Decision-making in a neural network model of the basal ganglia

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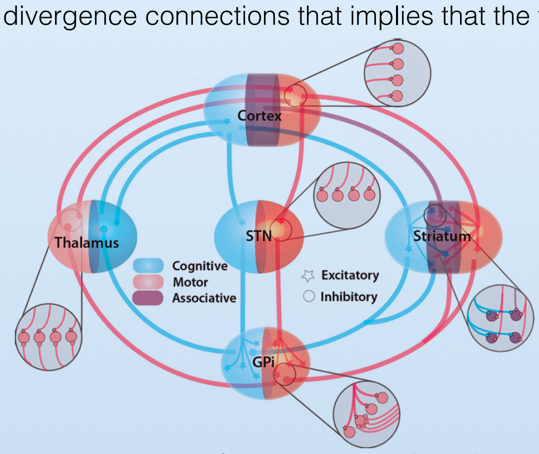
Introduction

Basal ganglia (BG) are known to host 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.



A previous BG model[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).

Behavioral task

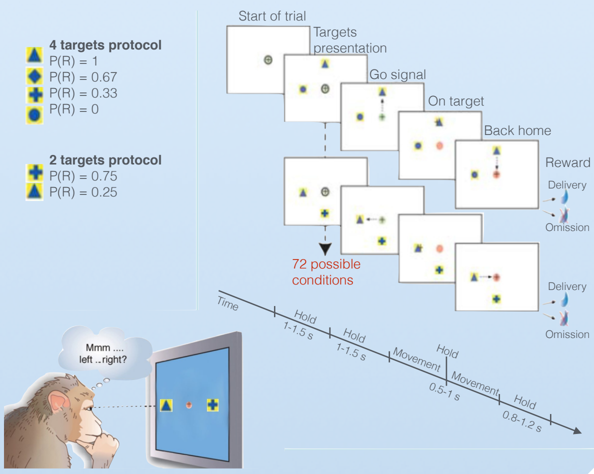
We submit the model to a protocol[2,3] for BG involvement in decision-making with monkeys in **conditions of uncertainty**. There are **4** different **cue shapes**, each with its **own reward probability** and 4 possible positions.

At each trial :

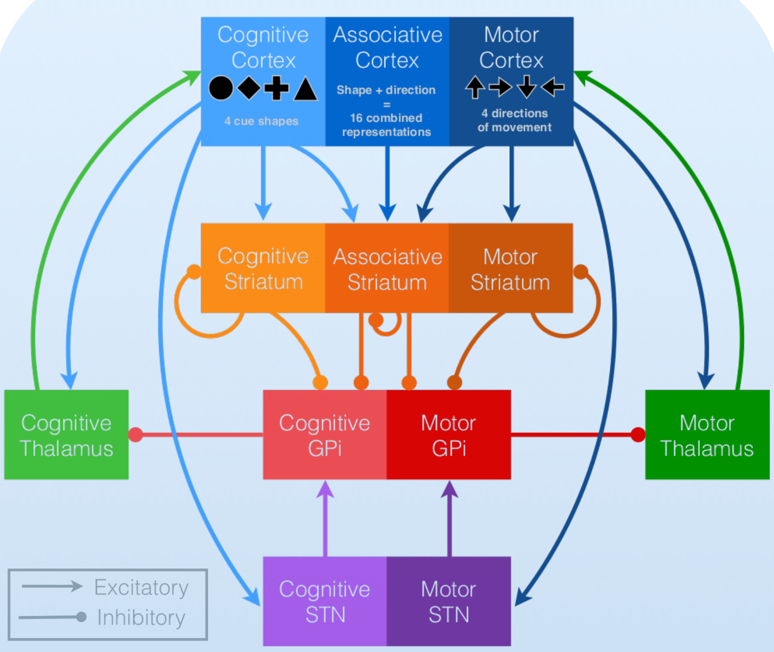
1. Random **presentation** of 2 cue shapes (at random positions)
2. **Choice** made by the monkey and the model
3. **Reward** given or not according to the reward probability of the shape

→ Probabilistic learning task

→The monkey and the model both have to **learn** to chose the optimum cue shape (the one with the best reward probability).



Network architecture



- **Spiking neurons**: Leaky Integrate-and-Fire (LIF) neurons and voltage jump synapses.
- **Learning**: adaptation of the cognitive corticostriatal projections strength modulated by a phasic dopamine release (≈ reward prediction error).

Results

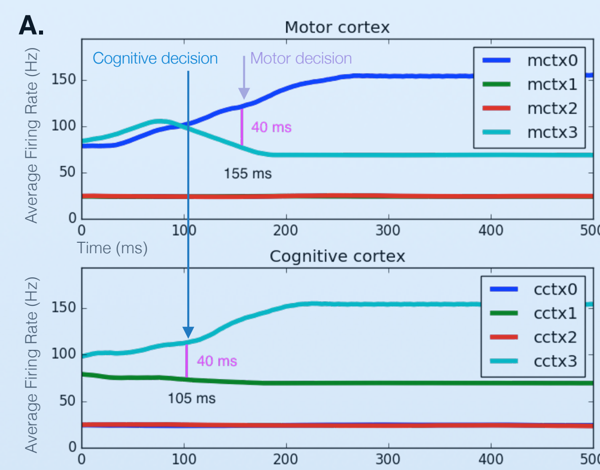
- Exploration:

An expected emergent property of the network is a **divergence** in the cortical activations of cognitive and motor sub-populations. In the absence of learning the network is still able to make a decision. This is equivalent to **decision-making** during the exploration phase of **reinforcement learning**.

→ With the time course of the average firing rate (A), we are able to see the evolution of **motor and cognitive cortex** for example.

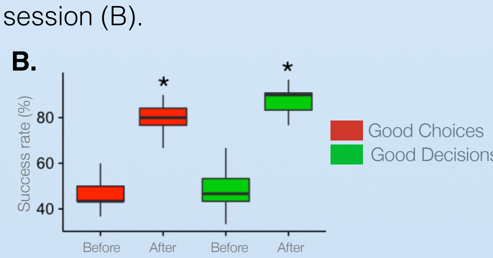
→ A decision is made when a difference in the activities more than 40 Hz is observed.

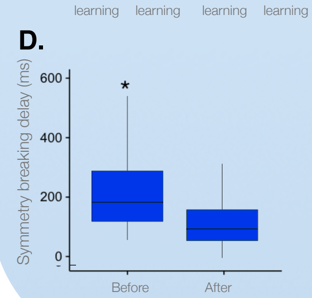
→ The **higher activity** represents the **choice**



- Exploitation:

A Good Choice (GC) is made when the **optimal shape** is selected and a Good Decision (GD) when the **associated direction** is selected too. Both are improved during a standard learning session (B).





During training, the model learns to create a **dynamic link** between the cognitive and motor sensory component of a cue. This can be assessed by the learning curves profile of the model (C).

→ The **average reward** and **GC** rate gradually increase along the session (C).

→ The **optimum** cue shape direction is preferentially selected (B).

→ The movement onset delay is decreased by the **learning** (D).

Conclusion

We have presented here, for the first time, a biophysically based, **spiking neuron model of the BG** that is able to perform 2 levels action selection. This model is closely based on the known anatomy and physiology of the basal ganglia and demonstrates a reasonable mechanism of network level **action selection**.

This cellular and synaptic level of description bridges the gap between top-down mesoscopic level of description[1] and a bottom-up approach relying on emerging properties of neuronal networks dynamics. Our model is also able to predicts some important behavioral characteristics like localized lesion consequences on **learning impairment** and intrinsic dynamics, **reversal learning** and **extinction protocol**.

References

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Institutes

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