2 Projects and Results

2.1 Theory and Data Analysis

The main research activities of the Department of Theory and Data Analysis are the analysis and interpretation of the empirical body of knowledge referring to psychophysical relations and extraordinary states of consciousness. In particular, this refers to:
1. Development of theoretical concepts for an integration of empirical results into the body of knowledge of the involved scientific disciplines.
2. Elaboration and application of new techniques of data analysis as well as proposals for future studies.
Specific research topics within this program require highly interdisciplinary approaches and have been successfully established and evaluated since the foundation of the department in 1998. They are anchored in the four research areas described in the following and involve background in statistics and data analysis, theoretical physics, cognitive neuroscience, and philosophy of science.

2.1.1 Concepts of Mind-Matter Relations

Contextual Emergence

Contextual emergence characterizes a specific kind of relationship between different levels of scientific descriptions of particular phenomena. It was developed and refined in collaborations within and outside the department, essentially since 2002. Contextual emergence utilizes lower-level (L) features as necessary (but not sufficient) conditions for the description of higher-level (H) features. It can be viably combined with the idea of multiple realization, a key issue in supervenience, posing sufficient (but not necessary) conditions at the lower level. In scientific areas such as physics, contextual emergence has been demonstrated as a formally precise and straightforwardly applicable inter-level relation. The situation becomes more challenging for less rigorously formalized fields of research. This is the case in the areas of cognitive neuroscience or consciousness studies, focusing at relations between neural and mental states.

Atmanspacher; together with Bishop, beim Graben

Publication: Atmanspacher (2009a)

Mental States from Neurodynamics

In recent theoretical work we showed how contextual emergence is to be understood in detail. The basic idea is that, starting at a particular neural level L of description, a two-step procedure can be carried out that leads (1) from an individual neural description L_i to a statistical neural description L_s and (2) from L_s to an individual mental description H_i. The essential goal of step (1) is to identify a partition consisting of equivalence classes of individual neural states, representing the multiple realizability of statistical neural states in L_s. The essential goal of step (2) is to assign individual mental states at level H to statistical neural states at level L. This is impossible without a context at H defining the set of observables at level H that is to be constructed from L_s. This context can be implemented as a stability criterion at level L.
It has been demonstrated how this procedure works for experimental data from cognitive neuroscience. For this purpose we used data from the EEG of subjects with sporadic epileptic seizures. The analytic procedure starts with the construction of a (Markov) transition matrix reflecting the EEG dynamics in the neural state space. The eigenvalues of this matrix yield time scales defining partitions of increasing refinement that can be used for the assignment of mental states. The result of the partitioning can be inspected in the originally recorded time series. This comparison of obtained mental states with corresponding episodes in the EEG dynamics showed perfect agreement between the distinction of normal and epileptic states and the bipartition resulting from the spectral analysis of the neural transition matrix.

Atmanspacher; together with Allefeld, beim Graben, Wackermann

Publications: Atmanspacher (2009a), Allefeld, Atmanspacher, Wackermann (2009)

Alternative Similar Approaches

Contextual emergence addresses the construction of a partition at a lower-level description by a higher-level context which adapts this partition to a specific higher-level description. An alternative strategy was proposed by Amari and colleagues in the 1970s to construct neural macrostates from neural microstates. They identified neural macrostates based on two criteria: (i) the structural stability of microstates as a necessary lower-level condition, and (ii) the decorrelation of microstates as a sufficient condition induced by the higher level. These criteria, however, do not exploit the dynamics of the system in the direct way which a Markov partition allows. A detailed study of the way in which contextual emergence appears in Amari's approach was finished. Moreover, Tononi's ambitious program of an "information integration theory" shares important features with contextual emergence which we have started to investigate.

Atmanspacher; together with Barrett, beim Graben

Publications: Atmanspacher (2009a), beim Graben, Barrett, Atmanspacher (2009)

Causal Closure and Overdetermination

Many debates of mental influences on brain processes are based on the assumption of the "causal closure of the physical". Briefly, this means that effects on physical states can only be caused by (previous) physical states. A detailed look at the notions involved shows that the causal closure assumption depends on time symmetries inherent in the fundamental physical equations of motion. Their solution always requires a specification of initial/boundary conditions and implies a breakdown of time symmetries due to the action of an experimenter or observer. This general objection against the causal closure of physical states is independent of the system considered.
In the philosophy of mind, the argument of overdetermination is often used against the causal efficacy of mental states

on neural states. If neural states are described as effects of previous neural states, then an additional mental influence (mental causation) "overdetermines" the neural states. This can lead to severe inconsistencies which can be avoided if mental states are well-defined on the basis of proper partitions of the underlying neural state space. This entails a correlational balance of mental and neural states which, according to the interlevel relation of contextual emergence, respects both neural and mental features.

Atmanspacher; together with Bishop, Harbecke

Panexperientialism in Dual-Aspect Models

Following up on a proposal by Primas, we studied the possibility to translate the mind-matter distinction into terms of mental and physical time. In the spirit of this idea, we hypothesized a relation between the intensity of mental presence and a time scale (some seconds) often referred to as a measure for the duration of nowness. This duration is experimentally accessible and might offer a suitable way to characterize the intensity of mental presence. Some features consistent with other, related ideas have been indicated and interesting consequences with respect to the idea of a generalized notion of mental presence, with human consciousness as a special case, have been outlined. In particular, the phenomenal experience of nowness can be regarded as a fundamental quale, thus providing a concrete option, to be explored in more detail, to address the idea of panexperientialism.

Atmanspacher; together with Franck

Publication: Franck, Atmanspacher (2008)

Riemann's Philosophical Speculations

Posthumously edited fragments of the distinguished mathematician Bernhard Riemann (1826–1866) document his attempts to integrate physical and mental phenomena in a universal framework. For this purpose Riemann adopted a basic idea of the philosopher Herbart (1776–1841) who conceived of science as the "reworking of concepts". One goal of this project was to outline Riemann's sketchy and often amazing speculations in their full breadth. Emphasis is put on the idea that Riemann may have sought the link between the material and the mental in the notion of an "agens", wherein the concepts of state and change converge. The interaction between Riemann and Herbart can serve as a case in point for the impact of philosophy on the development of science in the 19th century.

Ehm

Journal "Mind and Matter"

The journal "Mind and Matter" was established in 2003 and has received increasing visibility as a medium for questions of mind-matter research since then. The journal appears semi-annually, and the contents of all issues published so far can be found at `www.mindmatter.de`. The number of submissions grows continuously, the current aceptance rate is about 35%. Since 2005 the journal has been produced and distributed by Imprint Academic, Exeter (UK); the editorial office has remained in the hands of the IGPP theory group. The themes of the 2008 and 2009 issues were "Psychophysics: Puzzles and Prospects", "Consciousness Across Cultures", Free Will: Foundational Frameworks", and "Expounding Emotions".

Atmanspacher, Moos

Publications: Atmanspacher, ed., Mind and Matter 6(1), 6(2), 7(1), 7(2)

2.1.2 Generalized Quantum Theory

Quantum theory contains two key concepts, complementarity and entanglement, that are often metaphorically applied to situations beyond physics. In 2002 we proposed an axiomatically formalized, generalized quantum theory to make such applications more rigorous. The crucial formal criterion leading to complementarity and entanglement is the non-commutativity of particular observables of the system considered. The ordinary Hilbert space quantum mechanics can be recovered by stepwise adding the necessary features. This provides a hierarchy of formal frameworks of decreasing generality and increasing specificity.
Recently we started to work out more refined accounts of the notion of observables versus operations, of the distinction between ontic and epistemic states, and the consequences of these distinctions for Bell-type inequalitities. An earlier survey paper on generalized quantum theory was translated into French, and two articles accessible for non-experts have been published as well.

Atmanspacher, Filk; together with Römer

Publication: Atmanspacher, Filk, Römer (2009), Atmanspacher (2009d), Atmanspacher (in press)

Non-Commutative Operations in Psychology

Non-commutativity, hence complementarity, plays a significant role in many situations in psychology. In simple words this means that the result of successive operations A and B depends on their sequence. This is to be expected if measurement operations are conceived as interactions between measuring and measured system rather than mappings from measured to measuring system. Such interactive measurement operations can be formalized by multiplicative sets of operators which do not commute with each other, $AB \neq BA$. Pertinent examples are: (i) processes involved in the perception of bistable stimuli, and (ii) processes involved in learning operations in (small) networks. An additional topic that we started to study refers to context effects in questionnaires, indicating that the sequence of questions may be crucial for the responses.

Atmanspacher, Filk; together with Römer

Complementarity of Mental Descriptions

Descriptions of mental states and their dynamics are incompatible, or even complementary, if they are based on an improper partition of the underlying neural state space. Compatible descriptions at the psychological level, which are topologically equivalent, i.e. consistent, with the underlying neurobiological description, emerge only if the mental states defined at the psychological level are dynamically stable. If the neural dynamics is sufficiently complex,

e.g. chaotic, this requires that the partition providing these states be generating (or, more specifically, Markov). Generating partitions are defined by the dynamics of the neural states and give rise to particular, dynamically stable equivalence classes of neural states that can be re-defined symbolically as mental states. As a consequence, we suggest that the program of a unified science of psychology, with mutually compatible domains of description, depends on a proper choice of partitions of the neural state space.

Atmanspacher; together with beim Graben

Publication: beim Graben, Atmanspacher (2008)

Necker-Zeno Model for Bistable Perception

The Necker-Zeno model for bistable perception, inspired by the quantum Zeno effect, was previously used to relate basic time scales of cognitive relevance to one another in a quantitative manner. The model predictions have been compared with experimental results obtained under continuous and discontinuous presentation of ambiguous stimuli. In addition to earlier results of increasing "dwell times" (inverse reversal rates) for increasing and long inter-stimulus intervals, we have shown that the reversal dynamics according to the Necker-Zeno model is also in agreement with new observations for increasing dwell times for decreasing and short inter-stimulus intervals.

These results are non-trivial since they represent opposing trends for long and short inter-stimulus intervals, separated by a critical time scale of the order of 300 msec. Moreover, the model accounts for the experimentally observed distribution of dwell times and permits an experimental distinction between different attentional effects. The Necker-Zeno model also suggests modifications of cognitive time scales under conditions of psychopathological impairments and meditation-induced modes of awareness.

Atmanspacher, Filk, Kornmeier, together with Bach, Römer

Publications: Atmanspacher, Bach, Filk, Kornmeier, Römer (2008), Atmanspacher, Filk, Römer (2008)

Temporal Nonlocality of Mental States

The concept of temporal nonlocality refers to states of a system that are not sharply localized in time but extend over a time interval of non-zero duration. We investigated the question whether, and how, such a temporal nonlocality can occur in mental processes. For this purpose we exploited the empirically supported Necker-Zeno model for bistable perception, which is based on non-commuting operations implying an option for nonlocal states. We derived so-called temporal Bell inequalities and demonstrated under which conditions they can be violated in this model, indicating temporal nonlocality. Finally, we proposed an experimental realization of such a violation and discussed its important consequences for our understanding of mental processes.

Atmanspacher, Filk

Publication: Atmanspacher, Filk (in press)

2.1.3 Multistability and Acategoriality

Adaptation and Priming in Bistable Perception

Interpretations of ambiguous figures have stimulus- and observer-specific probabilities. The observation of an unambiguous version of an ambiguous figure ("conditioning stimulus") can bias these probabilities toward higher values for either identical (priming) or opposite (adaptation) interpretations of the subsequently presented ambiguous figure. We compared such conditioning effects for different types of ambiguous stimuli at different levels of abstraction (ranging from pictures to words). For low-level conditioning stimuli we found very similar adaptation effects across ambiguous figures. Words as conditional stimuli cause priming effects, but only for semantic types of ambiguous figures. Our results indicate that bistable perception can be influenced at different levels along the processing chain.

Kornmeier; together with Bach, Wörner; funded by DFG

Bottom-up versus Top-down Mechanisms

Prolonged observation of an unchanged ambiguous figure leads to sudden perceptual changes. Two alternative explanatory approaches assume either bottom-up or top-down mechanisms underlying this phenomenon. We investigated the interrelation of two factors, both strongly modulating the rate of perceptual reversals and each being interpreted as evidence for one of the two explanatory approaches: volitional control (top-down) and discontinuous stimulus presentation (bottom-up). We found that both factors strongly modulate reversal rates, operating independently of each other on different time scales. It turns out that the two explanations are not mutually excluding alternatives (as in many current discussions) but need to be integrated in a more comprehensive picture.

Kornmeier; together with Hein, Bach

Publication: Kornmeier, Hein, Bach (2009)

EEG Correlates of Binocular Rivalry

Binocular rivalry occurs when each eye views a different image and visual perception alternates irregularly between them. In a discontinuous presentation study where endogenous alternations were synchronized with stimulus onset we recorded event related potentials (ERPs) and compared the results with a situation where both eyes view identical gratings which were simultaneously replaced by an alternative pair of identical stimuli. We analyzed ERPs from pre- and post-alternation intervals. In the case of rivalrous stimuli an occipital ERP signature occurring about 1000 ms before the onset of the alternate stimulus predicted a perceptual alternation. We propose that this ERP signature is a marker of destabilization making the perceptual system susceptible to small perturbations.

Kornmeier; together with Roeber, OShea; funded by DFG

EEG Correlates of Object Representation

Slight figural modifications can change an ambiguous and perceptually unstable visual stimulus to an unambiguous

and perceptually stable stimulus. We compared event related EEG potentials, recorded during the perception of ambiguous and unambiguous versions of a geometric cube stimulus and a semantic face stimulus. For the unambiguous cube- and face-stimuli we found a strong positive deflection 400 ms after onset (P400), most prominent at parietal and central electrode positions. This P400 is absent for ambiguous stimuli. The dissimilarity of the two stimulus types together with the strong similarity of the P400 components across stimulus types makes explanations due to low-level processing unlikely. Our working hypothesis for the next experimental steps is that the size of the P400 may reflect the "attractor depth" of mental object representations.

Kornmeier; together with Bach; funded by DFG

Publication: Kornmeier, Bach (2009)

Bistable Perception and the Binding Problem

Synchronous oscillations of neural assemblies in the gamma frequency band (30-80Hz) are widely ascribed a key role for the solution of the binding problem. Ambiguous figures are well suited for testing the role of gamma oscillations for binding: de- and rebinding processes during endogenous perceptual alternations can be measured unconfounded with neural activity due to stimulus changes. Using a discontinuous presentation paradigm we could improve the temporal resolution of endogenous perceptual alternations to $\pm$ 30 ms and thus separate pre- and post-reversal gamma activity. This allowed us to identify a sequence of "components" localized in time, frequency, and spatial position. Most prominent was a pre-onset induced gamma modulation preceding endogeneous reversals and absent in exogenous changes of unambiguous stimulus variants. The recently discussed influence of miniature saccades on gamma oscillations was indirectly examined via correlated EEG spikes. A comparison of the data from reversal versus non-reversal conditions did not confirm such an influence.

Ehm, Kornmeier; together with Bach; funded by DFG

Acategorial States With Non-Conceptual Content

The distinction between non-categorial, acategorial and categorial mental states can be substantiated by approaches developed in cognitive neuroscience and in the analytical philosophy of mind. On the basis of a representational theory of mental processes, acategoriality characterizes a form of knowledge that presumes fully developed categorial mental representations, yet refers to non-conceptual contents (an important topic in current debates) of mental states beyond categories. It relies on a simultaneous experience of potential individual representations and their actual "representational ground", an undifferentiated non-categorial state often discussed, e.g., by Metzinger. This is possible if the mental state does not reside in a representation but in between representations. Acategoriality can be formally modeled as an unstable state of a dynamical mental system.

Atmanspacher; together with Feil

Publication: Feil, Atmanspacher (in press)

Acategoriality in Exceptional Experiences

Numerous reports of exceptional experiences (EEs) range from apparitions and extrasensory perception to meaningful coincidences and mediumship. Typical conditions under which such experiences occur can be characterized psychosocially as attempts to stabilize unstable situations often described as stressful or unhealthy. On the other hand, EEs are also reported as occurring along with the spiritual development of individuals. Depending on cultural traditions, they are sometimes referred to as "epiphenomena", and it is recommended more or less explicitly not to devote much attention to them in order to keep the process of development in flow. For a proper evaluation of this discrepancy, it is important to identify the type of EEs accompanying spiritual development and distinguish it from other types. This is possible on the basis of the dissociation or integration of a subject's models of self and world. It will be particularly interesting to see how the different EE-modes can be assigned to non-categorial, categorial or acategorial mental states of the subjects concerned.

Atmanspacher, Fach

2.1.4 Plasticity and Learning in Networks

Complexity of Learning Networks

We studied supervised learning operations in small recurrent networks, leading from a given set of input conditions to predetermined outputs. Networks that have optimized their output are asymptotically stable and can be characterized by attractors. As the mapping from a series of inputs onto a series of such attractors generally depends on the sequence of inputs, this process is non-commutative. Surprisingly, the size of the set of attractors, indicating the complexity of learning, was found to behave non-monotonically as learning proceeds.
More recent results showed that constraints on the network complexity during learning reduces its learning success in ways that depend on the nature of the applied limitation. Moreover, relaxing the criterion due to which changes of the network structure are accepted leads to a dramatic improvement of the learning performance. The non-monotonicity of network complexity during learning, which remains unchanged in both scenarios, is related to a similar feature in ϵ-machine complexity. So far we are unable to correlate the maximum of complexity with any other characteristic of the network.

Atmanspacher, Filk; together with Finke, Gruber

Publication: Atmanspacher, Filk, Finke, Gruber (2009)

Punctuated Equilibrium

The simulations of supervised learning also showed punctuated equilibrium: periods with almost no changes of the distance from the optimal output as a function of line changes are interrupted by periods of rapid learning success. The distribution of the plateau sizes (number of "generations" without changes in the network structure) exhibits a power-law behavior. This phenomenon is attributed to a bottleneck effect: some network configurations are locally al-

most stable in the sense that only very special changes lead to improvement, while for other networks there are many changes in the structure which lead to an improvement of their performance. This hypothesis is presently under investigation. Furthermore, we found that the deletion of individual lines or nodes typically leads only to a partial failure of pattern recognition.

Filk; together with von Müller

Publication: Filk, von Müller (2008)

Emergence of Small-World Properties

A key question for learning networks is which structural properties distinguish networks performing optimally ("learners") from random networks. In this context, we concentrated on *small-world* properties of networks, in particular on a generalization of the cluster coefficient. As has been shown in the literature, the distribution of certain motifs (particular sub-networks, notably triangles) can be considered as such a generalization. Comparing the distribution of motifs in learners with those in random networks, we found that particular motifs occur significantly more often in learners than in random networks. Furthermore, we investigated the eigenvalue distribution of the corresponding adjacency matrices. First results exhibit clear differences between learners and random graphs – for instance, the third moment, which is related to the abundance of triangles, changes drastically. Other features of these eigenvalue distributions are under investigation.

Atmanspacher, Filk; together with Scheingraber

2.1.5 Conceptual and Methodological Issues

Concepts of Neuroscientific Research

The dynamics of neuronal systems, briefly neurodynamics, has developed into an attractive and influential research branch within neuroscience. We identified and studied a number of conceptual issues in neurodynamics that are important for an appropriate interpretation and evaluation of its results. We demonstrated their relevance for selected topics of theoretical and empirical work. In particular, these are the notions of determinacy and stochasticity in neurodynamics across levels of microscopic, mesoscopic and macroscopic descriptions. The issue of correlations between neural, mental and behavioral states was also addressed in some detail. An informed discussion of conceptual foundations with respect to neurobiological results will be crucial for a viable future philosophy of neuroscience.

Atmanspacher, Rotter

Publication: Atmanspacher, Rotter (2008)

Research Between Anomaly and Orthodoxy

Scientific research takes place in the field of tension between accepted coherent knowledge and not understood, not integrated fragments: between orthodoxy and anomaly. Orthodox knowledge is characterized by laws and norms which can be conceived formally (deterministic or statistical laws), methodologically (criteria for scientific work), or conceptually (frameworks of thinking, regulative principles). We proposed to classify anomalies according to their feasibility of being systematically connected with accepted knowledge. In this way, one can distinguish anomalies at the frontier of our knowledge, interior anomalies surrounded by accepted knowledge, and anomalies in no man's land. Examples have been discussed which show essential characteristics of each of these groups. Anomalies are the salt in the soup of science and dissolve where the domain of accepted knowledge extends or deepens – either by being elucidated or by being abolished.

Atmanspacher

Publications: Atmanspacher (2009b), Atmanspacher (2009e)

Adaptive Analysis of Time Series

Statistically significant effects in the analysis of time series usually rely on a large number of single tests sensitive to local deviations in time, spatial position, frequency, experimental condition, etc. Depending on the size of the search space, the desired resolution, and the available a priori knowledge, the required number of single tests can be huge. Unknown stochastic dependencies between the test statistics presents another difficulty to control the alpha error. Often these problems are circumvented by defining regions of interest or abandoning finer resolution. We proposed a novel multiple testing procedure ("conquer and divide", CAD) based on an adaptive subdivision of the time domain. CAD starts at a coarse resolution level and zooms in only where effects are distinctive. Monte Carlo simulations demonstrated CAD to be efficient in regard to both specifity and sensitivity. For extensions to arbitrary search trees exact control of the family-wise error probability could be established.

Ehm, Kornmeier; together with Bach, Heinrich; funded by DFG

Phase Synchronization

Power analyses of EEG time series provide information about the collective behavior of spatially confined neuronal assemblies close to electrode positions. The integration of spatially and functionally separated brain areas, on the other hand, is supposed to be accomplished by a global synchronization of distant assemblies, with certain frequency bands playing specific roles. Detecting such synchrony requires extracting time- and frequency-resolved phase information from parallel recorded EEG time series and quantifying the coherence between groups of corresponding phase courses. To avoid phase enslaving and spurious synchrony due to narrow band filtering, we proposed a modification of the common "phase locking value" measure which adaptively damps down the influence of epochs where power is low. First results promise the new measure to be reliable and robust, and superior to wavelet coherence. After some experimentation with the choice of the tuning parameters, the procedure will be utilized to study phase synchronization in connection with the perception of ambiguous visual stimuli.

Ehm, Kornmeier; funded by the DFG

Publication: Ehm, Kornmeier (2009)