A Reconfigurable Classifier Model of the Visual System

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Neurons are costly for an organism to build and maintain, yet at the same time, there has apparently been strong selective pressure on organisms to incorporate additional functions into their nervous systems. Based on the known properties of dendritic trees and synapses (Koch, 2004), I propose a simple, biologically and evolutionary plausible architecture by which a neurons can be used for multiple different computations (time multiplexed). In such a model, signals extrinsic to an area selectively enable and disable parts of the dendritic trees of neurons within an area in a coordinated way. When this mechanism is extended to an entire pathway, like the ventral pathway, it gives rise to a notion of a *reconfigurable pathway* or a *reconfigurable classifier,* in which extrinsic signals can have the same pathway perform very different computations at different times (although some basic constraints remain due to overall connectivity; for example, V1 and V2 necessarily perform a kind of “feature extraction”, albeit tunable), and also route inputs and outputs from the pathway from and to different areas. In the rest of the paper, I explore the implications of such models.

From a pattern recognition point of view, I show that these kinds of models can be used to implement widely used models in pattern recognition, including decision trees, tree-structured SVMs, tree structured VQ, classifier combination, boosting, hierarchical mixtures of experts, and local learning. Such models have been very successful in many practical applications, but have often not been considered good candidates for implementation in neural hardware. In addition, I show that reconfiguration can provide good theoretical models for phenomena such as invariance properties in object recognition, attentional mechanisms, and context dependency of recognition.

From a neurophysiological point of view, I argue that a number of the puzzling observations about distributed coding and noisy responses can be well explained within a reconfigurable classifier model of the visual pathway. In particular, totem pole cells can be interpreted as the consequence not of a complex distributed coding scheme, but of temporal multiplexing. Furthermore, apparently “noisy responses” (i.e., failure of cells to rspond consistently to a stimulus) would also be the result of measuring responses in different configurations of the pathway. Reconfigurabilitiy is also closely analogous to results found in place cells and place coding.

From a psychophysical point of view, I argue that reconfigurability can account for the high variability and diversity of behaviors, capabilities, and responses observed in experiments. For example, in some experiments, the visual system behaves as if it computes texture statistics over large areas, while in other experiments, it detects precise long-range geometric alignment; some forms of recognition are invariant to transformations, while others are highly dependent on transformations. Furthermore, timing effects, such as priming, rivalry, familiarity effects, are often interpreted in terms of a complex dynamical system that needs to “settle” into a stable interpretation of the input, a process that is thought to be delayed if the input is noisy or ambiguous; I argue that these phenomena can be explained well in terms of reconfigurations of the visual pathway.

The reconfigurability hypothesis changes the interpretation of the function of cortical pathways in rather fundamental ways. A widely (explicitly or implicitly) made assumption is that each cortical area computes a well-defined representation. This has been argued strongly, for example, by Marr (1982). Under the reconfigurability hypothesis, many cortical areas compute different representations at different times, depending on which task they are solving. Furthermore, instead of a small set of well-defined, generally applicable computations (e.g., computation of the “primal sketch” or “2.5D representation”), cortical pathways would instead implement a large number of simpler and possibly ad-hoc computations. The reconfigurabilitiy hypothesis also presents an alternative to approaches like deep learning (Bengio, 2009) and the HMAX model (Riesenhuber and Poggio, 2000), which postulate the existence of hierarchies of features and computations. Many proposed models of brain functions also make extensive use of intrinsic feedback connections between areas, interpreting these connections as implementing a complex, nonlinear dynamical system (possibly message passing for performing Bayesian computations). Within the framework of the reconfigurability hypothesis, the interpretation of the dynamic behavior of cortical areas is considerably simpler and can be understood primarily as extrinsic control of pathway configurations (together with simple feedback mechanisms for gain control and similar functions).

Current experimental data does not let us determine with certainty to what degree experimental data can be accounted for by reconfigurability (as opposed to other, more complex dynamical systems models). However, the comparative simplicity and power of the reconfigurability mechanism means that it should be considered as a possibility in the interpretation of experimental results. Furthermore, I discuss some experiments that could be used to distinguish reconfigurability from other mechanisms.

References

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