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Dynamics of activity fronts in a continuum mean field model of cortex

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The functional organization of cortex appears to be roughly columnar, with the laminar sub-structure of each column organizing its micro-circuitry. These columns tessellate the two-dimensional cortical sheet with high density, e.g., 2,000 cm^2 of human cortex contain 10^5 to 10^6 macrocolumns, comprising about 10^5 neurons each. Continuum mean field models (cMFMs) describe the mean activity of such columns by approximating the cortical sheet as continuous excitable medium [1]. cMFMs can generate rich patterns of emergent spatiotemporal activity [2]. This has been used to understand phenomena from visual hallucinations to the generation of EEG signals. Pattern boundaries are here defined as the interface between low and high states of average neural activity.

cMFMs support travelling patterns as well as the formation of intricate structures, as in Fig. 1. Here we derive equations of motion for the pattern boundaries of a simple cMFM, showing that their normal velocities are driven by Biot-Savart-style interactions. The solutions of these exact, but dimensionally reduced, equations for activity fronts are in excellent numerical agreement with those of the full nonlinear integral equation defining the neural field. A linear stability analysis of the dynamics of the interfaces allows us to understand mechanisms of pattern formation arising from instabilities of spots, fronts, and stripes. We further test our results against partial differential equations equivalent to the original integral equation, c.f. [3], and perform numerical simulations on a large spatial grid that represents a sizable cortical sheet. In particular, we clarify how more realistic firing rates (computed with sigmoidal functions instead of Heaviside steps) influence the dynamics of activity fronts.

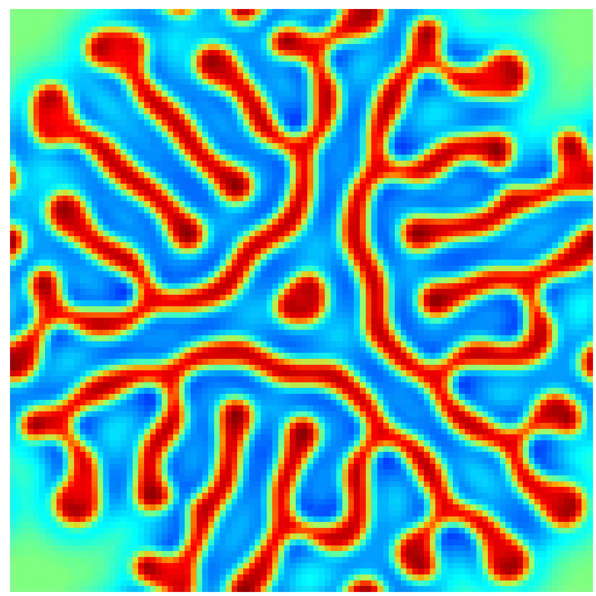

Figure 1 Pattern formation originating in an instable spot. cMFMs support travelling waves that underlie EEG signals; but also spots of localized high firing activity, which have been linked to models of working memory. These spots can become instable and pattern cortex with intricate structures, such as the labyrinthine one shown here. Red color indicates high activity, blue low. The original spot is still visible in the center.

Conclusions

Changes of brain activity are often of greater interest than the current state per se. On the cortical sheet, two-dimensional patterns can be defined by boundaries between high and low states of activity, and their dynamics can be specified by tracking the evolution of these interfaces. Using a simple cMFM, we show here

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that one can describe the motion of activity fronts with equations of reduced complexity, which nevertheless reproduce the observed dynamics faithfully. This improves our ability to study pattern formation and suggests more generally that modelling the interfaces of patterns, rather than the patterns themselves, may lead to novel, efficient descriptions of brain activity.

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