

Nonlinear Probabilistic Predictive Neural Computations

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ABSTRACT

The modern neuroscience demands *a mechanism* for the theory of mind. The brain stem and hypothalamus are the organs that regulate biochemical life and control the balance of required chemical activity (the biochemical body). They also represent the continuity of the given organism. The self originates from these biochemical processes: the interaction of self with the non-self is represented by second-order representation which occurs mainly in the thalamus. But theory of mind must include also the functions of extra-conscious (sub-conscious) intuition. It means the ability not only to hypothesize what other minds are thinking, but to hypothesize what they are thinking about what they are thinking. We see an underscored role of intuition, motor imagery (integration of premotor cortex and visual information based on intra-parietal sulcus “programmer”) using the neural mechanism of probabilistic prediction. Summarizing that human brain is working due the computational processes of probabilistically calculated predictions of reality.

Key Words: theory of mind, biochemical body, the self, intuition, intra-parietal sulcus, programmer, probabilistic prediction, conscious frame of reference

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“In the final analysis, nervous activity, either evoked or spontaneous, and its propagation in the neuronal network, can be explained by atomic properties.”

J. P. Changeux (1983) *Neuronal Man*
The Biology of Mind. Oxford University Press, p.96

Introduction

The evolutionary value of the theory of mind is given by the ability to anticipate the actions of others. In the case of *the Machiavellian mind* it implicate not only anticipate actions of others, but also try to manipulate them. The mechanism is working on the basis of mirror neurons. Mirror neurons are active both during execution of a particular action or production of a feeling, and also when an individual observes the same action or feeling in another individual. They mirror the action and thoughts of others.

Materials and Methods

Conscious Frame of Reference

Consciousness is the core of an individual sense of self, and the core of consciousness is

the Edelman’s re-entry in thalamus. The re-entrant mapping is a process of learning (resonance) by which reality perceived by senses is transformed into a representation of reality. Mathematically is this transformation described as mapping, but there is also a second process: the maps themselves are mapped by other groups of neurons. Different groups of neurons watching each other, this refers to a re-entrant mapping.

What is consciously perceived is not a single mapping of the images falling on the retina. The signals from the optic nerves are deconstructed and re-configured in a process demanding about *a third* of the cerebral cortex. Even the healthy brains are not completely free from optical illusions during image reconstruction. The world is *not* really colored; brain weaves signals together to create the phenomenon called color.

A fundamental property of conscious scene is both differentiated and also integrated

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(every conscious scene is experienced as “all of piece”). The brain is both: a selection system and also a partly instructional system (like a neurocomputer). From the complex repertoires are shaped circuits and selected by the constraints of value system. Value is mediated by diffuse ascending neural pathways in dopaminergic, catecholaminergic and cholinergic brainstem nuclei. Reentry is the dynamic recursive exchange of signals across massively parallel axonal system reciprocally linking maps and nuclei of the brain. Consciousness is constructed by extensive reentrant interactions among neuronal populations in the thalamocortical system (Edelman, 2006).

Conscious scenes (low-amplitude, fast 17-70Hz gamma brain activities) occur serially: only one conscious scene is experienced in a given frame of the reference at a time. The intentionality is shaped by an egocentric frames of the reference. Below proposing a neural mechanism of relevant complexity for properties of neuronal dynamics leading to synchrony.

The generation of each conscious scene involves the integration of ongoing signals reflecting sensation and intention with a past history of value-dependent categorization, learning and memory. At the neural level brain exhibit rich organization at multiple levels of description, from molecular interactions within individual synapses, to the dynamics of cortical microcircuits, to reentrant interactions among functionally segregated brain regions (Seth *et al.*, 2006).

In models of a neuronal unit, postsynaptic phase tends to be correlated with the phase of the most strongly active presynaptic inputs (Abeles, 1982). Synapses between neuronal units with strongly correlated firing phases are potentiated, and synapses with weakly correlated phases are depressed. The magnitude of change is determined with pre- and postsynaptic activities. Neuronal units project to each other, and some of them project back to both via reentrant voltage-dependent connections.

The probability distributions from which postsynaptic phases are chosen for these units, if their reentrant connections are intact, than distribution for all neurons become peaked at the same phase. If reentrant connections absent, the probability distributions due to their phase-independent

input varies randomly over time. Neuronal synchrony indicated by groups of neuronal units sharing similar phase was necessary for the formation of multiple global circuits to each objects in view (Seth *et al.*, 2004).

If the reentry is a core of the consciousness, than principally it could be not excluded that recent computers may fulfill the minimal criteria for an artificial consciousness.

Extra-conscious frame of reference

A mechanism of attention focuses on parietal and frontal areas, distant from early stages of sensory processing (higher order consciousness). These areas bind and select objects in a visual scene by means of an executive mechanism as a spotlight of attention that combines visual features at a specific location in space (decision making neurons, planning area of prefrontal cortex).

Coding of reward probability and uncertainty by dopamine neurons

The frontal cortex is influenced by the dopamine, A10 nucleus in the brainstem involved in regulating attention. The A10 nucleus acts as a “regulator” of the frontal lobe during internal focusing of the attention in this brain area and allows it to act algorithmically as a comparator.

The Intuition as Nonlinear Probability Predictor

The brain continuously makes predictions and compares outcomes (or inputs) with those predictions. Predictions are fundamentally concerned with probability. Substantial evidence indicates that dopamine neurons of the primate ventral midbrain code errors in the prediction of reward. Dopamine neurons of ventral midbrain areas A8-A9, and A10 were identified solely on the basis of electrophysiological characteristics, particularly the long waveform of their impulses (1.5 to 5.0 ms).

The phasic activations varied monotonically with reward probability. Statistical analysis revealed a significant effect of uncertainty on the population response ($p < 0.005$ in each of four data sets) indicating that the sustained activation codes uncertainty. The peak of sustained activation occurs at the time of potential reward, which



corresponds to the moment of greatest uncertainty (Fiorillo, 2003).

The uncertainty is signaled by dopamine neurons, and the common measures of uncertainty (variance, standard deviation, and entropy) are all maximal at $p = 0.5$, having highly nonlinear relations to probability, being very sensitive to small changes in probability near the extremes, $p = 0$ or 1 (Honkela, 2006).

The error-likelihood model of decision making

During a dynamic decision-making task is involved the comparison of two quantities (two frequencies of vibration presented to a fingertip), separated by a delay. We propose the medial frontal cortex (MFC) is a comparator system. By coding prediction error over the full range of probabilities, dopamine neurons can be seen as fuzzy predictor for intuitive operations.

During conscious operations is prevailing the algorithm of classical probability, but an intuition is based more on the nonlinear probability (the synapses and neurons in far-from equilibrium situations achieving new forms of coherence, self-organization and dissipative structures, nonlinear probability distributions contains additional information for prediction of future evolution, resonances produce a coupling of events, free energy is at its minimum at equilibrium, a nonequilibrium system may evolve to a state of increased complexity, synapses far from equilibrium acquires new properties, synapse at equilibrium is “blind”, but far from equilibrium it begins to “see” due the appearance of long-range correlations, the system far from equilibrium “chooses” one of possible branch, this introduces an irreducible probabilistic element, result has important consequences for the origin of fluctuations observed in the cortex *in vivo*).

Neurons in the prefrontal cortex, showed differential preferences for the low versus high quantity also during the delay interval, during which they sustained their preferential firing patterns. In the decision phase, however, prefrontal cortex neurons no longer encoded information about high versus low quantities, but rather encoded information for $S_2 < S_1$ or $S_2 > S_1$, respectively (Ridderinkhof, 2005). The firing rates of single neurons in the prefrontal cortex: first encode the quantity of

S_1 , and then represent the active maintenance of that quantity in working memory, and finally reverse sign to encode the appropriate decision (Englitz *et al.*, 2008). Results clearly show that the networks of prefrontal cortex neurons can dynamically adapt and reconfigure the encoding functions represented in their firing patterns as the cognitive flow develops, without changing their connectivity (Machens, 2005; Kostur *et al.*, 2007).

Probabilistic computations

Both error detection and conflict monitoring are part of the computational process in which activation of MFC neurons is proportional to the perceived likelihood of an error taking place. The representations of the likelihood of error by the MFC develop through experience. Such representations build: on reinforcement-learning processes, mediated by phasic decreases in midbrain dopamine projections to the MFC when ongoing events turn out worse than expected (Raichle, 1998; Brown, 2005; Knutson, 2005).

The limbic system and the hypothalamus give together the “heart”, and the “cortical resonance” represents “reason” in traditional language. The mental objects are images derived partly from the primary and secondary sensory representations and concepts from the association areas, such as the frontal cortex. Their associative properties allowing them to link together and to combine. This recombining activity of iterates represent a “generator of hypotheses” in neural mechanism of the intuition. A selection is possible by the comparison of mental objects in terms of the resonance or dissonance (Changeux, 1983).

Two resonant mental objects of the same resonant frequency tend to exchange energy efficiently, while interacting weakly with extraneous off-resonant mental objects. In any system of coupled neural resonators there often exists a “strongly coupled” regime of operation. In this regime the energy transfer can be very efficient. A system of two neural resonators, if they are in strongly coupled regime, working even if the distance between them could be several times larger than the sizes of the resonant mental objects.

The human intuition is able of modeling and computing a special kind of



natural and artificial anticipatory system which computes its current states in taking into account its past, present and potential future states.

Strong anticipation refers to an anticipation of events embedded in the system. A class of computing anticipatory systems is based on the differential difference equation with retardation and anticipation $dx(t)/dt = F(x(t), x(t-tr), X(t+ta))$, where t is the current time, tr a delayed time and ta is an advanced time.

Weak anticipation refers to an anticipation of events predicted from a model of the system. A class of computing anticipatory systems is based on the discrete incursive and hyperincursive equations. An incursive equation is an inclusive or implicit recursive equation such $x(t+1) = F(x(t), x^*(t+1))$, where each iterate $X(t+1)$ is computed at each time step $t = 1, 2, 3, \dots$ from a function F of $x(t)$ and $x^*(t+1)$, where $x^*(t+1)$ is the anticipation of $x(t)$ at the next time step $t+1$, computed from the system itself or from a model. A hyperincursive equation is (Dubois, 2001) an incursive equation which generates multiple iterates at each computing step.

The exact arithmetic puts emphasis on language-specific representations based on a left inferior frontal circuit, and is also used for generating associations between words. Symbolic arithmetic is seen as a cultural invention specific to humans, and depended on the improvement of number computing systems. The other domains of mathematics, as calculus, may depend critically on the invention of an appropriate mathematical language. Simple calculations activate a distributed network involving the parietal, prefrontal and premotor cortices. The posterior parietal cortex and prefrontal cortex are functionally interconnected, information could be transferred to the prefrontal cortex, where amplified, may be able to gain control over behavior (Dehaene, 1999).

Mathematical Intuition

In the early days of neurophysiology, a few neurons that encoded number were reported in the association cortex. Nieder and Miller (2002) recorded in monkey prefrontal cortex the number neurons (principal sulcus, arcuate sulcus). It was recording in parietal cortex, and

also in prefrontal cortex, reported the observation of neurons whose firing rate was tuned to a specific numerosity. This was possible to examine the neural code for an abstract psychological continuum. The stimulus compression occurs at a peripheral sensory level, a neural code for number can be described in better way by logarithmic than by a linear scale. The monkeys encode the numerosities on an approximate compressed scale confirms that this approximation is the natural way that number is encoded in the intuition without language (Dehaene *et al.*, 1998; Dehaene, 2003).

Neural computation of expected value

Comparative theorists proposed that regions innervated by mesolimbic dopamine projections play a critical role in the computation of expected value (EV). Because fMRI studies also indicate that: gain outcomes instead activate the medial prefrontal cortex (MPFC), increased gain probability (PRB) might increase MPFC activation, even during anticipation, the ventral tegmental area midbrain dopamine neurons that project to the nucleus accumbens (NACC), and MPFC have also been implicated in the neural computation of EV.

The main effect of probability coding is correlated with activation foci in the bilateral MPFC, the left parahippocampal gyrus, the posterior cingulate. The interaction MAG (gain magnitude) by PRB was only correlated with activation foci in the bilateral medial caudate and right putamen.

The bilateral MPFC showed activity consistent with representation of the probability, value terms of EV. The bilateral anterior cingulate activation might relate to integration of these two terms: the value and probability terms of EV. Investigation of the neural correlates of EV, mesolimbic regions (including the midbrain, NACC, and MPFC) showed activation correlated with a linear model of EV. Whereas NACC activity correlated only with anticipated MAG, MPFC activity also correlated with anticipated gain probability. Mirror neurons in bilateral temporal gyrus allowing empathy can be seen as an intentional probabilistic neurocomputer.

MPFC activation was associated with the perceived probability of obtaining large gains. These findings suggest that distinct mesolimbic regions play different roles in EV



computation. The MPFC showed linear but not quadratic trends, supporting probabilistic rather than uncertainty-based interpretations. EEG Brain mapping showed concerning normal and altered states that it is possible to represent alteration probabilities for the various topographic regions of the cortex (Sejnowski, 1987).

It may be still a question if the originality can be understood as a negative level probability of some ideas occurrence. Interfering areas of overlap in phase space as a measure of interfering transition probability amplitudes brings us to Wigner's phase space function, which provides directly the probability

$$W_{m,n} = |w_{m,n}|^2.$$

The overlap between the Wigner functions $P_m^{(W)}$ and $P_n^{(W)}$ integrated over the total phase space, yields the probability

$$W_{m,n} = 2\pi \int_{-\infty}^{\infty} dx \int_{-\infty}^{\infty} dp P_m^{(W)}(x,p) P_n^{(W)}(x,p).$$

The Wigner function approach deals in terms of probabilities. Interference effects must therefore originate from phase space domains where the Wigner function product $P_m^{(W)} \cdot P_n^{(W)}$ assumes also negative values as a pathological intuition. The jump probability $W_{m,n}$ is the weighted overlap in phase space between the Wigner functions representing the two states. Intuition is working due the compressed algorithms of logic (Dowling, 1991). The increased activity around point P_3 (a tertiary association area) may be regarded as the result of cross-modal synesthetic processes between visual and auditory association areas of the upper brain. Synesthesia as a left-hemisphere function may be related to the hippocampus having influence on perceptual filter selecting functions. From the cones (color receptors) in the eye, neural signals travel to area 17 in the occipital lobe. There an image is processed further within local clusters into simple attributes as color, motion, form and depth. Information about these separate features is sent forward and distributed to several regions in the temporal and parietal lobes. Concerning color the information goes to area V_4 in the fusiform gyrus of the temporal lobe. From there it travels to TPO (the junction of the

temporal, parietal and occipital lobes). These higher areas are dealing with more sophisticated aspects of color processing.

Numerical computation happens in stages. In the fusiform gyrus are represented the actual shapes of numbers, and the angular gyrus (a part of the TPO) is concerned with numerical concepts, such as sequence and quantity. If the angular gyrus is damaged by stroke, the patient can still identify numbers but can't divide or subtract. Because both colors and numbers are processed in the fusiform gyrus and the angular gyrus, the number-color synesthesia might be caused by cross wiring between V_4 and the number concept area (both in the TPO). The neurological basis of synesthesia make possible that many creative people share facility for using metaphor as making links between seemingly unrelated conceptual realms (Koch, 2005).

Results

Mind as a central frame of reference

Cells in the lateral intraparietal cortex (LIP), a brain region linking areas involved in visual processing to those that control eye movement fired off more pulses when the decision was easy. As the choice got harder, tuned cells responded with fewer pulses. Rather than reflecting either sensory or motor information, these neurons seemed to integrate both. Some authors pointed that these cells are "decision neurons". It is not clear if they could form the basis for a "central executive in the brain" (Kim and Shadlen, 1999).

In 1999 identified a population of the decision cells in the prefrontal cortex. They are connected due to visual processing with the middle temporal area (MT). The decision neurons make their choices by monitoring the activity of the (direction tuned) MT cells, and then send instructions to cells in the superior colliculus controlling movement. Other neuroscientists go one step further, proposing that the brain's frontal lobe contains decision-making cells that are independent of any of the senses. These cells could form the basis for a "central executive" in the brain, an area in overall control of decisions. Other neurophysiologists are suggesting that complex decisions are made in a distributed way. The locus of decision lies in the pattern of connections between sensory inputs and motor outputs.



These cells are communicating with “planning brain areas”, using probabilistic predictions are involved in deciding which of the images is actually seen. Other evidence hints that the frontal cortex may be the planning area (Brodmann area 6, 8, mid-dorsolateral cortex, etc.). The frontal lobe is active during perceptual shifts experienced in binocular rivalry. The frontal lobe deciding to see one image or another. Deciding may be similar to the decision of moving an eye to the left or the right. The difference is that the output of this behavior is not a motor response, but a perceptual change. Most of people intuitively feel that deciding what to see and making conscious decisions are different process.

But something in the brain is performing the role of an observer of the self as it is suggested by results of Libet. He showed (Libet, 1983; 1985) that the process leading to the act of simple decision making starts about three-tenths of a second before a subject is consciously aware of it. It means we must differentiate the observer from a decider in the brain. This may explain the feeling when subjects having done something that they had not actually wanted or intended to do (Kim and Shadlen, 1999).

Libet’s results could be interpreted for a free will, as a color vision is simply a powerful illusion. Confronted by an overwhelming mass of visual information, areas of the brain involved in visual processing constantly make also decisions that simplify what we see. Cells that control eye-movement are given instructions by decision-making cells, based on the latter’s observations of cells in the visual-processing region (Romo and Salinas, 2001).

The attention mechanism induce a state of expectancy in the respective cortical areas imposing on them a task-related dynamic activation pattern acting like a dynamic filter causing a rapid synchronization of selected responses in brain.

Different types of neocortical neurons can generate a variety of spiking patterns in response to the same input. The spikes are sent along neurites at variable velocities that give rise to axonal conduction delays that can be large as 40 ms (Izhikevich, 2004). Considering only strong connections ensures that firing of the anchor neuron enhances the probability that other connected neurons fire

in the order determined by the conduction delays. The majority of synapses are weak (median EPSP amplitude <0.1 mV) and only a small percentage produces EPSP >5 mV. Weak synapses play an important role in providing background synaptic drive to neurons, and they control the global state of the network (rhythmicity). Strong synapses determine the fine temporal structure of neuronal firing. They are responsible for the spike-timing dynamics leading to the formation of neuronal groups.

The receptive field of a neuron is the set of stimuli that make the neuron fire. The projective field of stimulus is the set of neurons that fire in response (Lehky and Sejnowsky, 1988). During the continuous coherent stimulation of neurons there are changes in projective fields: synchronicity is represented due overlap of neurons shared by the projective fields. These shared neurons indicate that in the case of synchronicity different groups cooperate when they are activated simultaneously, and the asynchronously activated groups compete.

Random firing of the neurons might result in synaptic connections being potentiated and selected by chance, while others are depressed. The initial potentiation will introduce weak correlations of neuronal firing, produce even greater potentiation and favor some synaptic organization over others. If once groups are formed their activation provides a coherent spatiotemporal pattern to local and distant postsynaptic targets promoting formation of neuronal groups. These groups are spatially overlapping their constituent neurons are anatomically interconnected by numerous intercortical links. If a neuron in either of the two groups’ fires, it sends input to neurons in the other group that affect their firing. This exchange of input acts to disrupt the distribution of synaptic strengths that influences firing pattern characteristic of the two groups. In this question is Sporns (1991) in contradiction with Seth (2004) and Izhikevich (2004). We support the position of latest two articles and propose to differentiate a question of overlap at the level of neuronal groups (molecular level) and at the level of probabilities (atomic and subatomic level).

Neuropsychological studies support the view that the brain makes use of multiple spatial reference frames and indicate that



parietal cortex is central to the construction of these representations. Damage to parietal cortex produces dramatic impairments of spatial perception and action. Colby (1998) emphasized the role of parietal cortex in generating spatial representations for the guidance of action. Parietal cortical areas are strongly linked with areas of frontal cortex (premotor cortex, frontal cortex and supplementary eye fields), which themselves encode object locations relative to a variety of reference frames. Neurons in area LIP have receptive fields at locations defined relative to the retina and carry visual, memory, and saccade-related signals, which can be modulated by orbital position. Heterogeneous signals reflecting the degree to which spatial attention has been allocated to the location of the receptive field. The spatial representation is not simply retinotopic, rather, neurons combine visual and eye movement information to construct a stable, eye-centered representation of space.

When a motor command is issued to shift the eyes in a given direction, a copy of that command, a corollary discharge is sent to brain areas responsible for generating internal image of the world. What we “see” is not a direct impression of the external world but a construction or internal representation of it. This internal representation is updated in conjunction with eye movements. Neurons in area LIP contribute to updating the internal image. The neuron responds to the onset of a stimulus in the receptive field. In a saccade task the neuron responds when an eye movement brings the receptive field onto a location containing a visual stimulus. A saccade moves the receptive field onto a stimulus (the decision neurons). In addition, an updated memory trace of the stimulus is also driving the cell (the value category memory). The neural mechanism underlying this information depends on a corollary discharge of the eye movement command (the central executive). An important implication of this finding is that neurons have access to visual information from the entire visual field, not just from the classically defined receptive field (the planning area).

Remapping updates the internal representation of space in conjunction with eye movements so that the internal image always matches the current eye position. The metrics of a saccade to update the visual

representation is a unique property of parietal cortex, which uses information about motor commands to transform visual input from retinal coordinates into an eye-centered representation. The stimulus is not being encoded in a simple retinotopic coordinate frame: stimuli moving through the same portion of visual space evoke quite different responses depending on the projected point of contact (the planning area). This neuron is encoding visual information in a head-centered coordinate frame. The entire visual field and the projected points of contact are a “selectors” guiding movements’ commands through attention.

Intended motor actions have an impact on receptive fields and spatial representation in both areas: the medial intraparietal area (area MIP) and LIP. These results underscore the importance of looking at the influence of behavior on sensory representations. The changes in spatial representation reflect the impact of feedback projections from frontal to parietal cortex (the deciding neurons).

Evidence from frontal cortex demonstrates that neurons can make use of quite abstract spatial reference frames. Neuropsychological evidence indicates that an object-centered reference frame is used to direct attention. Egocentric spatial representations are dynamically updated in conjunction with self-generated movements, including eye movements (area LIP) and tool use (area MIP). The mechanisms underlying updating of spatial representations is influenced by feedback from frontal cortex to parietal cortex. Cortical representations of space are not limited to egocentric reference frames. Neurons in frontal cortex construct an allocentric spatial representation in which locations are coded relative to an object of interest. Object-centered representations are useful for acting on, paying attention to, or remembering particular locations (Colby, 1998).

The cortical synapses exhibit spike timing-dependent plasticity (STDP) in which the precise timing of presynaptic and postsynaptic spikes induces synaptic strengthening (long-term potentiation: LTP) or weakening (long-term depression: LTD). Standard models posit a single postsynaptic, NMDA receptor-based coincidence detector for LTP and LTD components of STDP.



STDP provides an inherently Hebbian computationally powerful means for LTP and LTD induction *in vivo* and is implicated in training and deprivation-induced receptive field plasticity in sensory cortex. In standard models, postsynaptic NMDA (the *N*-methyl-D-aspartate) receptors (NMDARs) are proposed as the sole coincidence detector and primary calcium source for STDP. Pre-post firing order is generating strong NMDAR-mediated calcium signals to drive LTP. Post-pre firing order is generating weaker signals to drive LTD. Some theoretical and experimental studies suggest that other coincidence detectors may be involved, specifically to mediate the LTD component of STDP (Bender *et al.*, 2006). Their results showed that STDP at L4-L2/3 synapses involves two separate coincidence detection mechanisms. The LTP component was dependent on postsynaptic NMDARs and was driven by pre-post firing order at short intervals (5 to 30 ms). The LTD component instead involved group I metabotropic glutamate receptors (mGluRs), calcium release from IP₃R-gated stores, retrograde eCB signaling, and activation of non-postsynaptic, potentially presynaptic NMDARs.

We propose on the basis of this model that non-postsynaptic potentially presynaptic NMDA receptors regulate synapse efficacy by directly regulating release probability, or by indirectly affecting postsynaptic function.

Bender *et al.* results supports a different model for STDP at L4-L2/3 synapses, their involves postsynaptic NMDARs, t-LTD induction involves signaling molecules including mGluRs, calcium from IP₃R-gated internal stores and VSCCs, retrograde eCB signaling, and non-postsynaptic but presynaptic NMDARs. The LTP and LTD components of STDP involve two distinct sources of calcium and two distinct coincidence detection mechanisms. These mechanisms operate on different time scales and with different firing order dependence and combine to produce overall STDP. This model represents a major class of STDP across cortical synapses and propose that during t-LTD, postsynaptic calcium and/or mGluR signaling drive eCB synthesis and release, which activates CB1 receptors to decrease presynaptic release probability. The eCBs are best known mediators of short-term synaptic depression. There are two distinct

classes of STDP across neocortical and hippocampal synapses: postsynaptic NMDARs are the primary coincidence detector and calcium source from both t-LTP and t-LTD and the second class incorporate a distinct form of t-LTD involving postsynaptic mGluRs and retrograde eCB signaling (Bender *et al.*, 2006).

The pre- and postsynaptic spike trains may exhibit spike-by-spike correlations that affect the synaptic efficacy. To quantify the influence of this micro correlation, Senn *et al.* introduced the first-order spike correlation between pre- and postsynaptic spike train. The temporal asymmetry with on the average a presynaptic spike occurs between the last previous and the next following postsynaptic spike. For a presynaptic spike time t_{pre} , denoted the time of the previous postsynaptic spike by $t_{post}^<$, and the time of the following postsynaptic spike by $t_{post}^>$. The spike correlation c_s is then

$$c_s = \frac{1}{\Delta} (\langle t_{pre} - t_{post}^< \rangle t_{pre} - \langle t_{post}^> - t_{pre} \rangle t_{pre}),$$

with normalization

$$\Delta = \langle t_{pre} - t_{post}^< \rangle t_{pre} + \langle t_{post}^> - t_{pre} \rangle t_{pre}.$$

The spike correlation determines the distribution of the NMDA receptors over the possible states. A synapse is have a single site of release with a single vesicle discharges with probability P_{dis} at the arrival of a presynaptic spike. After discharge, the site of release is empty, and to be re-occupied by a new vesicle. The probability P_v that a vesicle is at the site of release is governed by the differential equation

$$\frac{dP_v}{dt} = \frac{1 - P_v}{\tau_v^{rec}} - P_{dis} P_v \delta(t - t_{pre}^{sp}),$$

where t_{pre}^{sp} is the time a presynaptic spike arrives. At the time of a presynaptic spike, P_v is reset with probability P_{dis} from its actual state back to 0. The probability P_v^{n+1} of encountering a vesicle ready for release at arrival of the $(n+1)$ th spike is now

$$P_v^{n+1} = P_v^n (1 - P_{dis}) e^{-\frac{\Delta n}{\tau}} + (1 - e^{-\frac{\Delta n}{\tau}}), \quad \tau = \tau_v^{rec},$$

where

$$\Delta_n = t_{pre}^{sp, n+1} - t_{pre}^{sp, n}$$



is the time elapsed between two spikes and P_v^n is the probability that a vesicle was ready at the previous spike. The probability of release for a presynaptic spike is $P_{rel} = P_{dis}P_v$. The instantaneous release frequency is calculated from the presynaptic spike frequency according to

$$f_{pre}^{rel} = P_{rel}f_{pre}^{sp} = P_{dis}P_vf_{pre}^{sp} \text{ (Senn et al., 2000).}$$

So called resonance condition states that in the molecule of acceptor must exist an excited energy level, which difference from the fundamental level is equal to the transmitted energy quanta. A burst of spikes increase the reliability of communication between neurons and bursts with some resonant interspike frequencies are more likely to cause a postsynaptic cell to fire. This frequency preference occurs at the level of individual synapses due to the interplay between short-term synaptic depression and facilitation (excitation) – synaptic level. At the postsynaptic level due to subthreshold membrane potential oscillations and resonance – neuronal level. The transmission of signals from pre- to postsynaptic cells is most effective if the presynaptic cell fires a burst of action potentials with a certain resonant interspike frequency. Short-term synaptic plasticity contributes to temporal filtering of synaptic transmission. Depression acts as a low-pass filter which is filtering out high-frequency presynaptic firing. Facilitation acts as a high-pass filter that enhances the efficacy of high-frequency presynaptic firing. It means that a synapse acts as a band-pass filter (the selection mechanism for “the selector of key-images”).

The mechanism of frequency preference is related to subthreshold membrane resonance. A response of the neuron with subthreshold oscillatory potentials depends on frequency content of burst of spikes (neuron as a “resonator”). The input burst to such a cell is resonant, if the intra-burst interval is near to the natural period of the cell, and non-resonant in other case. The same burst may be resonant for one neuron and non-resonant for another depending on their natural periods.

Filtering determines how the postsynaptic response depends on the frequency content of the presynaptic burst of spikes. An optimal, resonant interspike frequency maximizes the synaptic throughput,

and because it differs for different synapses, gives the presynaptic neuron a mechanism to influence postsynaptic neurons selectively. Such oscillations can contribute to synchronization (Izhikevich *et al.*, 2003).

A central problem of the coincidence detection at the molecular and atomic level is the calculation of the overlap, what is a scalar product between two states. We can visualize this quantity as the area of overlap between two bands in phase space. In the case of more than one overlap the contributing amplitudes have to be combined with a phase difference again determined by an area in phase space. The probability shift is with a sudden radiative transition of molecule from one vibronic state to another. It illuminates the coupling between individual molecule dynamics and collective degrees of freedom. In a diatomic molecule the nuclei remain at their instantaneous position and keep their momenta during an electronic transition and the intermolecular potential changes suddenly. The radiative dissociation of diatomic molecule may change the binding potential from attractive to repulsive and vice versa. This can lead to a polarization of the intermolecular potential as the basis for overlap and resonance.

The probability for a transition to occur from the n th vibrational state of a diatomic molecule in one electronic state to the m th vibrational level of a different electronic state

$$W_{m,n} = |w_{m,n}|^2,$$

that is as the square of the Franck-Codon factors of the overlap integral

$$w_{m,n} = \int_{-\infty}^{\infty} dx u_m(x)v_n(x).$$

Thus $W_{m,n}$ is governed by the overlap of the scalar product between the two vibrational wave functions u_m and v_n in position space. This area of overlap is a tool for determining the transition probability (Dowling *et al.*, 1991).

Discussion

The brain generates transient representations of mental objects and pre-representations perceived as a “reality”. This reality is developed through a comparison of a percept with a pre-representation. Resonance manifests itself by potentiation of firing, dissonance by its extinction. A selection of the



resonant percept achieving the value of “true” when the comparator based on the coincidence detection is signaling good accordance with existing pre-representation. This spontaneous activity could be at the origin of the internal genesis of mental objects and their coupling together. The convergence of two oscillations on the same neuron may result, if they were in phase, due an amplification of the latent oscillations to a burst of impulses (Changeux, 1983).

The angular gyrus and mechanism of the entire visual field performs an elementary type of abstraction when use an algorithm of extracting the common denominator from a set of dissimilar entities. It can be seen as an example of functioning overlap based on the resonance.

Comparing activation during executed and mentally imagined movements revealed a substantial overlap of neuronal responses in the superior parietal lobe.

But neither presynaptic nor postsynaptic neurons “choose” their frequencies “at will”. The frequencies are determined by the intrinsic properties of neurons and the overall activity of the brain. By changing the frequency content of bursts and subthreshold oscillations the brain determines who talks to whom. The brain can rewire itself dynamically on a time scale of milliseconds without changing the synaptic hardware. From the neuro-computational point of view, such a neuron acts like a resonator. Subthreshold oscillations of membrane potential in neurons can be found in many brain regions, including cortex, thalamus, hippocampus and brainstem (Izhikevich, 2003). The phase of oscillation can be reset by a brief pulse of injected current and are generated by voltage-gated membrane currents. A depolarization inactivates (*closes*) the currents and hyperpolarization de-inactivates (*opens*) the currents. Such an amplified response of the system subjected to a periodic stimulation near its natural frequency is called resonance. The probability of the system’s response is greatest when the input is resonant; its period is near the natural period of the system.

The precise timing of pre- and postsynaptic action potentials plays a key role in the modification of synaptic efficacy. Stimulation protocols of two synoptically connected neurons is showing on possibility of

an algorithm that reproduces the experimental data by modifying the probability of vesicle discharge as a function of the relative timing of spikes in the pre- and postsynaptic neurons. When the presynaptic spike occurs up to 50 ms before vesicle discharge is down regulated when the presynaptic spike occurs up to 50 ms after the postsynaptic spike, the probability of vesicle discharge is up regulated. The proposed spike-based synaptic learning algorithm gives a general framework for regulating neurotransmitter release probability.

To formulate precise learning rules, as it looked Donald Hebb, which determine the change in synaptic efficacies from the known activities of the neurons; we propose the concept overlap base on the resonance condition. It was shown that the synaptic modification is a complex redistribution of synaptic efficacy between the spikes in the train without uniform strengthening of the connections. These redistributions, by our points of view, can result from the increase in the probability of neurotransmitter release. We refer to this probability as the probability of discharge. The processes involved in modifying P_{dis} are triggered either by pre- or postsynaptic spikes, by a spontaneous presynaptic release or by elevation of the postsynaptic membrane potential. The up-regulation of P_{dis} is only induced by a postsynaptic spike following a presynaptic release. Down-regulation of P_{dis} is only induced by a presynaptic release following a postsynaptic spike or voltage increase. When the postsynaptic membrane potential increases allowing calcium to flow through NMDA-channels into the postsynaptic cell. This calcium activates a secondary messenger which diffuses to the presynaptic site and up-regulates the probability of discharge ($P_{dis}^{\infty} \rightarrow P_{dis}^{\infty}$).

Due to additional computation as the integration of a third coincident signal provided by growth factors or neuromodulators (synaptic growth or unmasking of postsynaptic receptors) may be required for the induction of real synaptic strengthening.

The functional organization of one level of the cortex is ruled by the interplay of earlier and later representational stages of the sensory processing stream. The thalamus (one of the highest processing stages of the reptilian



brain) sends sensory information into the cortex and the cortex in turn sends processed information back to thalamus. When these top-down projections are inactivated, thalamic functional organization is dramatically degraded. There are ten times more fibers projecting top-down from the representational cortex (PFC) to the thalamus than are bottom-up projections from the thalamus to the cortex. Top-down processing from the prefrontal cortex determines the way in which sensory information is organized, processed and filtered.

Genetically encoded programs control the connections of these maps; their organization ultimately depends on the efficacy of the synapses. Representational zones are shaped by the temporal pattern of coincident experience. The thinking is a process identified mostly with consciousness, but the intuition is localized as extra-consciousness, and based on nonlinear computations.

The artificial consciousness is maybe a robot able to describe its own qualia-like experiences. Probably, the empathy of mirror neurons connected with prefrontal cortex is playing the role traditionally labeled as “the soul”, and the thalamus a role of “the self”. The program is to invent a new, in the beginning a non-commonsensical but scientifically successful theory of mind. In the space of consciousness, the “real” is already a virtual. The difference between real and virtual is stochastic: a matter of probabilities. In a conventional sense, the real is that which is most likely, most probable. It is the question of future tests to make clear the complex role of oxytocin (Changeux, 1983; Kosfeld, 2005) in human faith, trust, hope as global signals of the psychosomatization *and* a structure of probabilities in stabilizing neuronal groups that were previously unlikely.

The intuition also involve “off-line consciousness scenes” like dreaming, abstract thought, planning and imagery. The self-

fulfilling prophecy acts as a projective mechanism of positive psychosomatization. “Only paranoid survive”, said by Soros and it follows that emotions are also predictions and human brain can be seen as a “neuronal hope-computer”.

The common human model of reality in brain is selected out by the mechanism of complex probabilities (Tononi, 2004). The most probable predictions are defining actual view of reality, and the shared frame of these probabilities is based on a unitary human genetic program. At the level of synapses is ongoing selection of the correlation of phase in most strongly active presynaptic inputs. Strongly correlated firing phases are then potentiated in a terms of Darwinistic selection.

Genetic code for this mechanism of probabilities is shared commonly with 6 billion of humans at the Earth and form basis for the possible neurobiological anthropic principle. After inventing of human genetic program probably a next will be the electromagnetic program (“an electromagnetic code”) of control in a human biochemical organization. (Persinger, 1995; Levin, 2006; Blackman, 2007) The existence of several algorithms (for example the copulation algorithm, etc.) in human brain may lead us to propose the possibility of the neurobiological anthropic principle as a computation basis (Chalmers, 1994) allowing for a unitary perception of the reality. The repertoire of brain’s intuitive computational processes may have a growing importance also for models of extra-conscious intuition (ECI), artificial consciousness and artificial intuition (AIu) (probably with embedded algorithm for generator of paradoxes and metaphors based on the cross-domain mapping). ECI, AIu are elements of a neuronal selection mechanism determined by the nonlinear probabilities.

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