Understanding how our brain generates our perception of the visual world, and mapping the mechanisms by which cognitive processes like attention and working memory flexibly select behaviorally relevant information, are some of the major challenges that remain to be addressed in neuroscience.

By combining visual representations in a feedforward direction at a series of processing stages in a hierarchically organized system, our visual system allows visual information to transform from for instance simple line-like features in the first visual area (V1) to more complex objects like representations of faces and houses in higher visual areas.

In addition to this feedforward sweep, there is also a later recurrent phase of information processing. During this later phase of information processing the hierarchical organization of the visual system enables different brain areas to communicate with each other dependent on specific behavioral demands. Although this later recurrent phase of processing is thought to be essential for the implementation of various cognitive functions that depend on the flexible selection of information, how information is processed along the visual cortical hierarchy and the dynamics between cortical areas during the implementation of these cognitive functions remain largely unknown.

In this thesis, we addressed fundamental questions related to the organizational and computational principles in the hierarchically organized visual system and the mechanisms by which cognitive processes enable the flexible selection of behaviorally relevant information. To this end we recorded activity from neurons at different stages of the macaque visual system while the monkey performed complex visual tasks.

We found that whether a stimulus will be consciously perceived or not depends on the efficiency of feedforward propagation from lower to higher brain regions, and that to select information and use it for cognitive behavior the initial feedforward sweep needs to reach areas that are at the top of the visual hierarchy. We showed that a combination of behavioral and neurophysiological measures of pre-stimulus cortical state predicts perceptual outcome with accuracies of 60-65%. Our experiments also showed that when a stimulus elicits sufficient activity in higher areas for the stimulus to be perceived, this conscious perception of a visual stimulus is associated with a later processing phase with enhanced sustained activity at all the stages of the cortical hierarchy. This sustained activity presumably reflects recurrent interactions between widespread brain regions that make the visual information globally available, and thereby enable the visual stimulus to be consciously perceived.

We found that both AMPA and NMDA receptors contribute to persistent firing that is observed in higher cortical areas during working memory related processes, and that NMDA receptors do not have a specific and critical role in persistent firing but contribute to spiking activity in a general multiplicative way. These results suggest that persistent activity during working memory related processes is not maintained solely by intrinsic dynamics of single neurons, but that internally sustained activity most likely involves recurrent processing during which reverberatory excitation between neurons within a cortical area or reciprocal excitatory loops between (sub)cortical areas takes place.

We showed that figure-ground modulation cannot arise from purely local horizontal interactions between neurons within V1, and therefore most likely is due to feedback from higher visual areas. The laminar profile of figure-ground segregation also suggests that feedback connections from higher visual areas play an important role in figure-ground segregation, and that this segregation relies on a number of different processes that unfold at characteristic time scales. We found that both figure enhancement and ground suppression contribute to figure-ground modulation; the representation of figure elements was enhanced first in higher visual area V4 and after a brief delay also in lower visual area V1. After an additional delay the representation of background elements was suppressed.

Together, our experiments strongly suggest that the task specific behavioral modulation of activity along the different areas of the cortical hierarchy during the later phase of information processing reflects recurrent interactions between widespread brain regions. This way, our perception of the visual world emerges from the global set of cortical states and task-specific interactions between multiple areas along the visual cortical hierarchy, thereby for instance enabling a visual stimulus to be consciously perceived, maintained in working memory or assigned to figure or background regions.