Do you need biological plausibility? A focus on basal ganglia

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Abstract

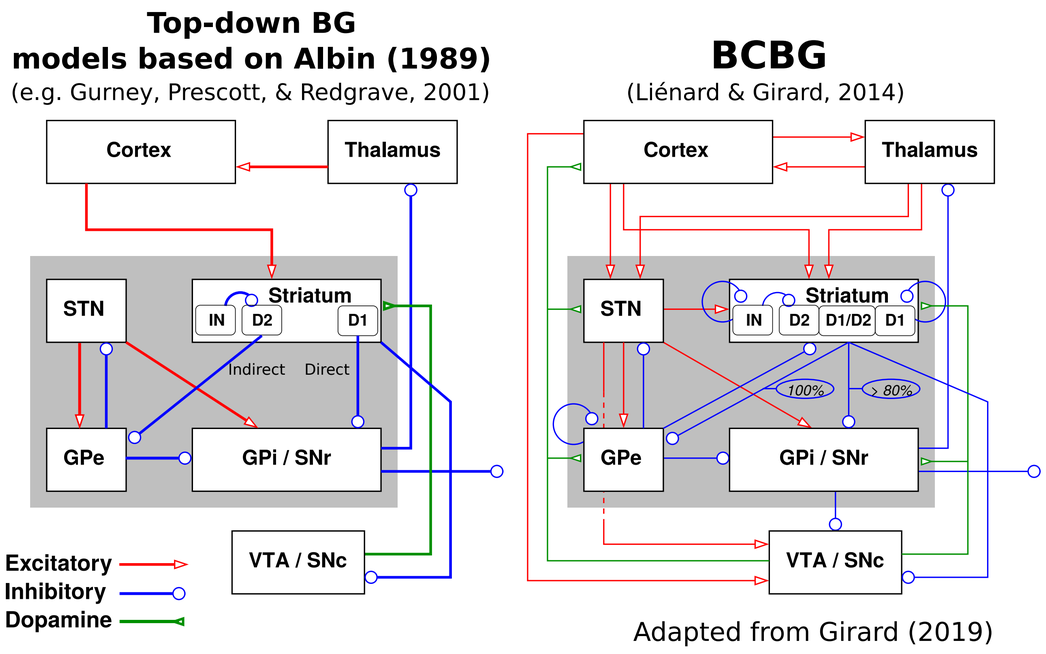
Two models of basal ganglia are used to study the relationship between biological plausibility, performance and interpretability in cognitive modelling. Some anatomical findings suggest a need to reevaluate the canonical theory of how basal ganglia may perform action selection. However, this theory is appealing in its simplicity and has given rise to efficient computational models. A more detailed model is compared to shed light on the need for biological plausibility.

Basal ganglia: function and circuitry

Basal ganglia are commonly thought to perform action selection. Albin (1989) has proposed that BG are divided in:

- **a direct pathway** that favors the action with the highest utility
- **an indirect pathway** that inhibits the execution of the competing actions

However, several findings suggest that the ouputs of the striatum are actually not segregated in primates. Liénard & Girard (2014) summarize the contradictory evidence and propose a new biologically constrained model of basal ganglia (BCBG) that has emergent selection properties.

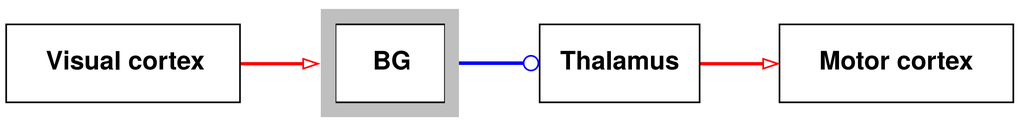


Adapted from Girard (2019)

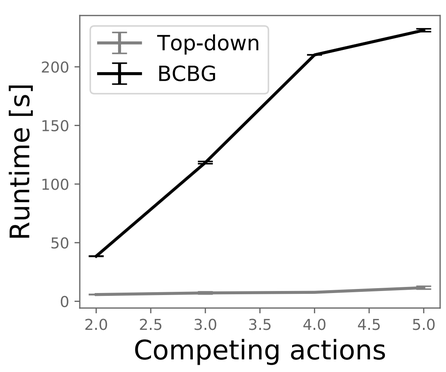
Motivation

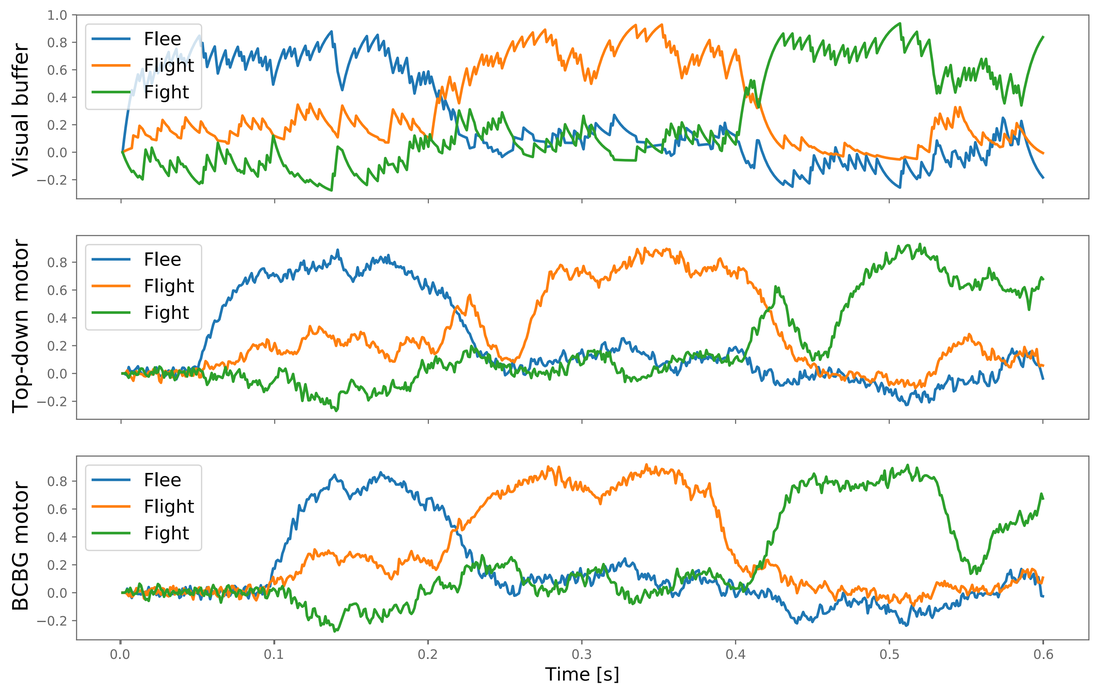
Biological plausibility is an important criterion for evaluating models in neuroscience, while artificial intelligence is more focused on efficiency for enginering ends. However, simplicity is a common goal. In neuroscience, simple and general principles are more elegant than the "bag of tricks" hypothesis and can potentially unify multiple subfields. Simplicity can also be the key to solve the interpretability concern in artificial intelligence. Neural networks are black boxes and their application in high risks domains such as autonomous driving, robotics or law is therefore limited. In these domains, agents must be able to give full account of their actions through the interpretability of their decision making process. A simple theory of how humans make decisions would be beneficial to both fields.

Action selection task

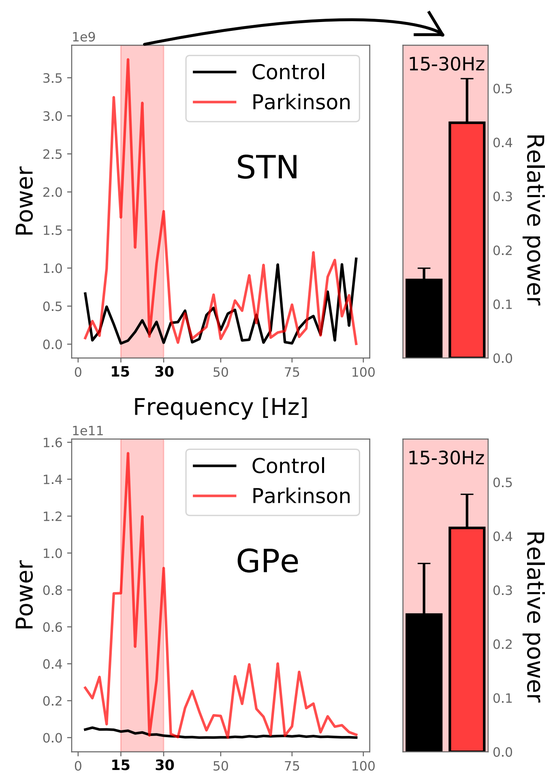


The simulations have been performed in Nengo. A visual buffer is fed a stimulus that should either drive a flee, fight or flight motor response. The visual buffer is connected to the striatum through corticostriatal neurons. The GPi/SNr nuclei serve as output of basal ganglia and project to the thalamus which itself projects to a motor buffer. BCBG is compared to the model of Gurney et al. (2001).





Parkinson's disease



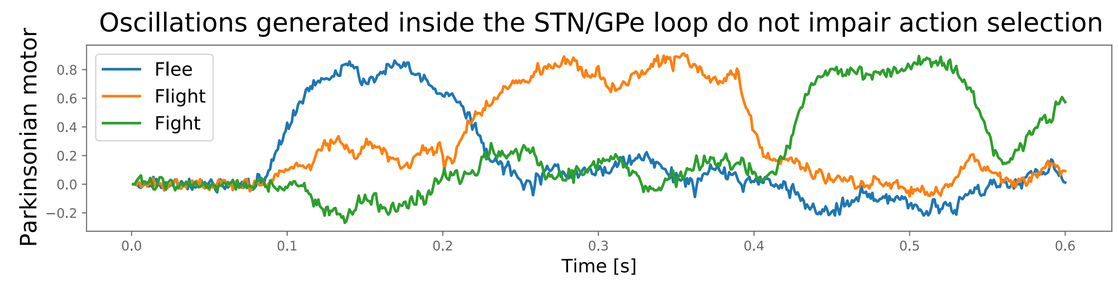
Parkinson's disease is characterized by:

- the death of dopaminergic neurons in the VTA and the SNc
- beta oscillations in the BG due to the lack of dopamine

Liénard et al. (2017) have shown that beta oscillations emerge when the dopamine is reduced in the STN-GPe loop only, while most studies focus on the depletion in the striatum.

However, it is not yet clear how the disease impairs motor control.

Oscillations generated inside the STN/GPe loop do not impair action selection



For engineering purposes, it seems more reasonable to use the model proposed by Gurney et al. (2001) or an even simpler Winner-Takes-All system. It is worth noting that BCBG is totally agnostic concerning the function of basal ganglia. Liénard & Girard (2014) have constrained the model on anatomical data only, and the selection capacities are ermergent. Therefore, BCBG will not be obsolete in case of paradigm shift. On the other hand, Gurney et al. (2001) followed a top-down approach to constrain their model with the assumption that basal ganglia perform action selection with segregated pathways.

References

Albin, R. L., Young, A. B., Penney, J. B., 1989. The functional anatomy of basal ganglia disorders. Trends in Neurosciences 12 (10), 366 – 375.

Benoît Girard.. 2019. YABG_ERC.pdf. DOI:https://doi.org/10.6084/m9.figshare.5418766.v1

Gurney, K., Prescott, T., & Redgrave, P. (2001). A computational model of action selection in the basal ganglia. Biological Cybernetics 84, 401-423.

Lienard, J., Girard, B., Jun 2014. A biologically constrained model of the whole basal ganglia addressing the paradoxes of connections and selection. Journal of Computational Neuroscience 36 (3), 445–468.

Lienard, J. F., Cos, I., Girard, B., 2017. Beta-band oscillations without pathways: the opposing roles of d2 and d5 receptors. bioRxiv.