Ergodic hypothesis in neural computation

(Applied to the model of medial superior olive in the auditory brainstem)

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Abbreviations

ITD – interaural time delay
LSO – lateral superior olive
MSO - medial superior olive

(1) Introduction

We propose the ergodic hypothesis of indistinguishable time and population ensemble encoding of the signals by spike trains. The ergodic assumption in physics was originally introduced in statistical mechanics of gases by Boltzmann in the nineteenth century. According to this assumption the average of a selected quantity is the same for the time average and for the statistical ensemble average.

(2) Model description

In the model the neurons are converging on to the MSO. We implement elementary neural operations realized on spike trains in individual parts of the circuit. Random delay, coincidence detection of spikes and convergence of spike trains are operations implemented by the following modules: input spike generator, jitter generator, coincidence detector and output ideal observer. Subsequent processing of spike trains computes azimuth in the circuit.

Acknowledgements

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References

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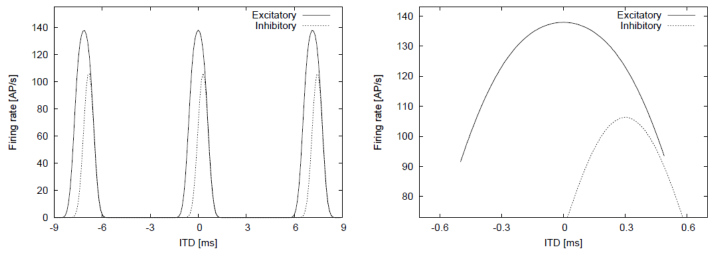


Figure 1 A and B.
ITD curves for the basic set of parameters. We can see that the curve is periodic and its peak is slightly shifted due to inhibition. On the right panel we see a detailed view of the peaks (with enlarged resolution in both axes).

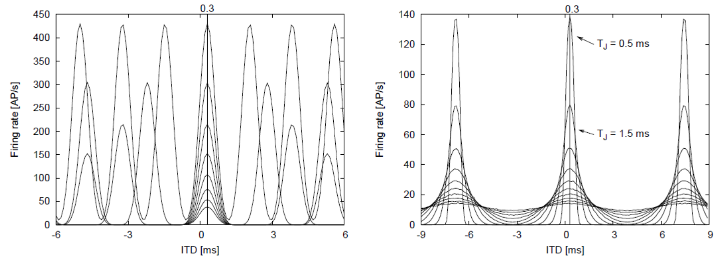


Figure 2 A and B.
ITD response curves for different input sound frequencies (left panel) and different values of spike timing jitter (right panel).
Left panel: For increasing sound frequencies with step 1.414 (50, 71, 100, 141, 200, 283, 400, and 566 Hz), the maximum firing gets higher. Right panel: The presence of high jitter values renders the response curve flat. The response increases as the magnitude of jitter decreases towards zero.

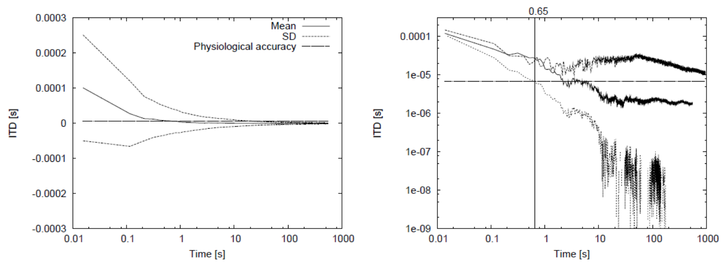
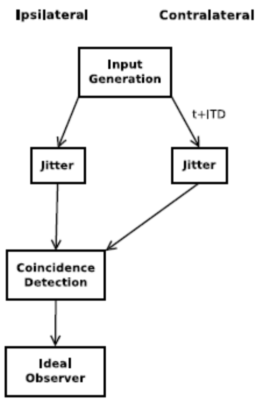


Figure 3 A and B.
Time required to reach a reliable (with a given precision) estimate of azimuth by a single neuron.
x-axis shows time, y-axis ITD, note the logarithmic scales used. Left panel: The middle line represents mean value obtained for 1000 simulation runs, dotted lines show standard deviation. Right panel: The top line shows mean convergence when using larger jitter 5 ms, middle line shows how convergence improves when using a wider coincidence detection window 3 ms and the bottom line shows faster convergence for the basic set of parameters, when jitter is 1 ms.
In both cases the flat line shows precision obtained in psycho-acoustical experiments. At the point in time, when the mean value crosses the threshold, the model has gained enough information to report the azimuth with the average precision corresponding to that of human listeners, within the range of 4 angular degrees.

Model scheme



	MSO Range	typical values	LSO range
sound frequency [Hz]	70-1400	313/ 4427	1400-14000
window size [µs]	500-1000	500	7000
spike timing jitter [ms]	0.125 - 8	1-5	0.125 - 8
firing rates [AP/s]	out: 20 - 200	60-100	in:100-200 out:<150

Table 1
Shows typical MSO and LSO working parameters. We compare the two nuclei to demonstrate two possible applications of the ergodic hypothesis.

	5 X slower	original values	10X faster
sound frequency [Hz]	28	140	1400
window size [µs]	3000	600	60
spike timing jitter [ms]	5	1	0.1
(JND) Just noticeable difference [µs]	50	10	1
detection time by 1 neuron [ms]	3250	650	65

Table 2
Shows time warping of typical MSO parameters.

(3) Applications

The ergodic hypothesis used in [Sanda] states that the same result is obtained when observing a process over a long period of time as when sampling a given number of shorter Independent realizations of the same process. Our other results [Bures] show that the ergodic hypothesis cannot be applied mechanically to any neural algorithm. As at least in the case of the lateral superior olive, parallel processing of several fibers may be beneficial over processing of one neural fiber for a longer time. A variant of the ergodic hypothesis has been used in [Toth] to estimate unknown parameters.

Conclusions

Ergodic hypothesis can be used as a tool in description of computations in neural circuit. We can obtain missing parameters otherwise difficult to measure. In the example of the MSO it is number of neurons needed to arrive to given precision.