Stochastic integration in counting, timing and binocular rivalry

M. Mattia
Dept. of Technologies and Health, Istituto Superiore di Sanità, Rome, Italy

In everyday life all of us experience a large random variability in our behaviour even when external environment does not provide any source of noise, e.g. to decide between competing opportunities. Often such variability shows up in intervals between behavioural events spanning a wide range of time scales.

At cellular level a source of randomness is apparent looking at the irregular firing pattern showed by neurons which may be related to behavioural variability. Synaptically coupled spiking neurons are proven to show firing rate dynamics such that a subset of cells may fall in “up” and “down” population states and there persist for arbitrary long time. Switching between such attractor states can be driven by endogenous firing fluctuations. Multi-stable stochastic neuronal networks of this kind have been used to successfully model the neuronal substrate of working memory and decision making.

The dynamics of a processing stage collecting several of these stochastic switches may span time scales much longer than the characteristic times of the single components of the system. In particular the fraction of active switches may give an accurate estimate of the “evidences” accumulated or subtracted in time about external stimuli. The above multi-modular system is then suggested as neuronal substrate of an integrator: an inner representation of a generic concept of magnitude.

The dynamics of the system driven by discrete and continuous stimulations is compared to recent results from experiments on counting and timing tasks. A failure of the Weber-Fechner’s law is predicted: the coefficient of variation of the sensed magnitude is roughly constant only for a limited interval of magnitudes, and a U shape is expected.

Finally, the neural integrator introduced is proposed as the building block of a model of binocular rivalry which accounts for recently observed long-memory effects in the statistics of perceptual dominance times for interrupted stimuli. The devised multi-modular architecture includes two families of stochastic switches: a layer which integrates on short time scales features extracted from visual stimuli, a “deeper” layer which slowly accumulates information about the active percept, and a readout state which, based on a threshold mechanism, determines the currently active percept.