BE9-MMMB – Mathematical Methods for Bioengineers

Coursework One
*Deadline: **3pm**, Fri 26th Nov.*

Each coursework consists of a set of "real" data analysis and/or mathematical modelling tasks, which you should be able to carry out with the aid of what you have learned from the lectures and problem classes.

Your coursework should be created as a Jupyter Notebook. To submit this through Blackboard, first convert it to html. To do this, from the notebook itself run the following command:

```
! jupyter nbconvert --to html your_notebook_name.ipynb
```

Your coursework submission should include markup text describing your answers to the questions, and explanations, your code, and inline figures. Your figures should be of publication quality – label all axes, provide legends where appropriate, etc.

You may discuss with colleagues, but you must write up your report **completely independently** (this will be checked), and reference all sources beyond the material on Blackboard.

Coursework One

1. Load the calcium imaging dataset provided in the directory dataset3_m62 using the skeleton code provided ('skel_coursework1.py'). This dataset is from a two photon calcium fluorescence imaging experiment, which was explained in Lecture 1. Further explanation of this dataset can be found in the paper here:
   https://www.biorxiv.org/content/10.1101/2020.10.18.344184v1.abstract
   The skeleton code shows you how to load both the behavioural data (x and y position, radial position, and angle phi in degrees) as a function of time, and the fluorescence time series dfonf ($\Delta F/F$ from the paper). The latter variable provides a matrix of fluorescence intensities with matrix dimensions Cells x Time-Duration.
   (a) Plot the fluorescence time series for cell 1 (i.e. the second cell – python indexing starts at 0). **See Note A below**.
   (b) As a subplot with the same time axis but different vertical axis, plot the angular position of the mouse as a function of time.
   (c) On separate axes, plot the trajectory of the mouse in space (Cartesian coordinates) throughout the duration of the recording.
   (d) Plot the average response of this cell at each angular position phi. You can either use the raw fluorescence signal, or a processed version (e.g. thresholded), but justify your choice. Is this cell tuned for spatial location?
   In your answers to the above questions, briefly explain what the various features in your plots signify.

   [30 marks]

2. Produce a delay embedding, with m=2, for this cell. Choose a time lag tau that shows the dynamics of the calcium transient appropriately. Describe what is happening in the calcium dynamics using your plot. [20 marks]

3. Make a recurrence plot of the activity of this same cell, and explain the features you see in the plot. Choose an appropriate tolerance ε to see meaningful structure in the data. [20 marks]

4. Now plot the activity of the whole population of neurons over time as an image with dimensions C x T (where C is the number of cells and T is the number of time points). Using Principal Components Analysis (PCA), produce a 3-dimensional embedding of the neural population activity. Plot the resulting 3 x T dimensional matrix as a trajectory in a three-dimensional space. Explain why this manifold takes the shape that it does. [30 marks]

Note A. These data were collected by concatenating multiple 4-minute video files collected from the microscope. Each of these is separated by an unknown gap in time – for this reason, the time variable 't' does not linearly increase but restarts each for each video. This means that you can expect the spatial position of the mouse to jump at each of these discontinuities. For the purpose of the current analysis, this does not matter, but you may wish to make a new time variable which just counts time linearly from the start, and take note of the times at which these jumps in position occur.

Prof Simon Schultz
Friday, 4 November 2022