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New symbolic method for studying brain connectivity during sleep onset

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Abstract. We present new technique of symbolic time-series analysis which are useful for analyzing biological signals. The method is based on coarse-graining of the first range difference of the analyzed time series. The paper include prelimary results of analysis EEG-data for sleep onset.
Keywords: Symbolic dynamics, EEG, Sleep, Mapping, STM

1. Introduction

The idea of symbolic data analysis is not new. There are many different techniques for symbolic time series analysis based on conversion of the amplitude of measured signal into a few possible symbols, corresponding to chosen amplitude ranges. The effect of such coarse-graining (partition of data space) is such that large-scale feature are captured, while noise is reduced. The choice of the data space partition affects the characteristics of symbolic description of the data. From this point, the techniques start to differ, for example, the alphabet i.e. the set of used symbols may be different. Two-symbol alphabet {0, 1} is often used. The greater the alphabet the more details of the original signal may be captured, but the tradeoff is that reduction of noise is diminished. For two-symbols alphabet the data median or data mean are often used as threshold for data space partition, but in non-stationary signals mean and median often change abruptly.

In the presented work, a solution to this problem is proposed. We use the first range difference of source signal instead of the signal itself. In consequence, we obtain a natural threshold for the partition of the data space. The first range difference gives information about monotonicity of the signal - when the signal is increasing this difference is positive while when the signal is decreasing it is negative. Therefore, we use two-element alphabet - symbol "1" when the signal is increasing (or not changing) and symbol "0" when the signal is decreasing. After symbolization the sequences of the given symbol (0 or 1) give us information how long are periods when the signal is increasing or decreasing.

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2. Material and Methods

Data for analysis were provided by the Department of Psychiatry, Medical University of Warsaw Polysomnograms were collected using data acquisition system DigiTrack™ made in Poland by P.I.M. ELMIKO, Warsaw. EEG-signals in these polysomnograms were collected according to standard 10-20 system from 21 channels, filtered with a band-pass filter 0.5 – 70.0 Hz and sampled with f_s = 128 Hz.

The presented method is based on multistep procedure. The first step is symbolization. If we have a signal represented by the time series $x(i)$ (that is often a sampling of a continuous measurement $v(t)$), we calculate the first range differences and represent the differences by symbols from the two-elements alphabet:

$$s(i) = \begin{cases} 1 \text{ if } \left[x(i+1) - x(i)\right] \geq 0 \\ 0 \text{ if } \left[x(i+1) - x(i)\right] < 0 \end{cases}, \quad i = 1, \ldots, (I-1) \tag{1}$$

As a result of symbolization we obtain the binary sequence of symbols 0 and 1, for example P = {00100100100101001001000…}.

The second step is partitioning of sequence P into windows of width W symbols each. It is a sliding window technique. If the shift is smaller then W then the consecutive windows overlap.

The third step consists of counting mono-sequences *Nx0* (or *Nx1*) in the j-th window; *mono-sequence* of length *N* (*N=1,…,W*) is a homogenous sub-sequence containing only one type of symbol, *S* (0 or 1). As the result we obtain the number of mono-sequences consisting of *N* symbols *0* in the j-th window, $L_j\{Nx0\}$ (or, equivalently, the number $L_j\{Nx1\}$). We repeat this for all possible values of *N*. Knowing numbers Lj*{Nx0}* we calculate *binary occupancy* of the window *j* by mono-sequences *Nx0*

$$O_j\{Nx0\} = \frac{L_j\{Nx0\} \cdot N}{W} \quad (N = 1\ldots., W) \tag{2}$$

In such a way we obtain spectrum of mono-sequences' length for every window. Change of this spectrum with time (from one window to the next one) includes information about evolution of the signal.

A simple relation between the length of a sequence and frequency is illustrated in Fig. 1.

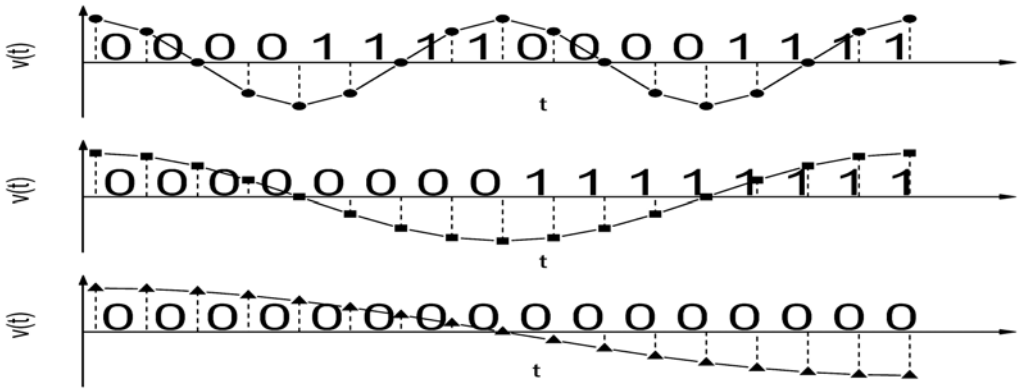

Figure 1. *Symbolization of three signals with characteristic frequencies equal 4f, 2f, f, respectively.*

If the sampling frequency is f_s then relationship between mono-sequence length *N* and characteristic frequencies *f* is the following:

$$f = \frac{f_s}{2N} \tag{3}$$

The distribution of occupancy *Oj*{*N*x0} in the window *j* is similar to spectrum of frequencies.

Moreover, we can sum distribution of mono-sequences of consecutive lengths (for example: from *G* =4 to *D*=8) to create bands' distribution:

$$C_j\{\text{band}\} = \sum_{N=G}^{D} O_j\{Nx0\} \tag{4}$$

Such analysis is very useful when the source of analyzed signal works in few regimes characterized by different frequency bands.

3. Results

We calculated occupancy (Eq. 4) in five bands only partially corresponds (Eq. 3) to classical EEG rhythms (Table 1):

Table 1. *Relationship between frequncies bands and sequences bands.*

Classic EEG bands	*Sequence's length N*
Gamma	1,2 and 2,3
Beta	3,4
Alpha	5-8
Theta	8-14
Delta	14-85

3.1. Sleep evolution on spatiotemporal maps (STM)

Spatio-temporal Maps (STM) enable to observe evolution and dynamics of EEG activity on all used channels. The example of results for one person on all bands is shown on the Fig. 2.

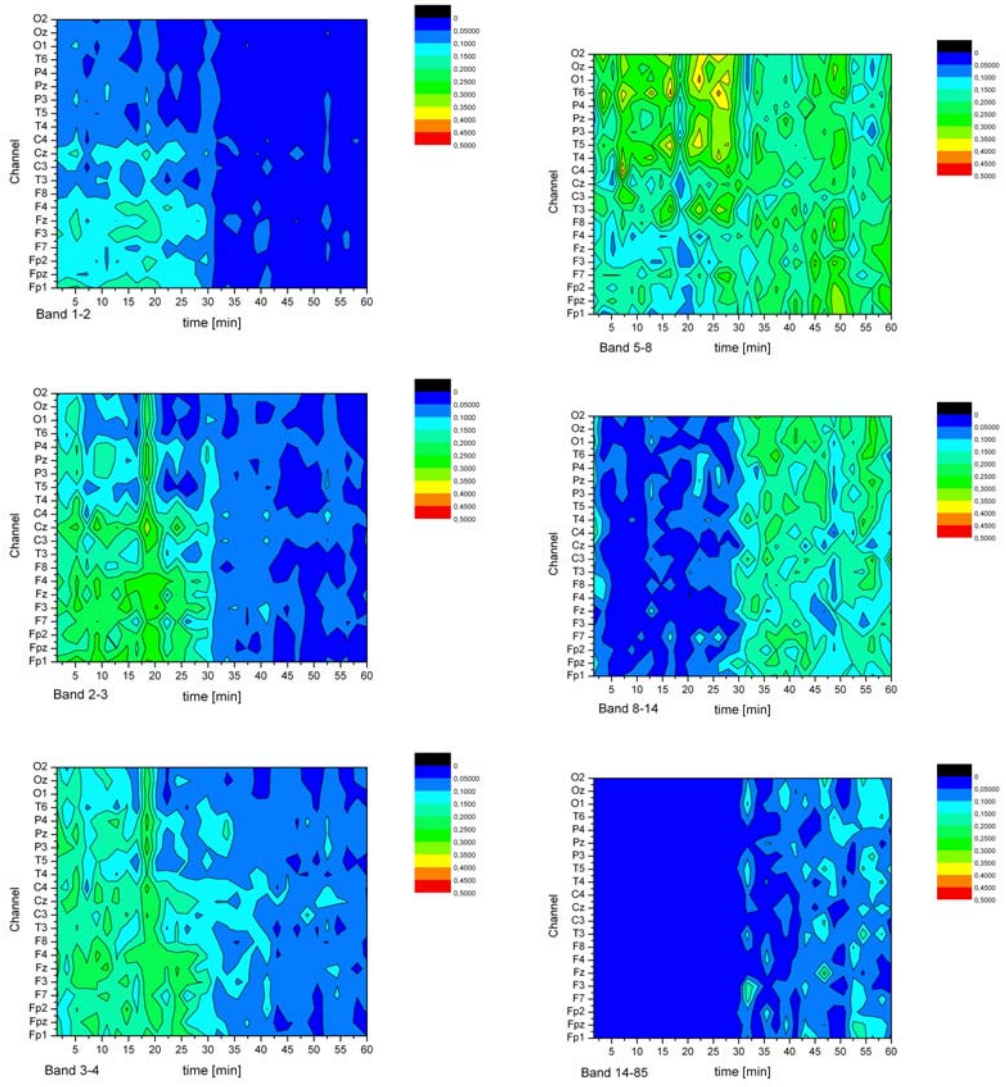

***Figure** 2. The spatiotemporal maps for one subject in all bands*

The best results to mark sleep onset we obtain on the band 8-14. We observe clear edge between waking and sleep (Fig. 3).

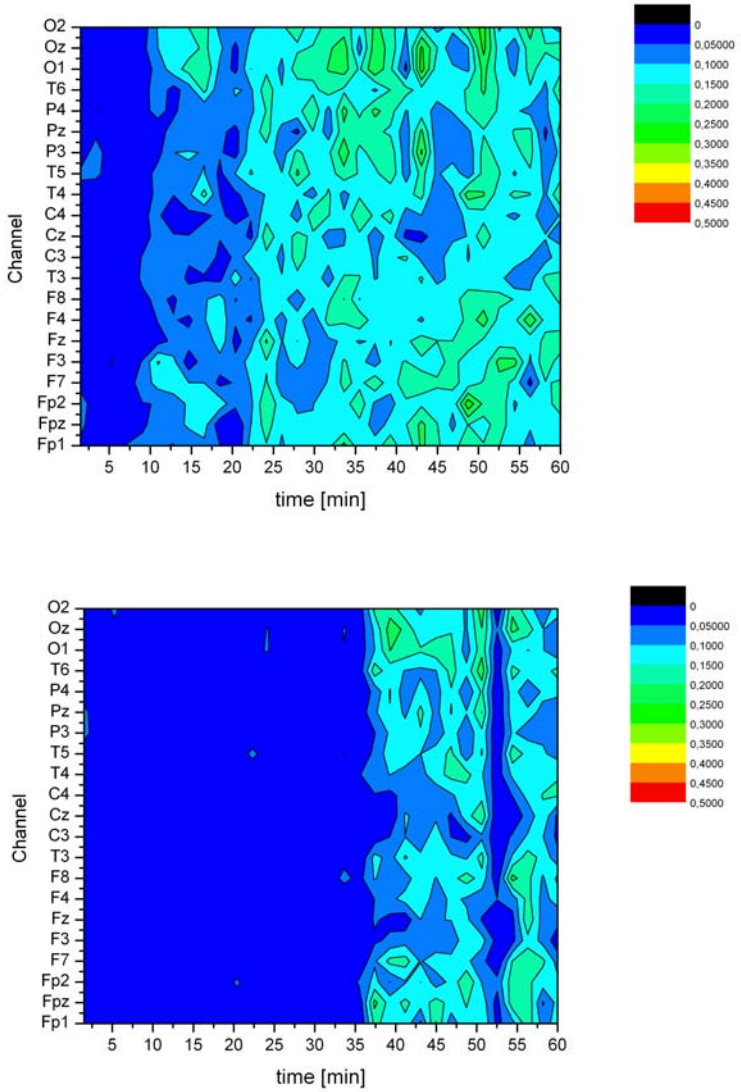

Figure 3. The STM of binary occupancy in the band 8-14 for two subjects.
For the irst subject-sleep onset is observed at 11 minute; for the second sleep start at 37 minute.

3.2. Maps in the vicinity of sleep onset

Fig. 4 shows example of the maps of brain activity for 10 healthy people. The measures of activities are means of binary occupancy calculated during 20 seconds 2 minutes before sleep onset, during first 20 seconds of sleep, and during 20 seconds, 2 minutes later.

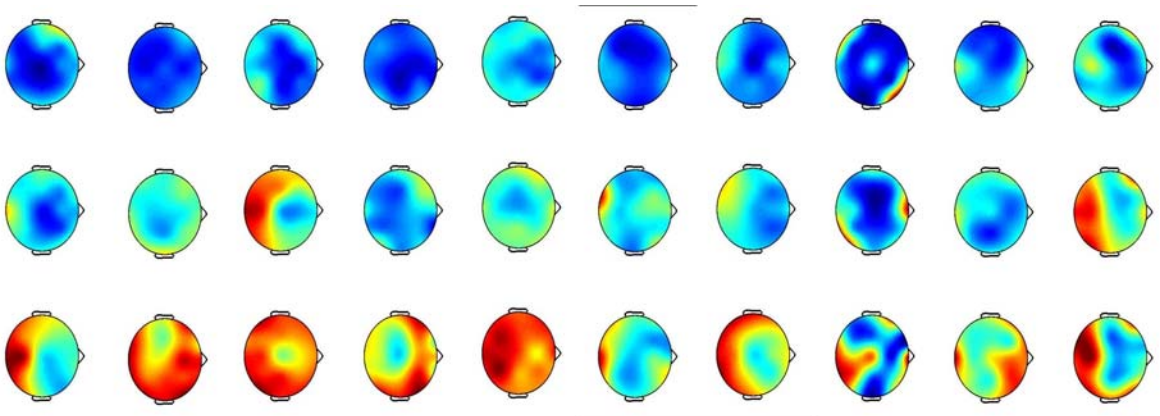

Figure. 4. Sequences of binary occupancy average maps in the band 8-14 for 10 healthy person.

The maps was drawn by MATLAB's topoplot script by Andy Spydell, Colin Humphries, Arnaud Delorme & Scott Makeig (CNL / Salk Institute, 8/1996-/10/2001; SCCN/INC/UCSD, Nov. 2001)

4. Discussion

The sleep onset has topographical diversity, but it is difficult to find the typical sequences of activation and deactivation of different parts of brain. It seems that the changes of bioelectrical activity are weak in central parts.

We see that brain activity in the band 8-14 increases when subjects are falling asleep and during sleep. The pattern for transition is not obvious, but in the STM, we observe that increases in frontal channels precede that in the temple and occipital ones.

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This paper with color figures may be downloaded from ftp://ftp.gbaf.eu/download/new_symbolic.pdf