Decision making mechanisms in a connectionist model of the basal ganglia

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INTRODUCTION

Basal ganglia (BG) are known to hosts mechanisms of action selection and its adaptation to a changing environment. Their architecture consist of several parallel functional loops connecting back to distinct areas of cortex (motor, cognitive and limbic) and processing different modalities of decision making. The picture of parallel loops is complicated by partial convergence and divergence connections that implies that the various loops are interacting.

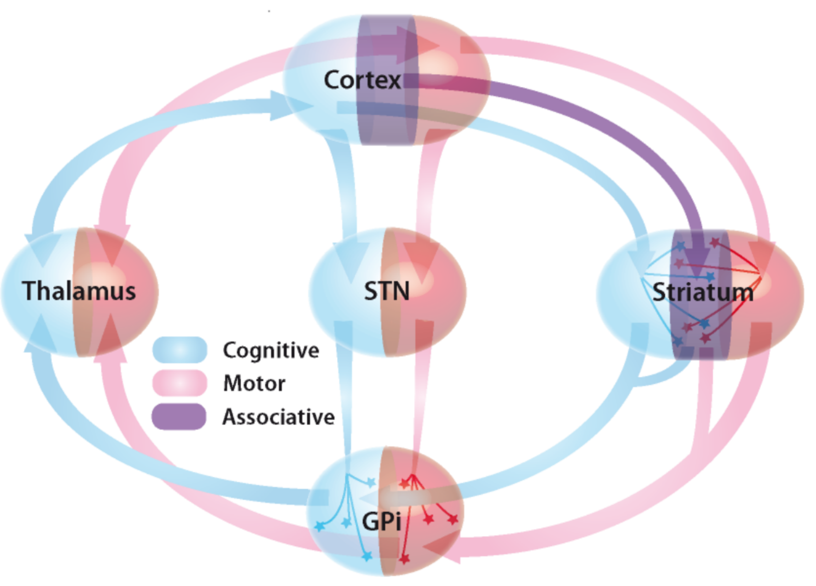


Figure 1. Overview of model architecture

A previous BG model (developed by M. Guthrie[1]) was built of interacting bloc-diagram based on rate-models. It was able to learn optimized action selection during a probabilistic reward task. The aim of the present work is to refine and extend these results to a cell-synapse level through a bottom-up approach:
→ Highlighting of the structure-function relationship and circuitry emerging properties
→ Investigation of cell-scale mechanisms impact on the whole model capacities (learning and decision-making)

NETWORK ARCHITECTURE

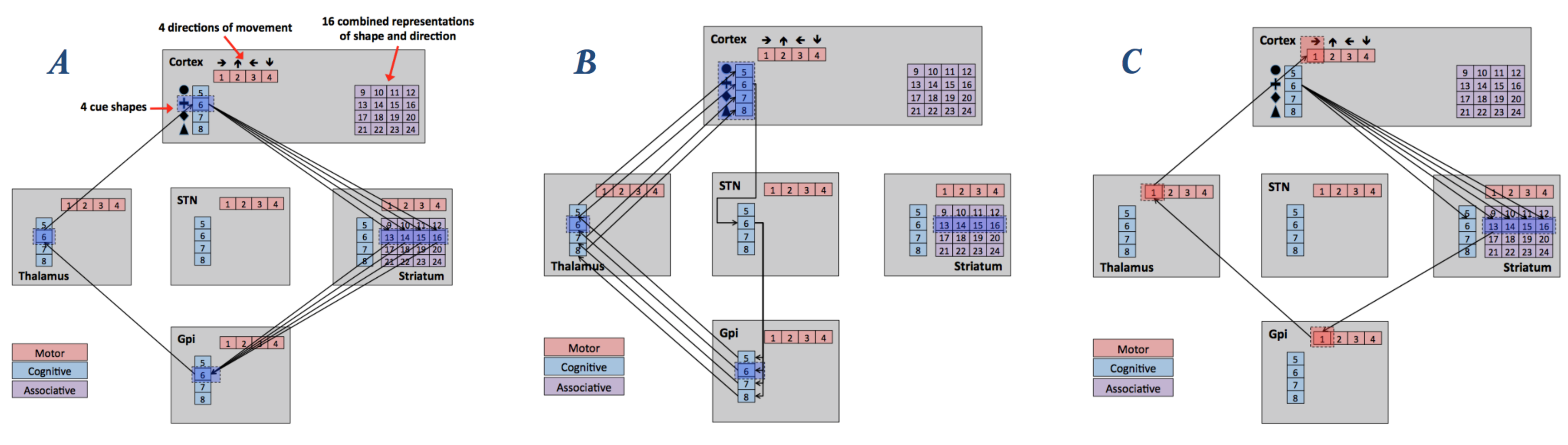


Figure 4. Model pathways. A) Direct pathway. B) Hyperdirect pathway. C) Pathway crosstalk

Leaky integrate-and-fire neuron model: $C_m \cdot \frac{dV_m(t)}{dt} + \frac{V_m(t)}{R_m} = I(t)$

Learning takes place when a reward is obtained. It is implemented as an increase in the synaptic weights corresponding to the projection from the cognitive cortex to the striatum.

RESULTS

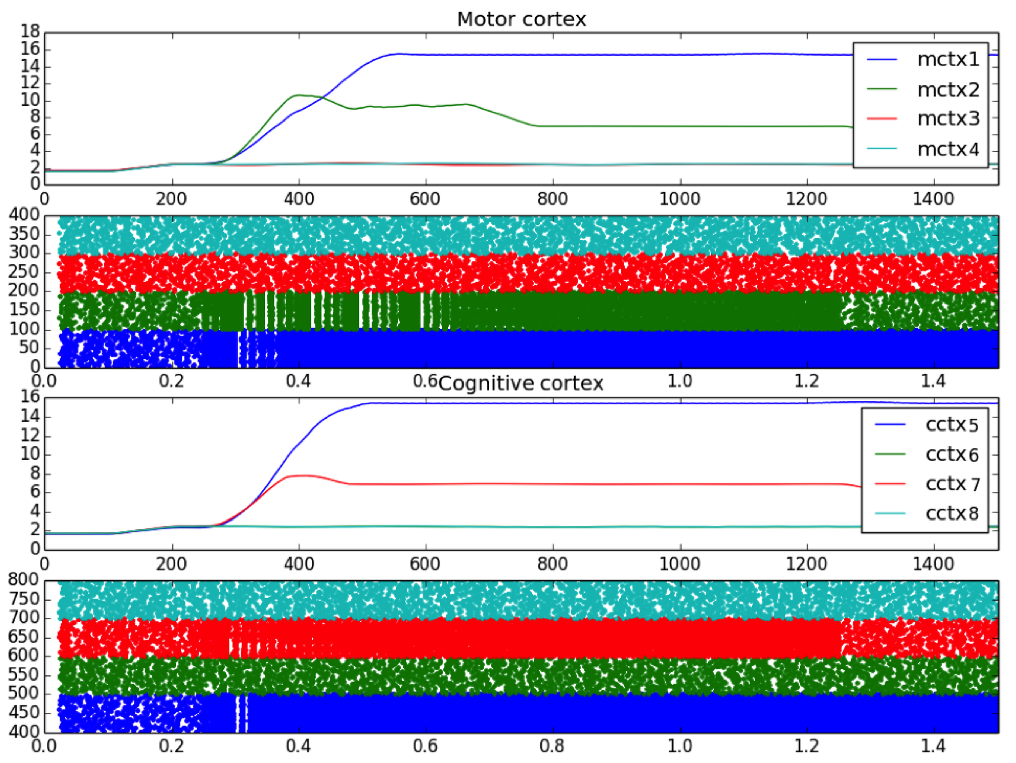


Figure 5. Example of the cortex activity in a naive network

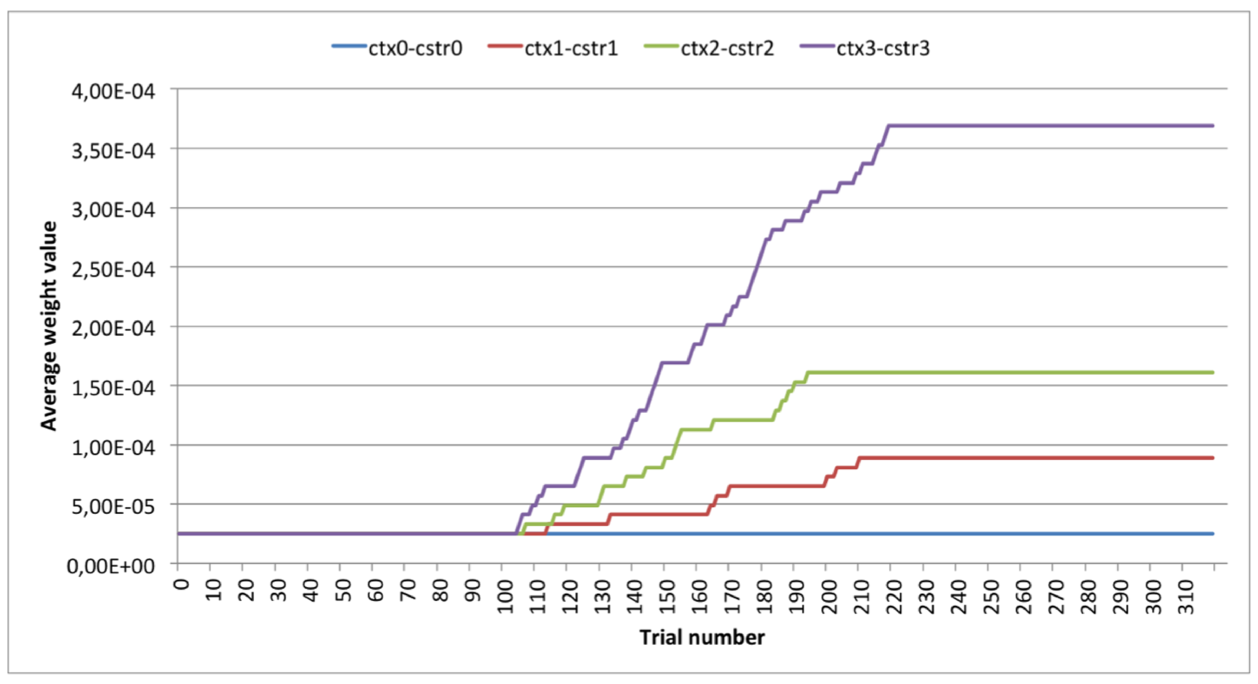


Figure 6. Example of the cortex activity after learning

Naive network
Ability of spontaneous action selection (defined here by a sufficient difference in the activity between two regions of the motor cortex).
→ Exploration phase ⇔ Target selection of the primate.

Trained network
Ability to preferentially select the optimum target (highest reward probability).
→ Exploitation phase ⇔ Successful learning from the primate.

Before/after learning
Better percentage of success (chosing the optimum target, p-value<5%) after learning than before.

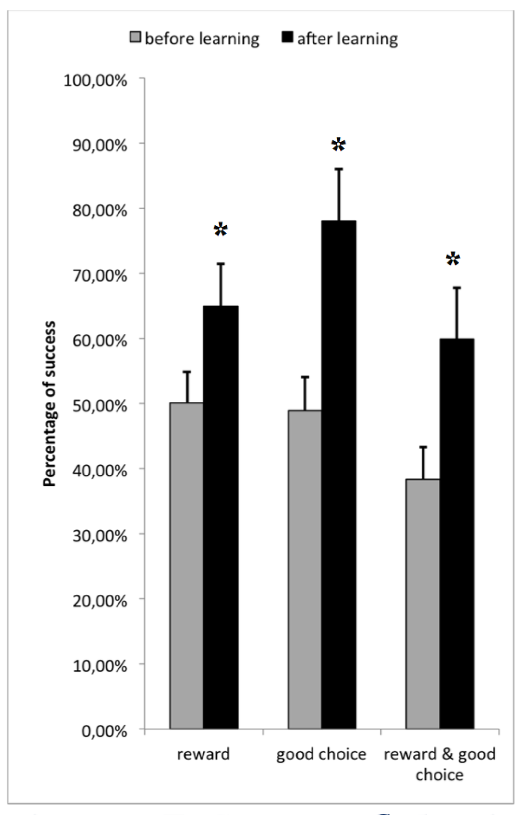
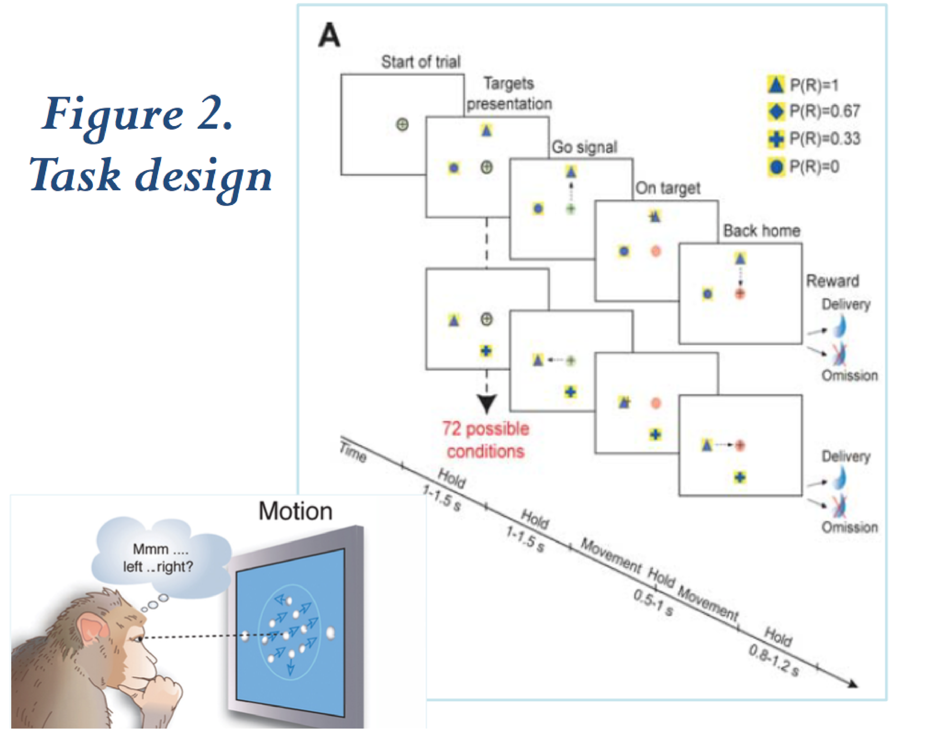


Figure 7. Successful trials before/after learning

BEHAVIORAL TASK

Figure 2. Task design



4 target shapes ⇔ 4 different reward probabilities.
At each trial[2]:
- random presentation of 2 targets, at random positions
- choice made by the model
- reward given or not according to the reward probability (probabilistic learning task)
→ The model has to learn to choose the optimum target on each trial.

IMPLEMENTATION

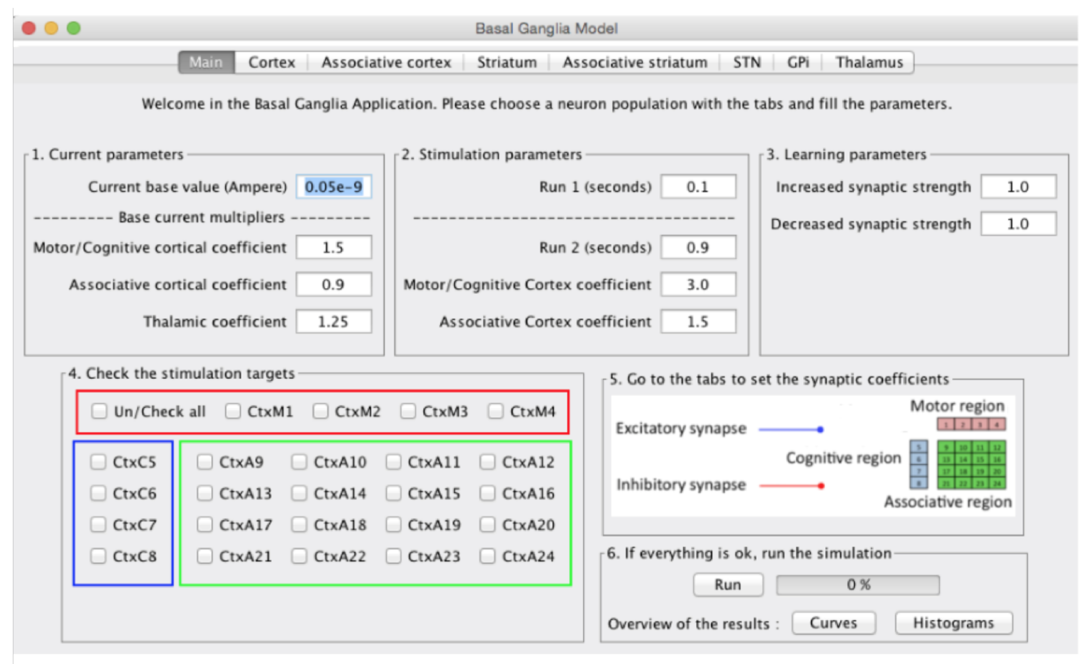
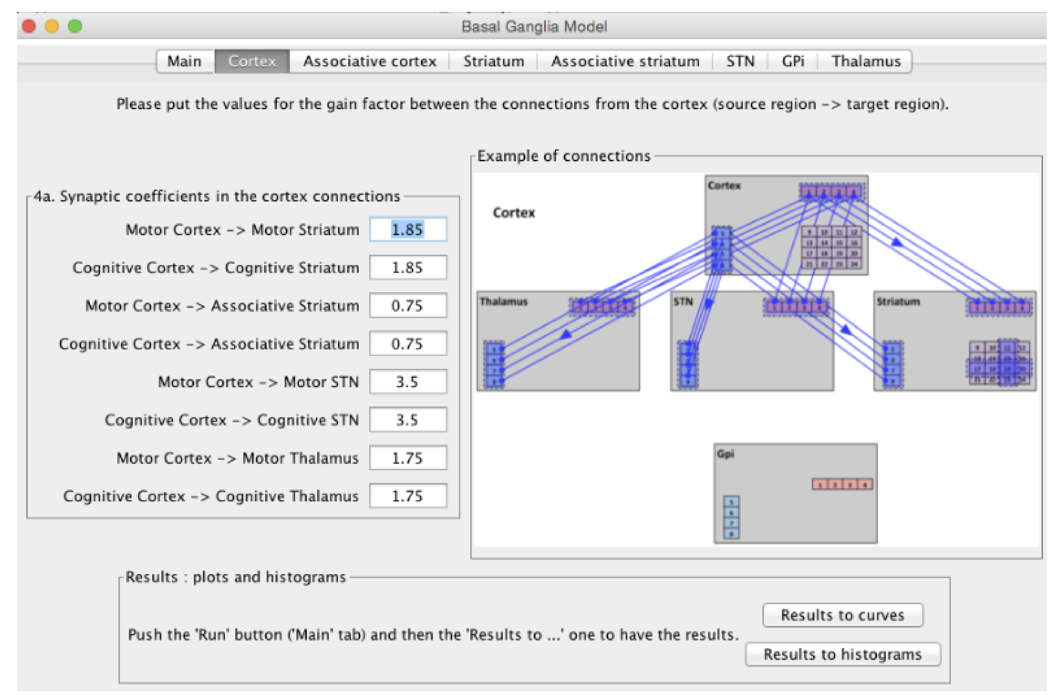


Figure 3. Modeling tool with Java implementation



DISCUSSION

The neural network implementation of a BG stochastic model is developed, embedded in a sensory-motor closed-loop environment and applied to an action-selection task. Once finalized, this neuron level description model allows for a better understanding of the information flows dynamics in the BG and for an investigation of the physiopathological models including synapses, cells and neuromodulators properties.

To achieve this study, an accurate implementation of a dopamine modulated LTP mechanism will be done to reproduce a complete learning. To validate the model, lesional tests and changes in the conditions of the task are planned.

REFERENCES

[1] M. Guthrie et al. Interaction between cognitive and motor cortico-basal ganglia loops during decision making: a computational study, 2013 *J. NeuroPhysiology*

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INSTITUTES

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