Program Number: 689.14 **Day / Time:** Tuesday, Nov. 15, 9:00 AM - 10:00 AM

Extracting dynamical structure embedded in neural activity

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Spiking activity from neurophysiological experiments often exhibits dynamics beyond that driven by external stimulation, presumably reflecting the extensive recurrence of neural circuitry. Characterising these dynamics may reveal important features of neural computation, particularly during internally-driven cognitive operations. For example, neurons in premotor cortex (PMd) are active during a planning period separating movement-target specification and a movement-initiation cue. Recent evidence suggests that PMd neural activity settles to a movement-specific state during this period (Churchland et al.). What circuitry underlies this convergence? Can trial-to-trial variation in behaviour be predicted from the dynamics of settling? Current methods to characterise recurrent neural dynamics on a single trial basis, and thus answer these and related questions, are limited. Standard methods average activity from different trials or different cells, and so cannot express variable dynamics. We show that the dynamics underlying PMd plan activity can be captured by a low-dimensional non-linear dynamical systems model, with underlying recurrent structure and stochastic point-process output. Such a model is capable of expressing rich dynamics, including convergence to point or line attractors, but the task of learning the model parameters from spike data is challenging. We present and validate latent variable methods that simultaneously estimate the system parameters and the trial-by-trial dynamical trajectories. These methods are applied to characterise the dynamics in PMd data recorded from a chronically-implanted 96-electrode array while monkeys perform delayed-reach tasks.

Support Contributed By: Gatsby, NDSEGF, NSF, MARCO C2S2, MSTP, CRPF, BWF, ONR, Sloan, Whitaker

Citation: M.Sahani, B.M.Yu, A.Afshar, G.Santhanam, S.I.Ryu, K.V.Shenoy. Extracting dynamical structure embedded in neural activity. Program No. 689.14. *2005 Abstract Viewer/Itinerary Planner.* Washington, DC: Society for Neuroscience