Genetic networks specifying the functional architecture of orientation domains in V1

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Although genetic information is critically important for brain development and structure, it is widely believed that neocortical functional architecture is largely shaped by activity dependent mechanisms. The information capacity of the genome simply appears way too small to contain a blueprint for hardwiring the cortex.
Here we show theoretically that genetic mechanisms can in principle circumvent this information bottleneck. We find in mathematical models of genetic networks of principal neurons interacting by long range axonal morphogen transport that morphogen patterns can be generated that exactly prescribe the functional architecture of the primary visual cortex (V1) as experimentally observed in primates and carnivores. We analyze in detail an example genetic network that encodes the functional architecture of V1 by a dynamically generated morphogen pattern. We use analytical methods from weakly non-linear analysis[1] complemented by numerical simulation to obtain solutions of the model. In particular we find that the pinwheel density variations, pinwheel nearest neighbor distances and most strikingly the pinwheel densities are in quantitative agreement with high precision experimental measurements[2].
We point out that the intriguing hypothesis that genetic circuits coupled through axonal transport shape the complex architecture of V1 is in line with several biological findings. (1) Surprisingly, transcription factors have been found to be transported via axons and to be incorporated in the nucleus of the target cells[3]. (2) A molecular correlate was recently found for ocular dominance columns in V1[4]. (3) We estimate that the speed of axonal transport is rapid enough to achieve appropriate timescales.
This theory opens a novel perspective on the experimentally observed robustness of V1's architecture against radically abnormal developmental conditions such a dark rearing[5]. Furthermore, it provides for the first time a scheme how the pattern of a complex cortical architecture can be specified using only a small genetic bandwidth.

References

[1] Cross, M., & Hohenberg, P. (1993). Reviews of Modern Physics

[2] Kaschube, M. et al. (2010). Science

[3] Sugiyama, S. et al. (2008). Cell

[4] Tomita, K. et al. (2012). Cerebral Cortex

[5] White, L. E. et al. (2001). Nature