Functional Sensory Representations of Natural Stimuli: The Case of Spatial Hearing

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In this thesis I attempt to explain mechanisms of neuronal coding in the auditory system as a form of adaptation to statistics of natural stereo sounds. To this end I analyse recordings of real-world auditory environments and construct novel statistical models of these data. I further compare regularities present in natural stimuli with known, experimentally observed neuronal mechanisms of spatial hearing.

In a more general perspective, I use binaural auditory system as a starting point to consider the notion of function implemented by sensory neurons. In particular I argue for two, closely-related tenets:

- The function of sensory neurons can not be fully elucidated without understanding statistics of natural stimuli they process.
- Function of sensory representations is determined by redundancies present in the natural sensory environment.

I present the evidence in support of the first tenet by describing and analysing marginal statistics of natural binaural sound. I compare observed, empirical distributions with knowledge from reductionist experiments. Such comparison allows to argue that the complexity of the spatial hearing task in the natural environment is much higher than analytical, physics-based predictions. I discuss the possibility that early brain stem circuits such as LSO and MSO do not "compute sound localization" as is often being claimed in the experimental literature. I propose that instead they perform a signal transformation, which constitutes the first step of a complex inference process.

To support the second tenet I develop a hierarchical statistical model, which learns a joint sparse representation of amplitude and phase information from natural stereo sounds. I demonstrate that learned higher order features reproduce properties of auditory cortical neurons, when probed with spatial sounds. Reproduced aspects were hypothesized to be a manifestation of a fine-tuned computation specific to the sound-localization task. Here it is demonstrated that they rather reflect redundancies present in the natural stimulus.

Taken together, results presented in this thesis suggest that efficient coding is a strategy useful for discovering structures (redundancies) in the input data. Their meaning has to be determined by the organism via environmental feedback.