

# First analysis of Emmett’ data

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## 1 Introduction

Here I use svGPFA (Duncker and Sahani, 2018) to explore the low dimensional structure of Emmett’s switching-task recordings.

## 2 Methods

### 2.1 Data

I epoched the recordings from 0.2 seconds before to mouse entered the first port (port 2) to 0.2 seconds after it exited the last port (port 7).

I only used trial that were shorter than five seconds (257 trials out of 400 trial with correct sequences).

I only used neurons with a firing rater larger than 0.1 spikes/sec (230 out of 400 neurons).

### 2.2 svGPFA model

The svGPFA model estimates  $K$  latent variables in the form of Gaussian processes:

$$x_k^{(r)}(t) \sim GP(\mu_k(t), \kappa_k(t, t')) \quad k = 1, \dots, K$$

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I concatenate the latent variables  $x_k^{(r)}(t)$  into a latent vector  $\mathbf{x}^{(r)}(t)$ :

$$\mathbf{x}^{(r)}(t) = \begin{bmatrix} x_1^{(r)}(t) \\ \vdots \\ x_K^{(r)}(t) \end{bmatrix} \quad (1)$$

The latent variables are combined linearly to produce the log pre-intensity,  $\mathbf{h}^{(r)}(t) = [h_1^{(r)}(t), \dots, h_N^{(r)}(t)]^\top$ , where  $h_n^{(r)}(t)$  is the log pre-intensity of neuron  $n$  and trial  $r$ , for a total of  $N$  neurons:

$$\mathbf{h}^{(r)}(t) = C\mathbf{x}^{(r)}(t) + \mathbf{d} \quad (2)$$

The log pre-intensity of neuron  $n$  and trial  $r$  is exponentiated to produce the conditional intensity function of neuron  $n$  and trial  $r$ :

$$\lambda_n^{(r)}(t) = \exp(h_n^{(r)}(t)) \quad (3)$$

which can be interpreted as the instantaneous firing rate of neuron  $n$  and trial  $r$  at time  $t$ .

The conditional intensity function of neuron  $n$  in trial  $r$  is used to calculate the probability of spikes  $\{t_{i,n}\}_{i=1}^{\Phi(n,r)}$  in a trial  $r$  of length  $\tau$ :

$$P(\{t_{i,n}\}_{i=1}^{\Phi(n,r)} | \lambda_n^{(r)}(t)) = \exp\left(-\int_0^\tau \lambda_n^{(r)}(t) dt\right) \prod_{i=1}^{\Phi(n,r)} \lambda_n^{(r)}(t_{i,n})$$

### 3 Results

I arbitrarily set to 10 the number of latent variables ( $K$  in Eq. 1 of [Duncker and Sahani, 2018](#)) of the svGPFA model. Figures 4-13 plot the orthonormalized latents for all trials. Figure 14 shows a scatter plot of orthonormalized latents 0, 1 and 2. Figures 15-30 plot intensity functions (Eq. 3), for all trials, of different neurons. Figure 32 plot the left singular vectors of the matrix  $C$  (Eq. 2), corresponding to the orthonormalized latents, and the offset vector  $d$ . Figure 33 displays the estimated lengthscale parameters of the squared exponential kernels of all latents.

## 4 Conclusions

The intensity functions in Figures 15-30 show diverse tuning of single cells. The majority of them fire more when the mouse enters the reward port 7 (e.g., neurons 1 (Figure 16), 2 (Figure 17), 4 (Figure 19), 6 (Figure 20), 7 (Figure 21), 17 (Figure 31)). Other neurons fire more when the mouse enters other ports (e.g., neurons 0 (Figure 15), 15 (Figure 29), 16 (Figure 30) fire more around port 1, neuron 3 (Figure 18) around port 3, neuron 12 (Figure 26) around port 2).

Despite this diversity at the single cell level, the first three orthonormalized latents show a pattern at the population level (Figure 14). For most trials, there appears to be an extreme point around the time where the mouse pokes in a port.

In addition, in Fig. 14 trials are sorted systematically, possibly indicating some type of learning, or drift in neural activity.

## References

Duncker, L. and Sahani, M. (2018). Temporal alignment and latent gaussian process factor inference in population spike trains. In *Advances in Neural Information Processing Systems*, pages 10445–10455.

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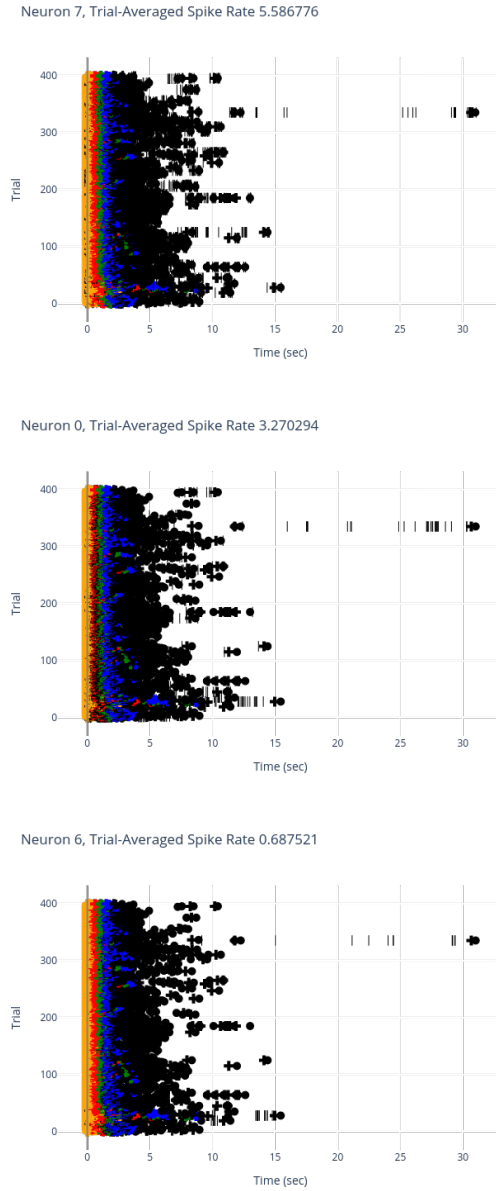


Figure 1: Binned spikes and PSTH (red trace) for neurons 7 (top), 0 (middle) and 6 (bottom) tuned to port 7, 1 and 3, respectively. Click on the image to access its interactive version.

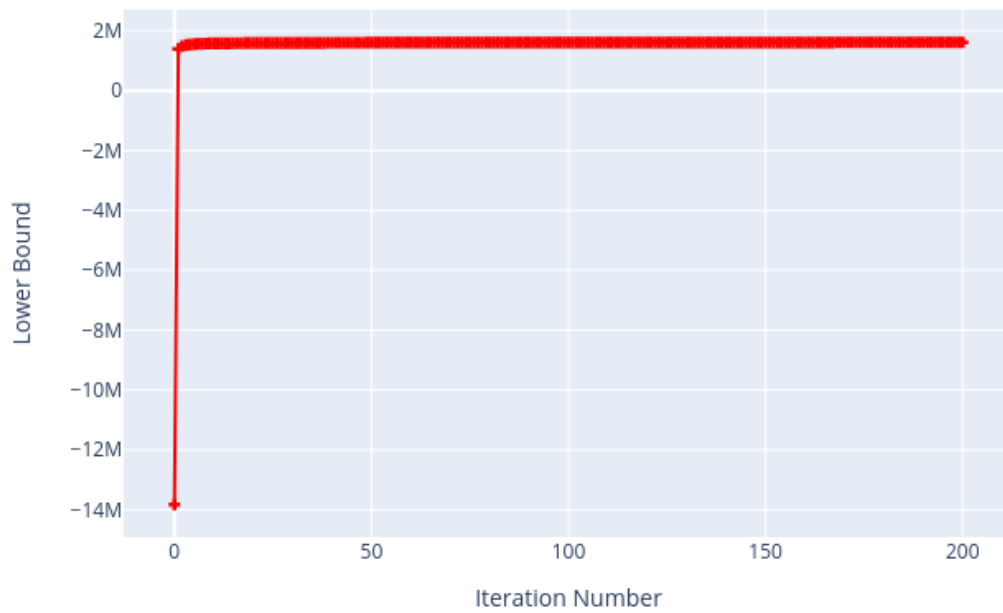


Figure 2: Lower bound vs iteration number. Click on the image to access its interactive version.

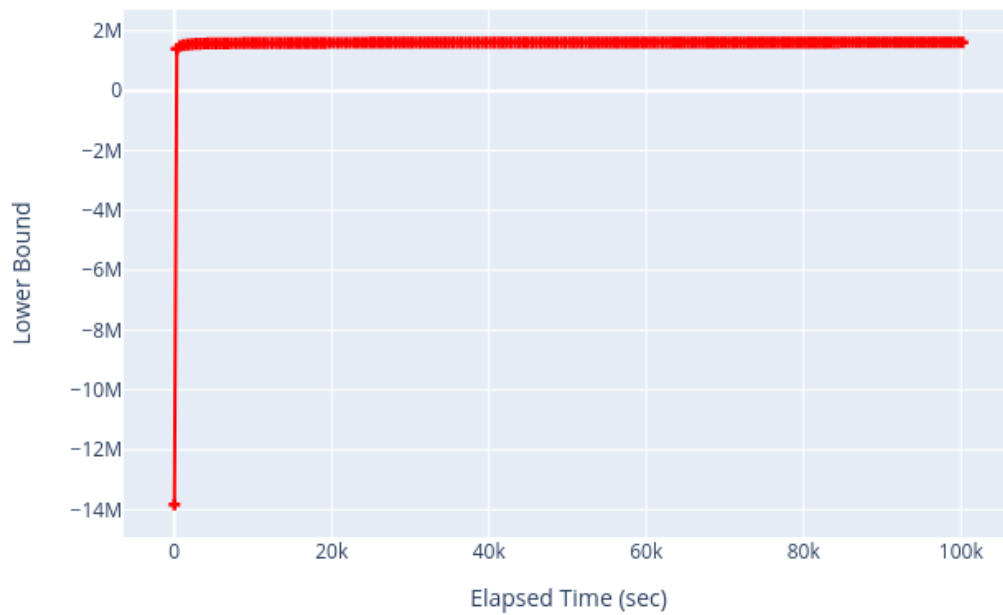


Figure 3: Lower bound vs elapsed time. Click on the image to access its interactive version.



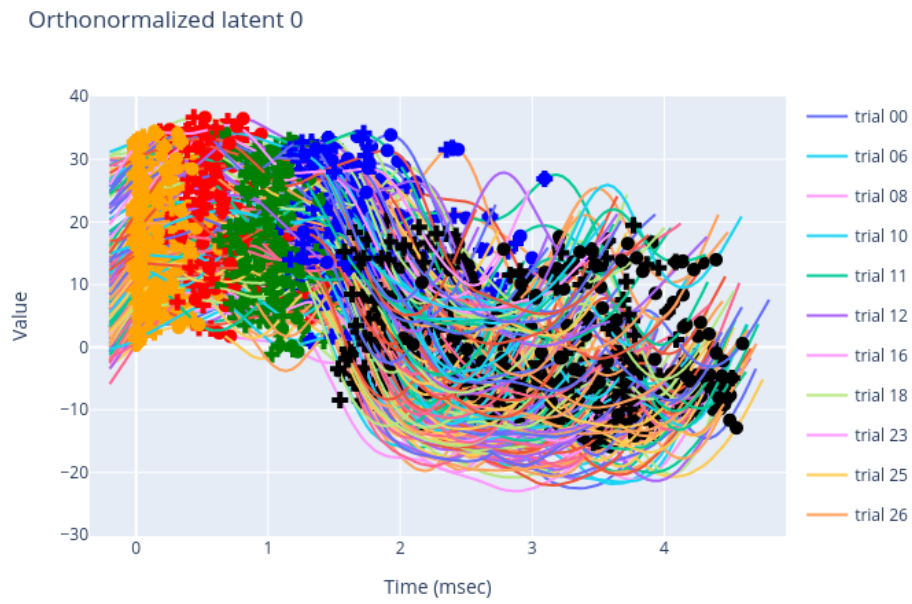


Figure 4: Orthonormalized latent 0. Orange, red, green, blue and black markers correspond to ports 2, 1, 6, 3 and 7, respectively. Crosses and circles correspond to poke in and out, respectively.

Orthonormalized latent 1

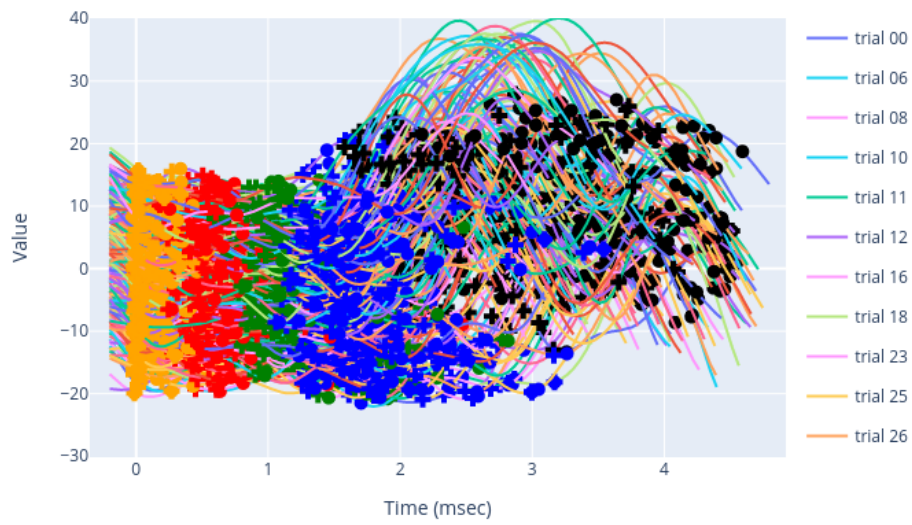


Figure 5: Orthonormalized latent 1. Same format as in Figure 4. Click on the image to access its interactive version.

Orthonormalized latent 2

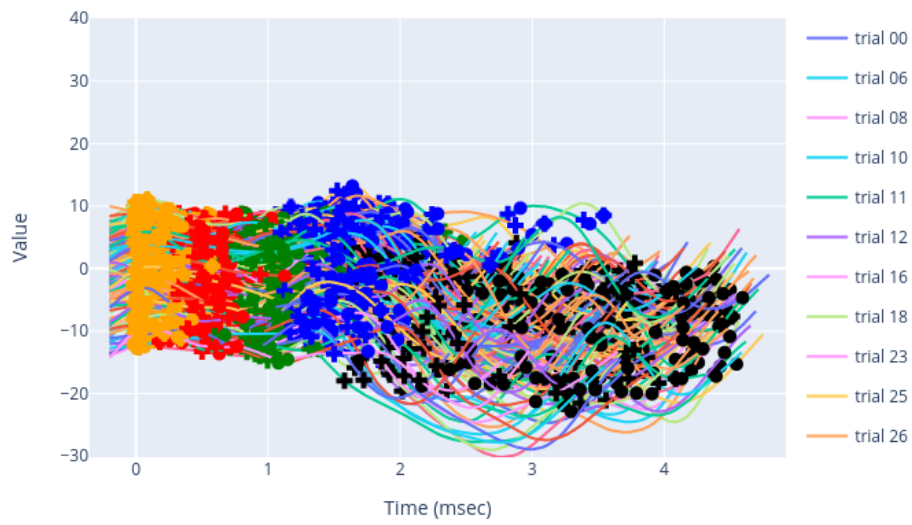


Figure 6: Orthonormalized latent 2. Same format as in Figure 4. Click on the image to access its interactive version.

Orthonormalized latent 3

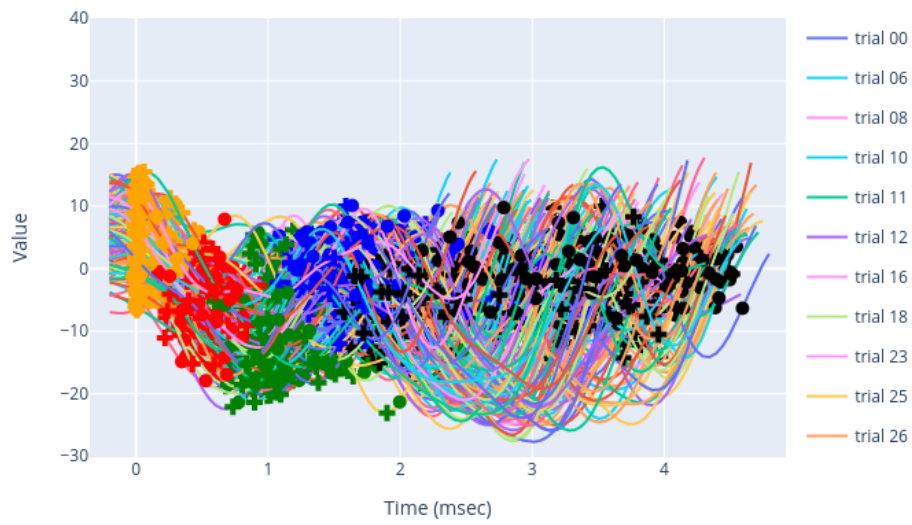


Figure 7: Orthonormalized latent 3. Same format as in Figure 4. Click on the image to access its interactive version.

Orthonormalized latent 4

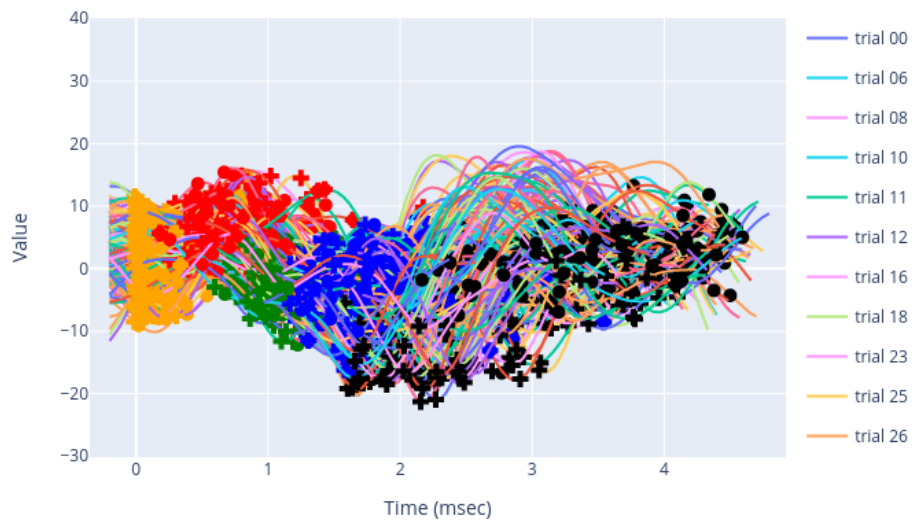


Figure 8: Orthonormalized latent 4. Same format as in Figure 4. Click on the image to access its interactive version.

Orthonormalized latent 5

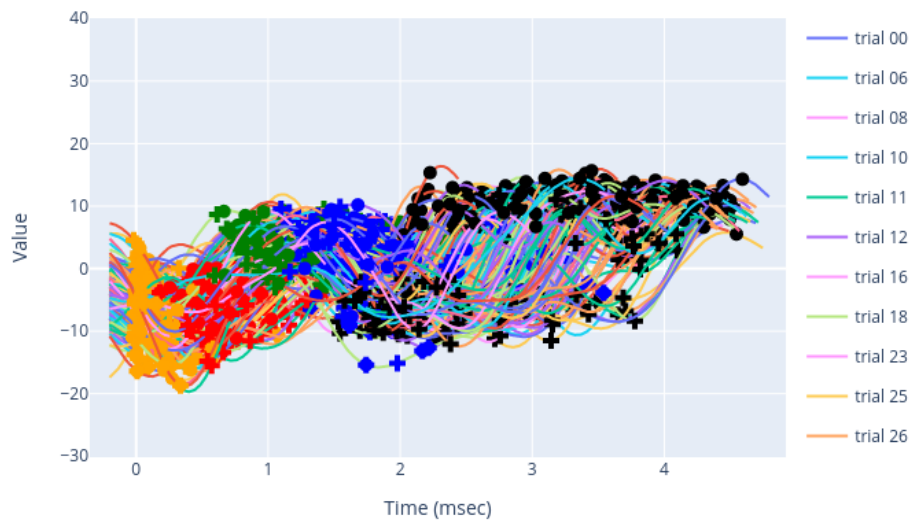


Figure 9: Orthonormalized latent 5. Same format as in Figure 4. Click on the image to access its interactive version.

Orthonormalized latent 6

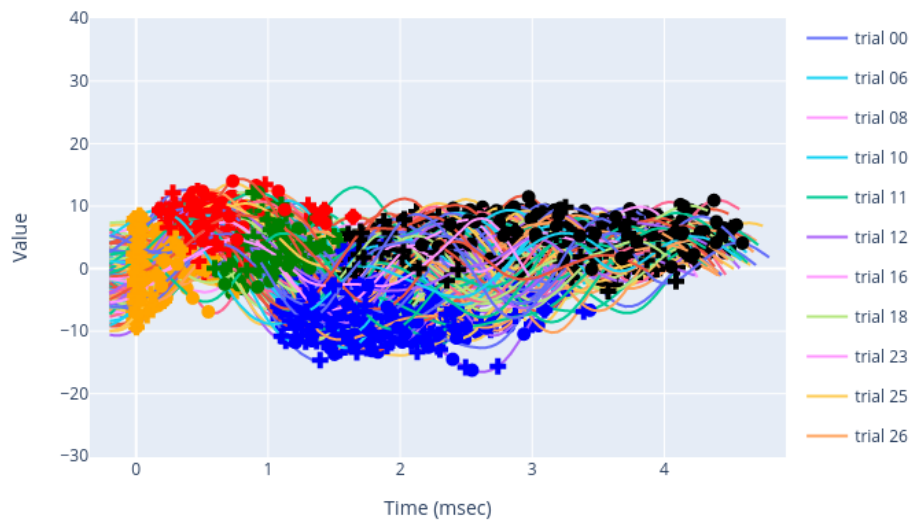


Figure 10: Orthonormalized latent 6. Same format as in Figure 4. Click on the image to access its interactive version.

Orthonormalized latent 7

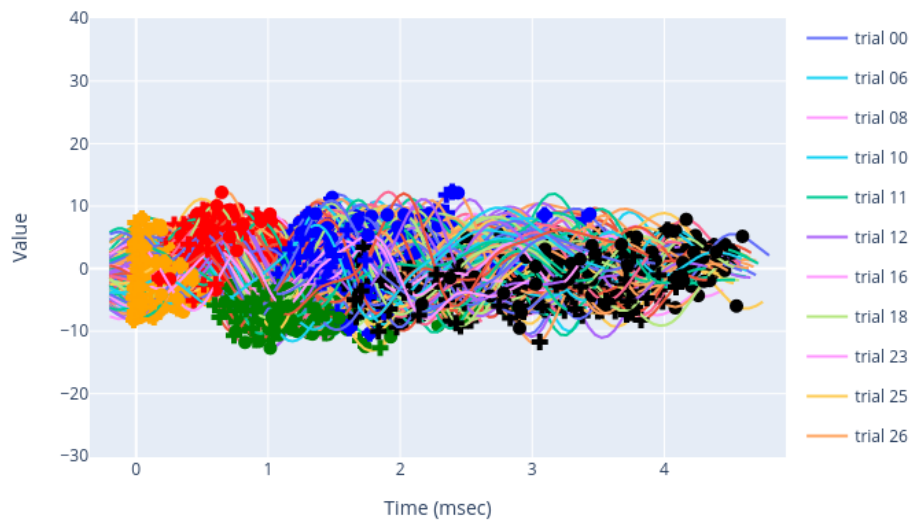


Figure 11: Orthonormalized latent 7. Same format as in Figure 4. Click on the image to access its interactive version.



Orthonormalized latent 8

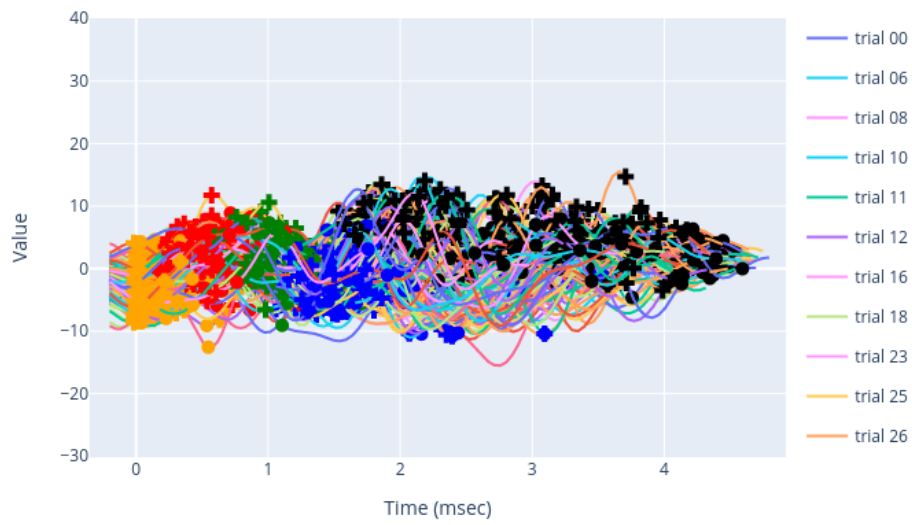


Figure 12: Orthonormalized latent 8. Same format as in Figure 4. Click on the image to access its interactive version.

Orthonormalized latent 9

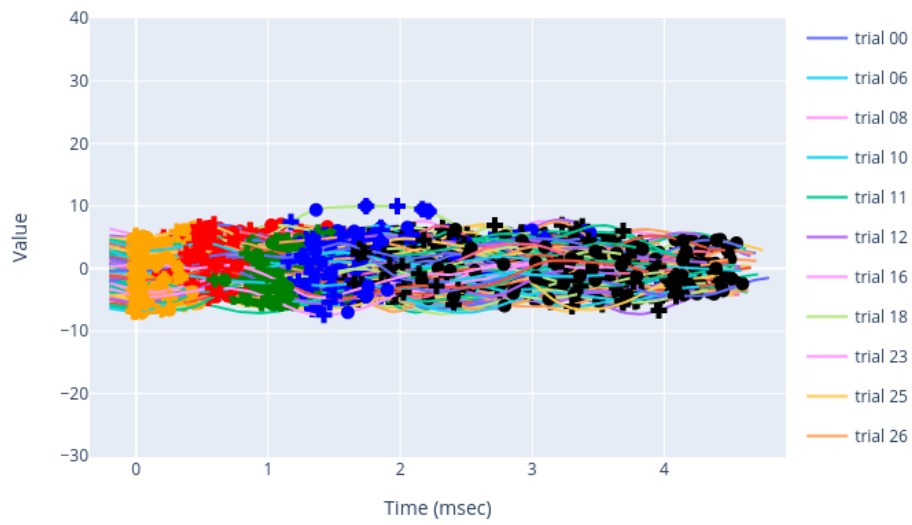


Figure 13: Orthonormalized latent 9. Same format as in Figure 4. Click on the image to access its interactive version.

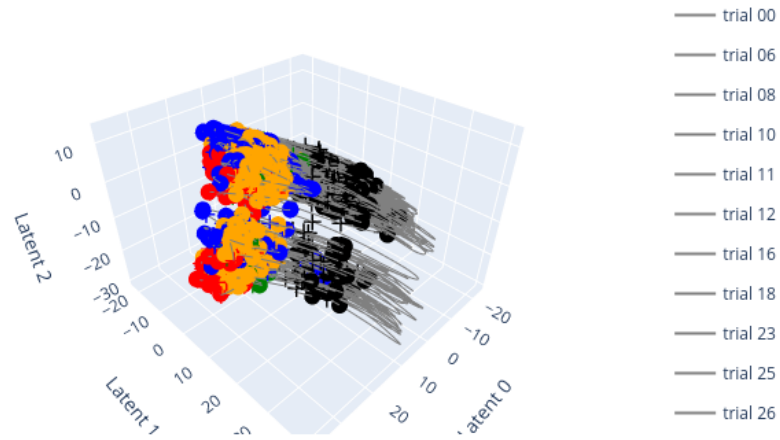


Figure 14: Scatter plot of orthonormalized latents 0, 1 and 2. Same format as in Figure 4. [Click on the image to access its interactive version.](#)

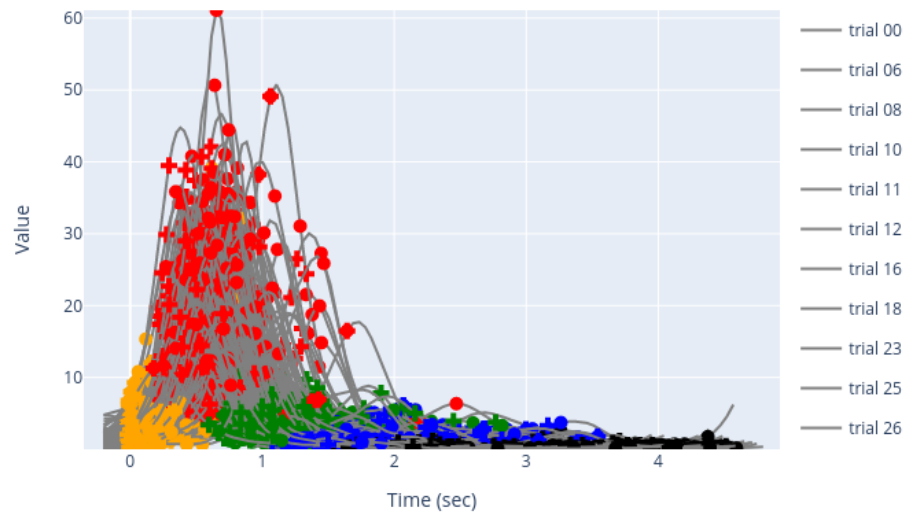


Figure 15: Intensity function for neuron  $n = 0$  ( $\lambda_n(t)$ , Eq. 3). Same format as in Figure 4. Click on the image to access its interactive version.

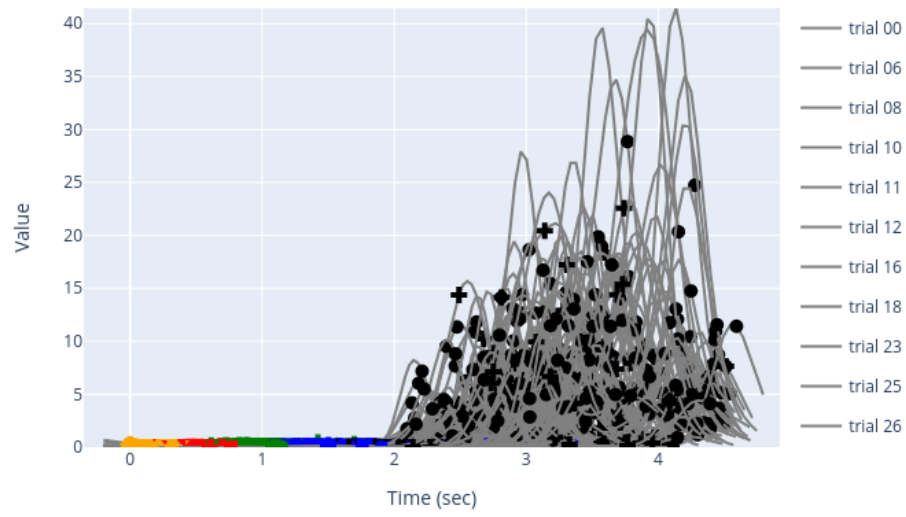


Figure 16: Intensity function for neuron  $n = 1$  ( $\lambda_n(t)$ , Eq. 3). Same format as in Figure 4. Click on the image to access its interactive version.

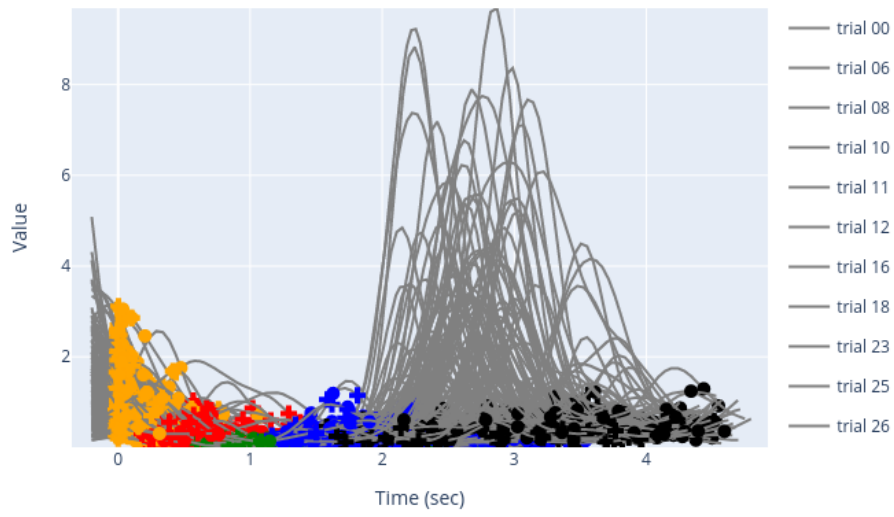


Figure 17: Intensity function for neuron  $n = 2$  ( $\lambda_n(t)$ , Eq. 3). Same format as in Figure 4. Click on the image to access its interactive version.

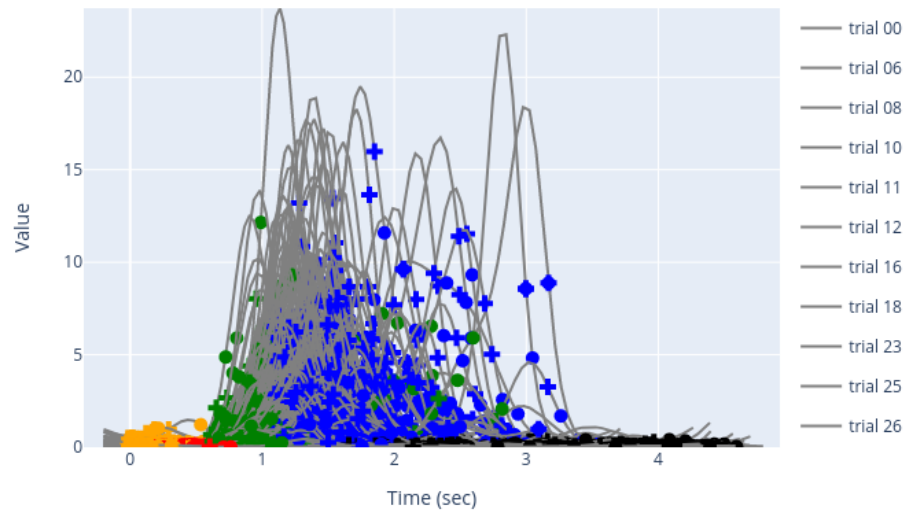


Figure 18: Intensity function for neuron  $n = 3$  ( $\lambda_n(t)$ , Eq. 3). Same format as in Figure 4. Click on the image to access its interactive version.

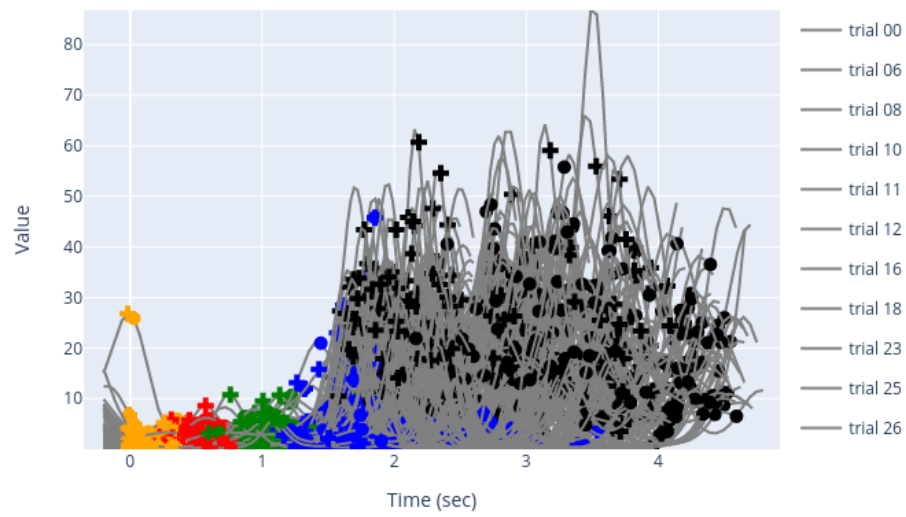


Figure 19: Intensity function for neuron  $n = 4$  ( $\lambda_n(t)$ , Eq. 3). Same format as in Figure 4. Click on the image to access its interactive version.



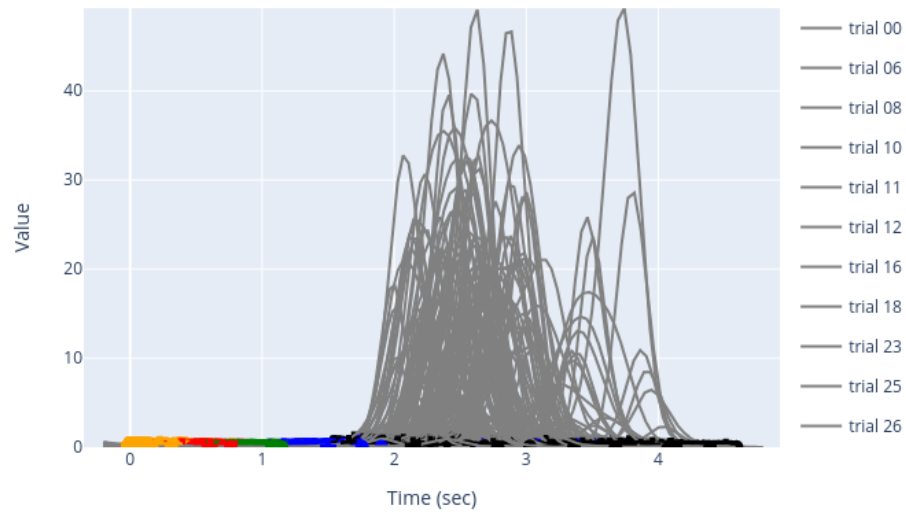


Figure 20: Intensity function for neuron  $n = 6$  ( $\lambda_n(t)$ , Eq. 3). Same format as in Figure 4. Click on the image to access its interactive version.

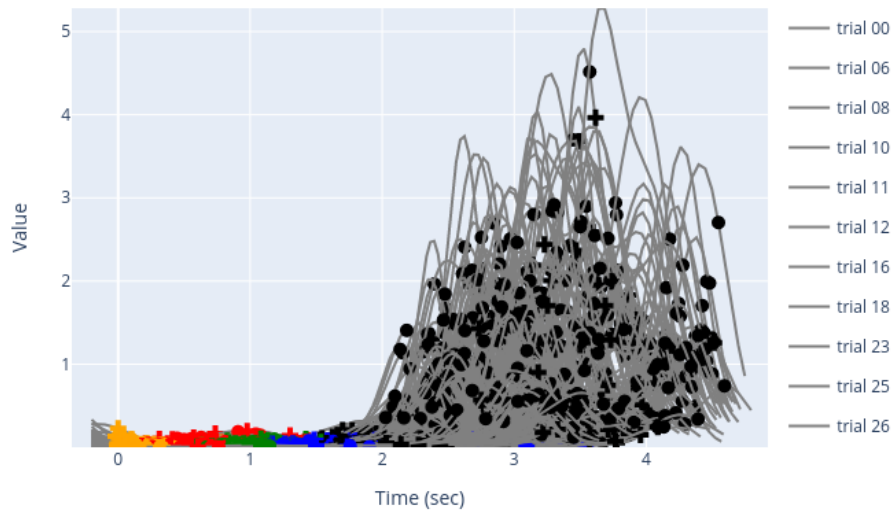


Figure 21: Intensity function for neuron  $n = 7$  ( $\lambda_n(t)$ , Eq. 3). Same format as in Figure 4. Click on the image to access its interactive version.

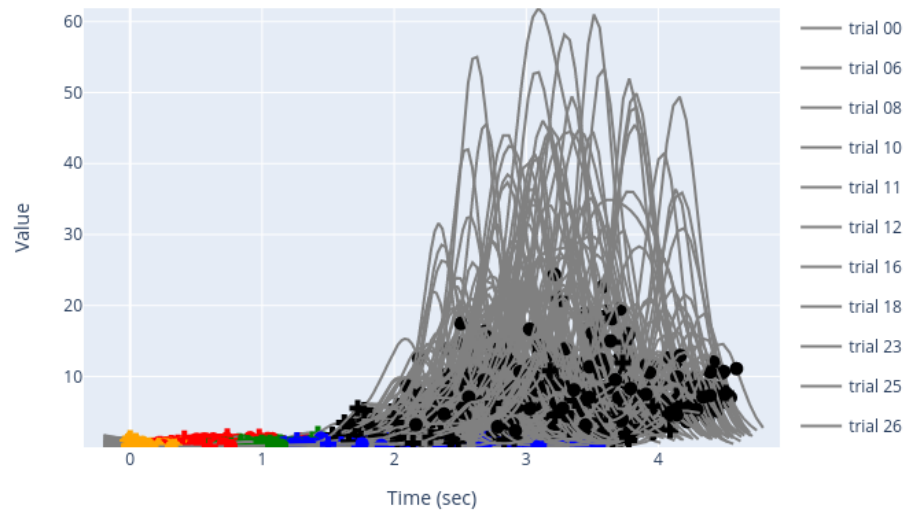


Figure 22: Intensity function for neuron  $n = 8$  ( $\lambda_n(t)$ , Eq. 3). Same format as in Figure 4. Click on the image to access its interactive version.

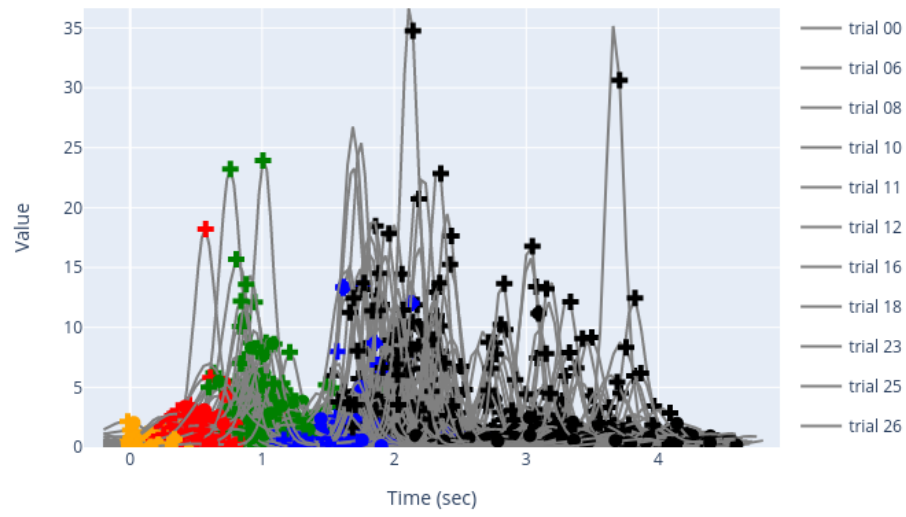


Figure 23: Intensity function for neuron  $n = 9$  ( $\lambda_n(t)$ , Eq. 3). Same format as in Figure 4. Click on the image to access its interactive version.

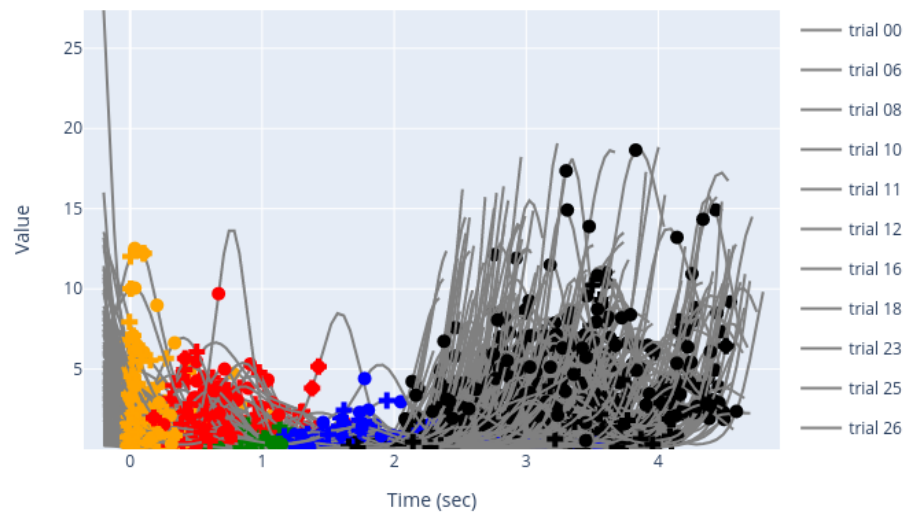


Figure 24: Intensity function for neuron 10. Same format as in Figure 4. Click on the image to access its interactive version.

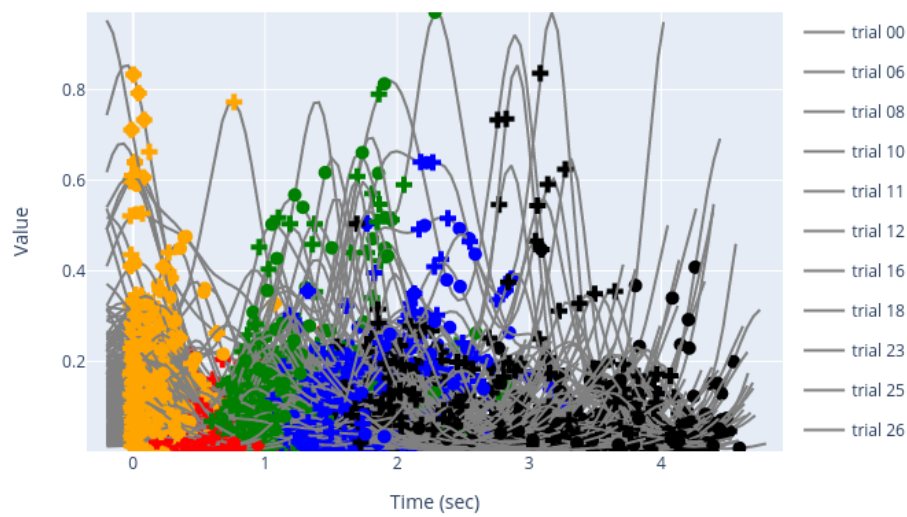


Figure 25: Intensity function for neuron 11. Same format as in Figure 4. Click on the image to access its interactive version.

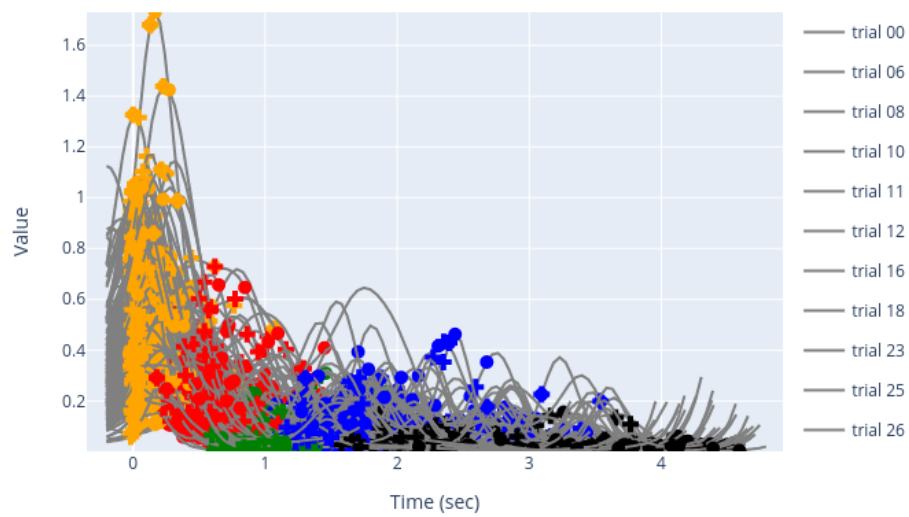


Figure 26: Intensity function for neuron 12. Same format as in Figure 4. [Click on the image to access its interactive version.](#)

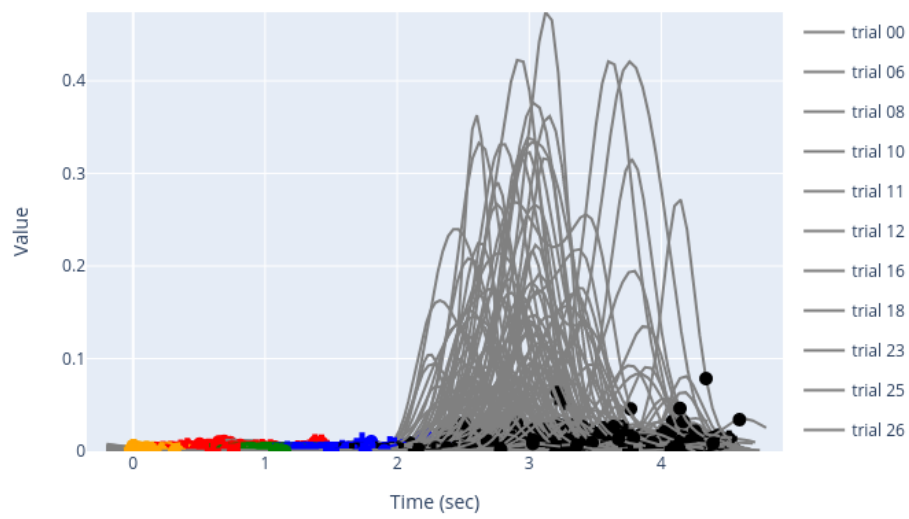


Figure 27: Intensity function for neuron 13. Same format as in Figure 4. Click on the image to access its interactive version.



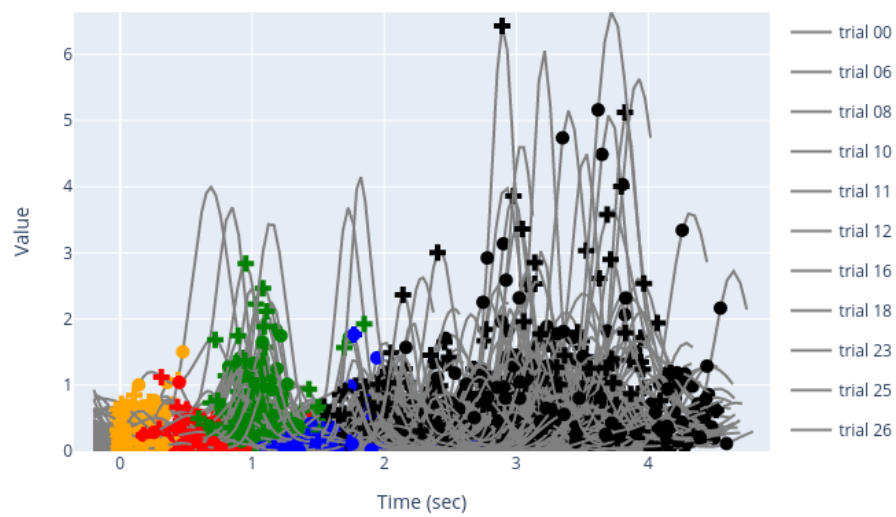


Figure 28: Intensity function for neuron 14. Same format as in Figure 4. Click on the image to access its interactive version.

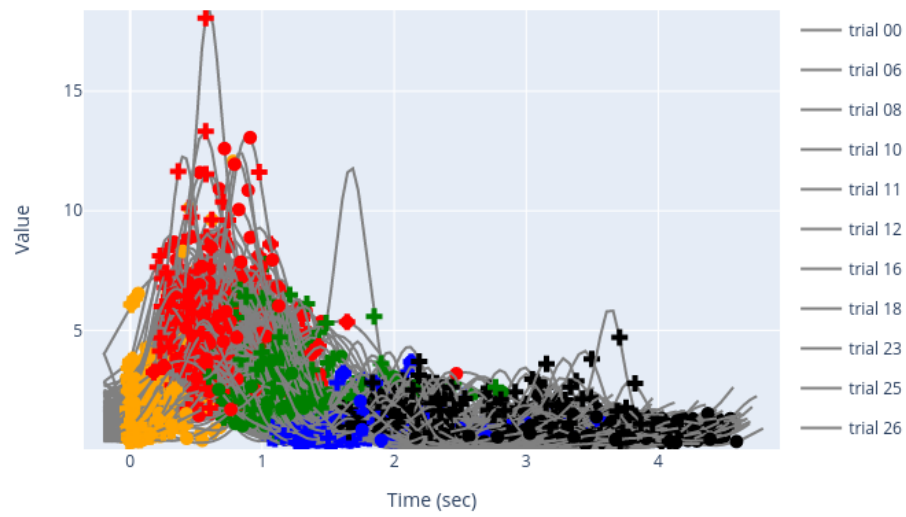


Figure 29: Intensity function for neuron 15. Same format as in Figure 4. [Click on the image to access its interactive version.](#)

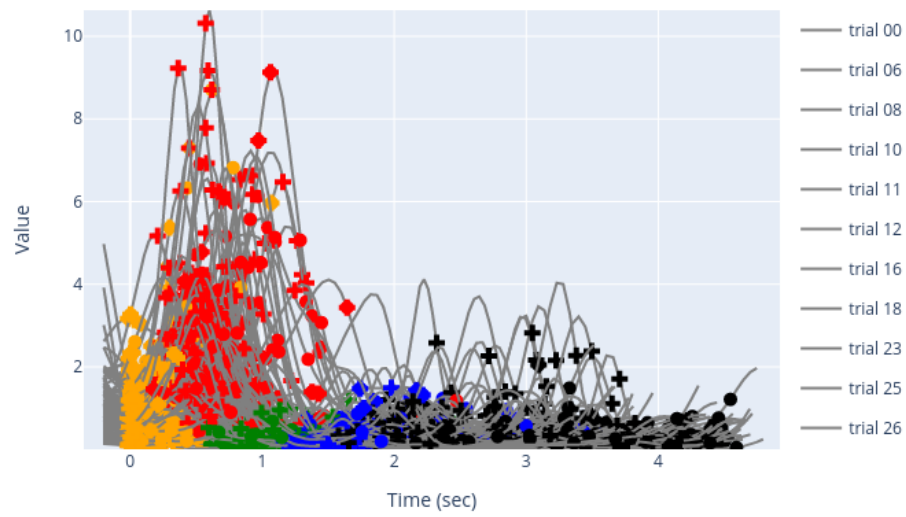


Figure 30: Intensity function for neuron 16. Same format as in Figure 4. Click on the image to access its interactive version.

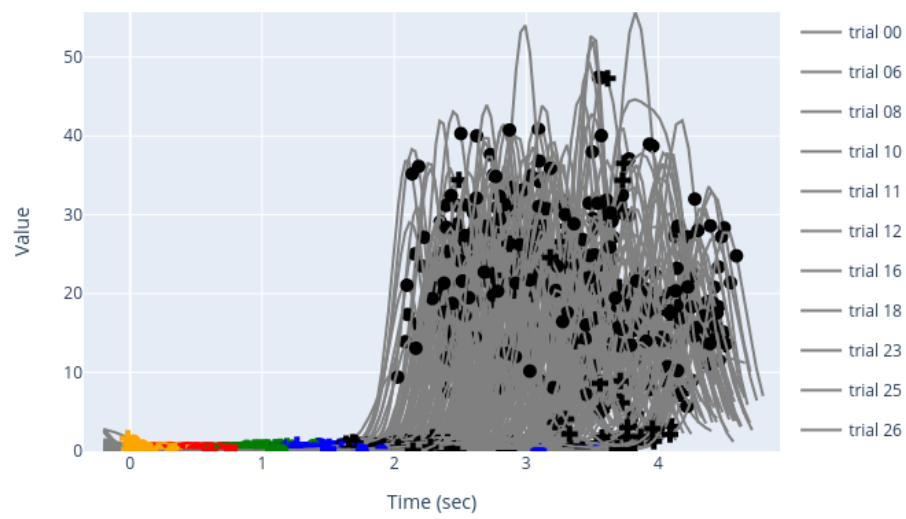


Figure 31: Intensity function for neuron 17. Same format as in Figure 4. Click on the image to access its interactive version.

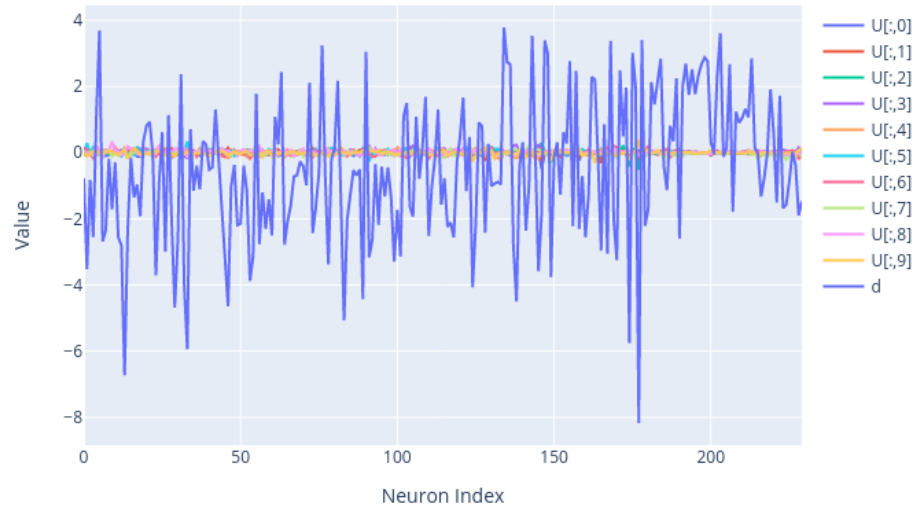


Figure 32: Left singular vectors of the matrix  $C$  corresponding to the orthonormalized latents, and offset vector  $\mathbf{d}$ , (Eq. 2). [Click on the image to access its interactive version.](#)



Figure 33: Estimated lengthscale parameters of the squared exponential kernels of all latents. Click on the image to access its interactive version.