Note: Computational application of noise-induced gain modulation (stochastic gating)

M. Rule

August 29, 2019

In nonlinear stochastic networks, noise can interact with nonlinearities to alter the effective transfer function of neurons. This figure outlines a hypothetical application of this phenomenon.

Consider a sensorimotor task, in which a desired sensory outcome is obtained by an appropriate movement. Similar sensory outcomes may require different movements, depending on the task and context. For example, the force required to move a block on a lever could be congruent with, or opposite of, the direction of motion, depending on the lever configuration (Fig. a). The particular details are not important, only that there be some context-dependent sensorimotor mapping.

In a deterministic network, one could switch between possible sensorimotor outcomes using a gating signal, which selects the desired sensorimotor transformation, and inhibits incompatible ones. In a stochastic network, the same result may be accomplished by manipulating the structure of noise correlations (Fig. b).

Context-dependent noise can therefore act as a gating signal if different neurons receive different amounts of variability (Fig. c). For example, if neurons are below threshold, those receiving more noise will fire more often, as noise pushes the neuron over threshold as a random event (Fig. d). In this hypothetical scenario, we use noise to push one of two different neuronal pools over threshold, to set the direction of motion required to obtain a desired sensory outcome (Fig ef).

It is commonly assumed that in-vivo neuronal noise can be modeled as Poisson, or at least roughly proportional to the mean firing rate. This is a necessity in sparse, binary networks, since there must be some activity in the first place in order for that activity to be variable. It is therefore reasonable to expect that different activity states could lead to different structure in noise correlations, and nonlinear computations would need need to account for the effect of this variability on network computations.

The scenario we consider here has context-dependent noise but no context-dependent shift in mean drive. More realistic scenarios would likely include a mixture of mean effects, and changes to the noise correlation structure.

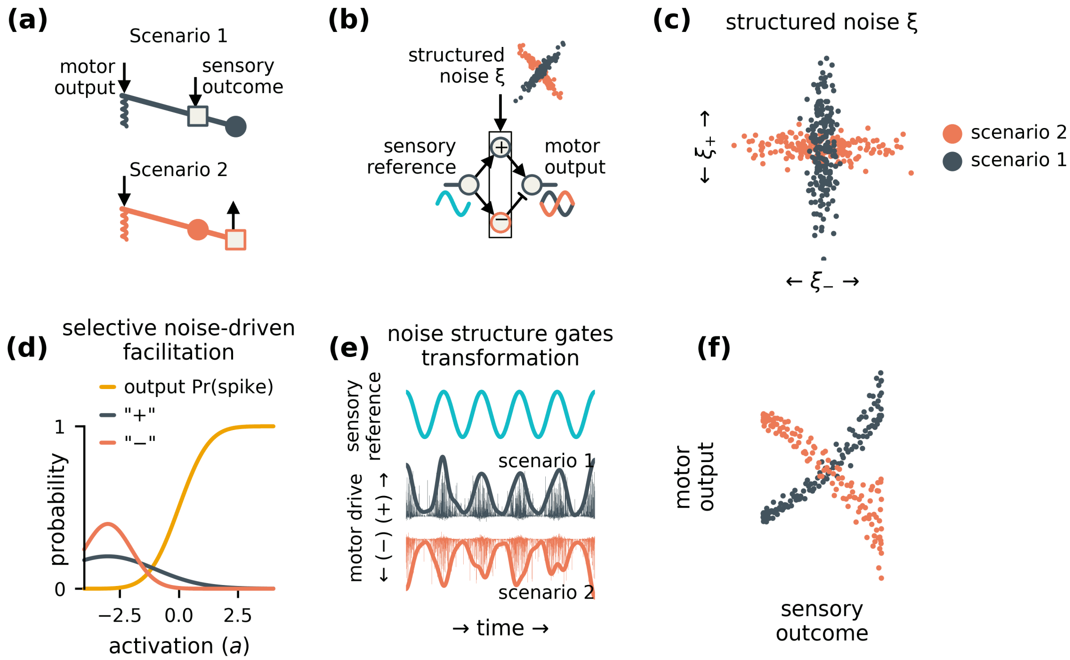

Figure: stochastic gating in a sensorimotor task (a) Consider a computation, for example transforming a sensory goal into the appropriate movement. Different context may require different sensorimotor transformations, shown here as different lever configurations to move a block. **(b)** A gating signal could be used to select the appropriate transformation. In the case of nonlinear, stochastic networks, the shape of noise correlations themselves could act as a gating signal. **(c)** Depending on the configuration of synaptic weights, dendritic averaging can either suppress noise, or allow noise through. This allows different sub-networks to be tuned to different directions of noise correlation. **(d)** If the input activity is mostly below threshold, the presence of noise will help push some neurons to fire occasionally. In this scenario then, neurons that receive more noise are facilitated. **(e)** Selective facilitation and inhibition by noise correlations can act as a gating signal, determining the overall transformation computed by the network. In this example, noise selects between two possible directions of motion to achieve a desired sensory outcome. **(f)** In this way, structure in the noise correlations can dictate the computational mode of the network. This in turn dictates the overall sensorimotor correlations observed on slower timescales.