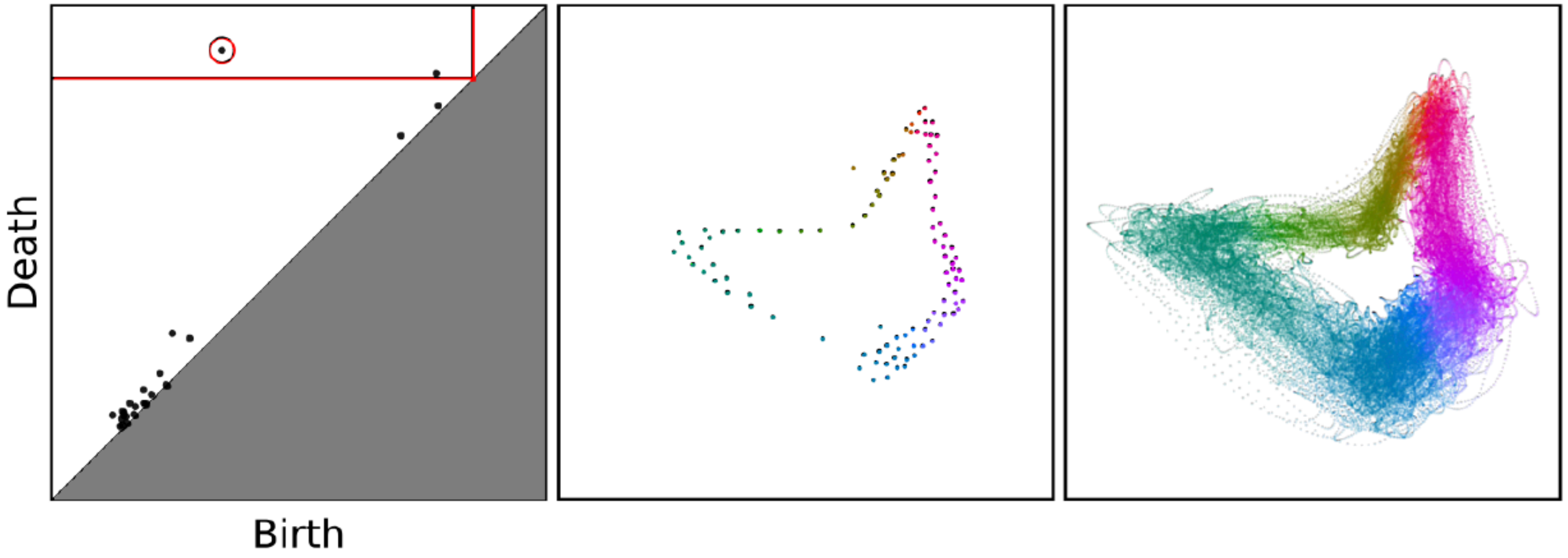




Firing rates (250ms)
PCA
Radial distance &
Topological denoising (Kloke & Carlsson, 2010)
A
B
C
Death
D
90°
180°
0°
270°
E
F
H1
Birth
Circular parametrization
de Silva et al., 2011
Match to
closest point

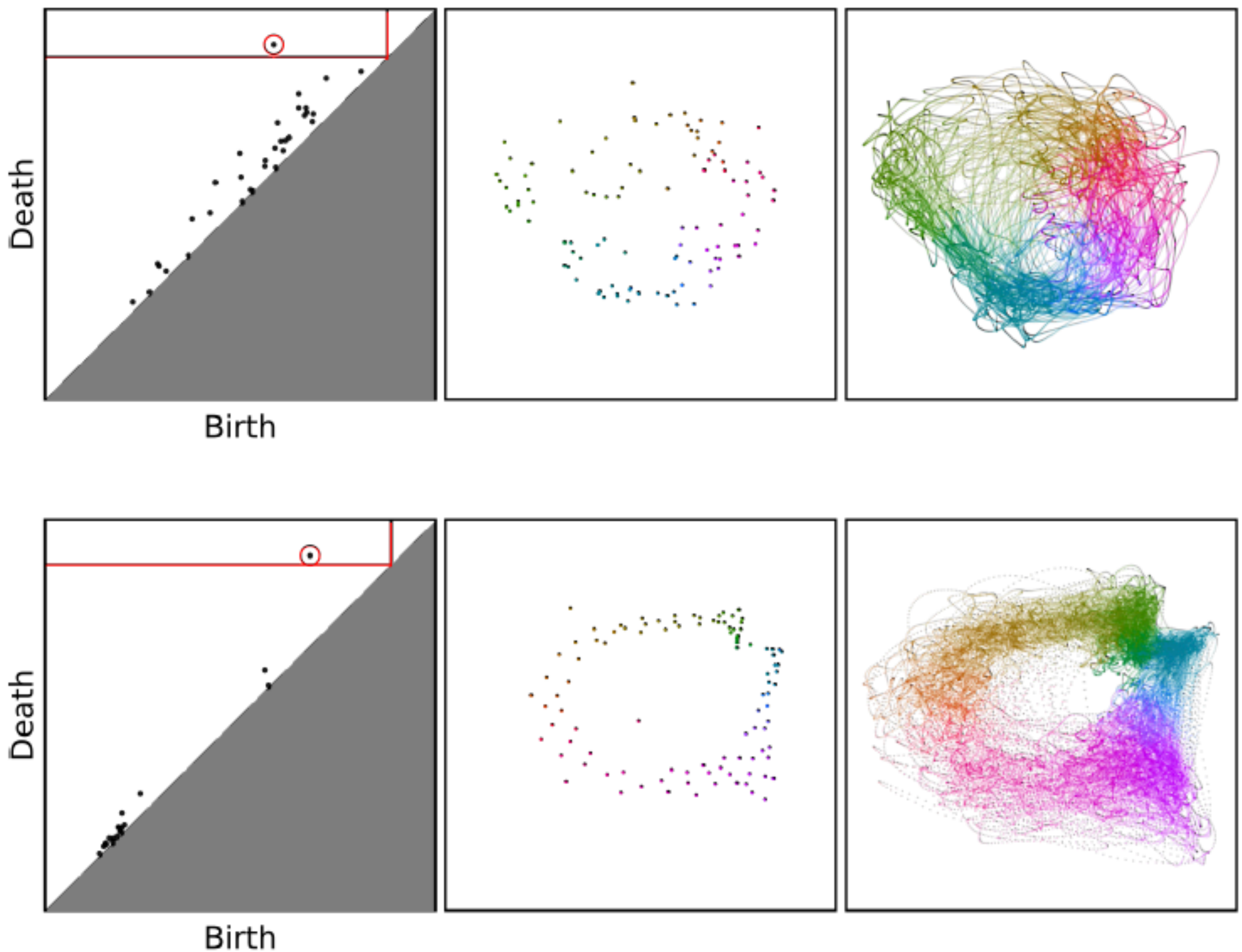


A circle from all neurons

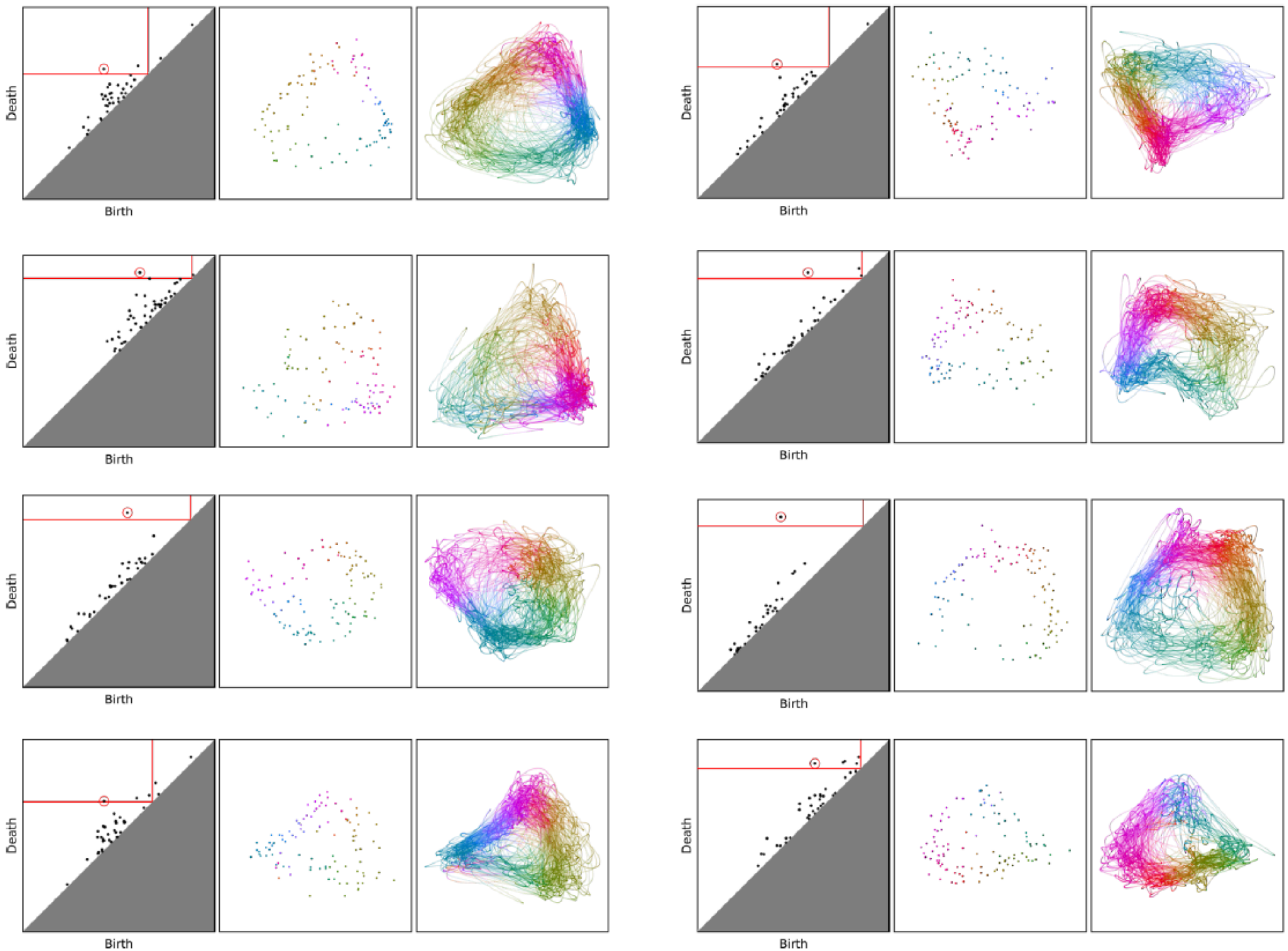


After removal of untuned neurons

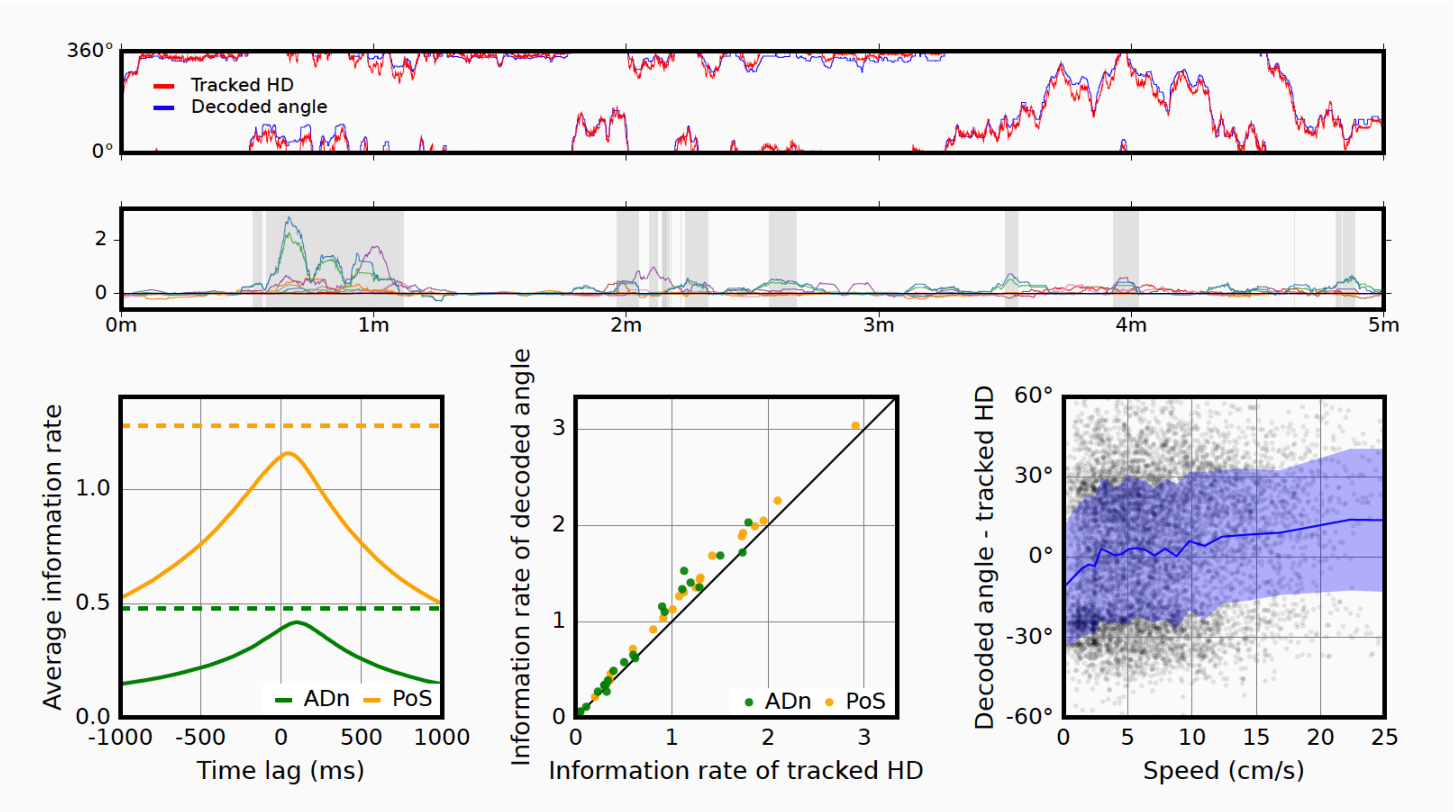
A tricky one



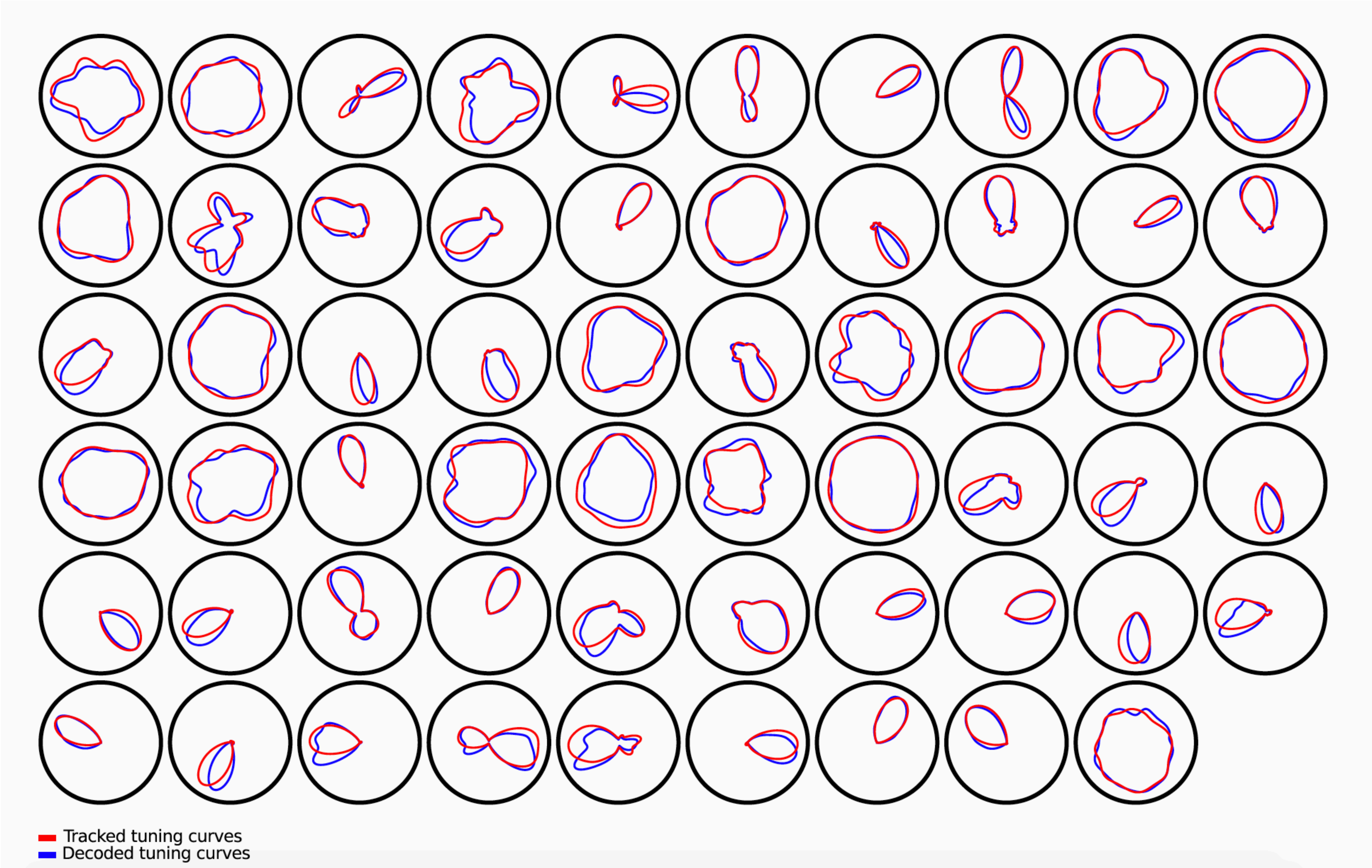
More examples



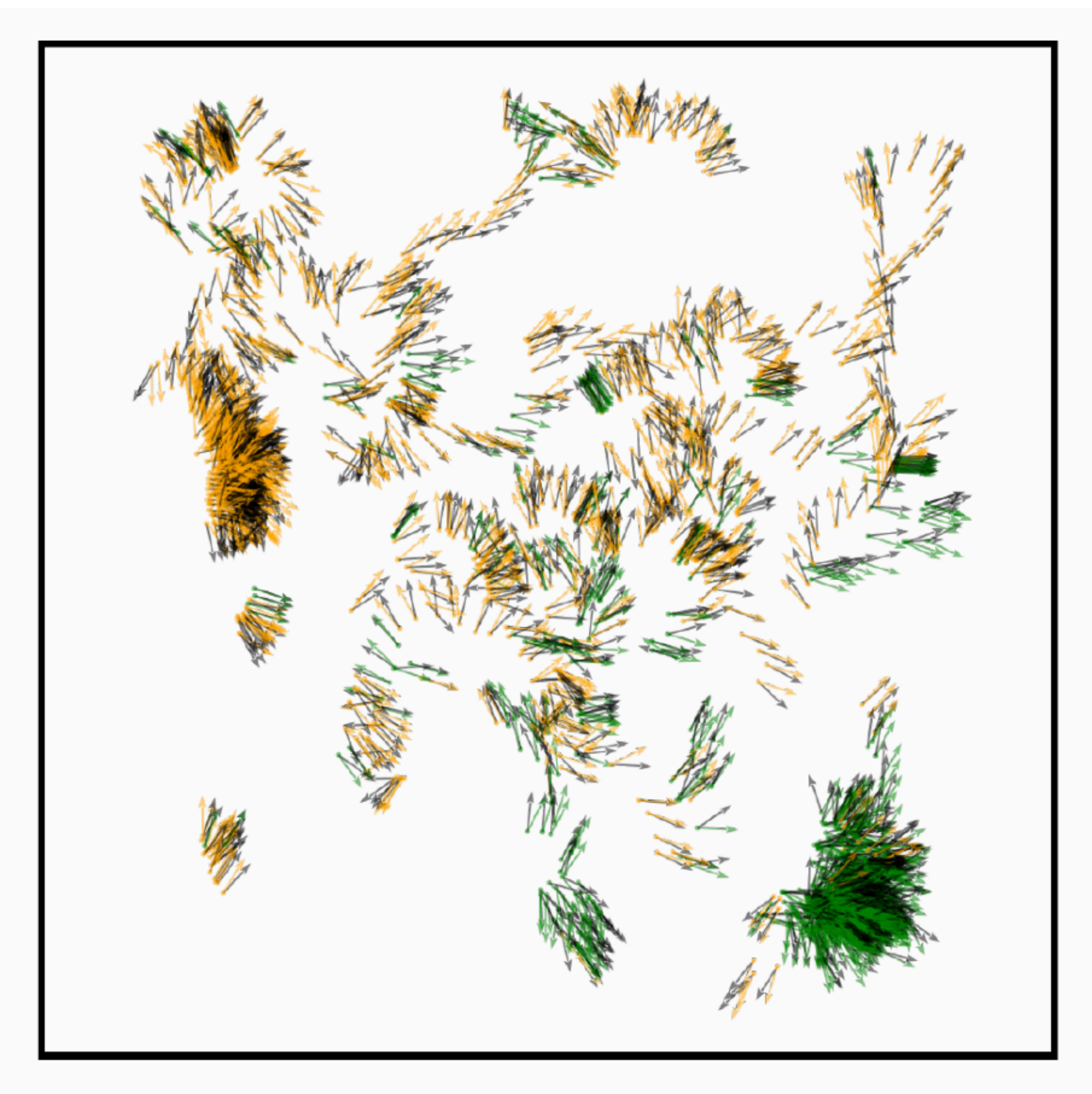
Comparison with tracked head direction

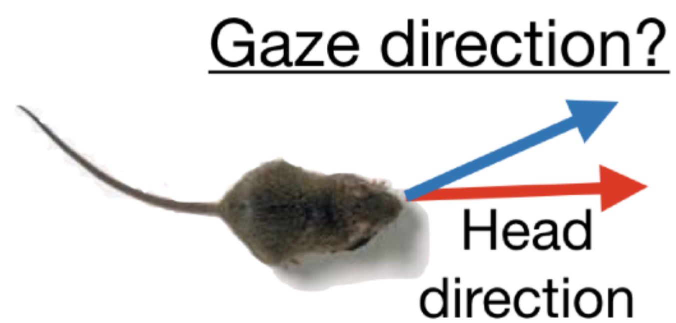


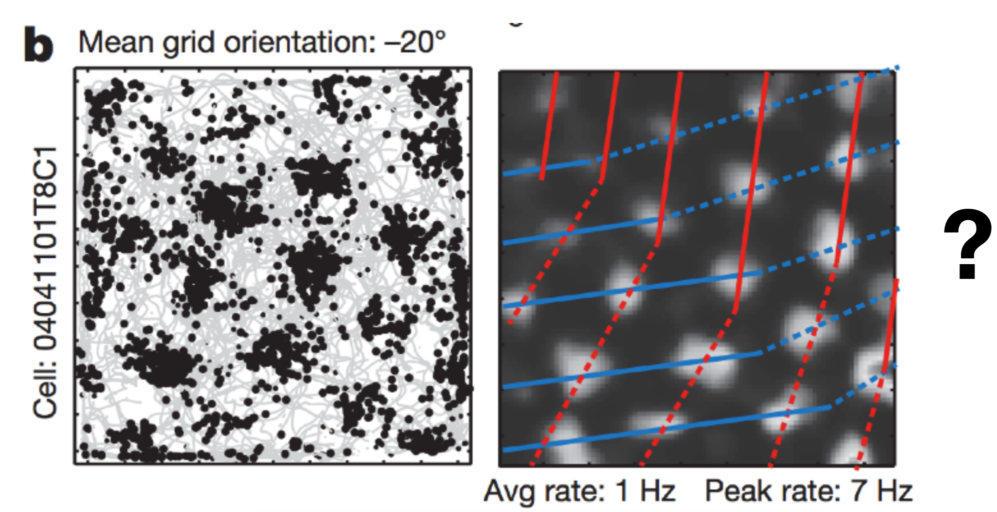
Comparison with tracked head direction



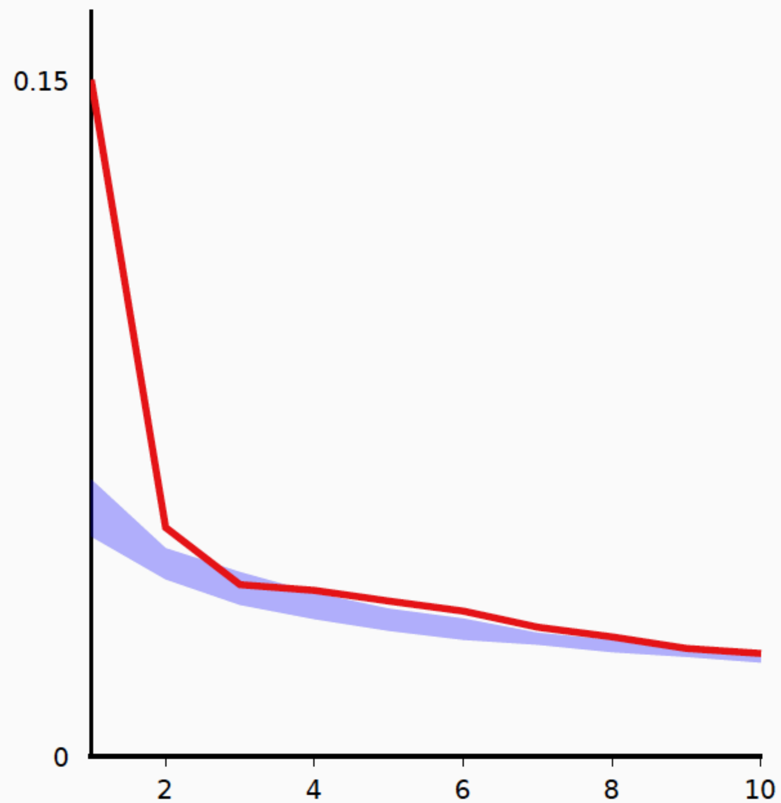
Comparison with tracked head direction
Unexpected benefit

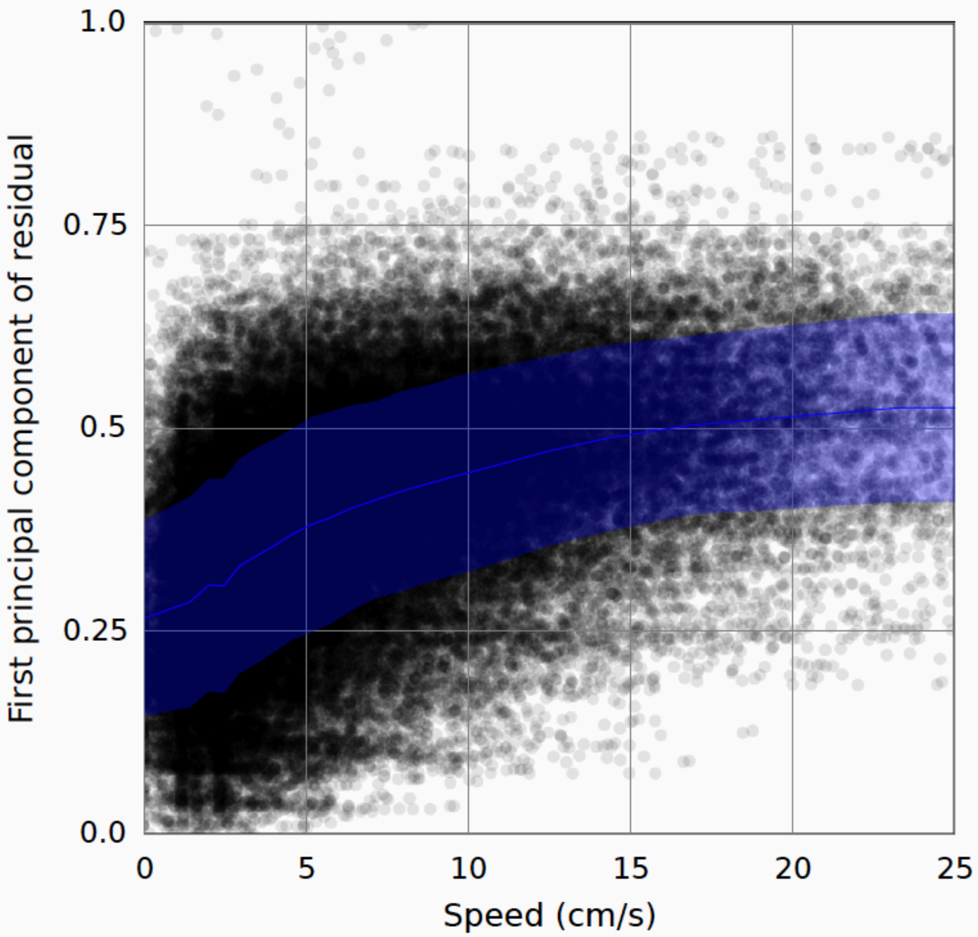




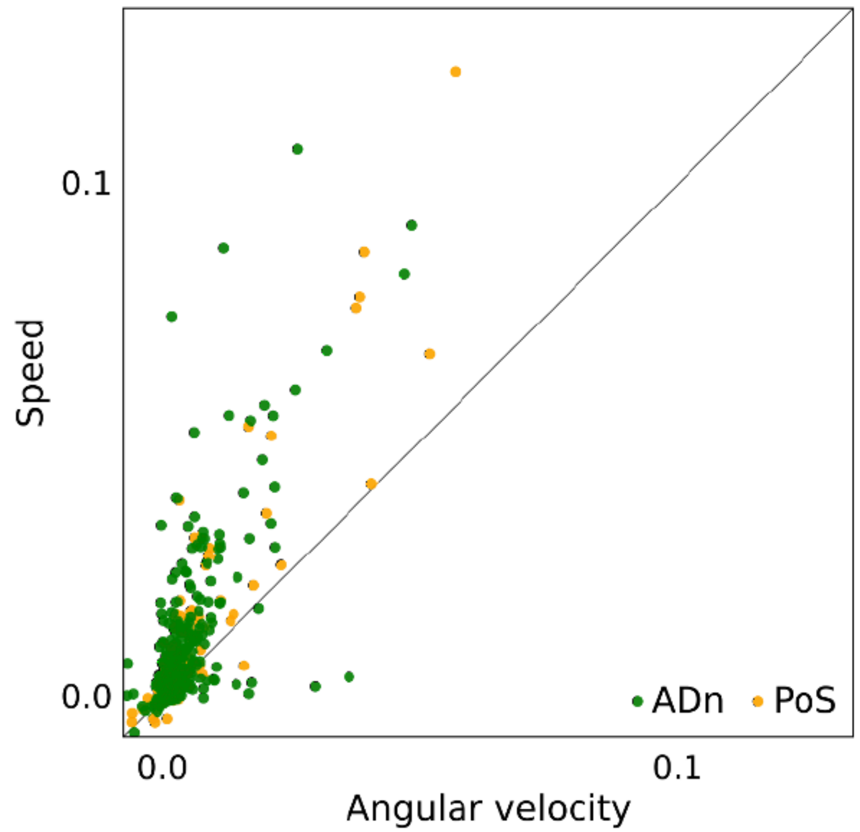


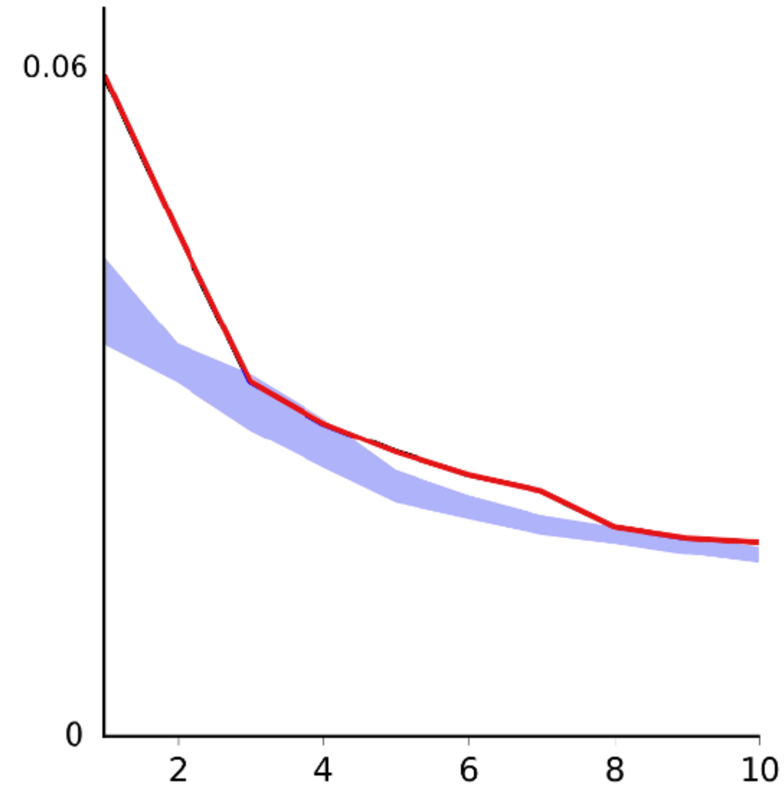
Looking at the residuals (as before)



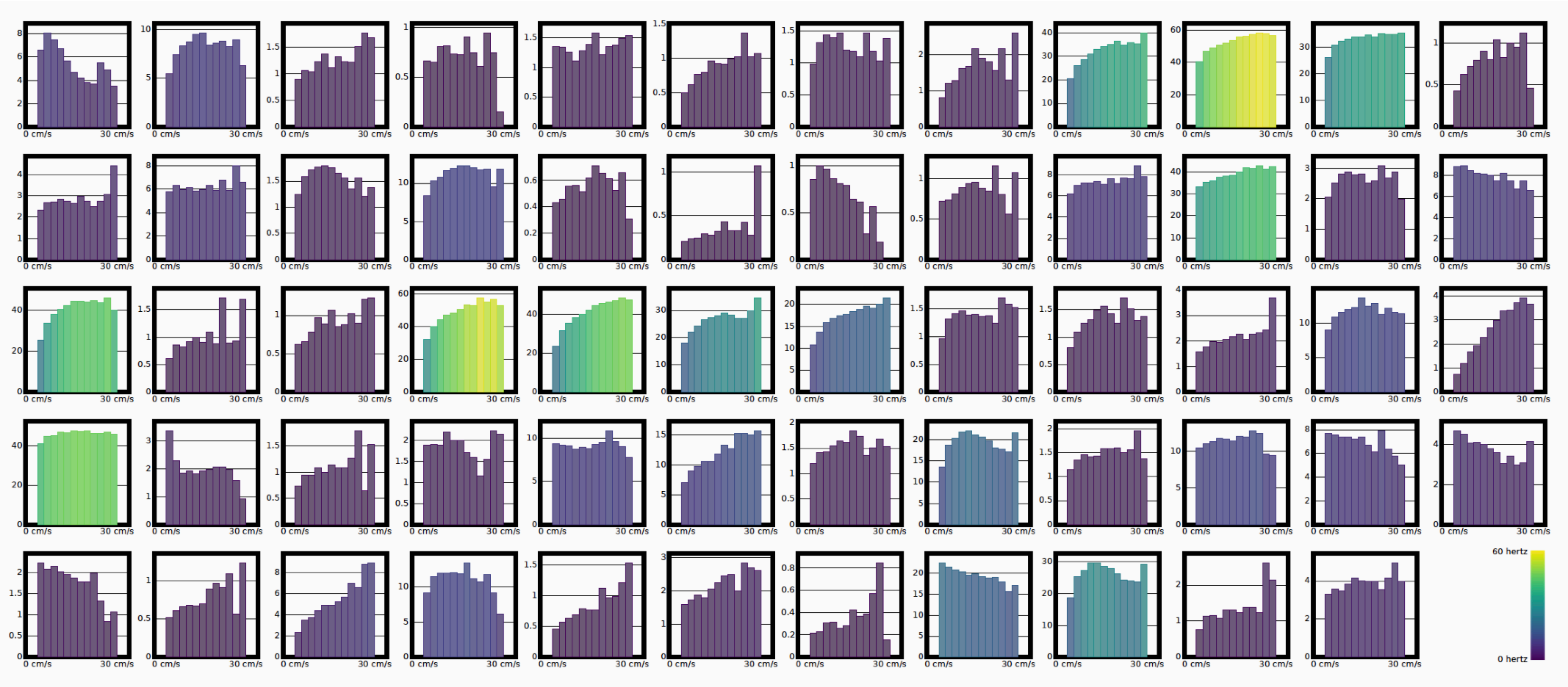


Speed tuning stronger than angular velocity



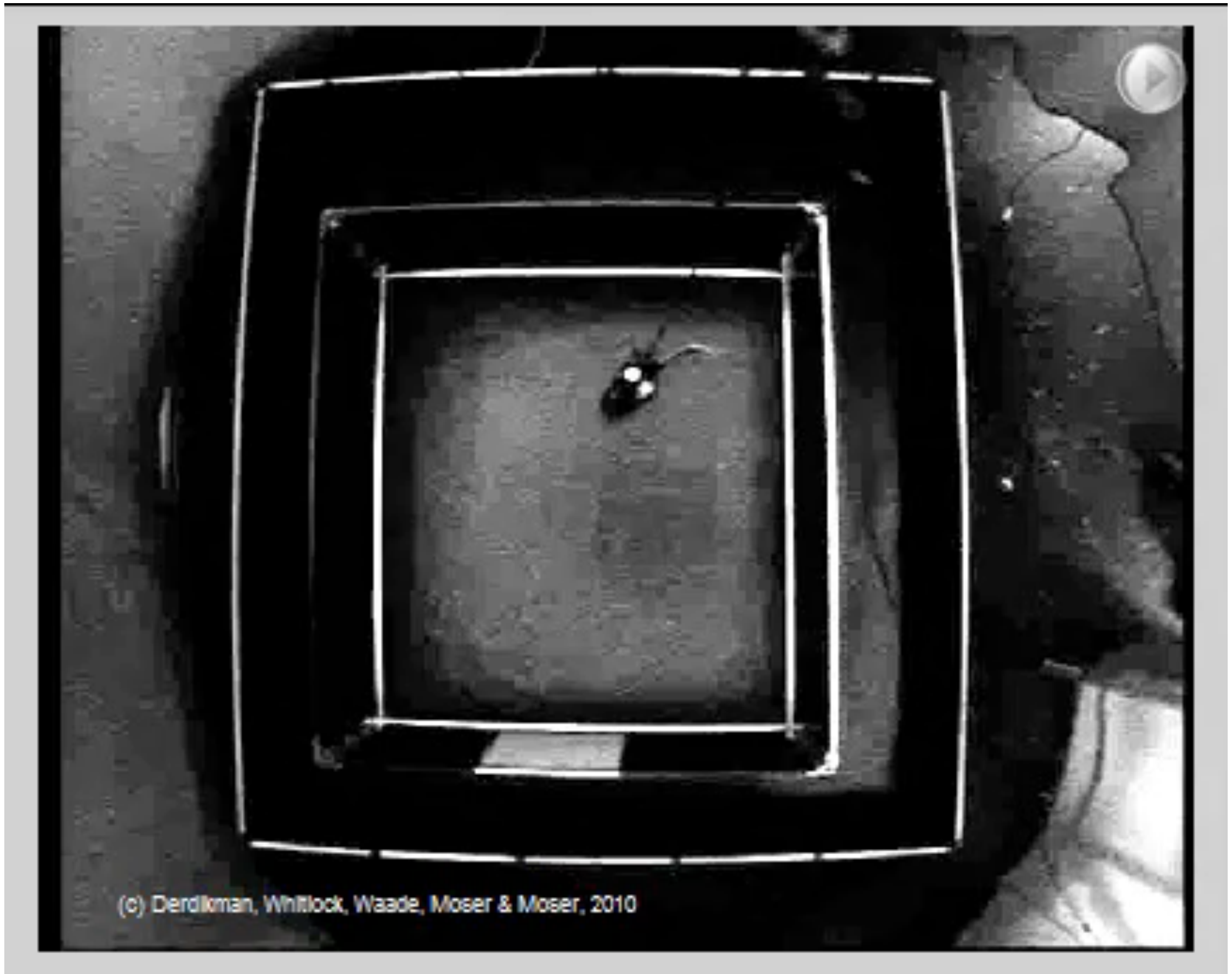


Example “speed” selectivity

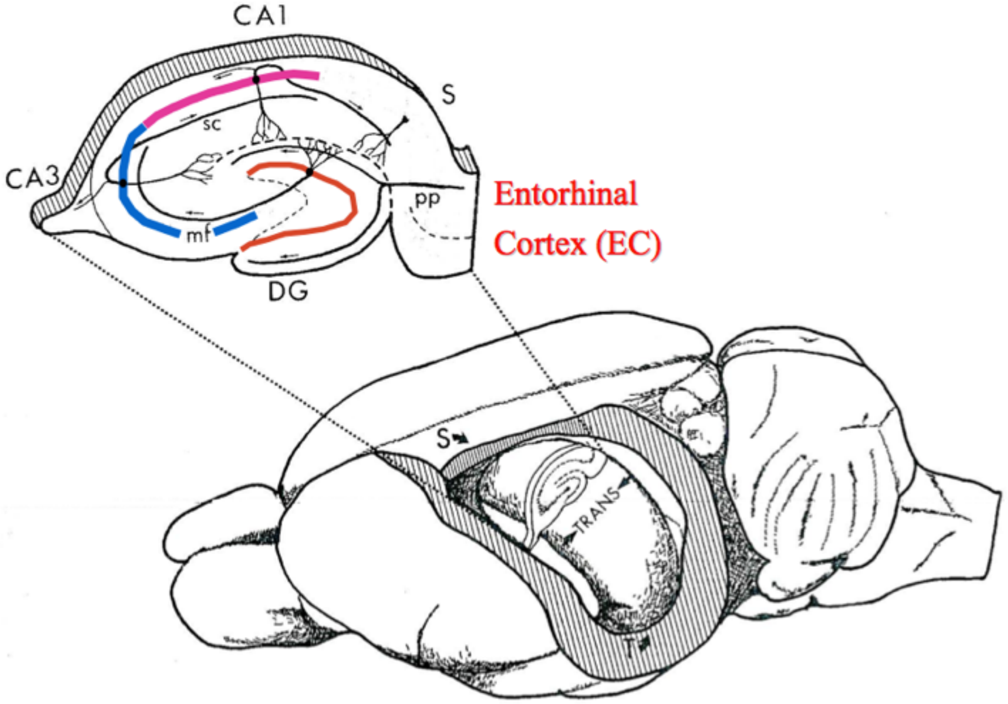


Optimistic next steps

Grid cells



Fyhn et al., 2004,
Hafting et al., 2005

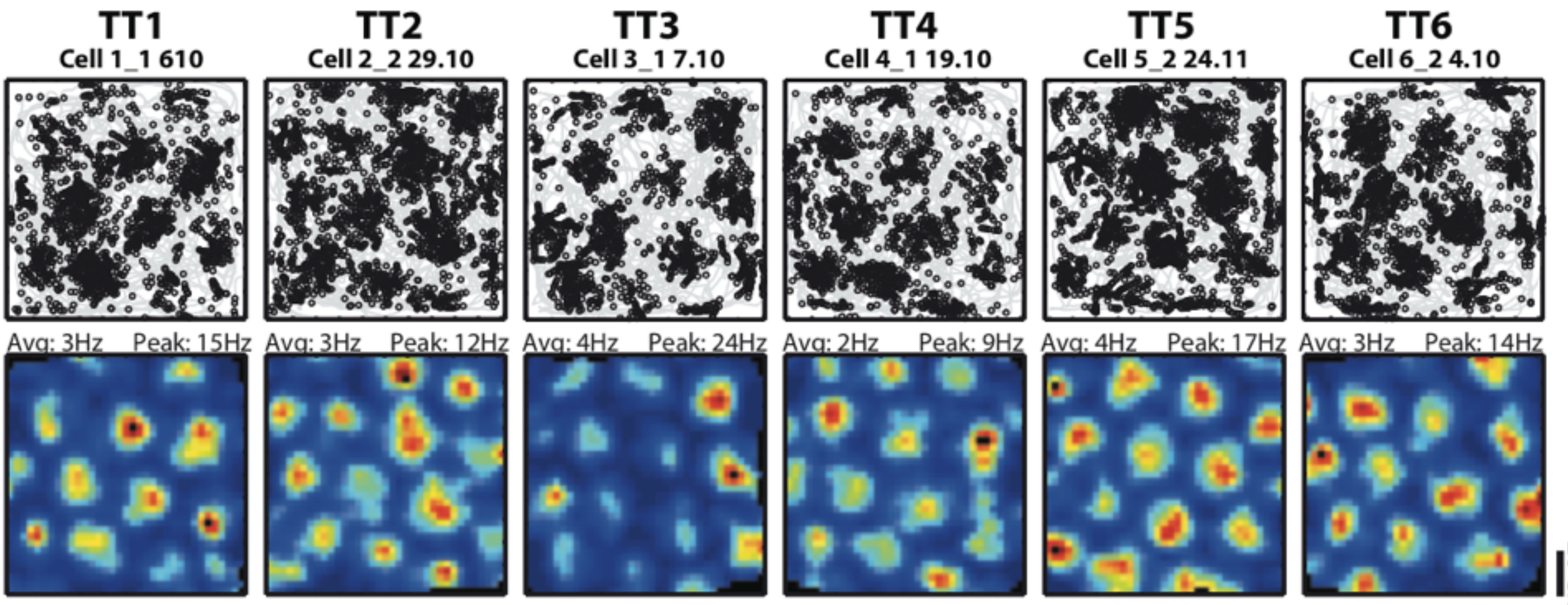


(Amaral and Witter 1989)

Would they have seen this if it wasn't location???

Grid cell modules

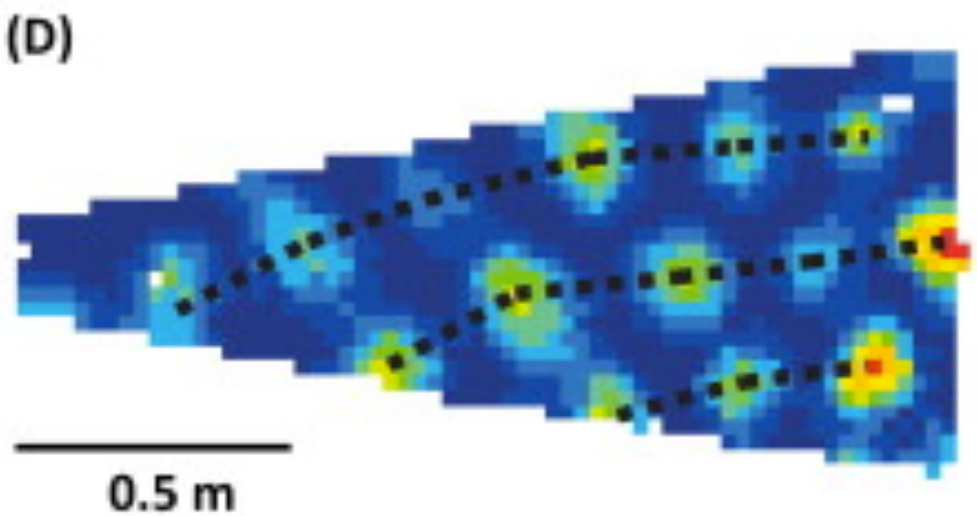
Grid cells group according to their spacing and orientation, forming modules that behave coherently



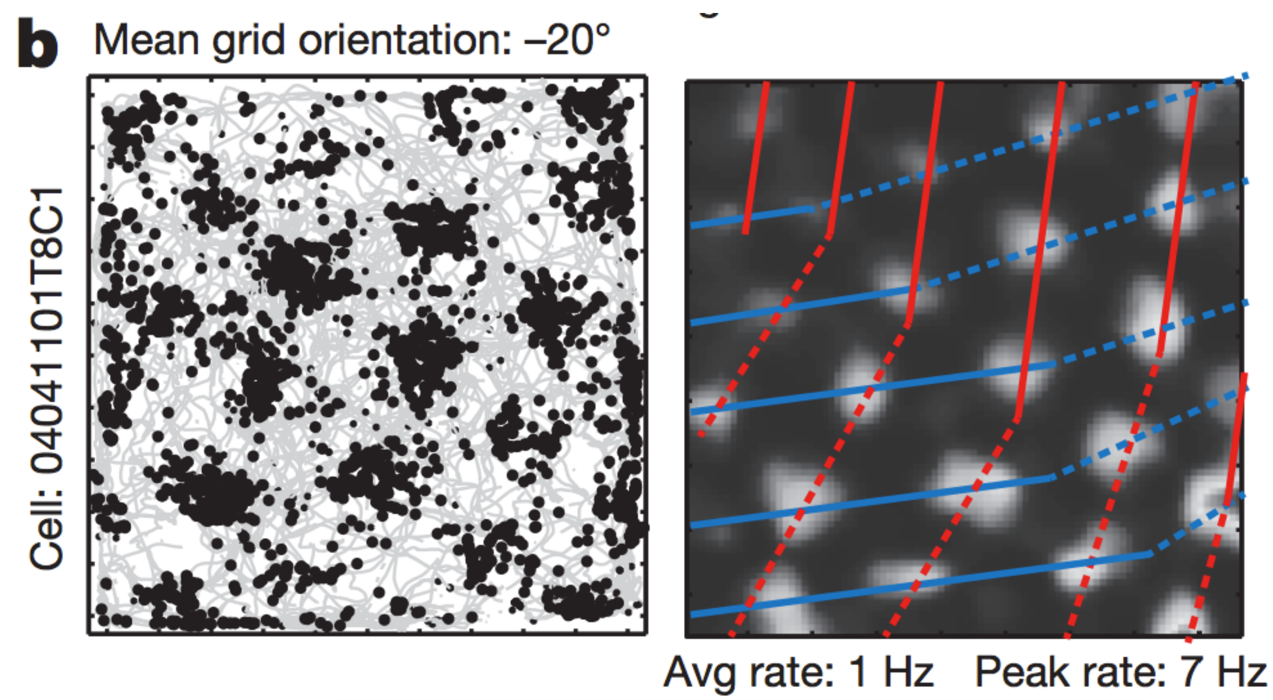
Fyhn et al, 2007

Stensola et al. 2013

Other examples

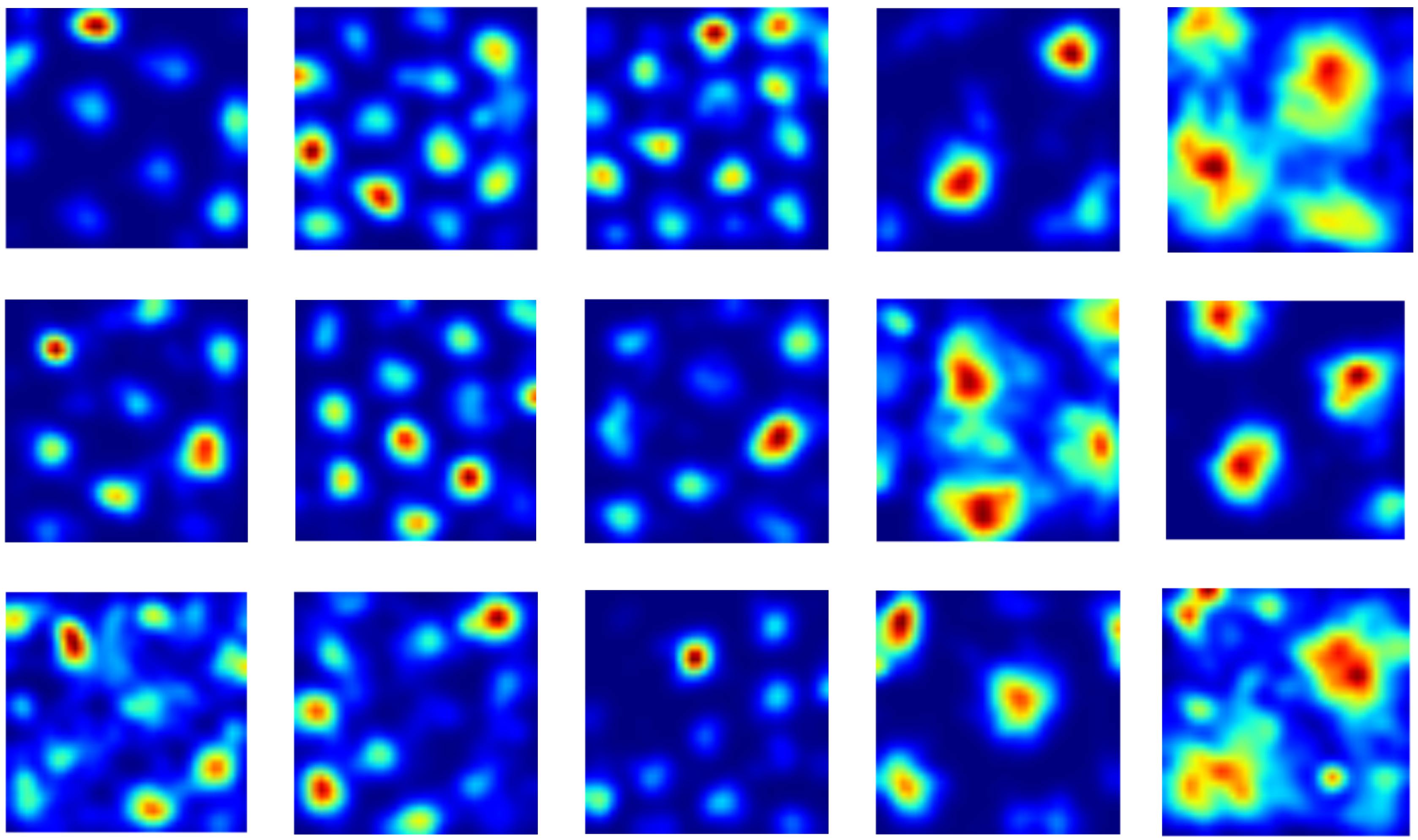


Krupic et al, 2015



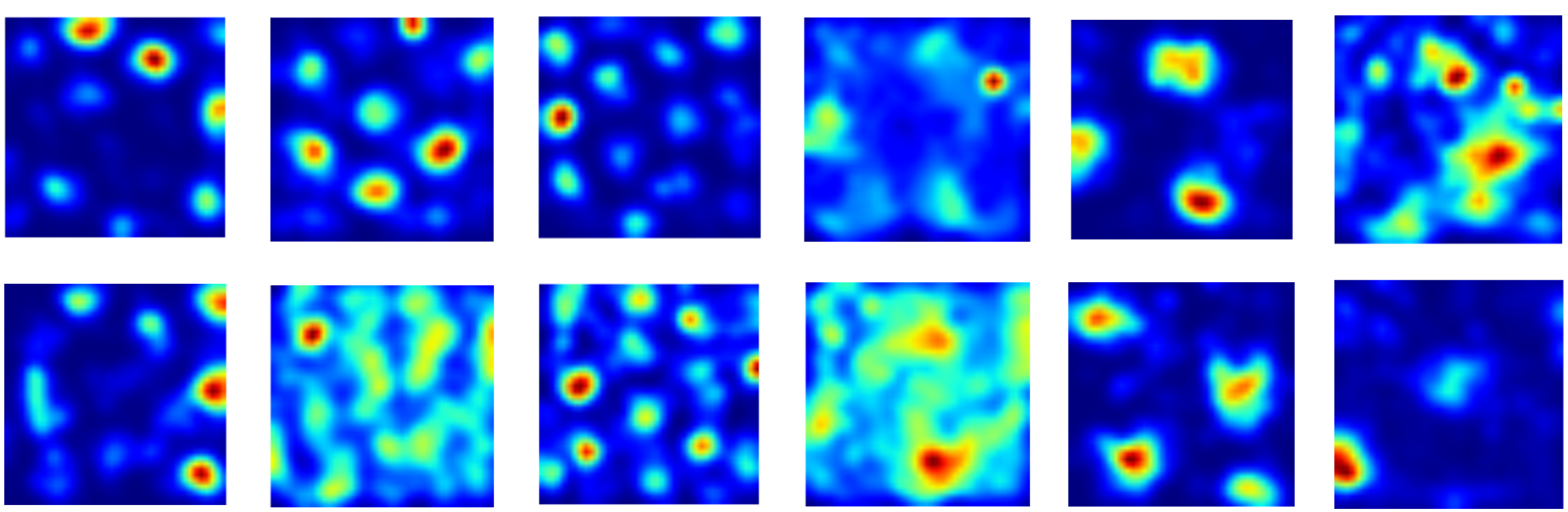
Stensola et al, 2015

But… you get mixed bag of “modules” and other neurons (head direction, border, etc.)



also, they are not “on” always

Stensola et al., 2013



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Future plans