The human brain is a complex system whose activity is reflected by a highly complex neurodynamics. This dynamics is characterized at a macroscopic level by oscillations, chaos and fluctuations, apparent in EEG and depending on underlying neural processes, external stimuli and various neuromodulatory mechanisms. The different organisational scales of the brain, from ion channels to neurons to networks, are coupled via specific processes, each with a characteristic time scale.

We use computational models of different brain structures, both from paleocortex and neocortex, to investigate how cortical neurodynamics may depend on structural properties, such as connectivity and neuronal types, and on intrinsic and external signals and fluctuations. In particular, we study the underlying mechanisms for phase transitions in cortical neurodynamics of hippocampus, and the olfactory and visual cortices.

With the aid of our computational methods, we address questions such as: How can the nervous system shift its neurodynamical states quickly, as a response to external or internal stimuli? How can arousal and attention modulate the cortical neurodynamics, and lead to a more efficient information processing? What is the dependence on various intrinsic parameters, such as neuronal types, excitability, connectivity, and ion channel densities? What is the relation between microscopic and macroscopic processes? How does the brain respond to artificial inputs, such as anesthetics, or electric pulses, as used in e.g. electroconvulsive therapy (ECT)?

Our results are suggestive for the neural mechanisms underlying EEG, as well as for the dynamical effects of anaesthetics and ECT on human EEG. We demonstrate some plausible relations between structure, dynamics and function of cortical structures, and also suggest mechanisms and processes involved in phase transitions of cortical neurodynamics. By regulating the network dynamics, shifting between a noisy or chaotic-like dynamics and a more regular oscillatory behavior, functions such as learning and memory can become more efficient. Further, for certain optimal noise levels, system performance can be maximized, analogous to stochastic resonance phenomena. We finally discuss the relevance of these results to clinical and experimental neuroscience.