# Multiscale fluctuation analysis of interspike intervals from unanesthetized rats

Leonid A. Safonov (PY)[a], Hideyuki Câteau[a,b,c], Yoshikazu Isomura[a],
Siu Kang[a], Zbigniew R. Struzik[d], and Tomoki Fukai[a,e]

*a* Laboratory for Neural Circuit Theory, RIKEN Brain Science Institute,
2-1 Hirosawa, Wako, Saitama 351-0198, Japan

*b* RIKEN BSI-TOYOTA Collaboration Center (BTCC), 2-1 Hirosawa, Wako, Saitama 351-0198, Japan

*c* Graduate School of Life Science and Science Engineering, Kyushu Institute of Technology,
2-4 Hibikino, Kitakyushu, Fukuoka 808-0196, Japan

*d* Educational Physiology Laboratory, Graduate School of Education,
University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan

*e* Department of Complexity Science and Engineering, University of Tokyo, Kashiwa, Chiba 277-8561, Japan

safonov@brain.riken.jp

**Abstract**— We analyze scaling properties of probability density functions of interspike intervals time series from unanesthetized rats brains. The technique is used to characterize the dependence of non-Gaussianity of the distribution on the temporal scale. We show that the data for sleep and awake states have significantly different scaling properties suggesting different sources of complexity in the two states.

*Keywords*— **multiscale analysis, unanesthetized rats, multifractal**

Non-Gaussianity of probability densities of time-series fluctuations in many phenomena have been studied in recent years. Also, analysis of spatial and temporal properties on different scales is a common method to study of complex systems. However, a combined multiscale analysis of probability density has been proposed only recently.

We consider a time series $b(i)$ which we integrate $B(i) = \sum_{j=1}^{i} b(j)$. The resulting "walk" is divided into segments of size $2s$. In each segment $[s(k-1)+1, s(k+1)]$, where $k$ is the index of the box, we fit the walk with a $q$th order polynomial. After this we obtain differences $\Delta_s B(i) = B^*(i+s) - B^*(i)$, where $B^*(i)$ is the deviation from polynomial fit.

To characterize how different the PDF is from a Gaussian distribution, we obtain standardized PDFs (the variance is set to one) of $\Delta_s B(i)$, and then use parameter estimation based on Castaing's equation introduced in the study of hydrodynamic turbulence [1].

It has been demonstrated that a non-Gaussian PDF with fat tails can be modelled by log-normal multiplicative processes [1] such as

$$\Delta_s B(i) = \xi_s(i) e^{\omega_s(t)},$$

where $\xi_s$ and $\omega_s$ are independent Gaussian random variables with zero mean and variance $\sigma_s^2$ and $\lambda_s^2$ respectively. The PDF of $\Delta_s B(i)$ has fat tails and is expressed by

$$P_s(\Delta_s B) = \int F_s\left(\frac{\Delta_s B}{\sigma}\right) \frac{1}{\sigma} G_s(\ln\sigma) d(\ln\sigma), \qquad (1)$$

where $F_s(\xi_s)$ and $G_s(\sigma_s)$ are Gaussian with zero mean and variance $\sigma_s^2$ and $\lambda_s^2$, respectively. In this case (1) is referred to as Castaing's equation and converges to a Gaussian

$$G_s(\ln\sigma) = \frac{1}{\sqrt{2\pi}\lambda} \exp\left(-\frac{\ln^2\sigma}{2\lambda^2}\right)$$

when $\lambda \to 0$. The original Kolmogorov-Obukhov theory [2] predicts that the non-Gaussian parameter $\lambda^2$ is proportional to $-\ln s$, where $s$ is the temporal scale.

Equation (1) provides a good approximation to PDFs observed not only in turbulence, but also in foreign exchange rate [3], stock index [4], and human heartbeat [5, 6] fluctuations.

In this study we apply the multiscale PDF analysis to recordings of interspike intervals from live unanesthetized rats. We analyze recordings (around 8hrs long) from six rats. The rats are in alternating sleep and awake states.

Spike trains from each head-fixed rat are recorded using five tetrodes (four in the neocortex and one in the hippocampus). Using a spike-sorting technique we

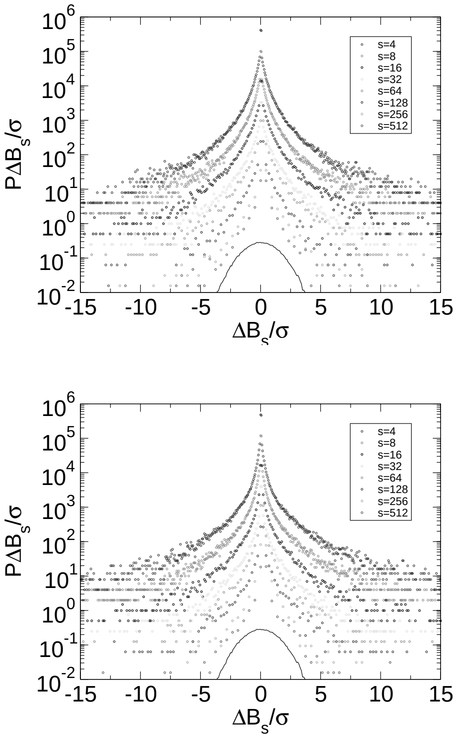


図 1: Deformation of PDFs across scales for all neurons for sleep (above) and awake (below) states. Plots are shifted arbitrarily in vertical direction for presentation purposes. Gaussian PDF is shown at the bottom.

separated spike trains from tetrodes into spike trains of individual neurons. The resulting spike trains are separated to sleep and awake parts according to videotaped iamges of rats. The total number of neurons with sufficiently long asleep and awake periods is 50.

We apply the multiscale PDF analysis to sleep and awake state time-series from each neuron. Deformation of PDFs on different scales is shown in Fig 1.

We estimate the $\lambda^2$ fitting parameter using the technique described in [7] and average $\lambda^2(s)$ values for all neurons at different scales and plot the averaged values in log-normal coordinates. The results are shown in

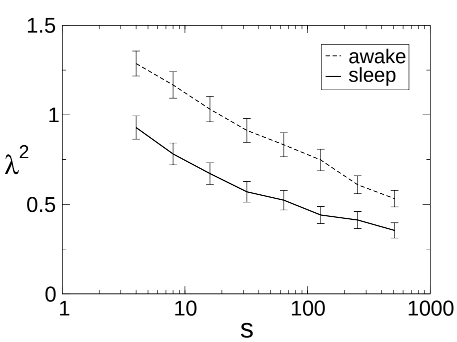


図 2: Scale dependence of the non-Gaussian parameter $\lambda^2$. Averaged over 50 neurons.

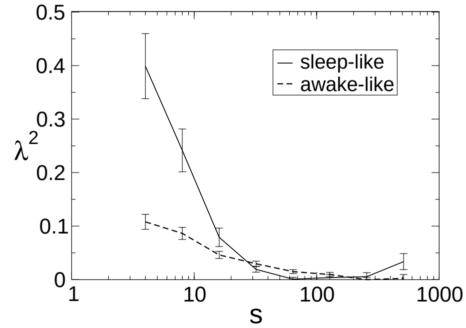


図 3: Scale dependence of the non-Gaussian parameter $\lambda^2$. Averaged over 21 neurons.

Fig 2. The plot for the awake state shows correspondence to the multiplicative cascade paradigm, while for the sleep state the plot is curved and may suggest power-law decay characteristic of non-Gaussian noise [7].

We also analyze the data obtained from the model described in [8]. The $\lambda^2(s)$ plots are shown in Fig 3. The degree of non-Gaussianity is much smaller than in the real data, and neither sleep-like nor awake-like data seem to fit to multiplicative cascade paradigm.

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