Neural Network Model of Motor Cortex

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The role of primary motor cortex (M1) in arm movement control has been the subject of lasting and often heated debates. Early views of low-level muscle control have been discredited by numerous correlations with higher-level parameters related to hand kinematics. The abstract directional coding hypothesis advanced to explain these observations has also been discredited, this time by numerous correlations with lower-level muscle- or joint-related parameters. These seemingly contradicting evidences make it hard to interpret M1 activity. Todorov [1] showed such contradiction can be resolved by ‘muscle-based-control’ model. In our current work, we demonstrate that neural-network model of M1 based on ‘muscle-based-control’ indeed explain all the experimental findings.

We trained recurrent neural networks that directly control a simulated arm model in closed-loop. The networks receive low-level sensory input from muscles and target information, and send control signals to muscles. The network is trained to optimize behavioral cost that generates human-like reaching movement. The training uses modified backpropagation-through-time algorithm to pass the cost-gradient through nonlinear-dynamical system (arm model).

We compare the network’s population activity to various movement features (target direction, hand velocity, external load). Preferred direction of neurons found this way matches well to M1 electrophysiology data in literature. The M1 network model, trained to control low-level muscle activation, shows correlation between neural activity to high-level movement features, consistent to the theoretical prediction of Todorov [1].

The network model also allows more fundamental understanding of movement generation by M1. We perform simulation experiment by perturbing of network activity during movement, analyze the perturbed arm movement, and suggest experimental prediction.

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References
[1] On the role of primary motor cortex in arm movement control