Recurrence Plots

Exemplary application to ERP data

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BASICS ABOUT RECURRENCE PLOTS

The method of recurrence plots (RP) was introduced to visualize the time dependent behavior of the dynamics of systems x_i, which can be pictured as a trajectory in the phase space (ECKMANN 1987). It represents the recurrence of the phase space trajectory to a certain state. The main step of this visualization is the calculation of the $N \times N$-matrix

$$\boldsymbol{RP}(i,j) = \Theta(\varepsilon - \|\vec{x}_i - \vec{x}_j\|)$$

where ε_i is a cut-off distance and $\Theta(\cdot)$ is the Heaviside function.

The recurrence plot exhibits its characteristic large-scale and small-scale patterns which are caused by typical dynamical behavior (ECKMANN 1987, WEBBER & Zbilut 1994), e. g. diagonals (similar local evolution of different parts of the trajectory) or horizontal and vertical black lines (state does not change for some time).

ZBILUT and WEBBER have recently developed the recurrence quantification analysis (RQA) to quantify a RP (ZBILUT & WEBBER 1992, WEBBER & ZBILUT 1994). They defined measures using the recurrence point density and diagonal structures in the recurrence plot, the *recurrence rate* RR (density of recurrence points), the *determinism* DET (ratio of recurrence points forming diagonal structures to all recurrence points), the *maximal length of diagonal structures* L_{max} (or the their *averaged length* $\langle L \rangle$), the *entropy* ENT (of the distribution of the diagonal lengths) and the *trend* TR (paling in the RP).

Analogous to the definition of DET and $\langle L \rangle$ we defined additionally measures based on vertical structures in the RP, the *laminarity* LAM (ratio of recurrence points forming vertical structures to all recurrence points) and the *trapping time* TT (averaged length of vertical structures).

A computation of these measures in small windows moving along the main diagonal of the RP obtains time dependent behavior of these variables and thus, transitions in the time series (e. g. TRULLA et al. 1996).

APPLICATION TO THE DATA OF THE ODDBALL EXPERIMENT

Procedure

Probands were seated in a dimly lit room in front of a monitor and were instructed to count tones of high pitch. Each subject was tested in nine blocks. The blocks varied in the probability of occurrence of the higher tones from 10 to 90%. Each block contained at least 30 target tones. Response was given in a three alternative choice (using cursor keys of the keyboard). During the test, the EEG was recorded.

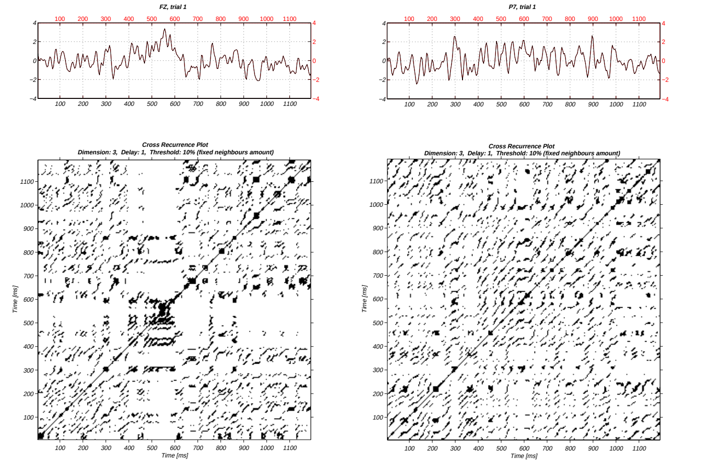
The stimuli were computer-generated beeps of 100ms length. Tones were either high (1400Hz) or low (1000Hz). They were presented with an ISI of 1000ms.

Data analysis and interpretation

After computing event-related voltage averages for the experimental manipulations (10% up to 90% target probability) one observes a P300 ERP component whose amplitude is correlated to the probability of the stimuli (surprise ERP).

This ERP reflects the switching between two modi of cognitive behaviour: During the episodes where the frequent stimuli are presented to the subjects, they went into a mode of automatic processing of the events. When suddenly the rare stimulus arises, the brain function is switched to controlled processing. The amplitude of the P300 reflects the switching costs.

A



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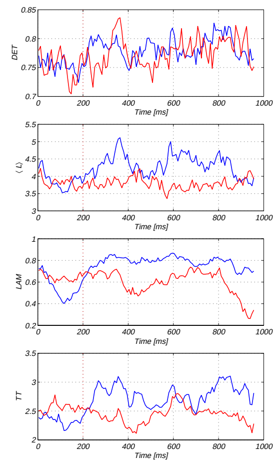
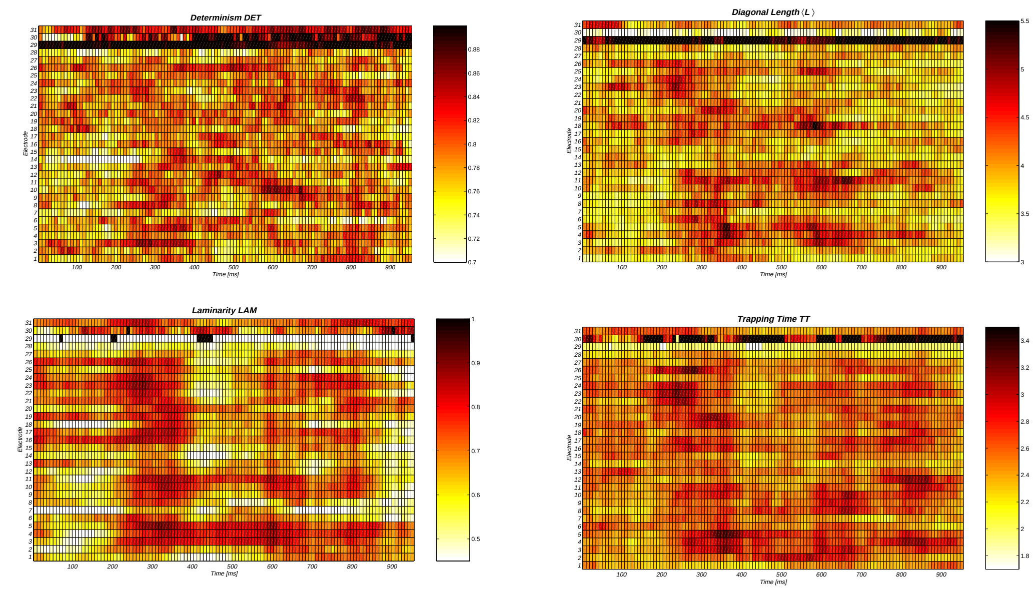


A Recurrence plots of the data of the electrode Fz (left) and P7 (right). Diagonal lines reveal „deterministic" behaviour. The clustering of the RP obtains the transitions in the signal derived from the electrode Fz. In contrast the RP of the signal P7 is rather homogenous.

B RQA parameters for the data of the electrode Fz (blue) and P7 (red) for the same embedding parameters as in the RPs. The red dotted line marks the onset of the signal. For Fz, the measures LAM and TT significantly reveal the reaction after the stimulus; for P7 these measures do not reveal clear differences.



Spatially RQA measures for the 31 electrodes. The vertical based measures LAM and TT significantly reveal transitions around the electrodes Fz (4) and Cz (18) after the stimulus at 200 ms.

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