Modeling the structure of the visual system based on structural connectivity and spike onset data

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Introduction

In the 1950s Hubel and Wiesel suggested that a *serial* scheme could account for the progressive increase in the complexity of receptive field properties in the visual cortex. Felleman & Van Essen [1] have recently taken this notion further, by a method called *hierarchical* analysis. Goodale & Milner [2] propose another, complementary, organizational principle by claiming the visual system is organized in *two pathways*, the 'Vision for perception' and the 'Vision for action' pathways respectively. If we take these theories together we arrive at the currently popular *serial, hierarchical, dual pathway model* of the organization of the visual system.

Recent single-cell data by Schmolesky [3] suggests that a serial and hierarchical model does not suffice to explain onset latency effects. They found that there was a functional sequence in the ventral stream wherein several modules demonstrated successively longer latencies. In contrast, there was simultaneous onset of firing in the modules of the dorsal stream. The dorsal pathway is dominated by the fast magno cells and the ventral pathway consists of mixed cell types, but the resulting speed difference [4] alone cannot account for the size of the effects. This means these effects cannot be attributed to different cell propagation speeds and therefore show a shortfall of the currently held beliefs. We modeled the structure of the visual system based on these single cell response data, constrained by a database (CoCoMac) of the known anatomical connectivity of the macaque brain [5].

Methods

The building blocks of our model are the functional modules of the visual system that were described by Felleman & Van Essen [1] and measured by Schmolesky [3]. With these blocks we generated semi-randomly all possible architectures by gradually increasing the probability of a connection existing between two modules. This was constrained by what connections are possible given the known connections in the brain as collected in the CoCoMac database [5]. We then measured the 'characteristic path length' [6] and 'congestion robustness' [7] of the generated architectures, to characterize and compare them. Finally we tested the architectures to see which architectures would fit the onset latency data best, by feeding activity to the input modules and propagating the activity through the model.

Results and Conclusion

The results show that for a dual pathway model to explain the current spike onset data in the visual system, the two pathways must have a different organization to attain different 'throughput speeds'. Generated models that show the best fit have smaller path lengths, and higher congestion robustness in the dorsal system. These different characterizations show that speed might be an important design consideration in the architecture of the visual system.

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