EDITORIAL

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What is the origin of meaning? How does the brain achieve symbolic computation? What are the neural correlates of cognitive processes? These challenging questions at the borderline between neuroscience, cognitive science, nonlinear dynamics, and philosophy are related to the *symbol grounding problem* posed by Harnad (1990): How is the meaning of words and utterances grounded in the dynamics of the brain and in the evolution of beings alive interacting with each other and with their environments? Simply by convention? Or is there an inherent correctness of names, of syllables, or even of sounds? These very questions had been already asked by the ancient philosopher Plato (428 – 347 B.C.) in his, rather ironical and humorous, dialog on the philosophy of language, *Cratylus* (Plato 1921):

> *Hermogenes*: Here is Socrates; shall we take him as a partner in our discussion?
> *Cratylus*: If you like.
> *Hermogenes*: Cratylus, whom you see here, Socrates, says that everything has a right name of its own, which comes by nature, and that a name is not whatever people call a thing by agreement, just a piece of their own voice applied to the thing, but that there is a kind of inherent correctness in names, which is the same for all men [. . .] (Plato 1921, 383a).

In the course of their conversation, Socrates, Hermogenes and Cratylus agree that the words had to be made by a “name-giver” (Plato 1921, 389a) supervised by a dialectician (Plato 1921, 390d) who had taken care that the name-giver was making the words appropriately in accordance with their inherent correctness. After treating several examples for names and composite words, Socrates will impart his “quite outrageous and ridiculous” notions about the “earliest names” and the meanings of sounds (Plato 1921, 426ab). What is the meaning of *I* or of *A*? According to Socrates, the name-giver employed *I* for “everything subtle, which can most readily pass through all things” (Plato 1921, 426e), whereas *A* “he assigned to greatness, and *E* to length, because the letters are large” (Plato 1921, 427c).

At a first glance, these ideas appear really to be “outrageous and ridiculous”. However, they are of particular relevance for contemporary linguistics and for the symbol grounding problem. Why, e.g. do we say zigzag instead of zagzig? Linguists call this phenomenon *iconicity* (Mayerthaler 1987); and the well-developed *optimality theory* (Prince and Smolensky 1997) states that the sound *I* is less marked and therefore less complex than the sound *A*. Another principle, called *Horn strategy*, requires that a complex meaning should be assigned to a complex form and vice versa (v. Rooij 2004). Following v. Rooij (2004) and Jäger (2004), the Horn strategy is evolutionary more stable than its competitors.

Hence, the meanings of sounds are, at least in this respect, evolutionary grounded in the linguistic behavior of embodied cognitive agents.

On the other hand, optimality theory is a two-level theory for cognitive computation. It consists of a low-level dynamics of neural networks and of a high-level interpretation of this dynamics as symbolic computation (Prince and Smolensky 1997; beim Graben 2004). Such models allow for the investigation of physical and physiological processes and require therefore advanced methods of data analysis, reduction and interpretation.

In March 2005, the research group "Conflicting Rules" at the University of Potsdam (a project funded by Deutsche Forschungsgemeinschaft) held a tandem workshop on *Advanced Methods of Electrophysiological Signal Analysis* as well as *Symbol Grounding? Dynamical Systems Approaches to Language*.[1] For four days, the outstanding scientists who were invited to this meeting presented their current results and discussed the state of affairs in this highly interdisciplinary field of research. Thanks to Franco Orsucci, the editor of *Chaos and Complexity Letters*, we were given the opportunity to publish some of the main results of this very fruitful meeting in the present special issue that includes the following contributions of the first part of the workshop.

Keller *et al.* give an introduction into the framework of ordinal pattern analysis, applied to time series using a sliding window approach. They describe a number of measures of complexity derived from the pattern distributions and discuss their properties. Additionally the authors demonstrate the application of the method to long-term EEG data.

Marwan *et al.* combine the order pattern analysis with the recurrence plot technique to analyze single-trial event-related potentials (ERPs) from an oddball task. They report a significant improvement of trial classification using order pattern recurrence plot analysis (OPRPA) descriptors in comparison to the classical threshold RPA.

The work of Roehm *et al.* is concerned with the use of event-related potentials for the investigation of language comprehension. They point out that the most important language-related ERP component, the N400, is not an unambiguous marker of a single neuronal process, and show that by using frequency-domain measures, it is possible to decompose complex ERP responses into their components as well as dissociate seemingly identical N400 effects into functionally specific subtypes.

Event-related brain potentials for emotionally-loaded words are analyzed by Gianotti *et al.* They segment time-series of potential maps into brain microstates by a clustering algorithm and employ the LORETA algorithm for source localization. Their results do neither support the "valence hypothesis of hemispheric specialization", nor the "right hemispheric dominance model" for emotional cognition.

Using a new method for the improved visualization of event-related potentials in single trials based on wavelet denoising, Quian Quiroga *et al.* review applications of single trial analysis. They present results on trial-to-trial changes reflecting habituation and sensitization; the mechanism underlying an increased mismatch negativity in a pattern recognition learning task; and differences in latency variability in a rhythm perception task.

How biomedical data analysis can be improved by a preprocessing that removes statistically anomalous data points (outliers) is demonstrated by Krauledat *et al.* They apply their

[1]We wish to thank Reinhard Blutner for an inspiring talk about "embodied optimality theory" given at the workshop and for subsequent discussions about "iconicity".

techniques in the context of average ERP analysis data and of real-time EEG classification used for Brain Computer Interfacing.

Le Van Quyen *et al.* pose themselves the question whether EEG time series can be described by a self-similar process with fractal properties. The authors investigate the scaling behavior of structure functions of long-term intracranial EEG and show that it exhibits a nonlinearity which indicates that EEG should be considered as a multifractal process.

The problem of determining the coupling direction of two systems from empirical data is treated by Paluš *et al.* They introduce a statistical test for a significant deviation from symmetric coupling based on a new type of bivariate surrogate data, and check its performance by comparing with "ideal" surrogates which are normally not available in real-world applications.

Wehling *et al.* propose to use partial directed coherence to identify transient patterns of functional connectivity in EEG data. After demonstrating the properties of this measure on simulation data of coupled linear and nonlinear systems, they apply it to EEG from an alternative forced choice task.

Hutt and Munk present a multivariate synchronization analysis technique based on a cluster analysis of instantaneous phases. The method is able to detect phase synchronization in single trials of local field potentials recorded from awake behaving monkeys.

Sarnthein and Jeanmonod recorded simultaneously single unit activity, thalamic local field potentials and surface EEG of a neurogenic pain patient during surgery. They assess synchronization by time-frequency coherence measures and report a loss of thalamic synchronization in the theta band after surgery.

Mainy *et al.* analyze intracerebral evoked potentials for cognitive tasks in the gamma band of the EEG using Morlet wavelets and compare them with low-frequency surface ERPs. They find remarkable timing differences between these frequency bands.

Eckhorn *et al.* review their recent work on visual object recognition in monkeys and humans. They argue that gamma band synchrony in the visual cortex is restricted to distances of a few millimeters, and that larger-scale object continuity is most likely represented in the phase continuity of traveling waves. The authors complement their empirical results with computational models that are able to reproduce the observed effects.

Maye and Werning present conceptual computational models of synchronized oscillatory activity in the visual cortex. Using eigenmode analysis to decompose the matrix of correlations between oscillators into invariant spatial patterns and time-dependent activation functions, the authors observe that these two aspects can be associated with epistemic possibilities of the visual system and actual object representations, respectively. This contribution provides the bridge to the second part of the workshop concerned with the symbol grounding problem. Werning and Maye interpret the stable oscillations of the neural network reported in the latter paper in terms of frame theory where attribute concepts are locally represented by particular populations while hierarchical substance concepts emerge from the synchronization of distributed activity.

The issues of reduction and emergence in the sciences are addressed in the contribution of Atmanspacher and Bishop. They argue that a simple reductionist account for the description of high-level properties in terms of low-level features is often not appropriate. Atmanspacher and Bishop propose the idea of contextual emergence as an alternative to reductionism and discuss the significance of stability conditions for its applicability.

Atmanspacher and beim Graben show how neural correlates of consciousness, brain microstates and symbolic cognition could emerge from neurodynamics in contextually given coarse-grainings with Markovian stability properties.

The contribution of Hermann and Hermann addresses the question of gene complexity. They define the codon usage frequency of a particular gene relative to the species-specific codon usage as a valuable complexity measure, and report higher complexities for cognition-related genes in comparison to structure-related genes reflecting their phylogenetic age.

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January 2006

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