Stochastic Axons in the Mammalian Brain

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All dynamical processes in vertebrate brains are physically embedded in a dense matrix of thin axons (fibers) that release serotonin (5-hydroxytryptamine), a neurotransmitter that modulates neural, glial, and vascular processes. Serotonergic axons appear to be an essential ingredient of any adaptive nervous tissue and may inform future architectures in machine learning. However, they typically do not form classical synapses and therefore cannot be understood within the connectomics framework. We have recently introduced the novel concept of the "stochastic axon systems," the scale of which may be comparable to that of the "deterministic," point-to-point axons systems. To advance the theoretical understanding of the trajectories of serotonergic axons, we propose two theoretical approaches.

The first approach is based on a random, step-wise 3D-walk driven by the von Mises-Fisher (vMF) directional distribution [1]. We have developed an algorithm to automatically trace serotonergic axons in 3D-confocal images in a transgenic mouse model and obtained estimates of the vMF-concentration parameter (κ) in several neuroanatomical regions. We hypothesize that the value of this parameter may control the self-organization of serotonergic fiber densities, with immediate implications for normal and diseased brain states. For example, an increase in serotonergic fiber densities have been reported in brains of individuals diagnosed with Autism Spectrum Disorder [2].

The second approach is based on fractional Brownian motion (FBM), a continuous stochastic process that generalizes normal Brownian motion. The model includes the recently discovered properties of the reflected FBM (rFBM) [3, 4]. In the superdiffusive regime, rFBM-paths reproduce some essential features of serotonergic fiber densities in the forebrain and brainstem. Our supercomputing simulations show that rFBM-walkers accumulate near the surface of brain-shaped domains, just as serotonergic axons tend to produce higher densities near the pial and ventricular surfaces [3]. The FBM model can be further enriched with a "diffusing-diffusivity" (DD) component, to reflect the heterogeneous environment axons travel in [5].

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