Learning and selecting actions: a computational model of the basal-ganglia cortical dynamic interplay

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The basal ganglia form loops with highly interconnected cortical areas through the mediation of the thalamus. This architecture has the potential of generating highly dynamical processes. Traditionally, cortex is though to implement fine sensorimotor transformations and more indirect cognitive input-output processing through its distributed, highly re-entrant circuits. Instead, basal ganglia, with the mediation of thalamus and the modulation of dopamine, are thought to select cortical contents through a disinhibitory mechanism involving compartmentalised channels. How in detail this basal ganglia-cortical architecture integrates these two functions is still an open issue. In this respect, Wickens and colleagues [1] proposed a model in which the activation of a cortical assembly disinhibits other assemblies through the basal ganglia, thus producing their sequential activation. Instead, Frank and colleagues [2] proposed that basal ganglia act by gating the thalamic input to cortical modules thus switching on and off their intrinsic dynamics.

Here we propose an alternative model that aims to explain how the computational processes of basal-ganglia, characterised by a different granularity in both space and time, interplay to produce adaptive behaviour. All components of the model are formed by populations of the same type of leaky neuron. A first key idea of the model is that cortex forms a system endowed with a complex intrinsic dynamics capable of expanding the input in both space and time so as to solve non-linearly separable problems and at the same time to form a fading memory of input sequences. These computational processes are captured in the model with a dynamic reservoir [3] that abstracts the micro circuits of cortex. The dynamics of cortex are sensitive to the high-frequency, detailed input from other cortical areas: this input represents body/environment changing states and is represented in the model with different sinusoidal signals. The cortical output is "read out" through units trained for simplicity with a supervised learning algorithm. The basal ganglia inner architecture is instead based on the GPR model [4] which is however integrated with cortex with afferent connections from the targeted cortex and efferent connections to thalamo-cortical loops. The functioning of basal ganglia is also regulated by dopamine. A second key idea of the model is that basal ganglia circuits lead them to integrate information at a lower temporal and spatial resolution with respect to cortex: this allows them to perform more reliable selections. These "selections" are then actually performed in terms of modulation of the cortical dynamics at a spatial and temporal coarse scale.

The model is tested by using its reading-out units to control a three degree-of-freedom simulated dynamic arm. The arm is requested to learn to perform various rhythmic movements (e.g., drawing a circle or a square) or discrete movements (e.g., reaching a point is space) on the basis different "task inputs" sent to basal ganglia. The results confirm how the basal ganglia and cortical components of the model are indeed best suited to process information at suitable spatial and temporal scales, and that the system performance deteriorates if inputs with a certain scale are sent to the wrong component (e.g., the task input to cortex or the context input to basal ganglia).

References

[1] Wickens, J., Hyland, B., and Anson, G. (1994) *J. Mot. Behav.* **26(2)**, 66–82.

[2] Frank, M. J., Loughry, B., and O'Reilly, R. C. (2001) *Cogn. Affect. Behav. Neurosci.* **1(2)**, 137–160.

[3] Lukovsevivcius, M. and Jaeger, H. (2009) *Computer Science Review* **3(3)**, 127–149.

[4] Gurney, K., Prescott, T., and Redgrave, P. (2001) *Biological Cybernetics* **84**, 401–410.