Statistical mechanics of neocortical interactions: Time delays

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ABSTRACT: In cases where there may be neuronal processing that take on the order of tenths of a second, and where specific neuronal circuitries are not found, then it may be reasonable to look to processes involving patterns or "representations" of information in patterns of minicolumnar activity.

KEYWORDS: short term memory; nonlinear; statistical

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Statistical mechanics of neocortical interactions (SMNI)

In the paper (Nijhawan, 2008), Romi Nijhawan (RN) presents strong arguments, supported by experiments, that visual compensation often is accomplished by specific neuronal circuitry within the visual sensory system. He also suggests that other sensory and motor systems similarly may accomplish compensations within their own regions.

In cases where there may be neuronal processing that take on the order of tenths of a second, and where specific neuronal circuitries are not found, then it may be reasonable to look to processes involving patterns of information in patterns of minicolumnar activity.

The present state of experimental knowledge explains why terms used frequently in RN -- e.g., "representation", "late mechanisms", "extrapolation mechanisms", "internal models" -- are not detailed, i.e., as to whether they are due to neuronal activity of specific circuitry, or to patterns of masses of neuronal firings, or some interplay between these two kinds of activity within or across cortical regions of sensory, motor and associative cortex. Such models must be able to be experimentally tested and realized, commensurate with the detail given to known specific neuronal pathways and circuitries (Ingber, 1995a; Ingber, 1996a; Ingber, 2000b). In this context, RN also highlights in his conclusion that "prediction may be a multilevel multimodal phenomenon."

Analysis of time delays in cortical processing that include "representations" of information, as discussed in RN in the context of interactions with specific neuronal mechanisms, should take into account models of these representations. A model of statistical mechanics of neocortical interactions (SMNI) calculates such delays, and also permits inclusion and description of interactions with other neural mechanisms. This is relevant in the context of RN since some specific time delays can be obtained from such models.

In SMNI, columnar activity and their time spans of information processing, and how interactions are developed with specific neuronal circuitries, were developed in a score of papers dating back to the early 1980's, using methods of mathematical physics developed for nonlinear multivariate nonequilibrium statistical mechanics. Instead of presenting math here, some description and references will suffice to convey the techniques.

SMNI was the first physical phenomenon to take advantage of new methods of mathematical physics (Graham, 1978; Langouche *et al*, 1979; Langouche *et al*, 1982), and it is not surprising that at first the math itself was denied as even existing by non-experts in these mathematical disciplines. However, tested contributions to SMNI, as well as to other disciplines, have affirmed the math, e.g., in physics (Ingber, 1986), nonlinear systems (Ingber, Srinivasan & Nunez, 1996), finance (Ingber, 1990; Ingber & Wilson, 1999; Ingber, 2000a), and combat analysis (Ingber, Fujio & Wehner, 1991; Ingber & Sworder, 1991). Some powerful computational algorithms had to be developed to process this nonlinear stochastic calculus. These algorithms include methods of Very Fast Simulated Annealing (VFSR) (Ingber, 1989), which has evolved into Adaptive Simulated Annealing (ASA) (Ingber, 1993), and numerical methods of path integration developed to process the time evolution of nonlinear multiplicative-noise probability distributions, including PATHINT (Ingber, Fujio & Wehner, 1991; Ingber, 2000a) and PATHTREE (Ingber, Chen *et al*, 2001). These methods of path integration also made it possible to develop statistical indicators, canonical momenta indicators (CMI), which were applied to several disciplines, including SMNI descriptions of short-term memory (STM) (Ingber, 1994; Ingber & Nunez, 1995) and fits to electroencephalography (EEG) data (Ingber, 1997; Ingber, 1998). Some description of SMNI below argues for the application of SMNI to the RN.

SMNI has developed appropriate conditional probability distributions at several levels (Ingber, 1981; Ingber, 1982; Ingber, 1983). Synaptic inter-neuronal interactions are described by the mean and variance of distributions of intraneuronal quanta of chemical transmissions across synaptic gaps. Mesocolumnar averaged excitatory and inhibitory neuronal firings are developed, detailing convergence and divergence of minicolumnar and macrocolumnar interactions. Macroscopic regions of neocortex are developed from many mesocolumnar domains, and SMNI details how regions may be coupled by long-ranged interactions.

SMNI calculates stability and duration of auditory and visual STM (Ingber, 1982; Ingber, 1983; Ingber, 1984; Ingber, 1985; Ingber, 1994; Ingber & Nunez, 1995) as tenths of a second, with capacities of 7±2 (Miller, 1956; Ericsson & Chase, 1982) and 4±2 (Zhang & Simon, 1985) resp., with times of processing information via non-myelinated fibers across minicolumns consistent with time delays associated with internal visual rotations of images. SMNI also explains the primacy versus recency rule of STM (Ingber, 1995b), and Hick's law of linearity of reaction time with STM information (Hick, 1952; Jensen, 1987; Ingber, 1999). These time delays are within the same time scales as information processing across regions of cortex via myelinated fibers, thereby permitting synchrony of local and global information within this relatively coarse time resolution. A reasonable correlation was made between SMNI and a large set of EEG data, utilizing specific neuronal circuitry across regions within which processing of events was described by macrocolumar activity (Ingber, 1996b; Ingber, 1997; Ingber, 1998; Ingber, 2000b). Since the first SMNI papers, more experience has been gained with larger sets of variables, and it is possible to include laminar circuitry in SMNI. Better correlations can be expected when synchronous multiple imaging is performed (Ingber, 2006). Similar calculations could be performed within any cortical region, e.g., a sensory or motor region.

As pointed out by RN, just because specific neural circuitries may explain "prediction" in time scales much less than a tenth of second, for some phenomena such as continuous stimuli, "late mechanisms" such as described by SMNI may also contribute important prediction capabilities after the onset of such stimuli and after an initial period permitting the formation of columnar patterns of activity. Other sets of experiments, e.g., gaze cascades, also highlight the importance of "late mechanisms" (Woo, 2007). The SMNI mechanisms are generic to columnar structures in cortex, and so, as RN states, such prediction processes may be expected to be present in all sensory and motor regions.

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