

NOISE AS A SYMMETRY BREAKER

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NEURODEGENERATIVES





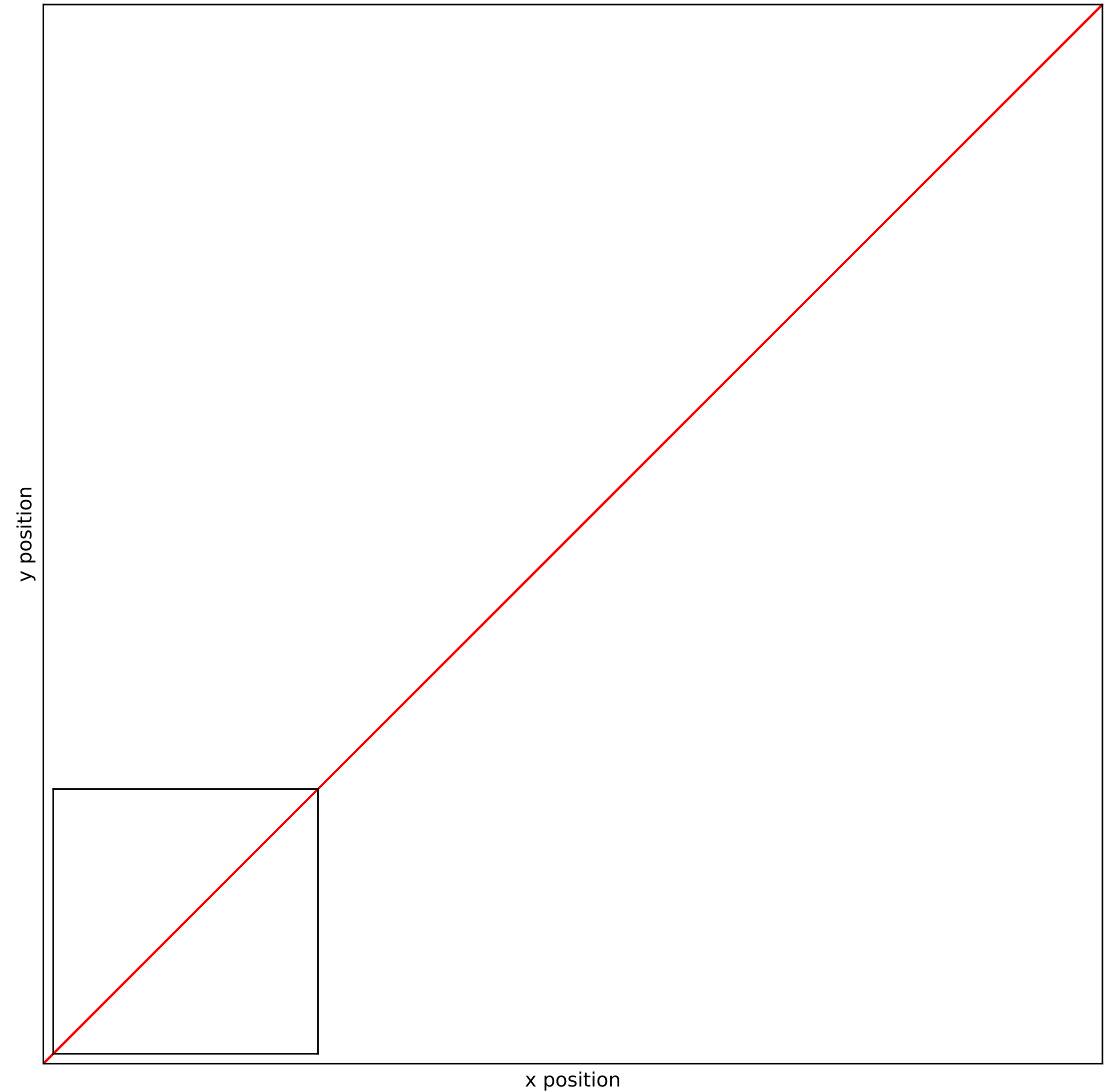
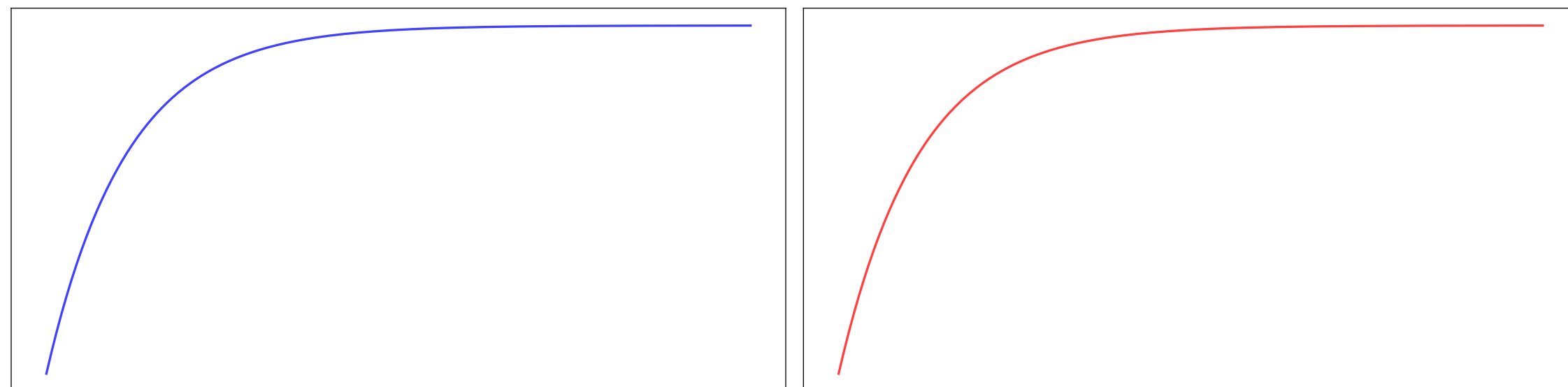
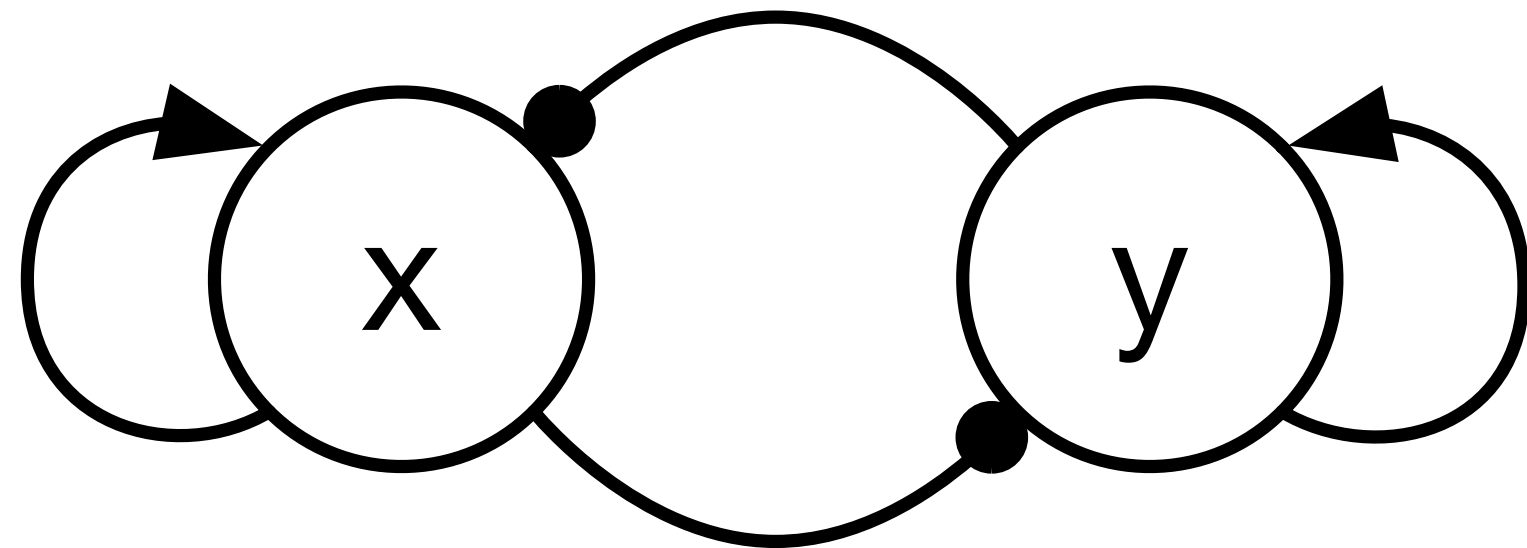
The executive decision maker
Brazil, Terry Gilliam, 1985

Unstable equilibrium

A dual particle system (degenerated neural field)

$$\dot{x} = \alpha(1 - x) + (x - y)(1 - x), x > 0$$

$$\dot{y} = \alpha(1 - y) + (y - x)(1 - y), y > 0$$



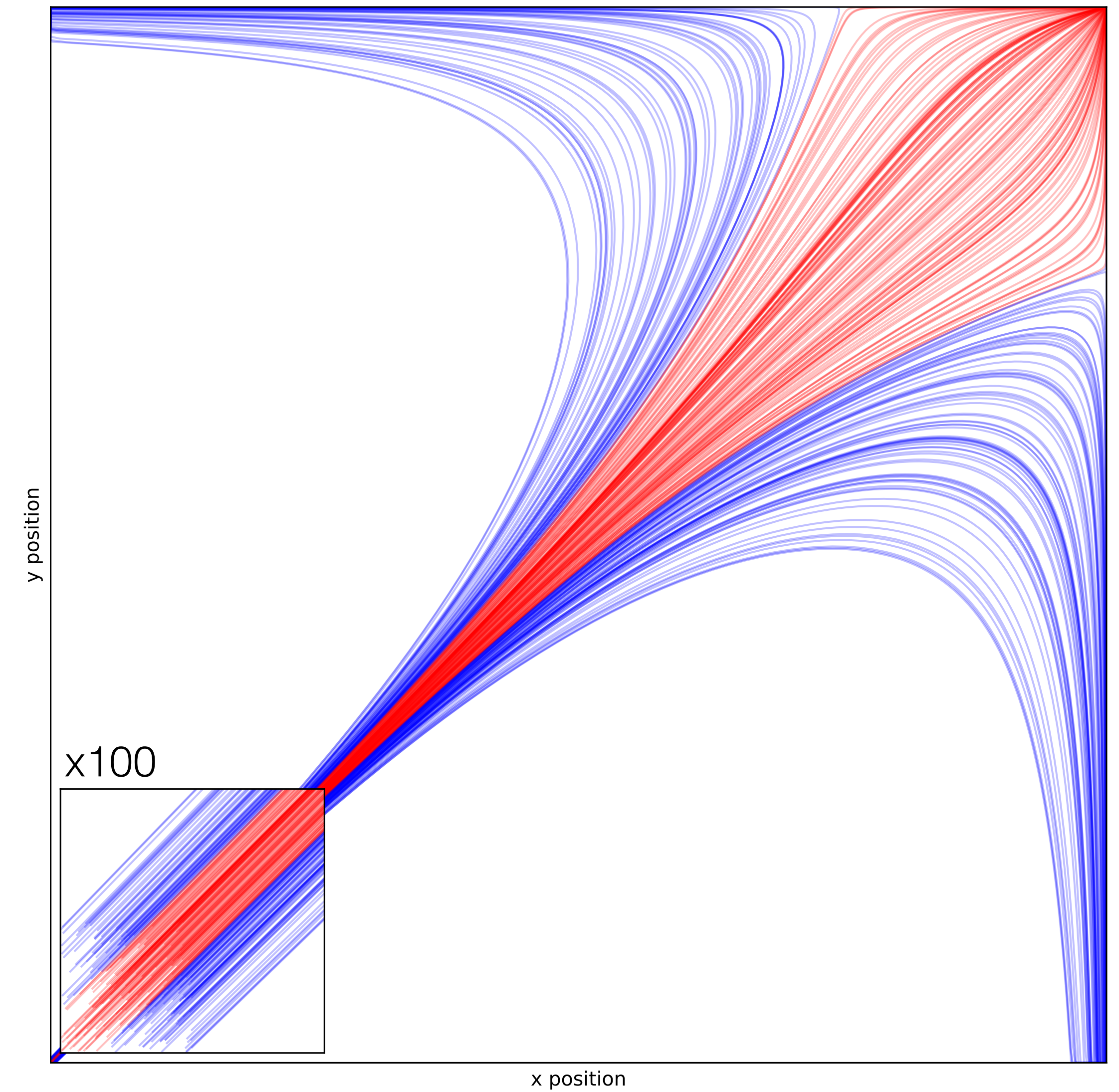
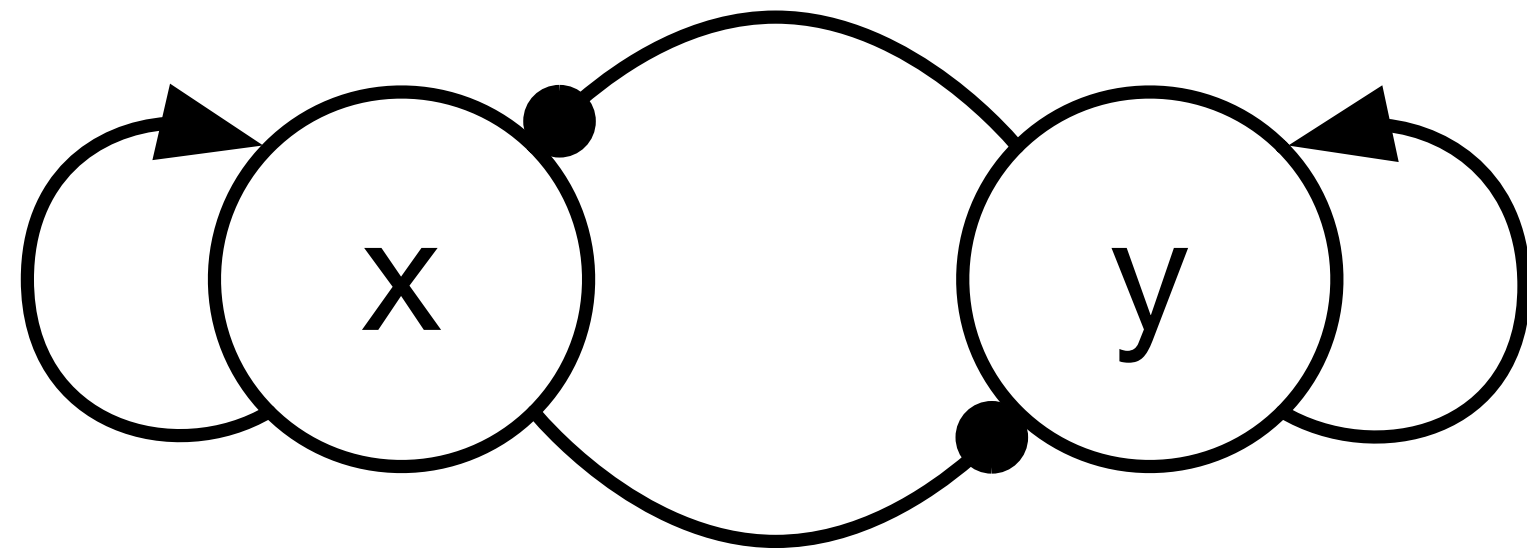
SYMMETRY BREAKING

Initial conditions

A dual particle system (degenerated neural field)

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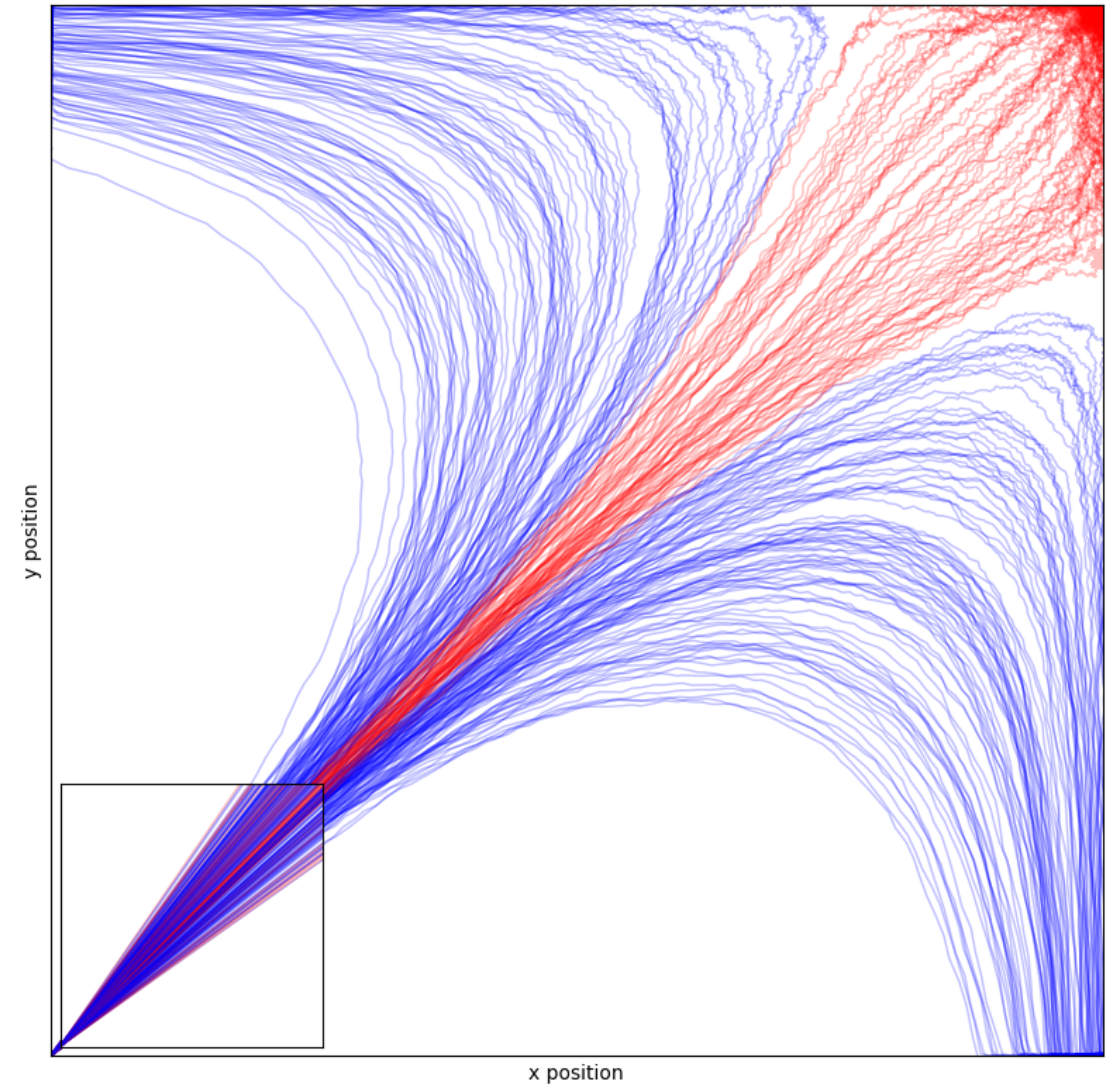
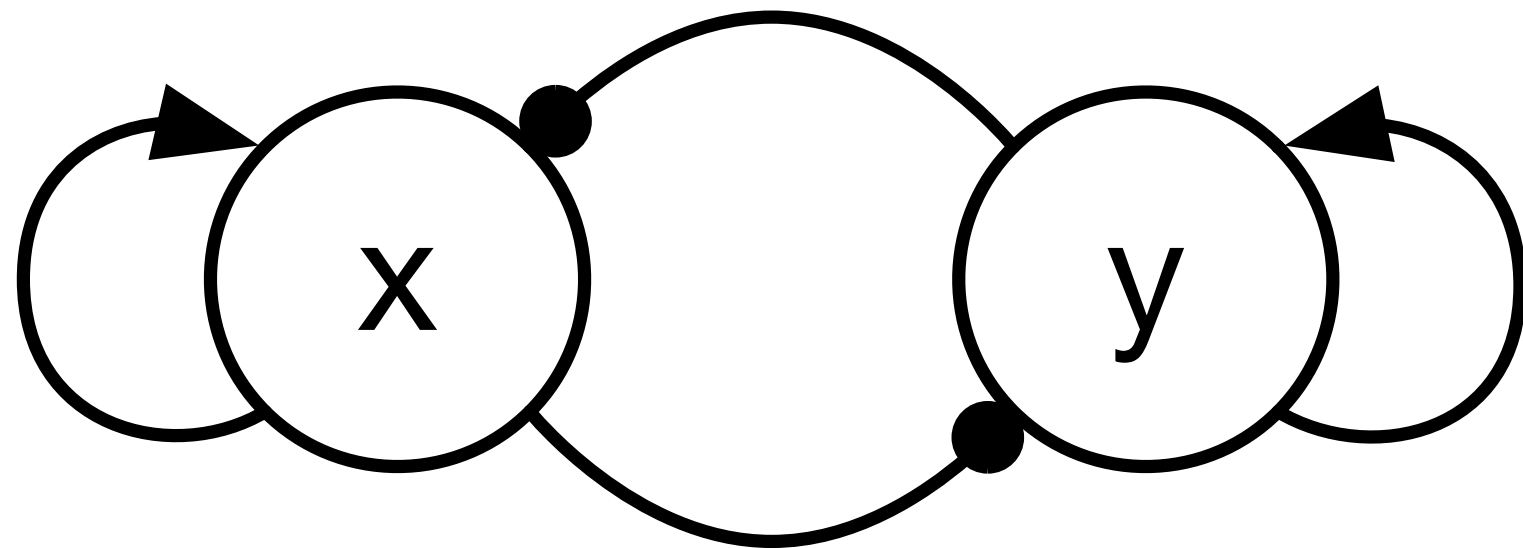


Numerical noise

A dual particle system (degenerated neural field)

$$\dot{x} = \alpha(1 - x) + (x - y)(1 - x), x > 0$$

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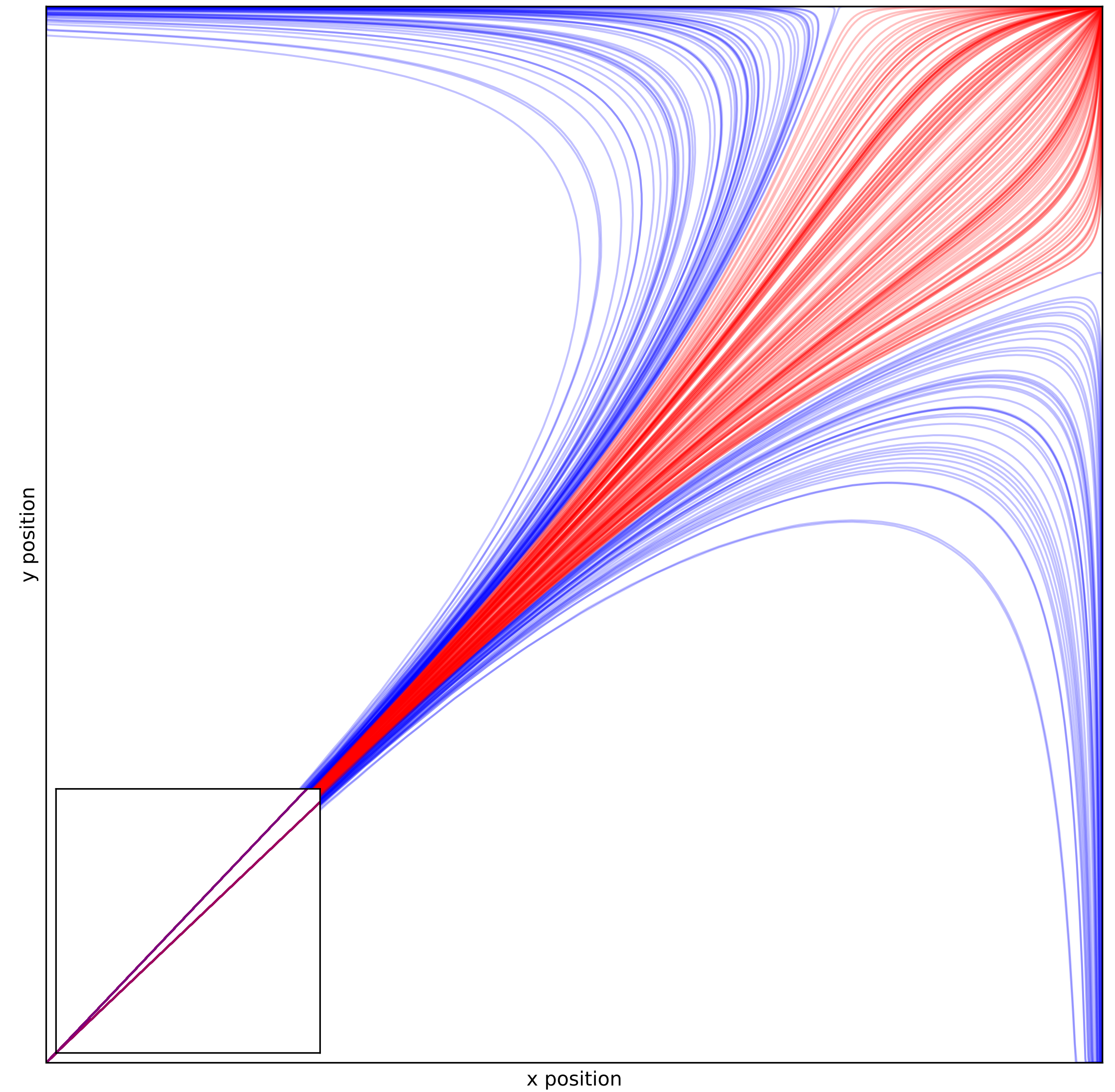
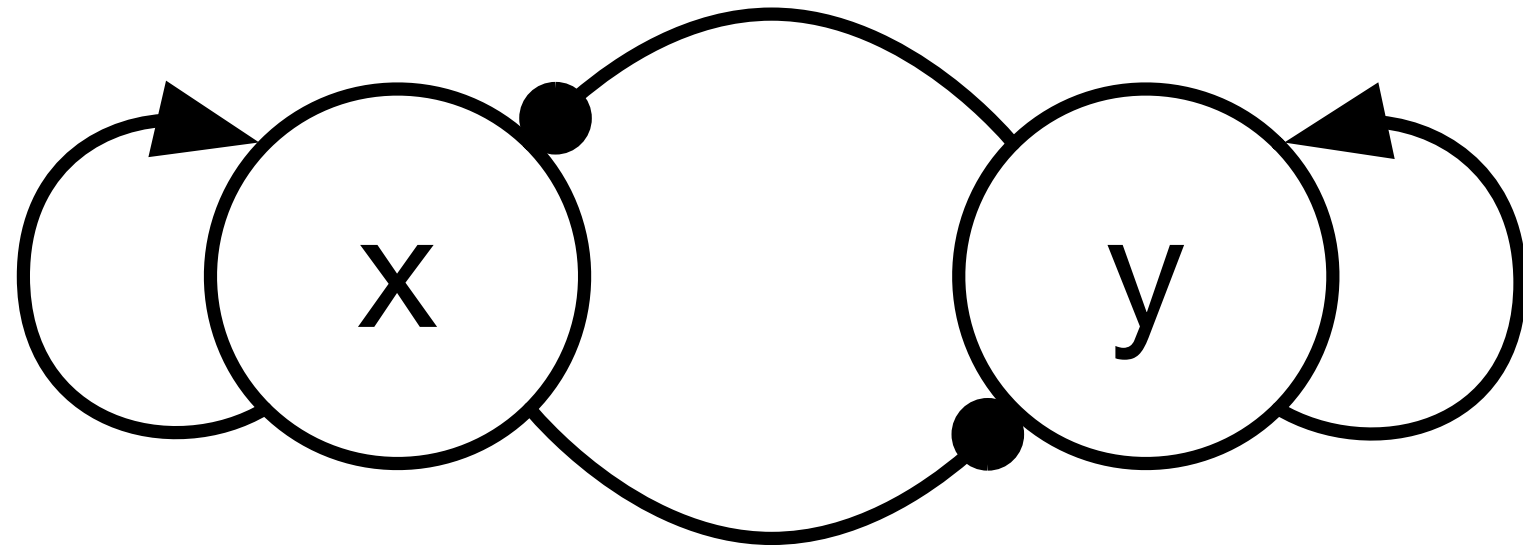
SYMMETRY BREAKING

Asynchronous evaluation

A dual particle system (degenerated neural field)

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$$\dot{y} = \alpha(1 - y) + (y - x)(1 - y), y > 0$$

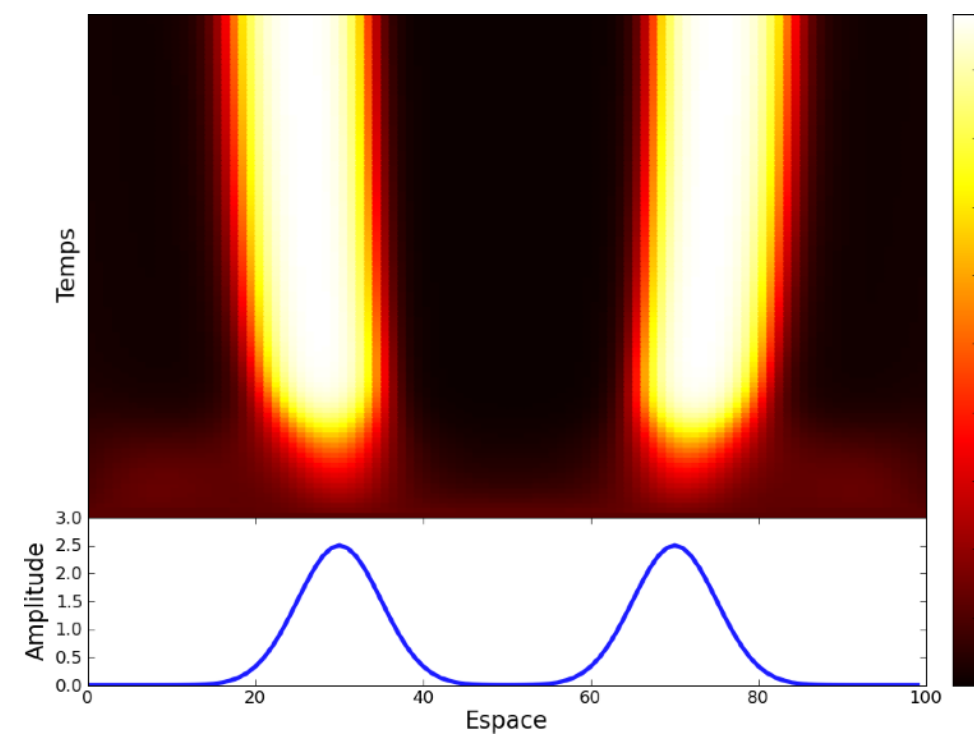
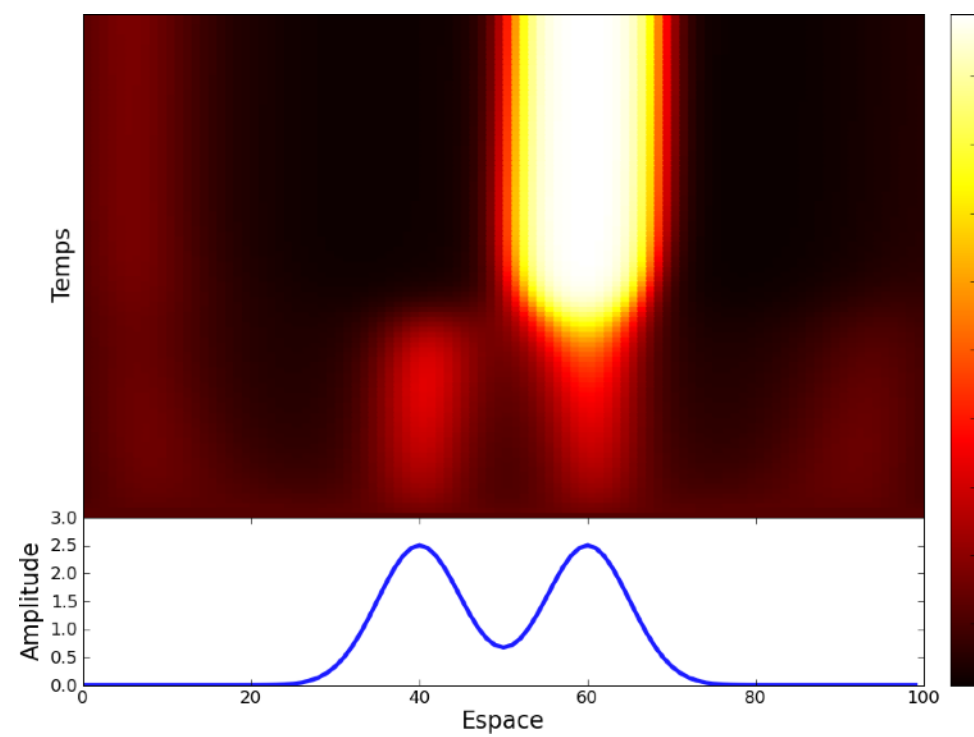


SYMMETRY BREAKING

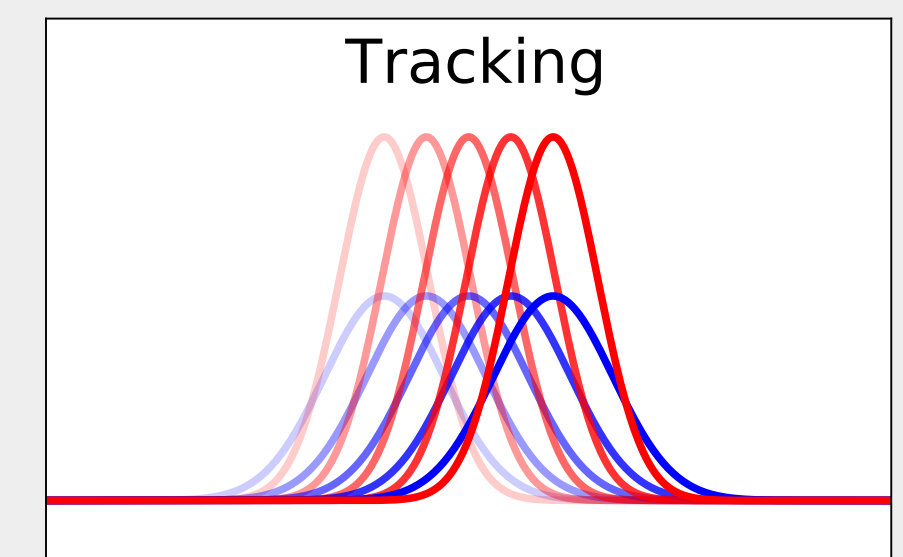
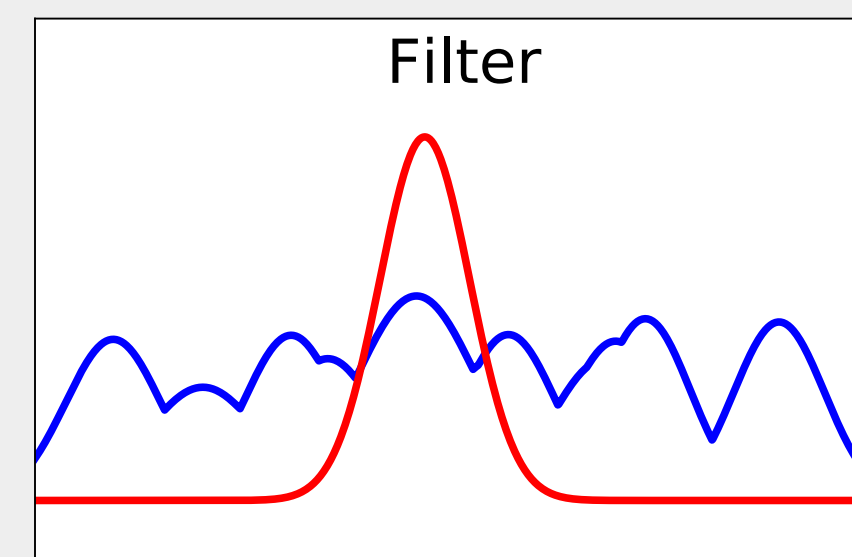
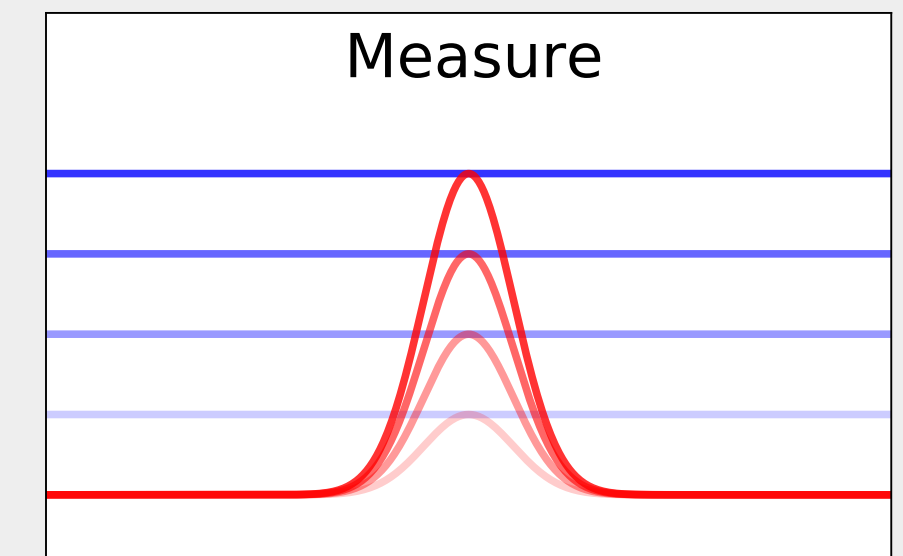
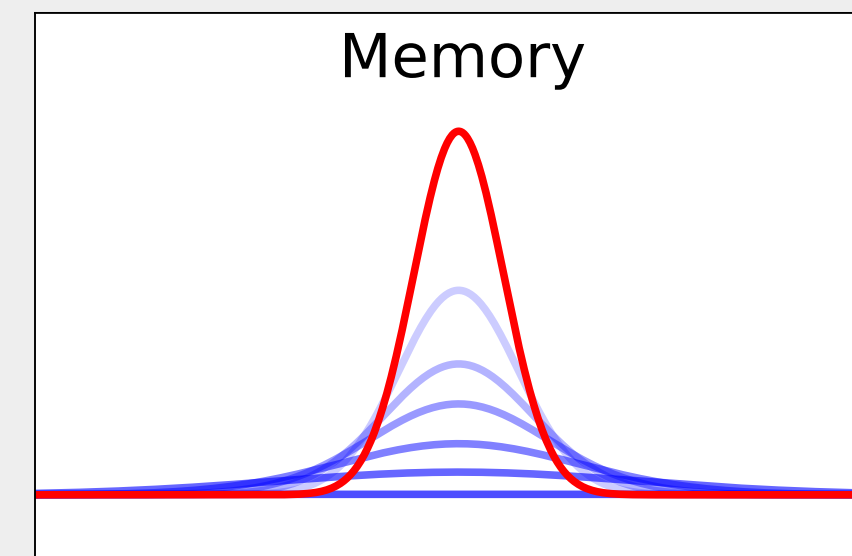
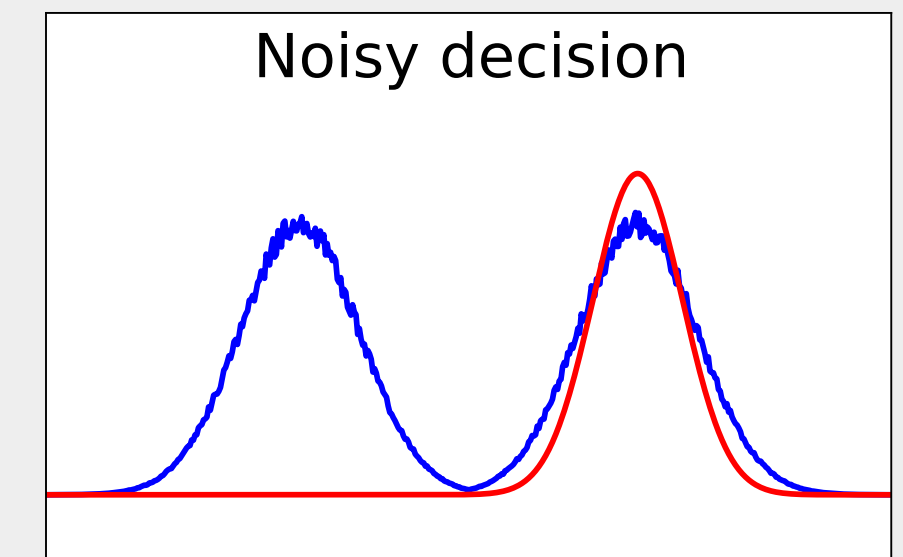
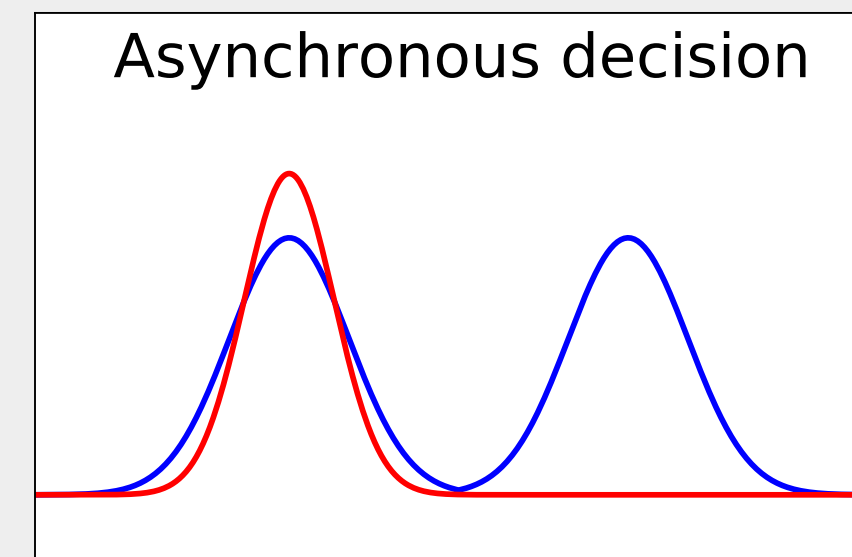
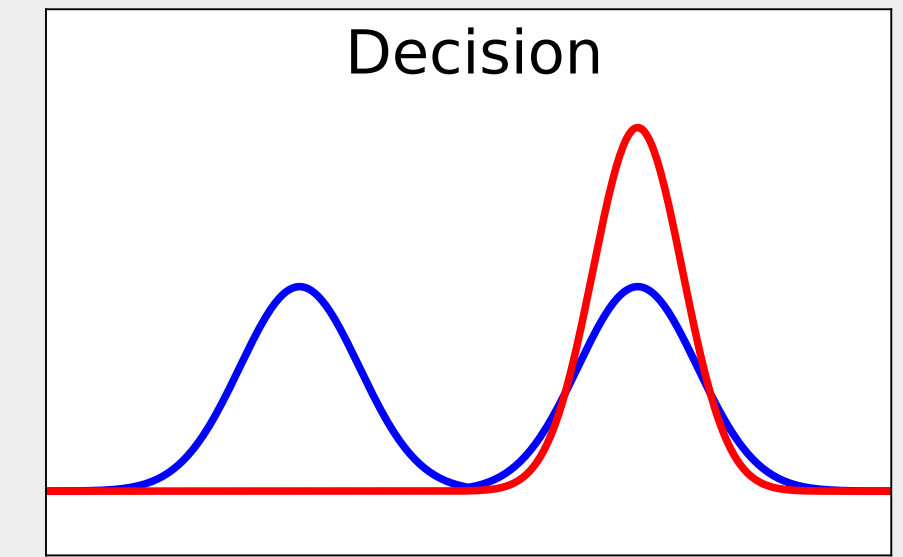
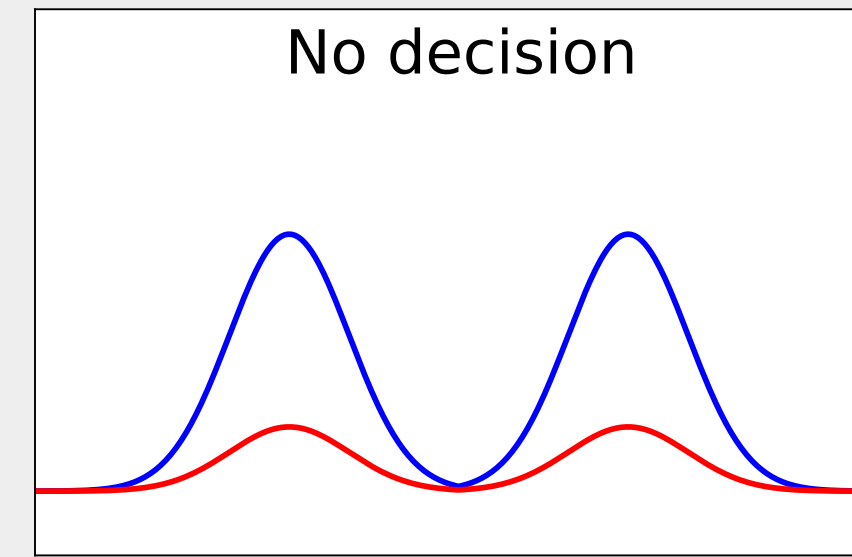
Dynamic neural field

A neural position \mathbf{x} represents a two-component quantity designating a position on a manifold Ω . The membrane potential at position \mathbf{x} and time t is denoted by $u(\mathbf{x}, t)$. There is lateral weight function $w(\mathbf{x}, \mathbf{y})$ (difference of Gaussians) as a function of the distance $|\mathbf{x} - \mathbf{y}|$ and an afferent input $I(\mathbf{x}, t)$. The resting potential is h .

$$\tau \frac{\partial u(x, t)}{\partial t} = -u(x, t) + \int_{\Omega} w(x, y) f(u(y, t)) dy + I(x, t) + h$$



Wilson & Cowan, Kybernetik, 13, 1973
 Amari, Biological Cybernetics, 27, 1977

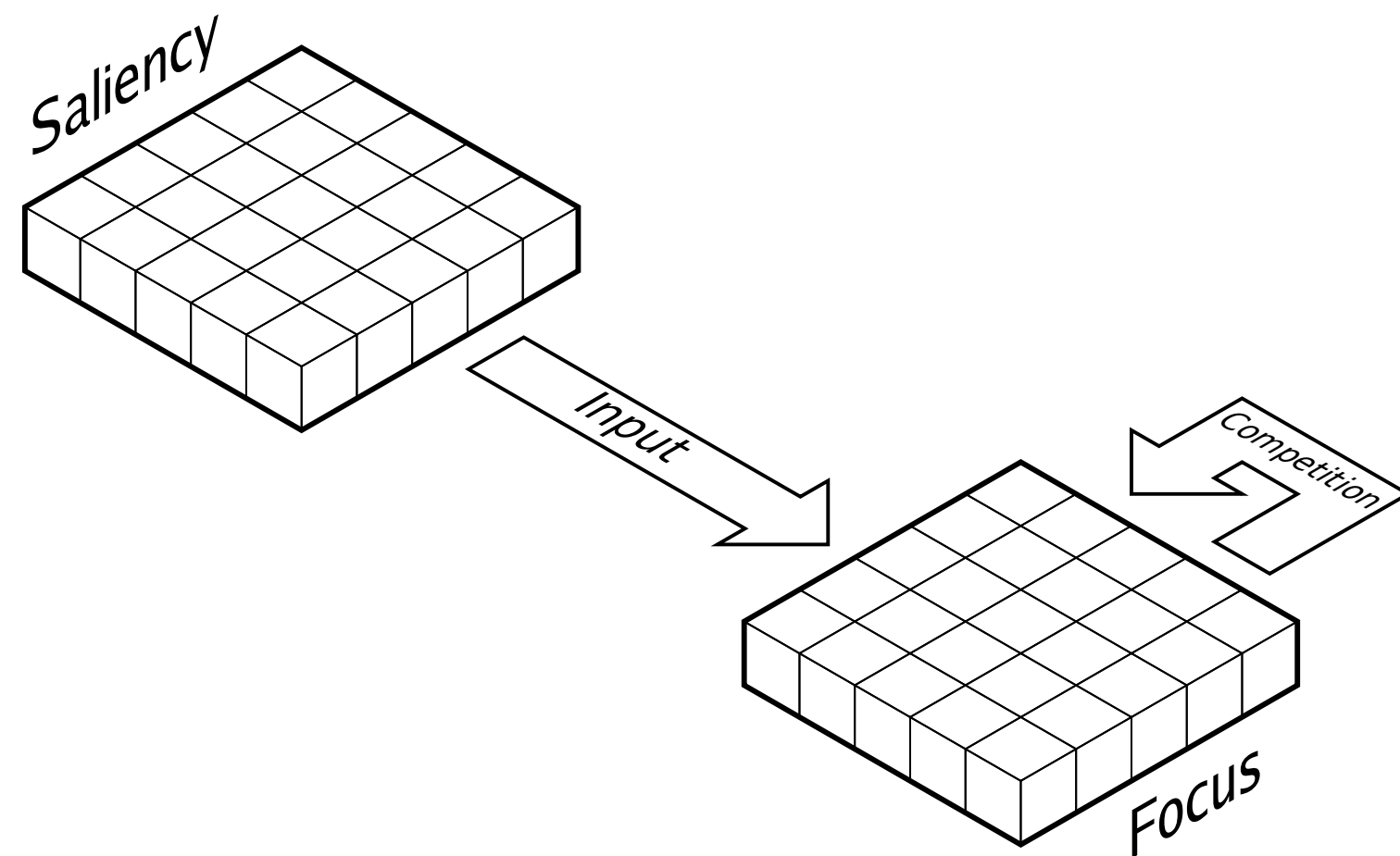


SYMMETRY BREAKING

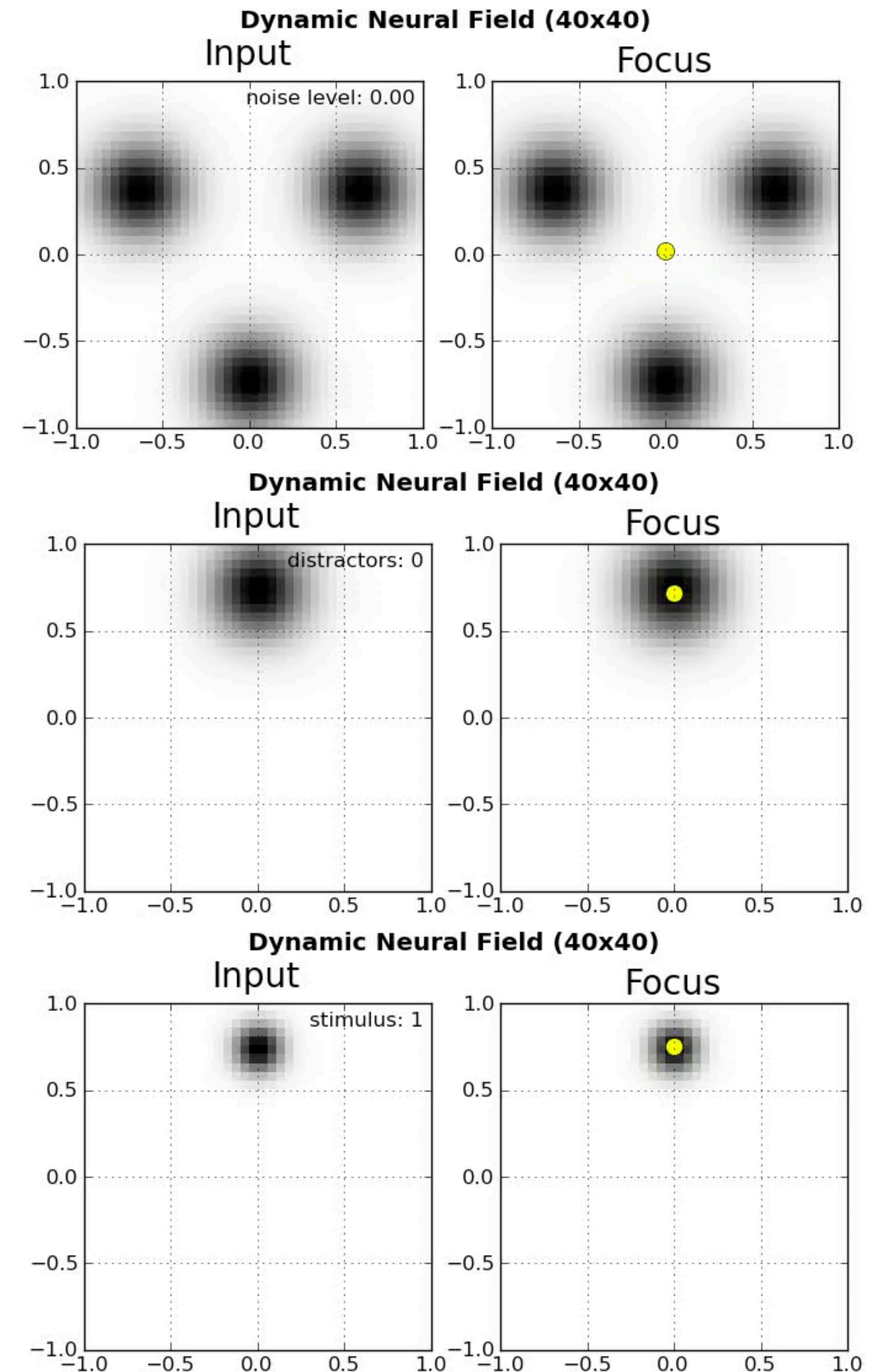
Visual Attention

A neural position \mathbf{x} represents a two-component quantity designating a position on a manifold Ω . The membrane potential at position \mathbf{x} and time t is denoted by $u(\mathbf{x}, t)$. There is lateral weight function $w(\mathbf{x}, \mathbf{y})$ (difference of Gaussians) as a function of the distance $|\mathbf{x} - \mathbf{y}|$ and an afferent input $I(\mathbf{x}, t)$. The resting potential is h .

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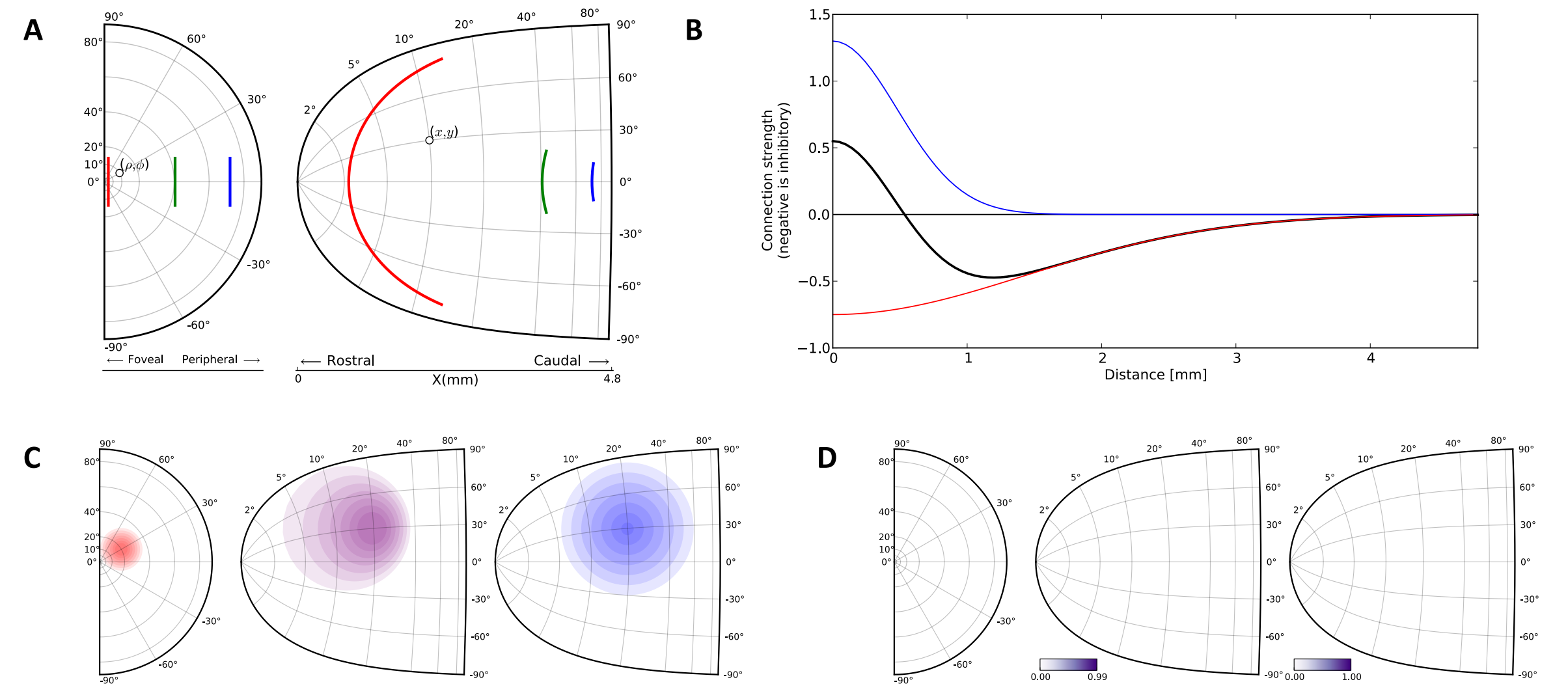
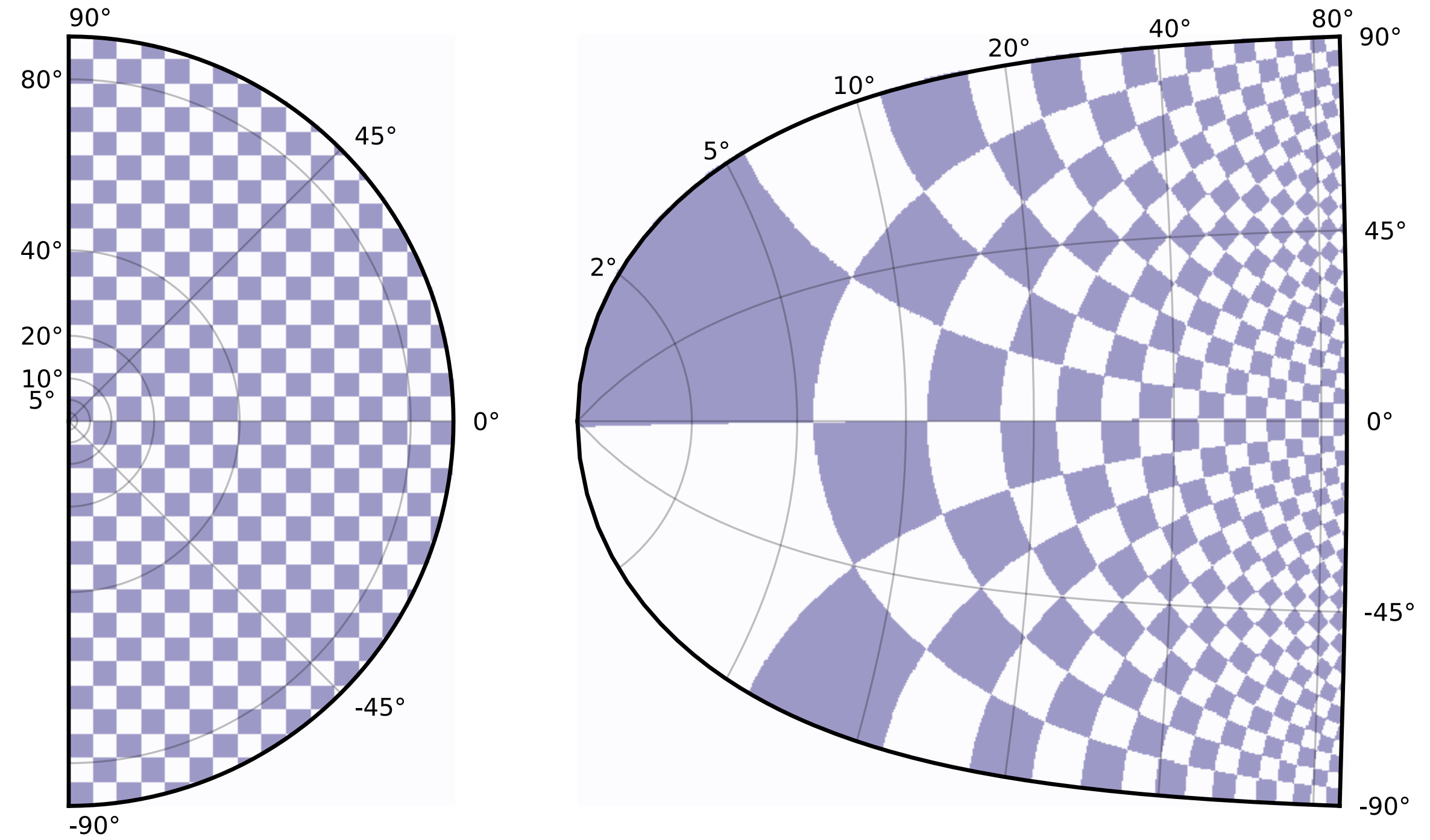
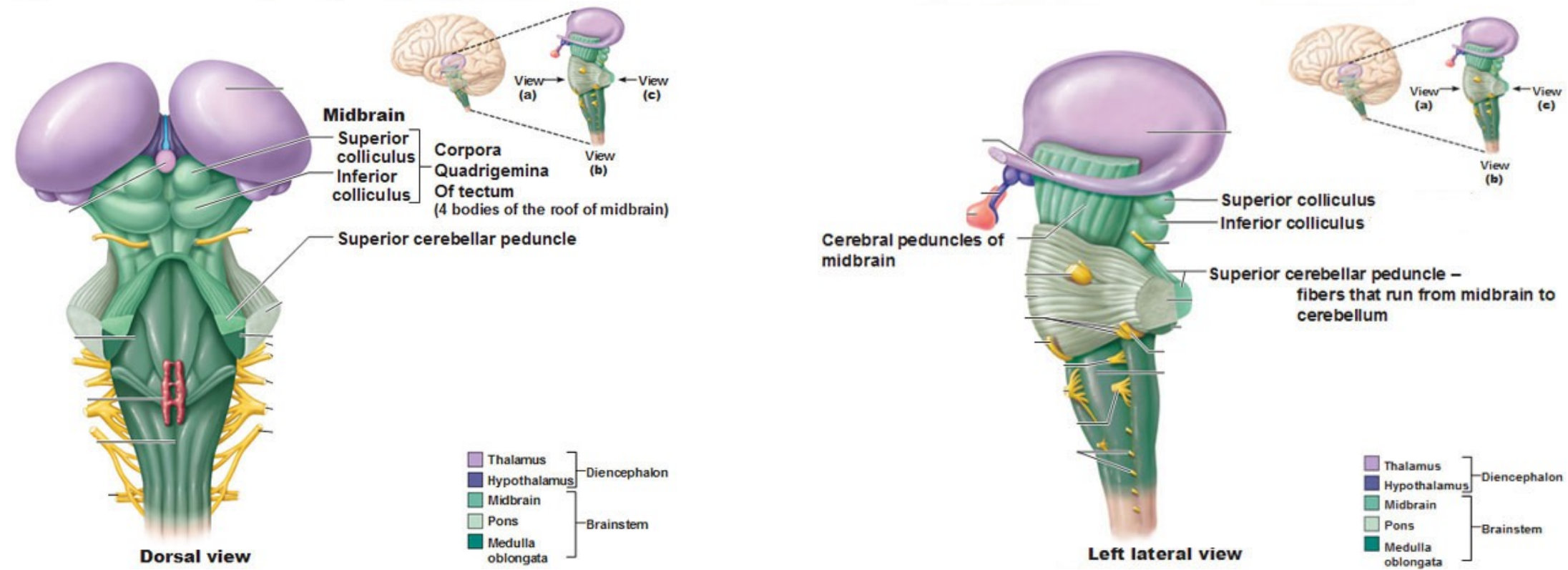
Rougier & Vitay, Neural Networks, 19:5, 2006



SYMMETRY BREAKING

Spatial noise

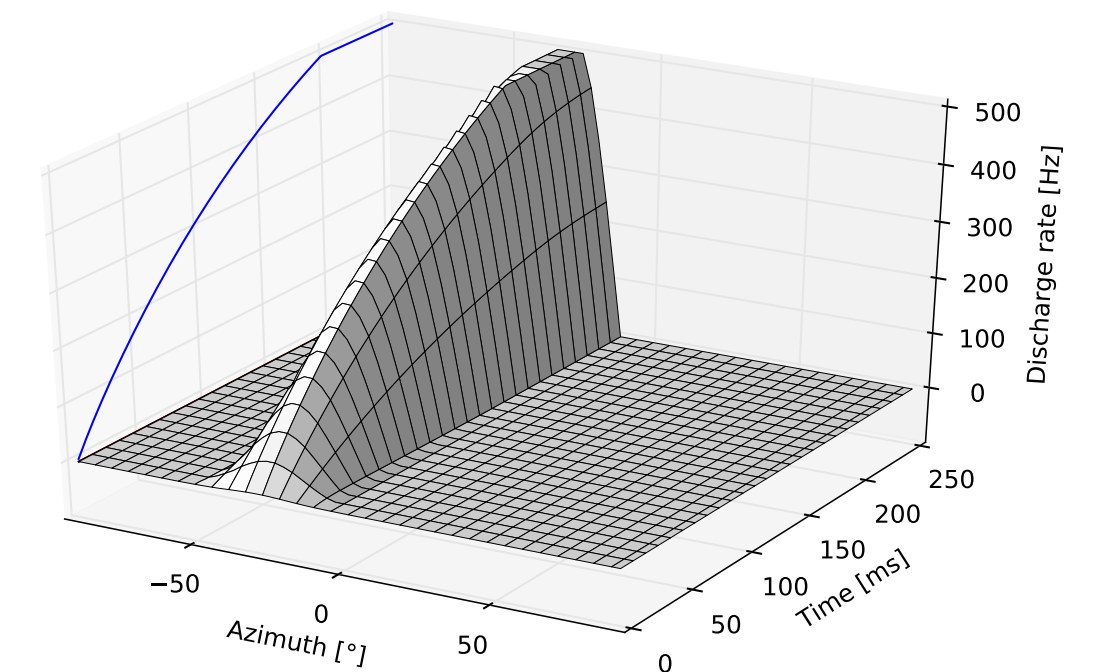
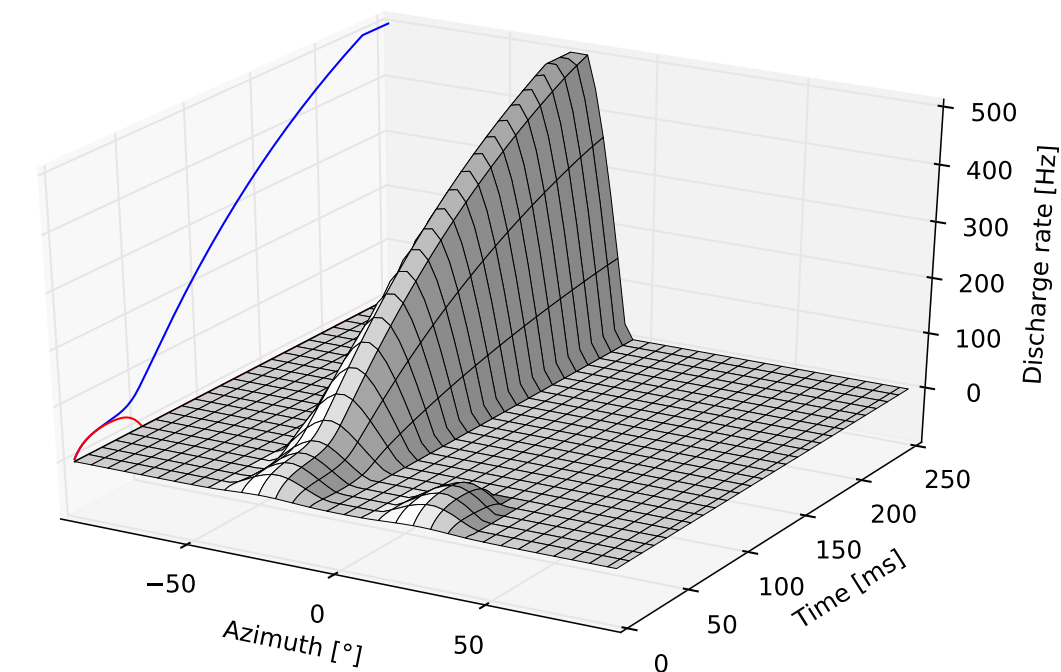
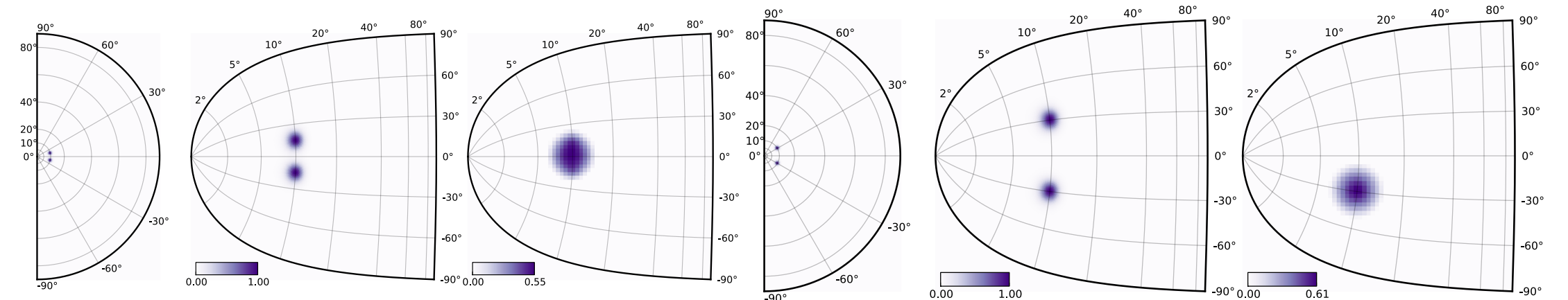
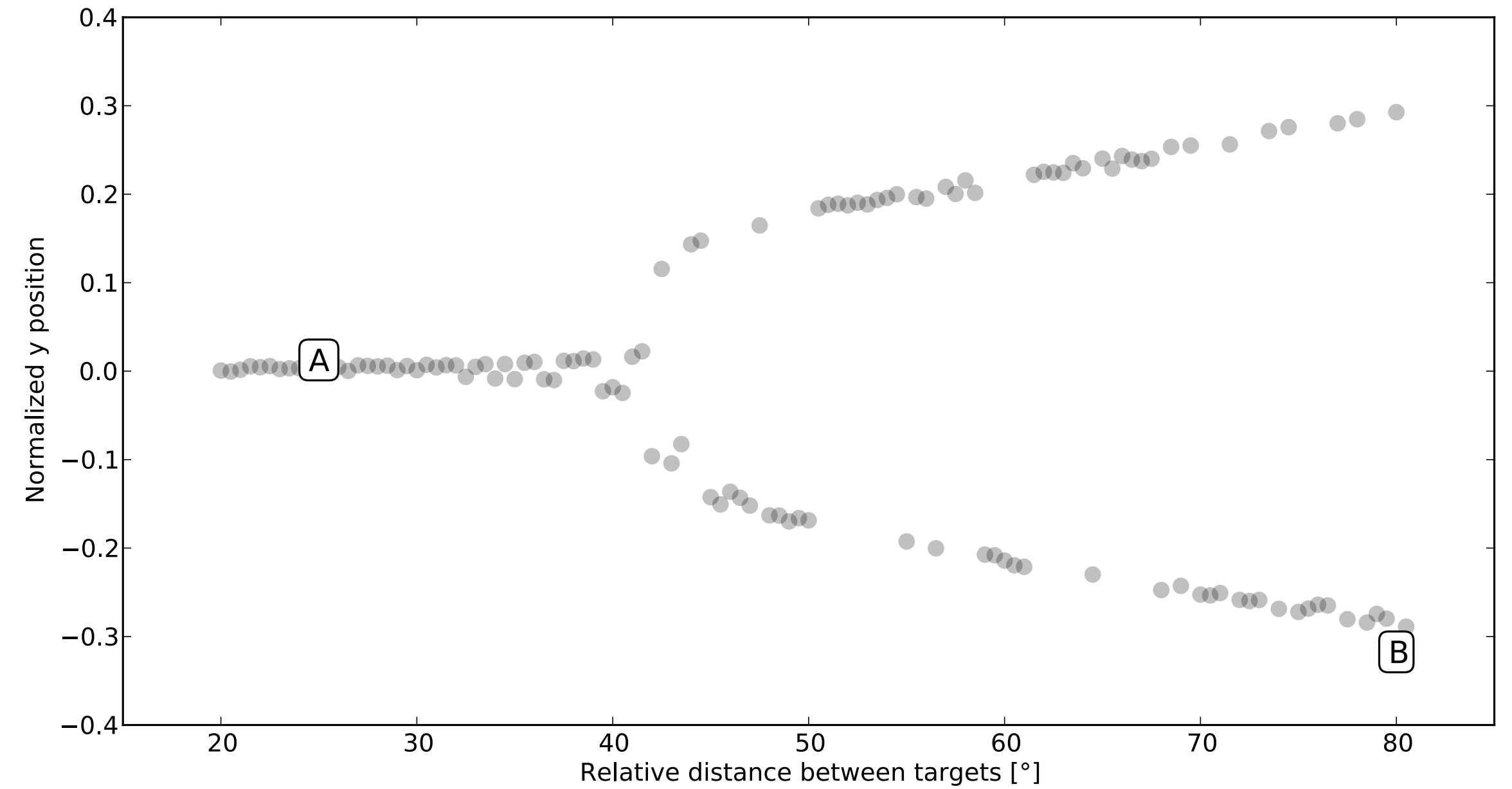
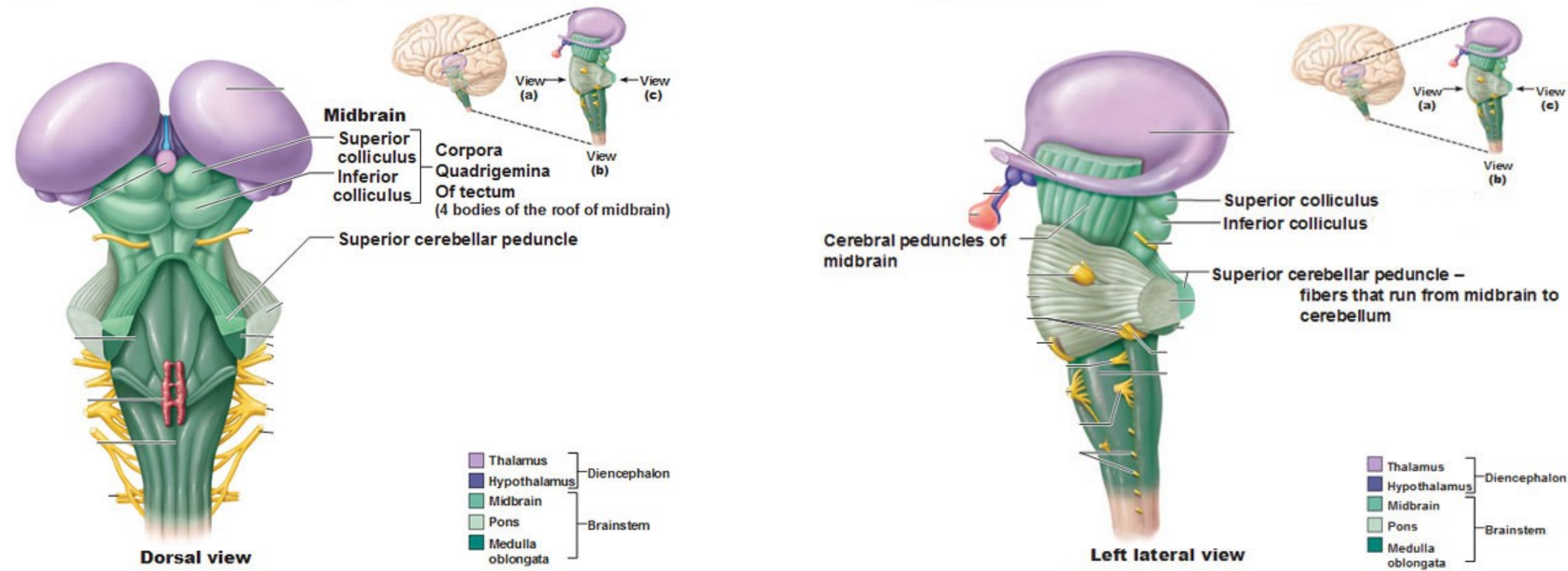
Several neurophysiological studies suggest that the population of active neurons in the SC encodes the location of a visual target to foveate, pursue or attend to.



SYMMETRY BREAKING

Spatial noise

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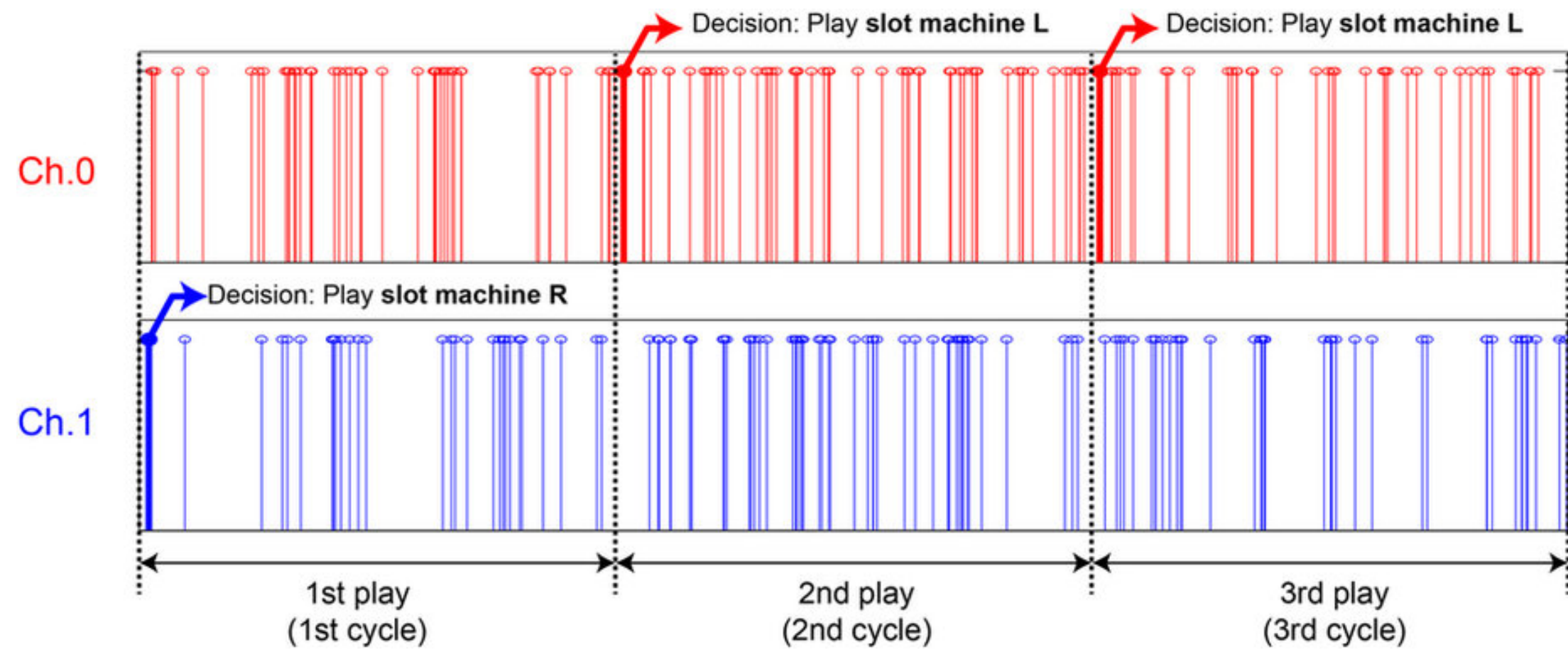
TAMING THE NOISE



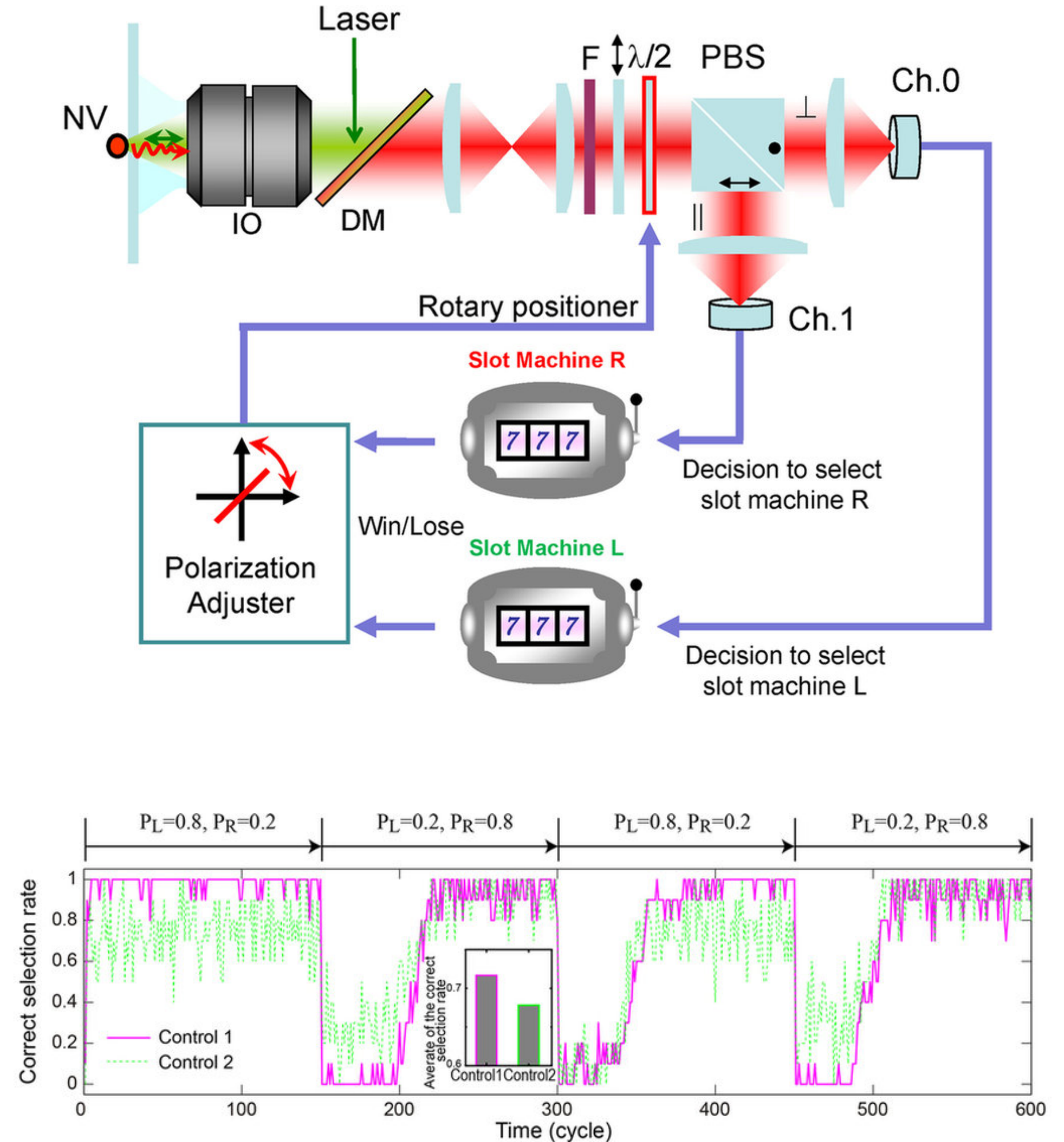
TAMING THE NOISE

Quantum noise

We demonstrate experimentally that single photons can be used to make decisions in uncertain, dynamically changing environments. Using a nitrogen-vacancy in a nanodiamond as a single-photon source, we demonstrate the decision-making capability by solving the multi-armed bandit problem. This capability is directly and immediately associated with single-photon detection in the proposed architecture, leading to adequate and adaptive autonomous decision making.



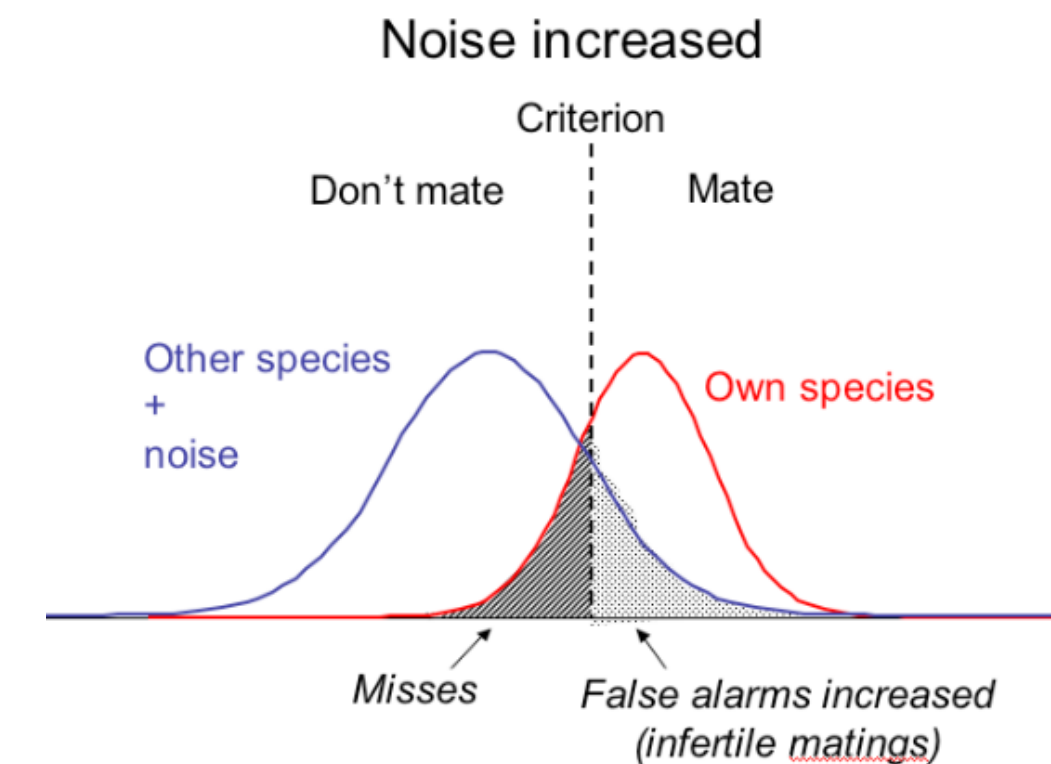
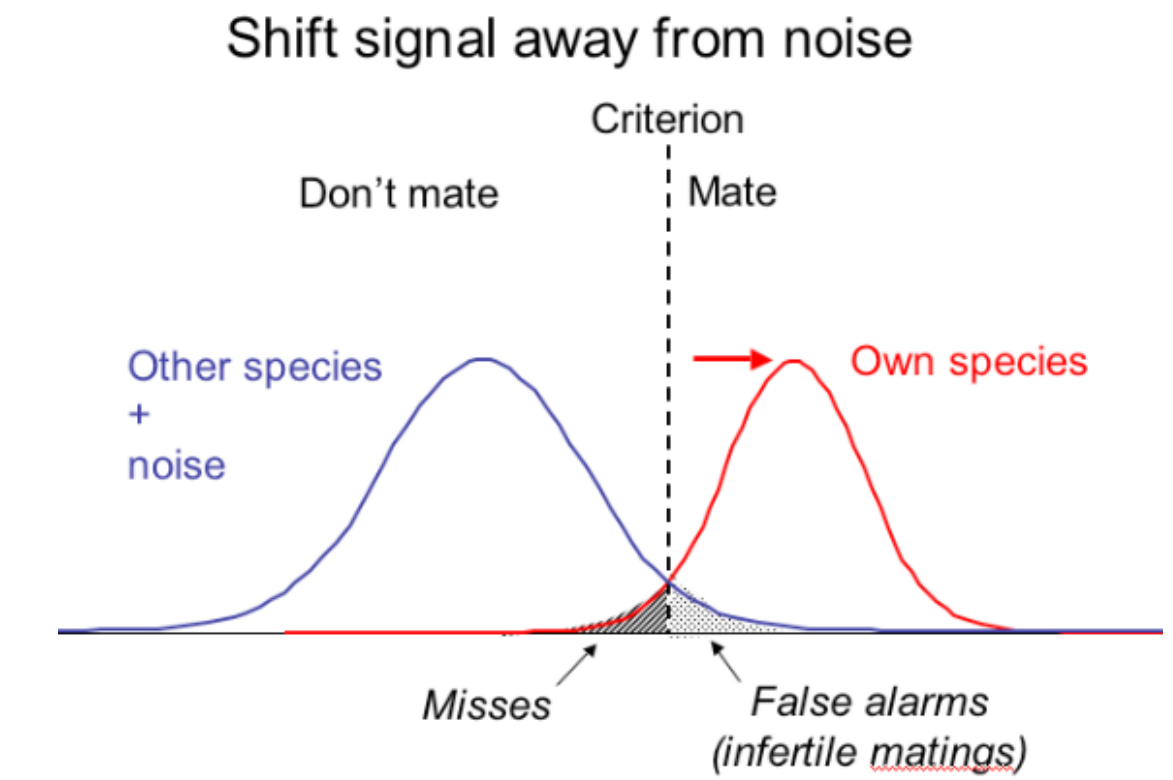
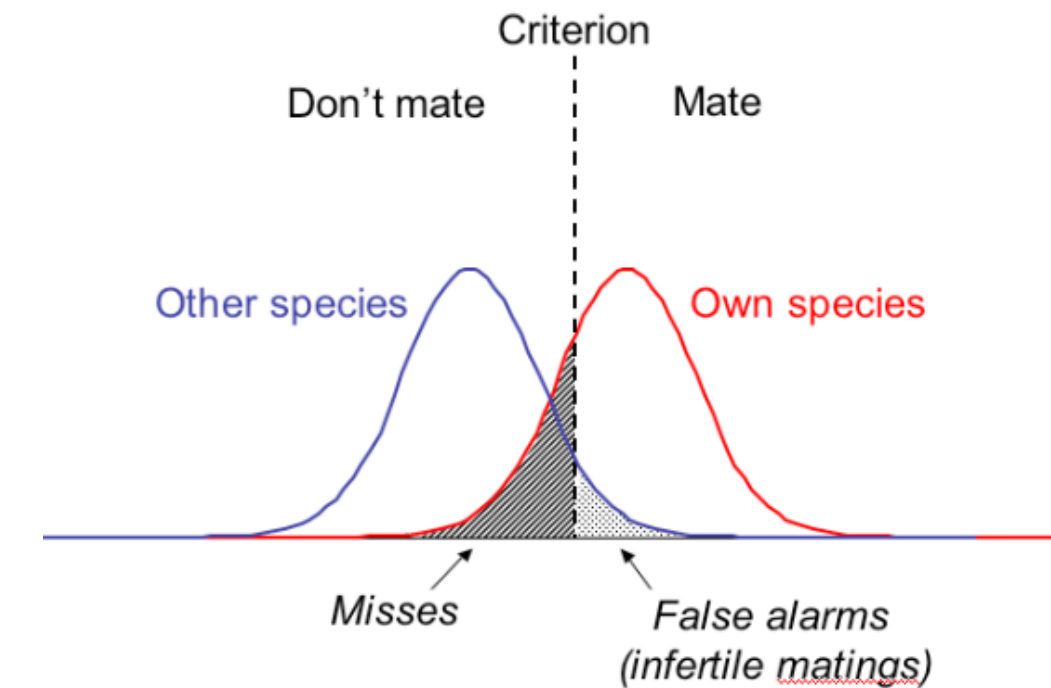
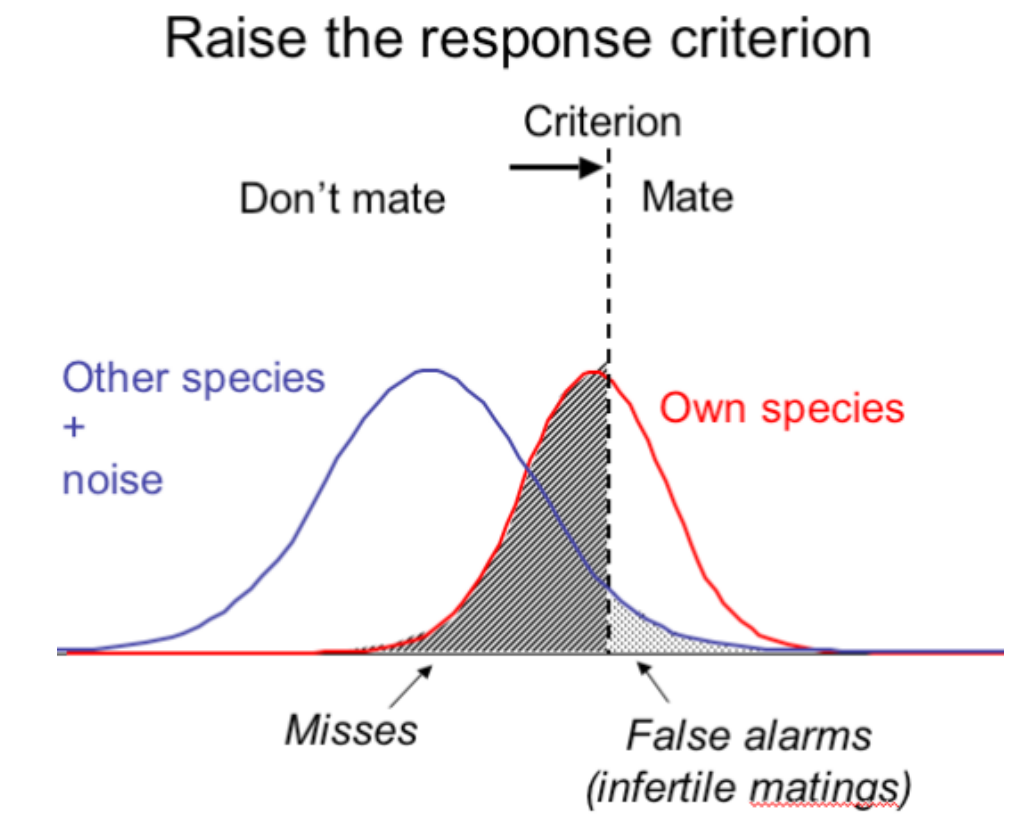
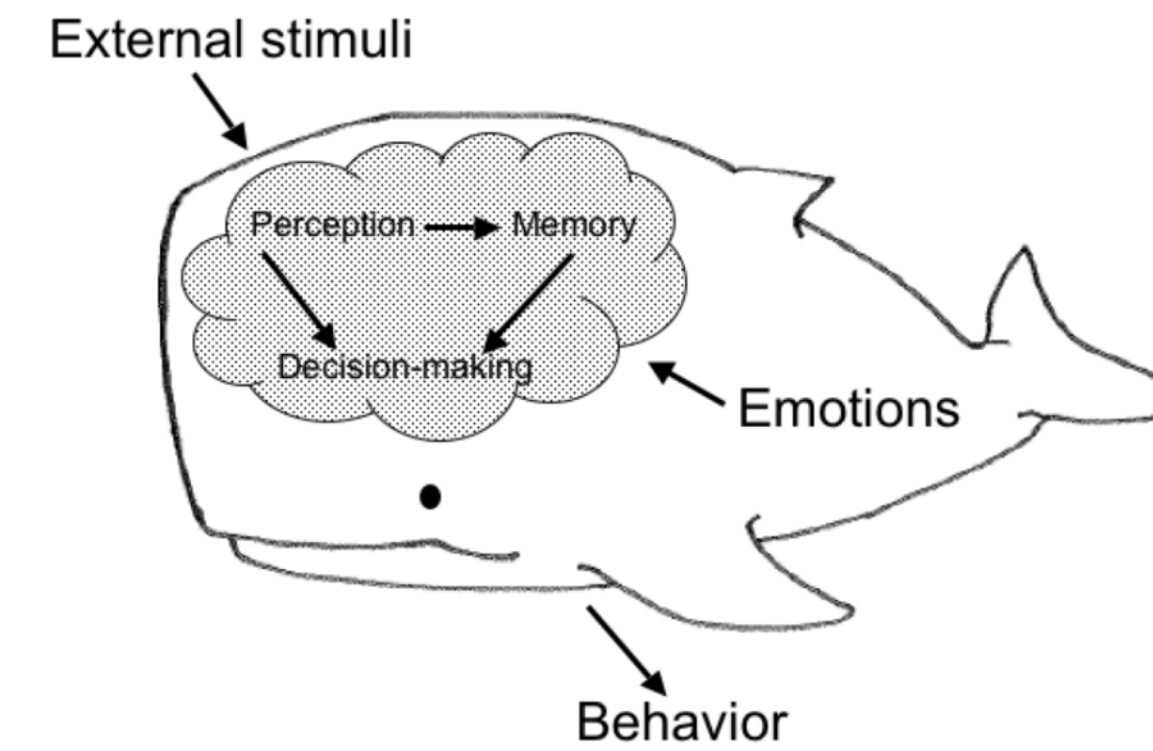
Naruse et al, Scientific Report, 2015



TAMING THE NOISE

Environmental noise

Anxiety is an emotion that functions as an early warning of potential threats, and is associated with a suite of changes in information processing including sensitization to stimuli potentially associated with threats, and pessimistic biases in decision-making resulting in increased risk aversion. Although these changes are clearly beneficial in the short term, chronic anxiety is likely to result in behavioral changes that will be detrimental to an animal's fitness in the longer term. Thus, there are likely to be **subtle effects of noise on decision-making** that have not so far been considered in relation to the effects of anthropogenic noise on marine mammal behavior.



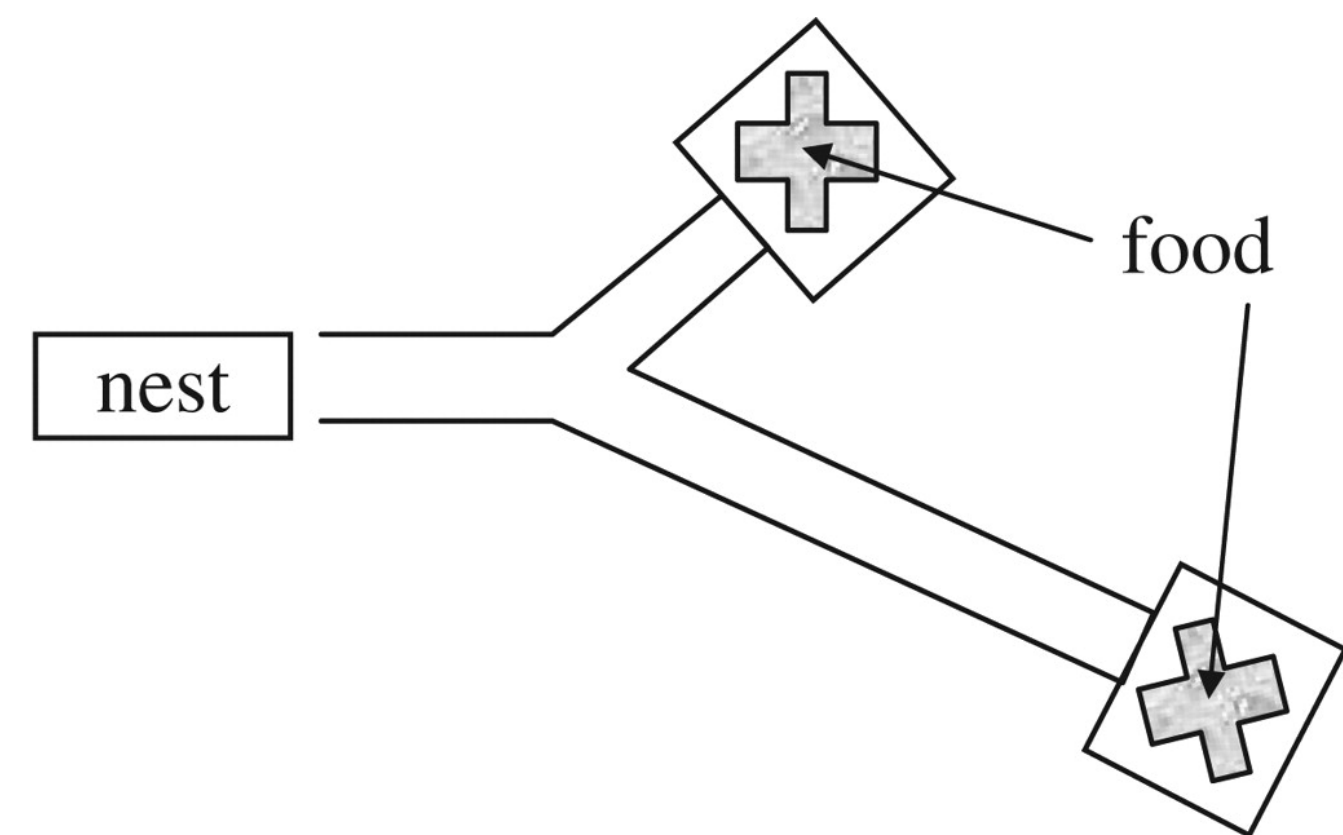
Taking advantage of light

*Self-organized mechanisms are frequently encountered in nature and known to achieve flexible, adaptive control and decision-making. **Noise plays a crucial role in such systems:** It can enable a self-organized system to reliably adapt to short-term changes in the environment while maintaining a generally stable behavior. This is fundamental in biological systems because they must strike a delicate balance between stable and flexible behavior. We analysed the role of noise in the decision-making of the true slime mold *Physarum polycephalum*, an important model species for the investigation of computational abilities in simple organisms.*



Distributed noise

*We study foraging decisions by colonies of the ant *Pheidole megacephala* under dynamic conditions. Our experiments show that *P. megacephala*, unlike many other mass recruiting species, can make a collective decision for the better of two food sources even when the environment changes dynamically. We developed a stochastic differential equation model that explains our data qualitatively and quantitatively. Analysing this model reveals that both **deterministic and stochastic effects (noise)** work together to allow colonies to efficiently track changes in the environment.*



DECISION MAKING



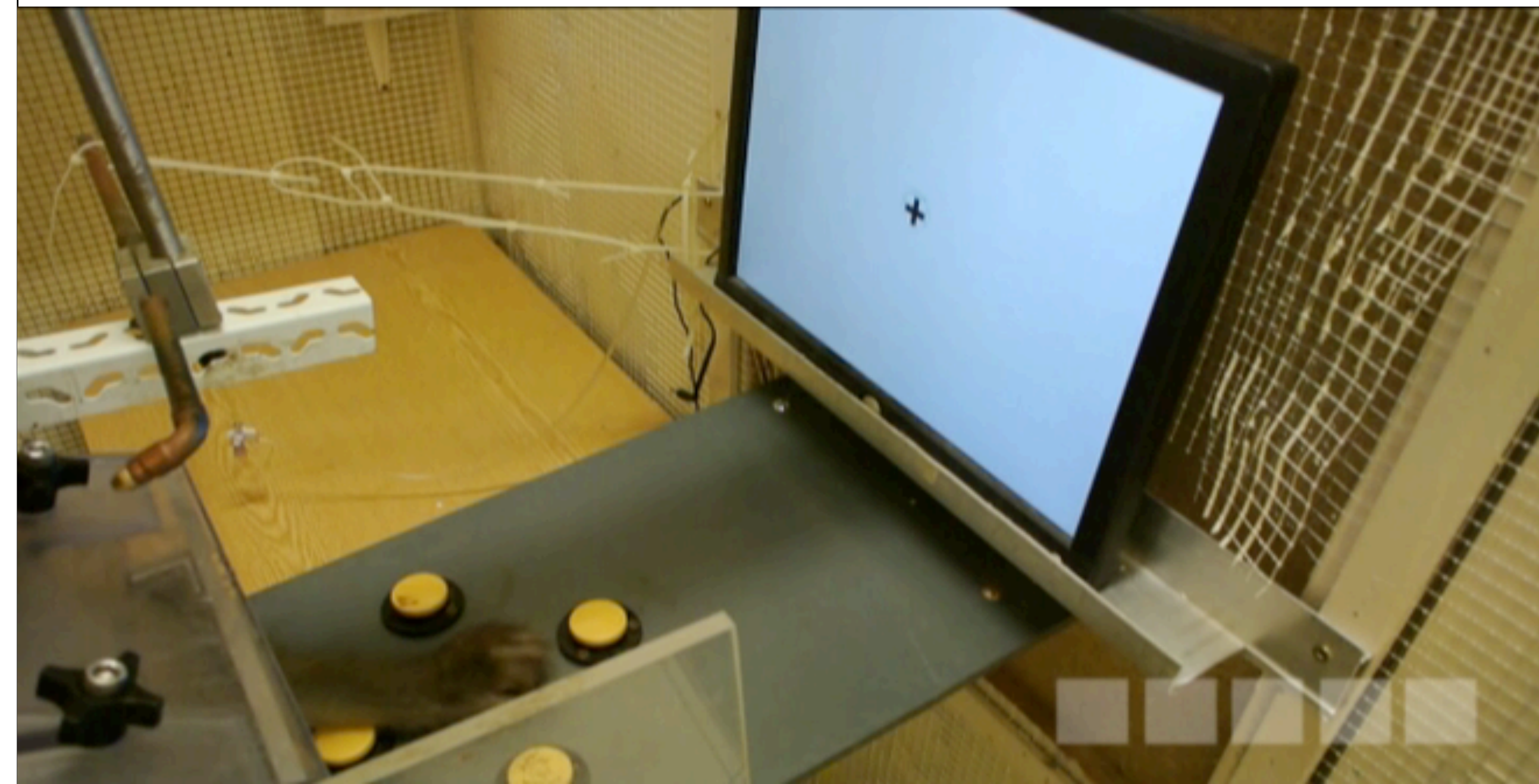
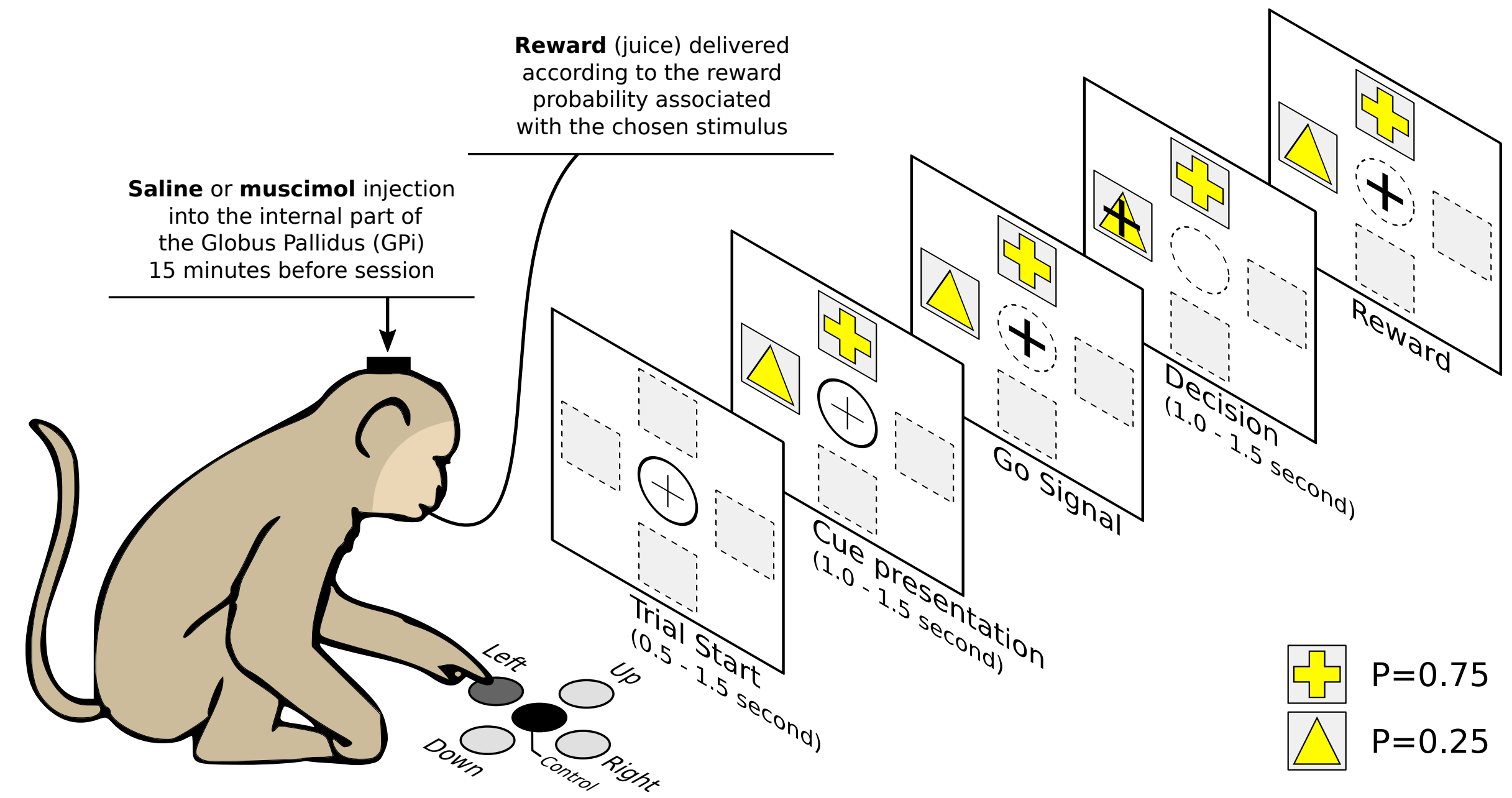
DECISION MAKING

Two armed bandit-task

We designed a simple two-armed bandit task where two stimuli A and B are associated with different reward probability (respectively 0.25 and 0.75). The goal for the subject is to choose the stimulus associated with the highest reward probability, independently of its position.

| | | | | | | | | | | |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| A | A | A | A | A | A | A | A | A | A | A |
| B | B | B | B | B | B | B | B | B | B | B |
| 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 0 |

Exploration / exploitation dilemma



DECISION MAKING

Segregated loops

Cortex

- Posterior
- Motor / Premotor
- Prefrontal

Thalamus

Striatum (STR)

- Caudate
- Putamen
- Nucleus Accumbens

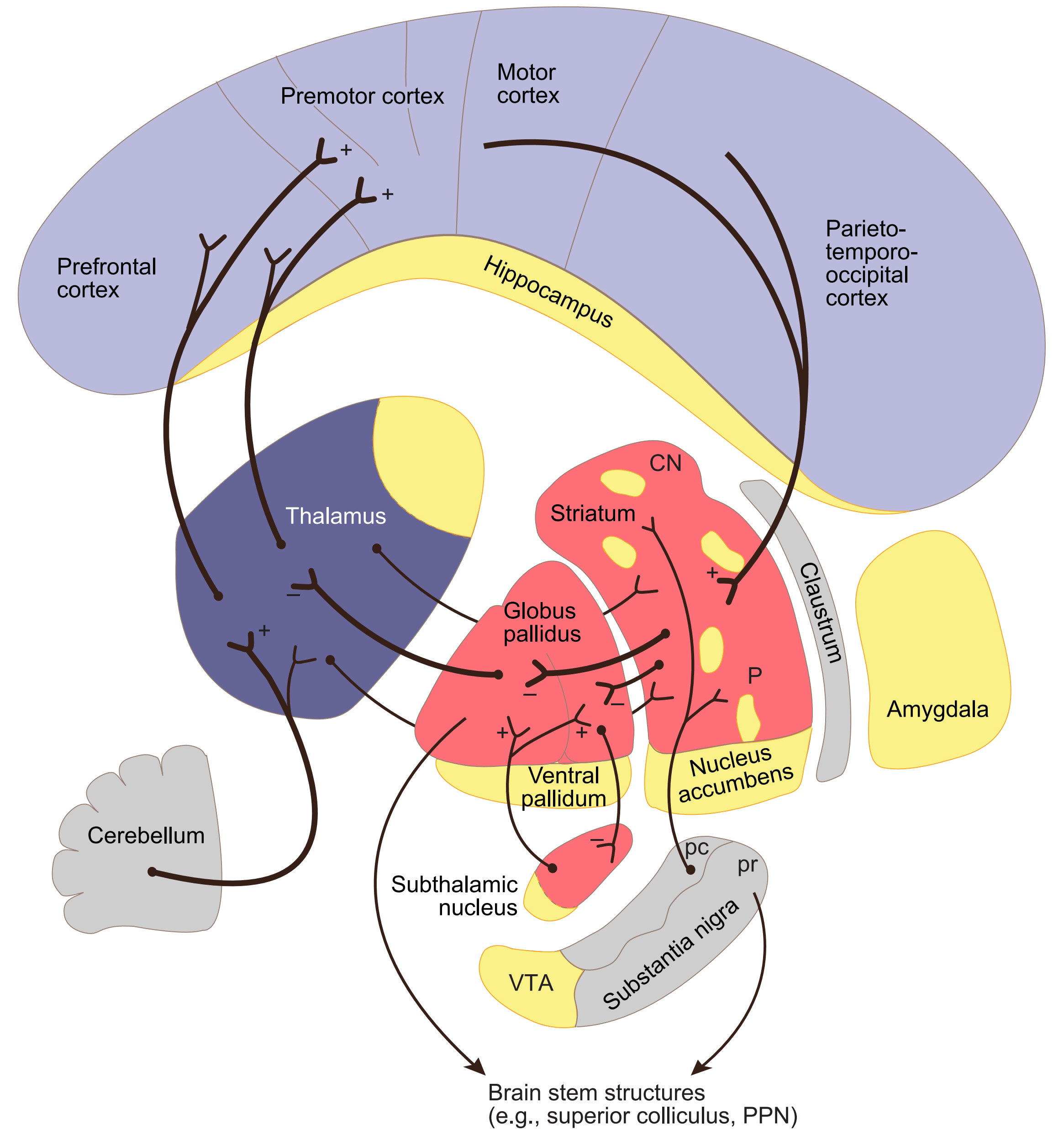
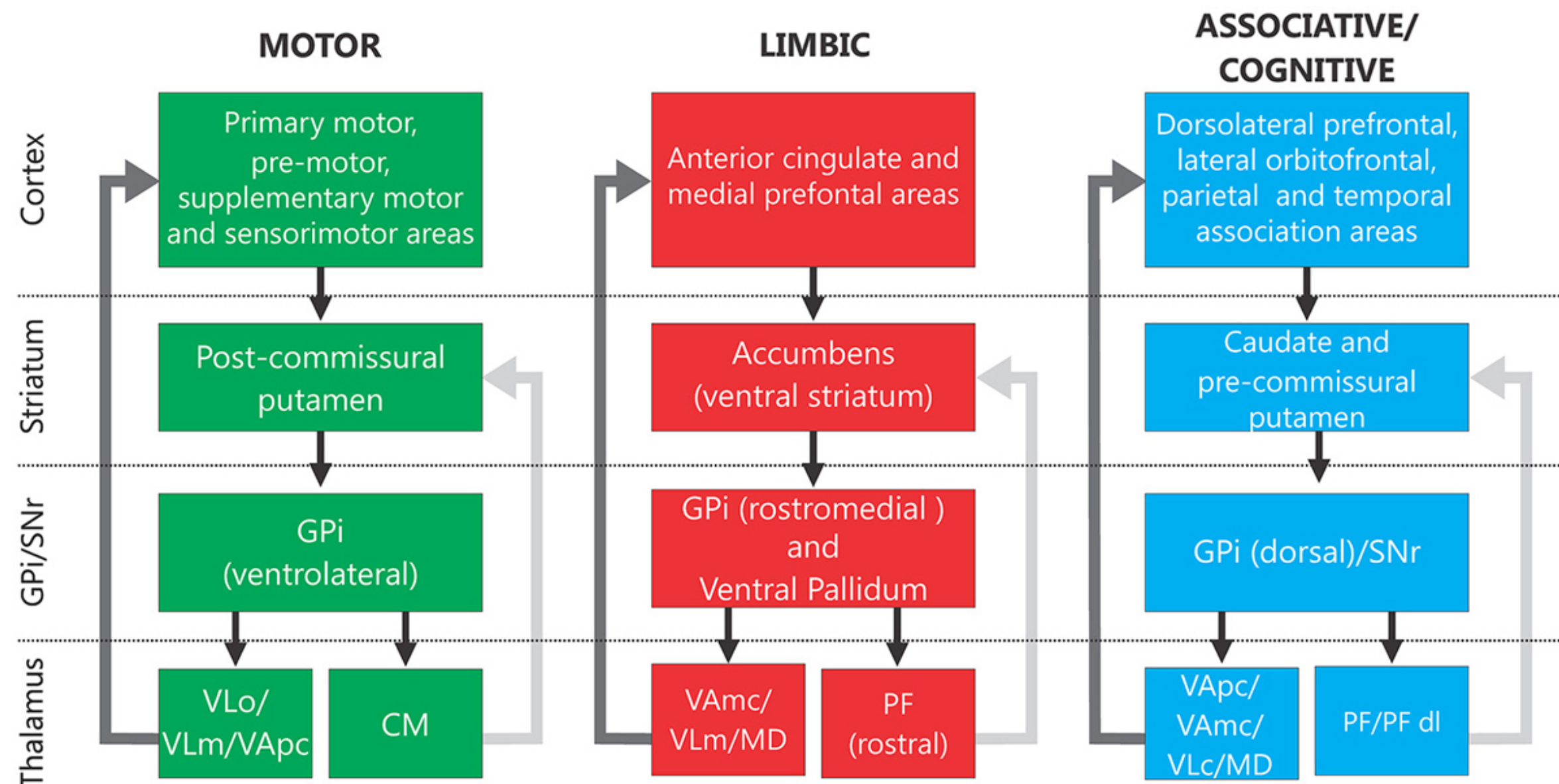
Subthalamic Nucleus (STN)

Globus Pallidus

- Internal (GPi)
- External (GPe)

Substantia Nigra

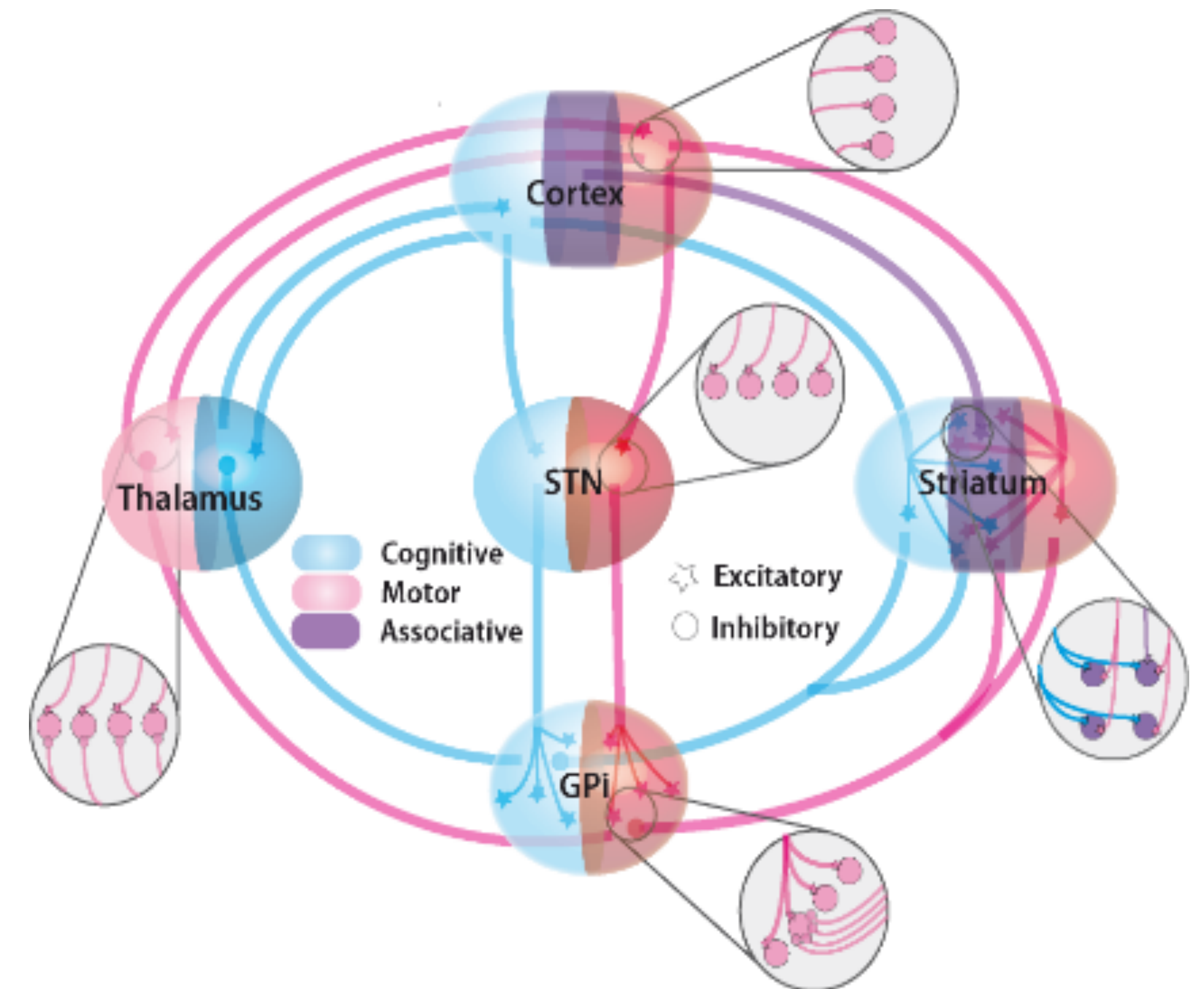
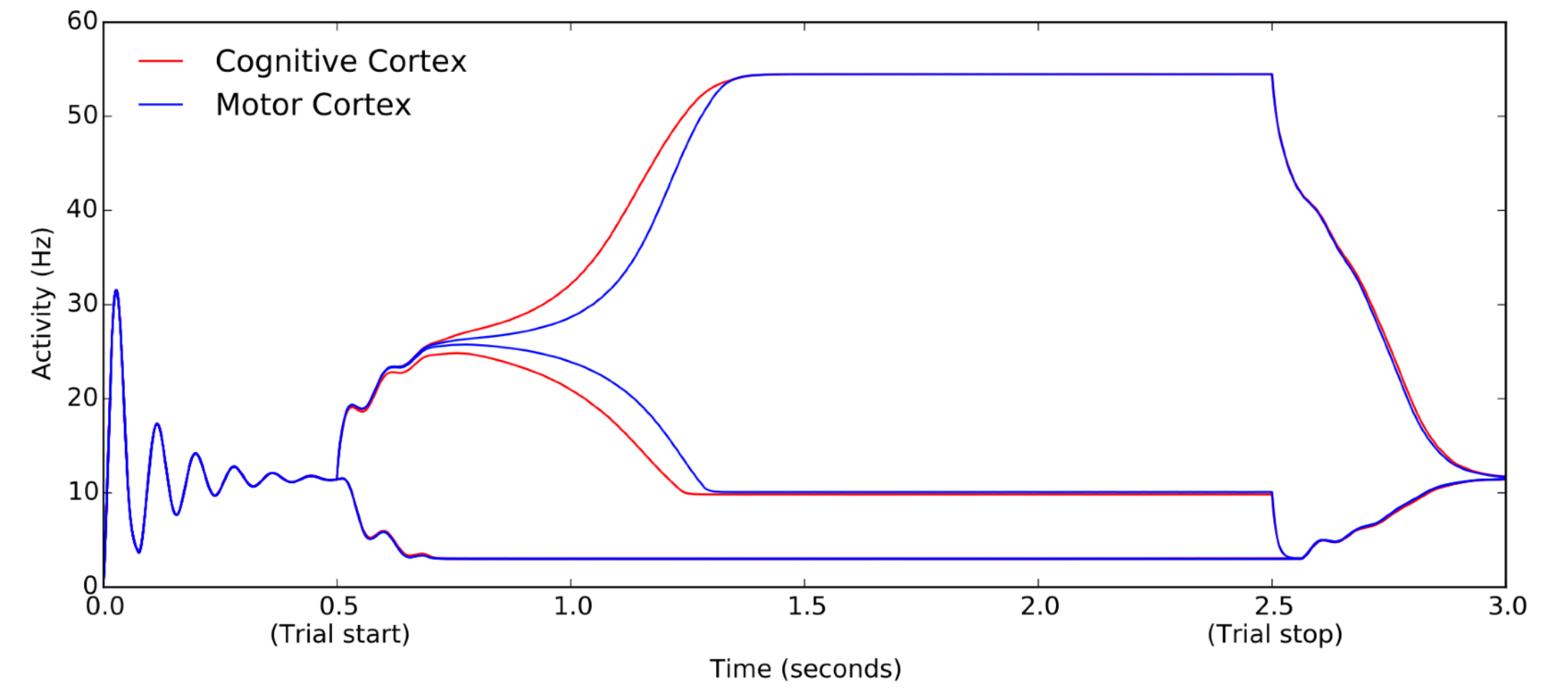
- pars Compacta (SNc)
- pars Reticulata (SNr)



DECISION MAKING

A computational replicated model

We propose in [2] a reference implementation of [1] that introduces an action selection mechanism in cortico-basal ganglia loops based on a competition between the positive feedback, direct pathway through the striatum and the negative feedback, hyperdirect pathway through the subthalamic nucleus.



[1] Guthrie et al, Journal of Neurophysiology 109, 2013

[2] Topalidou & Rougier, ReScience 1:1, 2015

SPONSORED CONTENT

The ReScience journal

ReScience is an open peer-reviewed journal that target any computational research and encourage the explicit replication of already published research promoting new and open-source implementations.

ReScience lives on github where each new implementation is made available together with explanations (article).

Each published article is archived on Zenodo.

Zenodo is a research data repository created by OpenAIRE and CERN to provide a place for researchers to deposit datasets.

GitHub is a web-based Git repository hosting service that offers all of the distributed version control and source code management functionality of git as well as adding its own features.



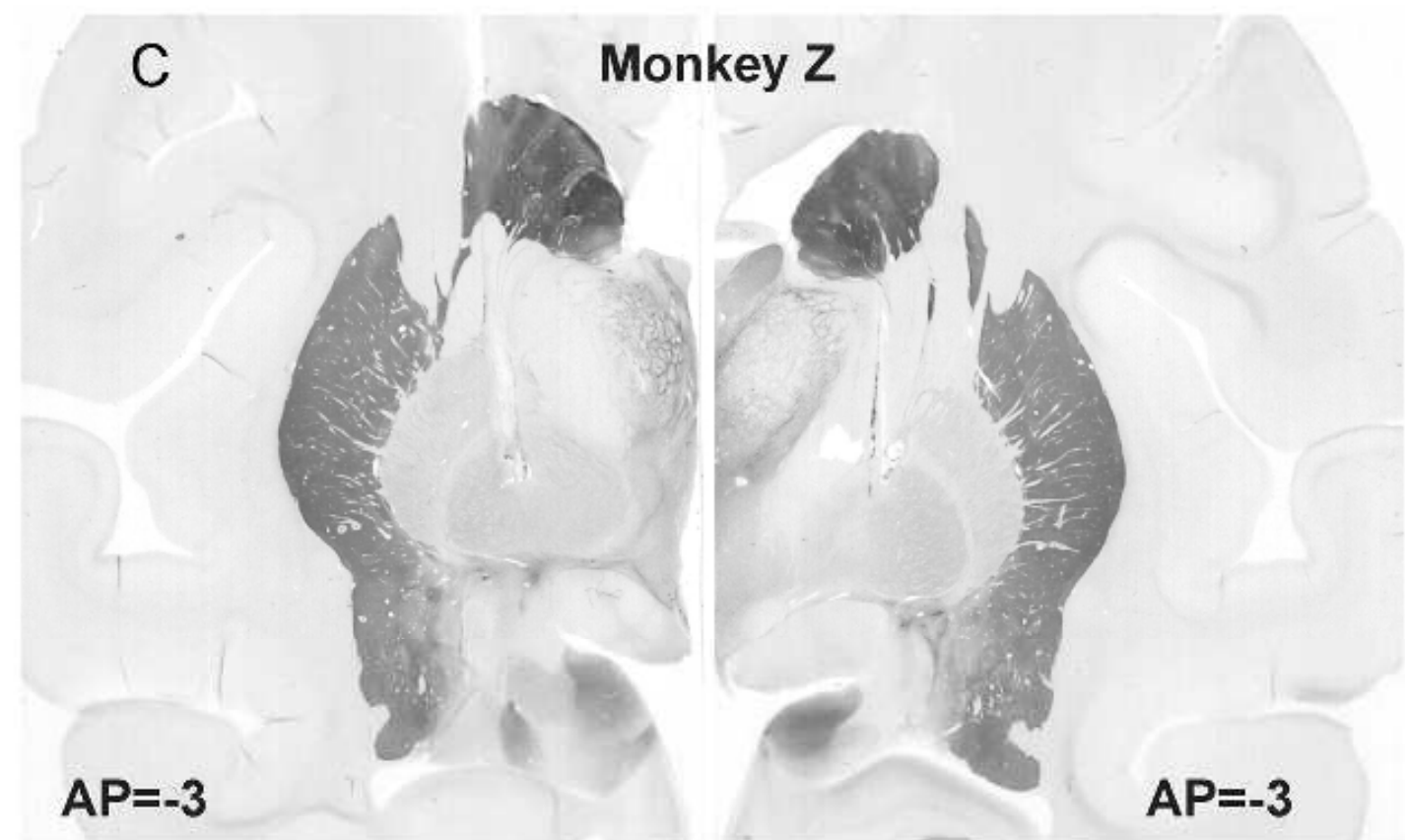
ReScience

Reproducible science is good. Replicated science is better.

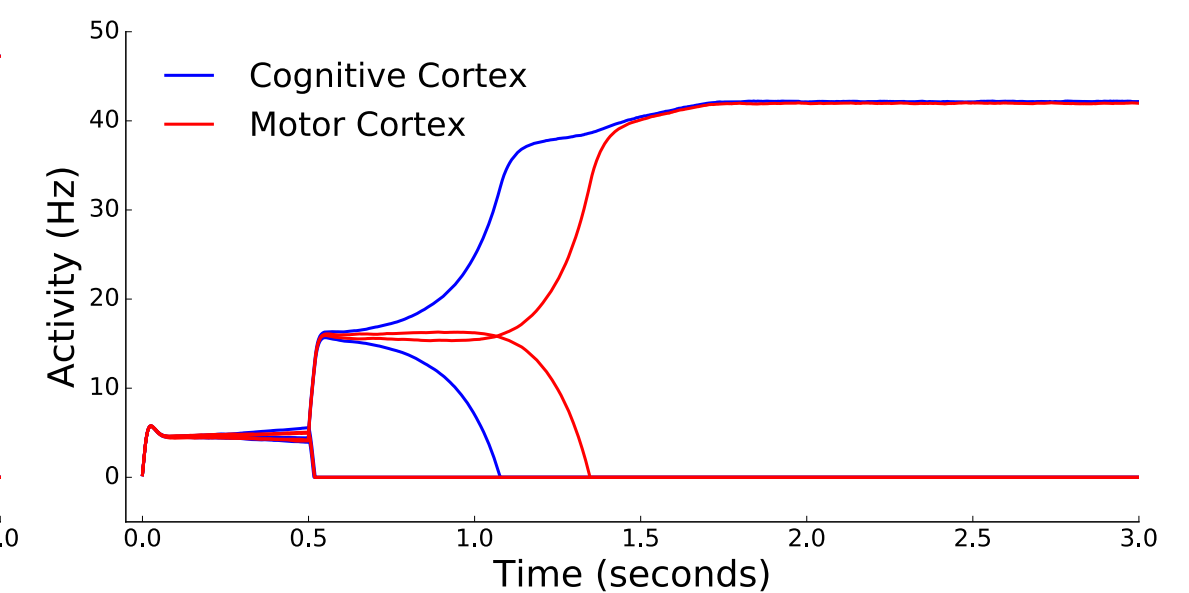
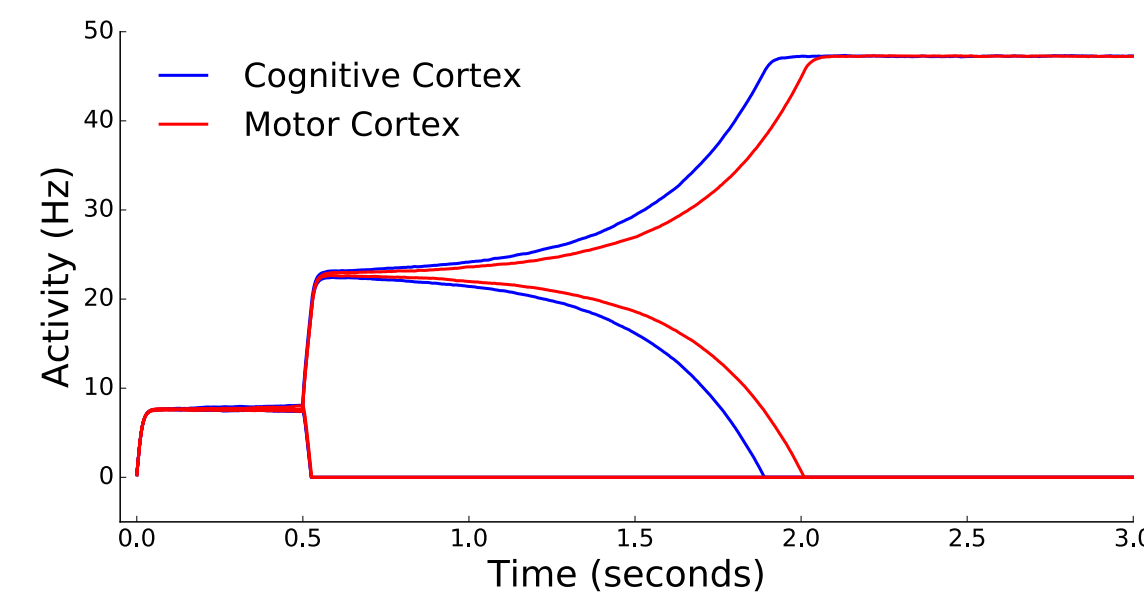
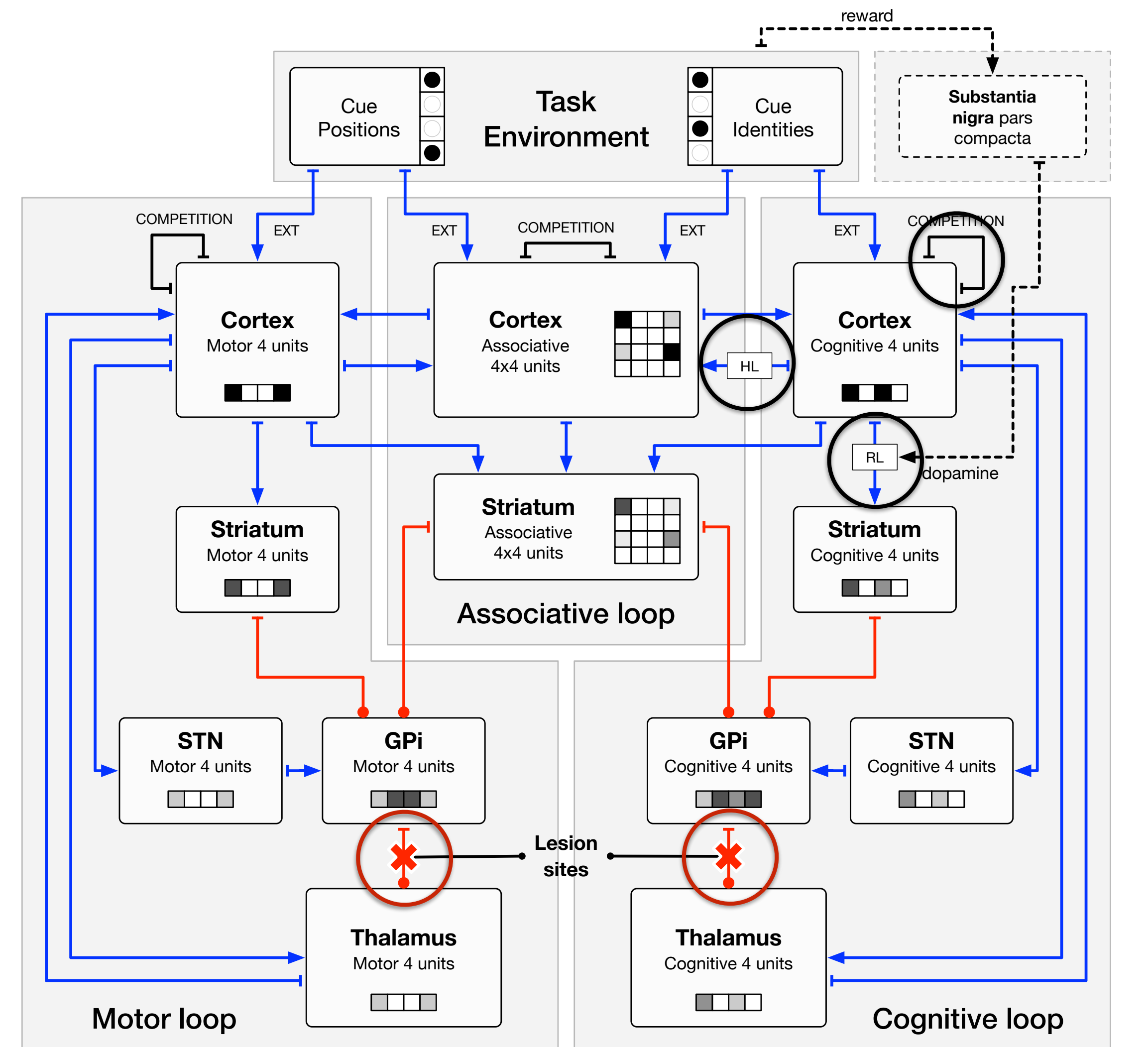
DECISION MAKING

A computational model

Bilateral inactivation of the globus pallidus interna, by injection of muscimol, prevents animals from learning new contingencies while performance remains intact, although slower for the familiar stimuli. We replicate in silico these data by adding lateral competition and Hebbian learning in the cortical layer of the theoretical model of the cortex–basal ganglia loop that provided the framework of our experimental approach.



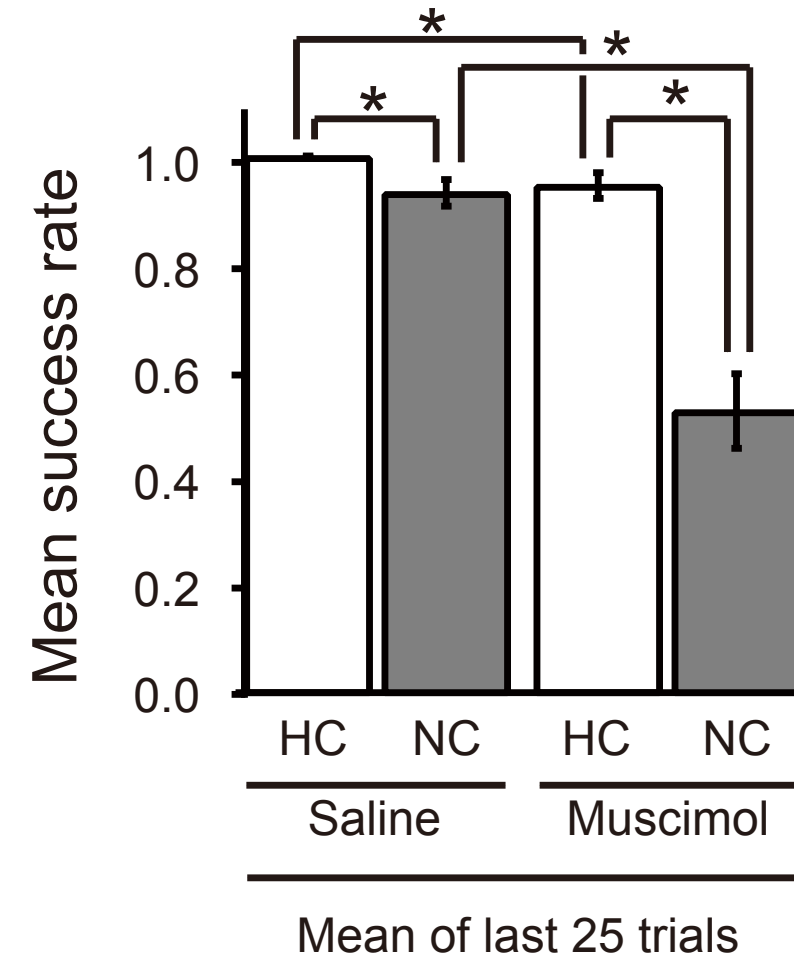
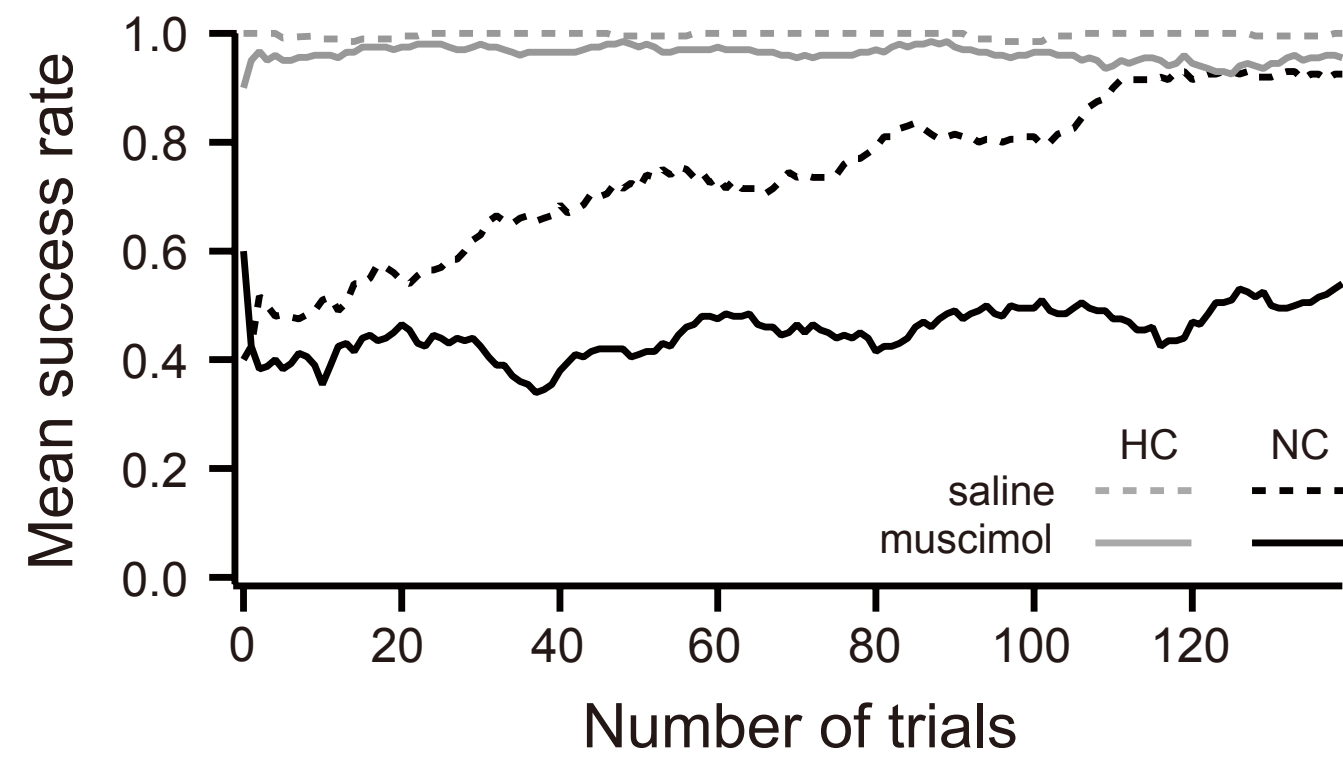
Piron et al., Movement disorders, 2016



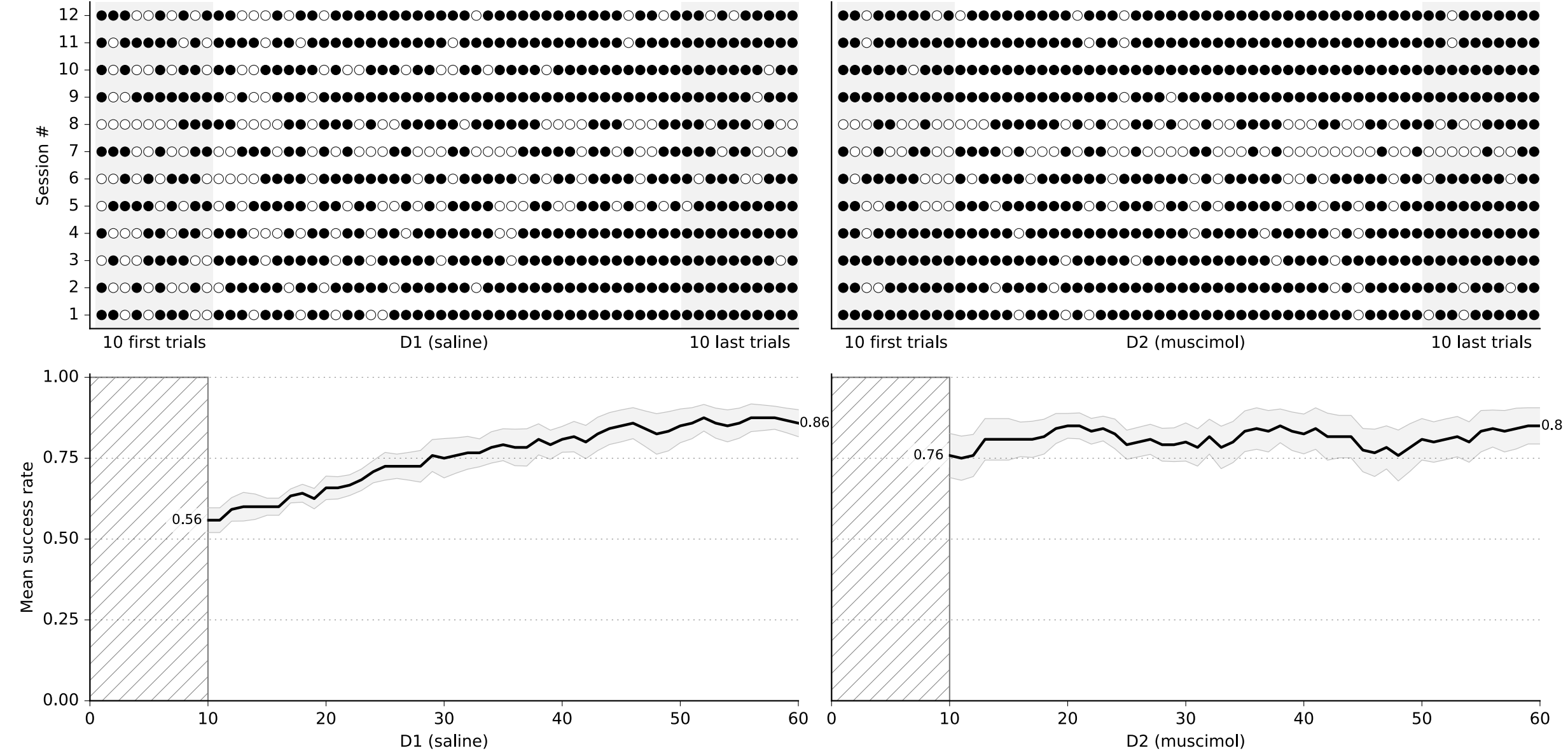
DECISION MAKING

Persistent learning

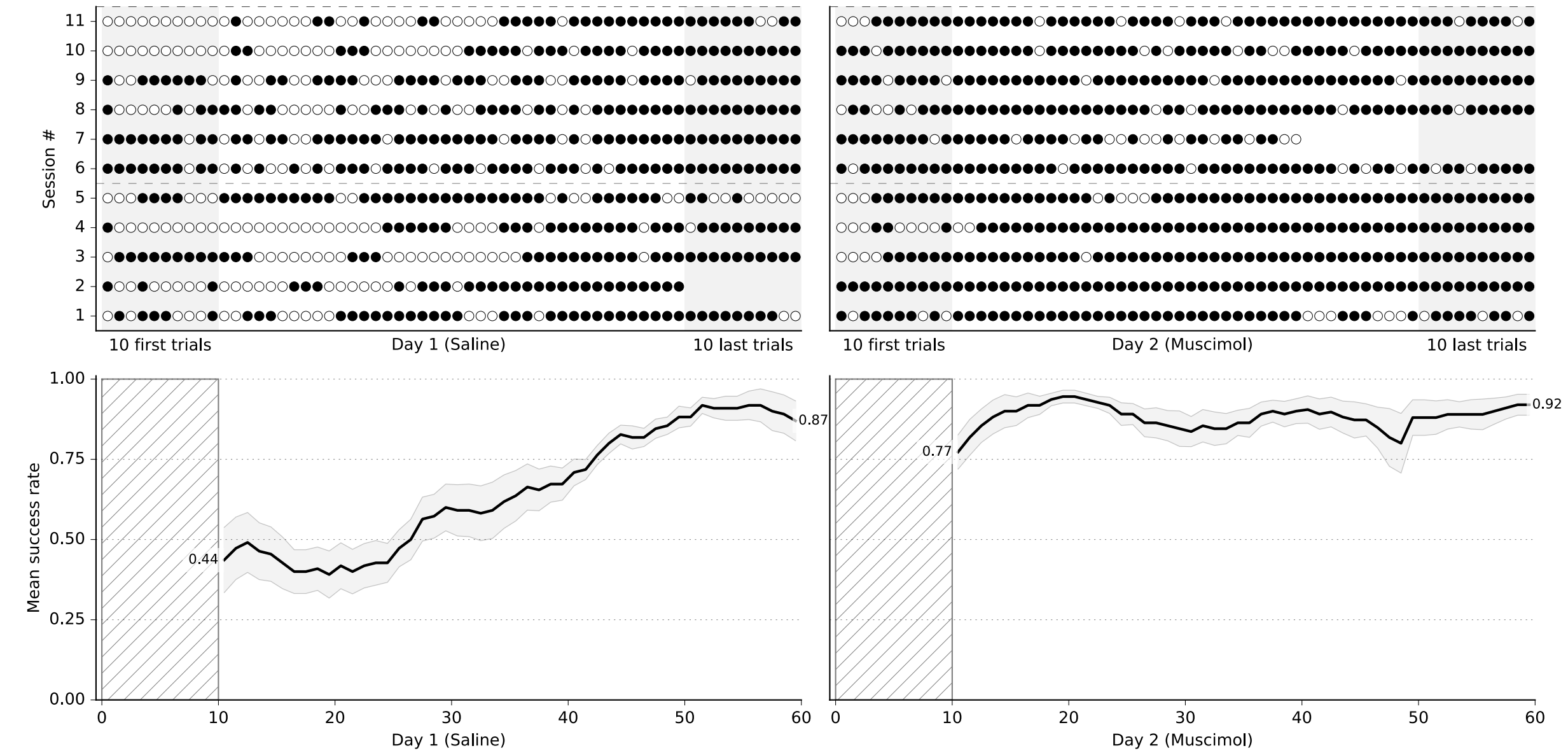
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Piron et al., Movement disorders, 2016



Muscimol / GPI OFF

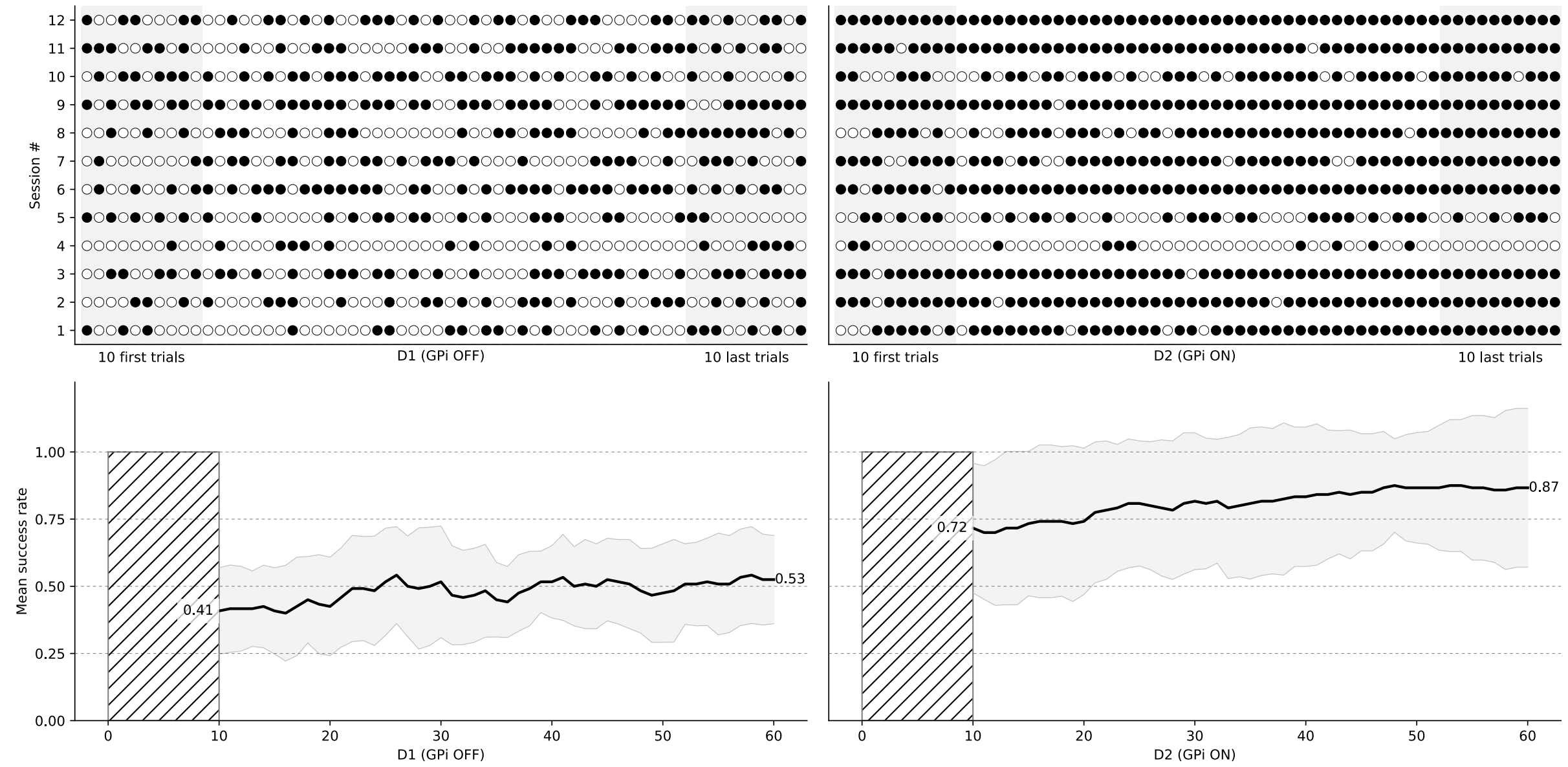
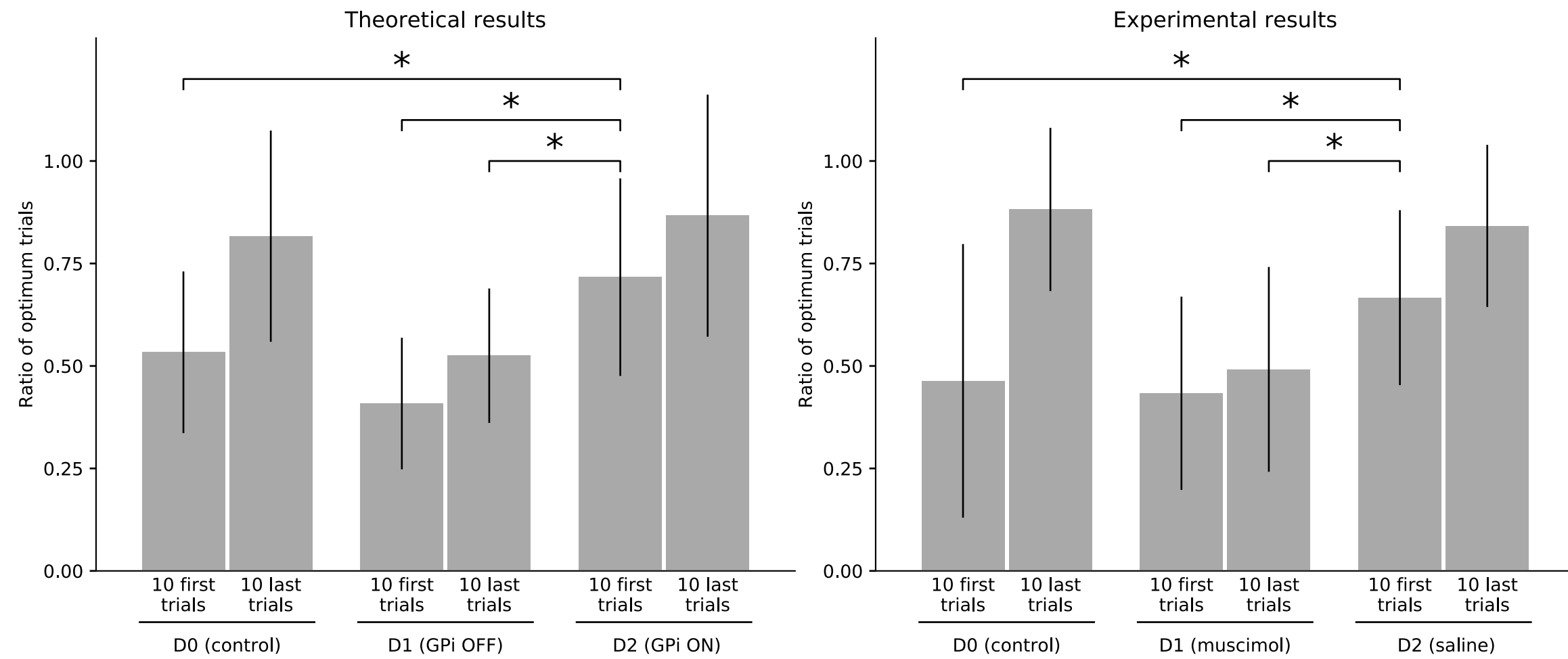


Saline / GPI ON

DECISION MAKING

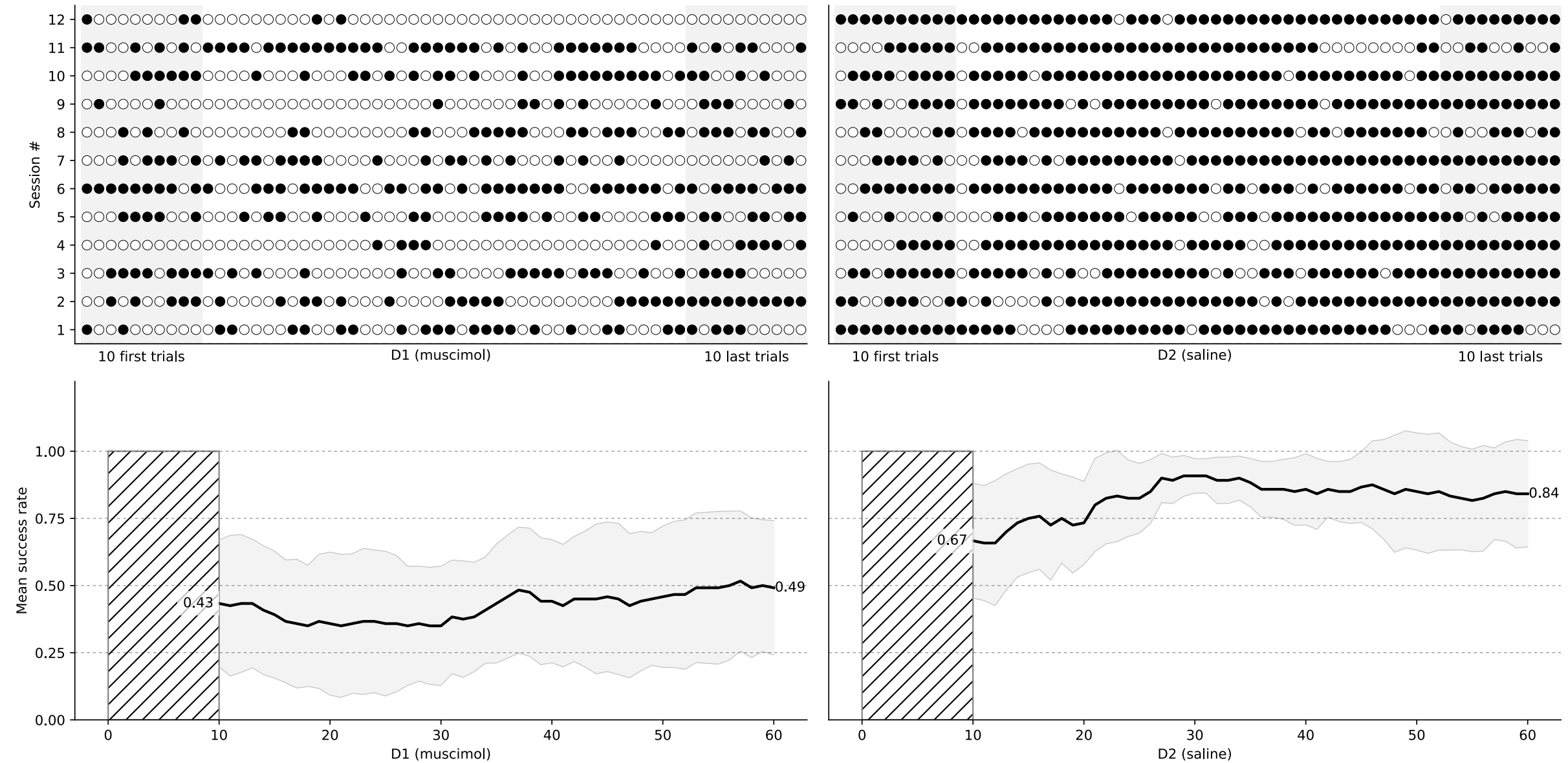
Covert learning

Prior to learning, we inactivate the internal part of the Globus Pallidus with injections of muscimol and we tested monkeys on a variant of a two-armed bandit task where two stimuli are associated with two distinct reward probabilities (0.25 and 0.75 respectively). Unsurprisingly, performance in such condition are at the chance level because the output of basal ganglia is suppressed and they cannot influence behaviour. However, the theoretical model predicts that in the meantime, values of the stimuli are nonetheless covertly evaluated and learned.



Saline / GPI ON

Muscimol / GPI OFF

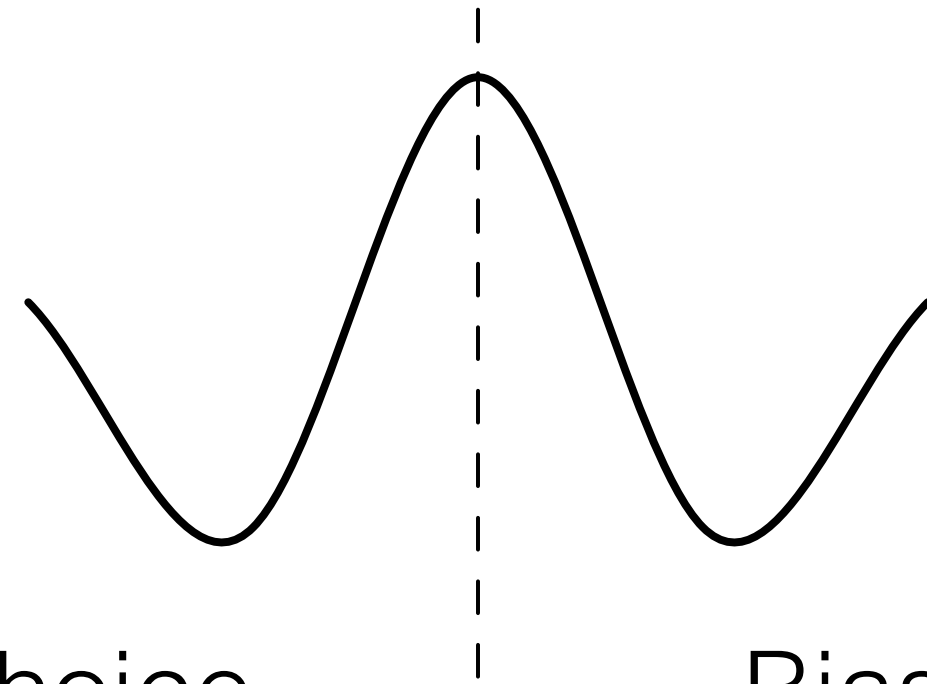


DECISION MAKING

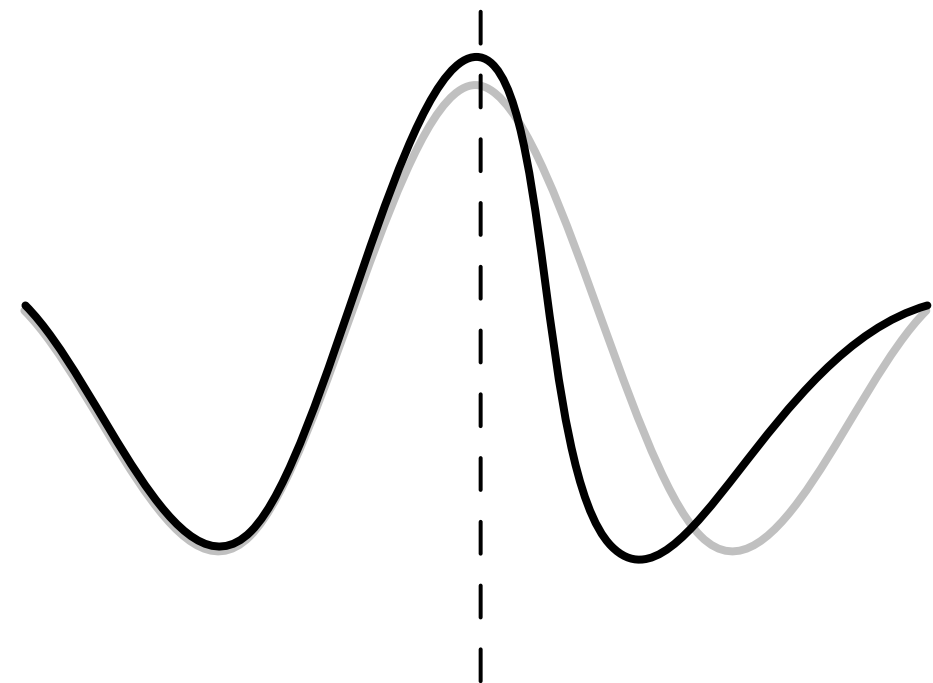
Two entangled decision systems

The final behavioral decision results from both the cooperation (acquisition) and the competition (expression) of two distinct but entangled systems. They can be congruent and incongruent.

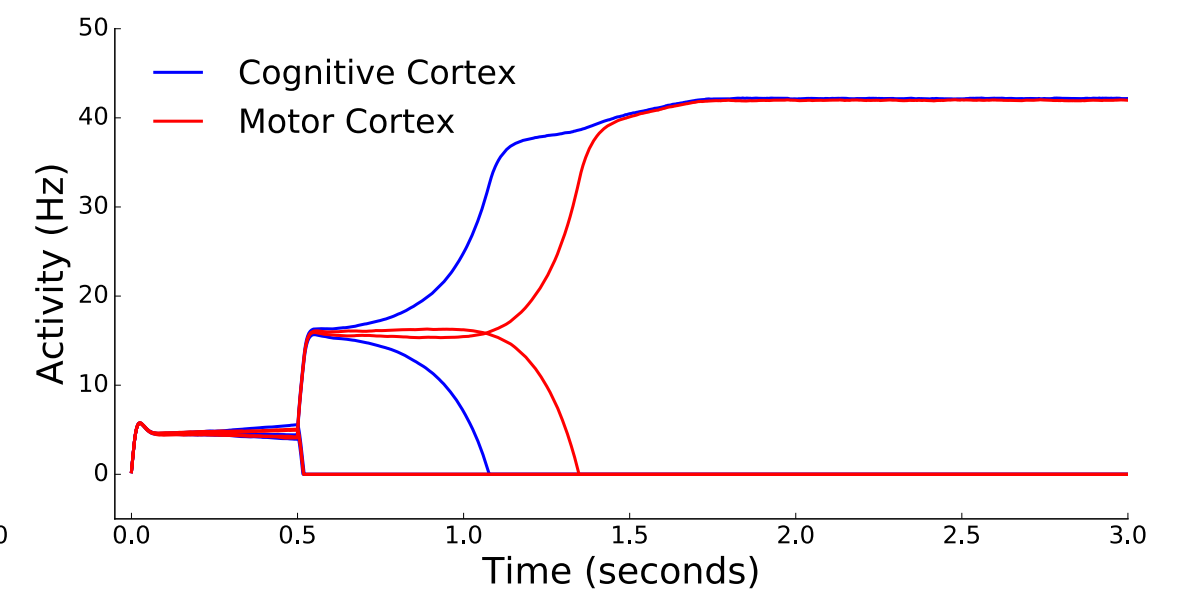
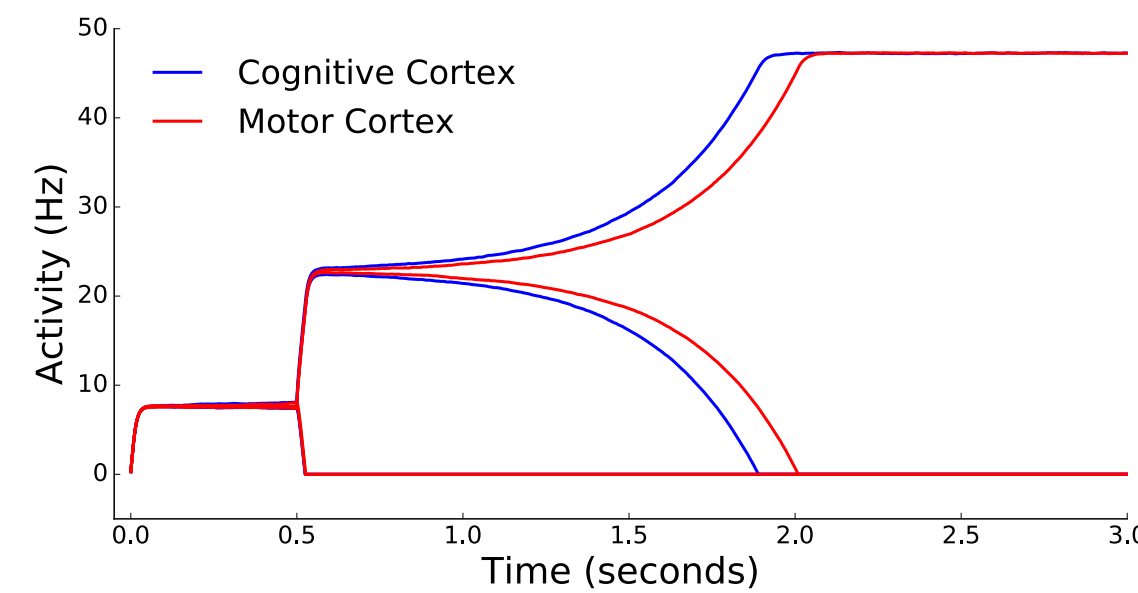
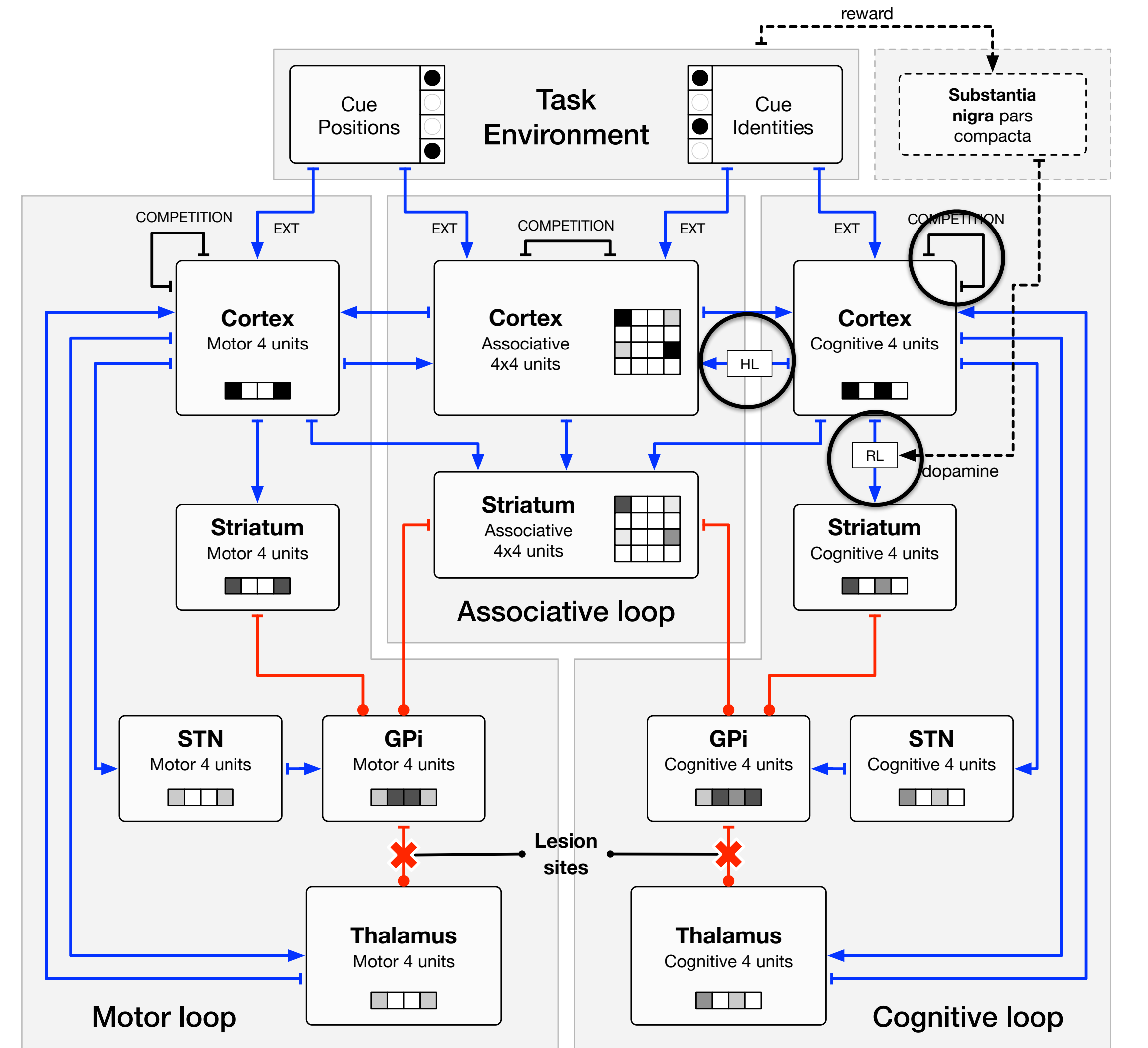
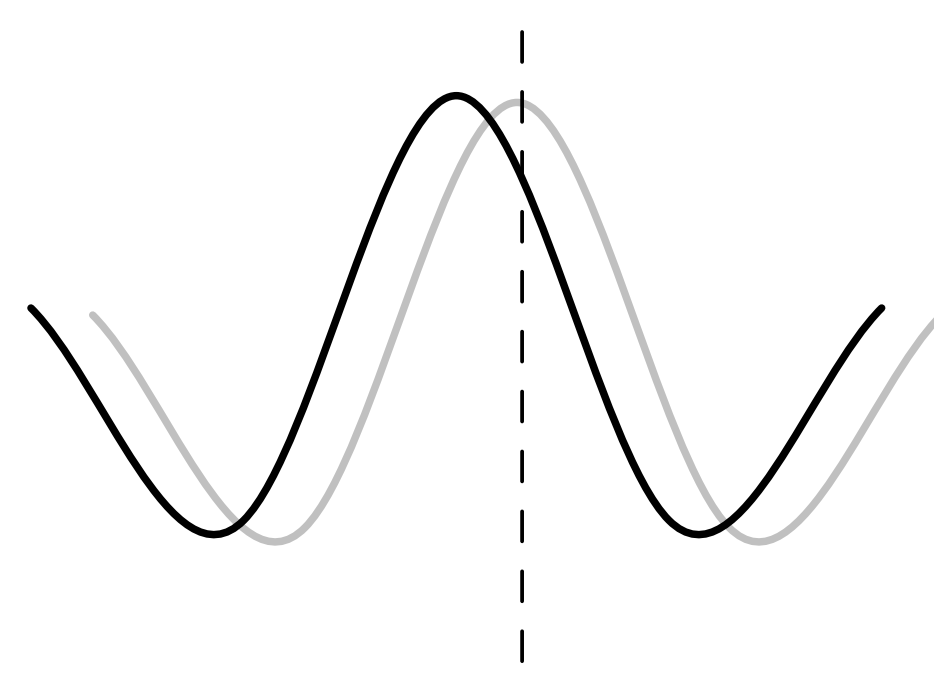
Random choice



Biased choice (short term)



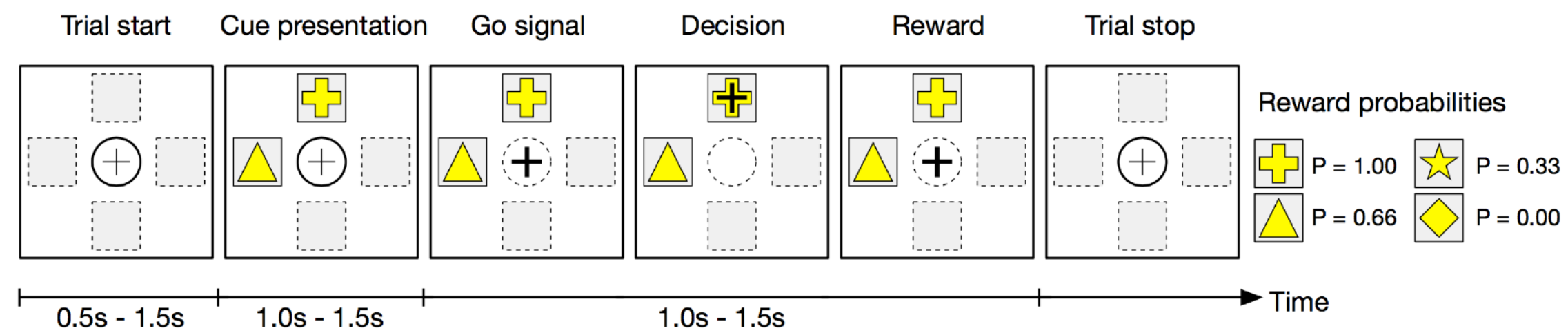
Biased choice (long term)



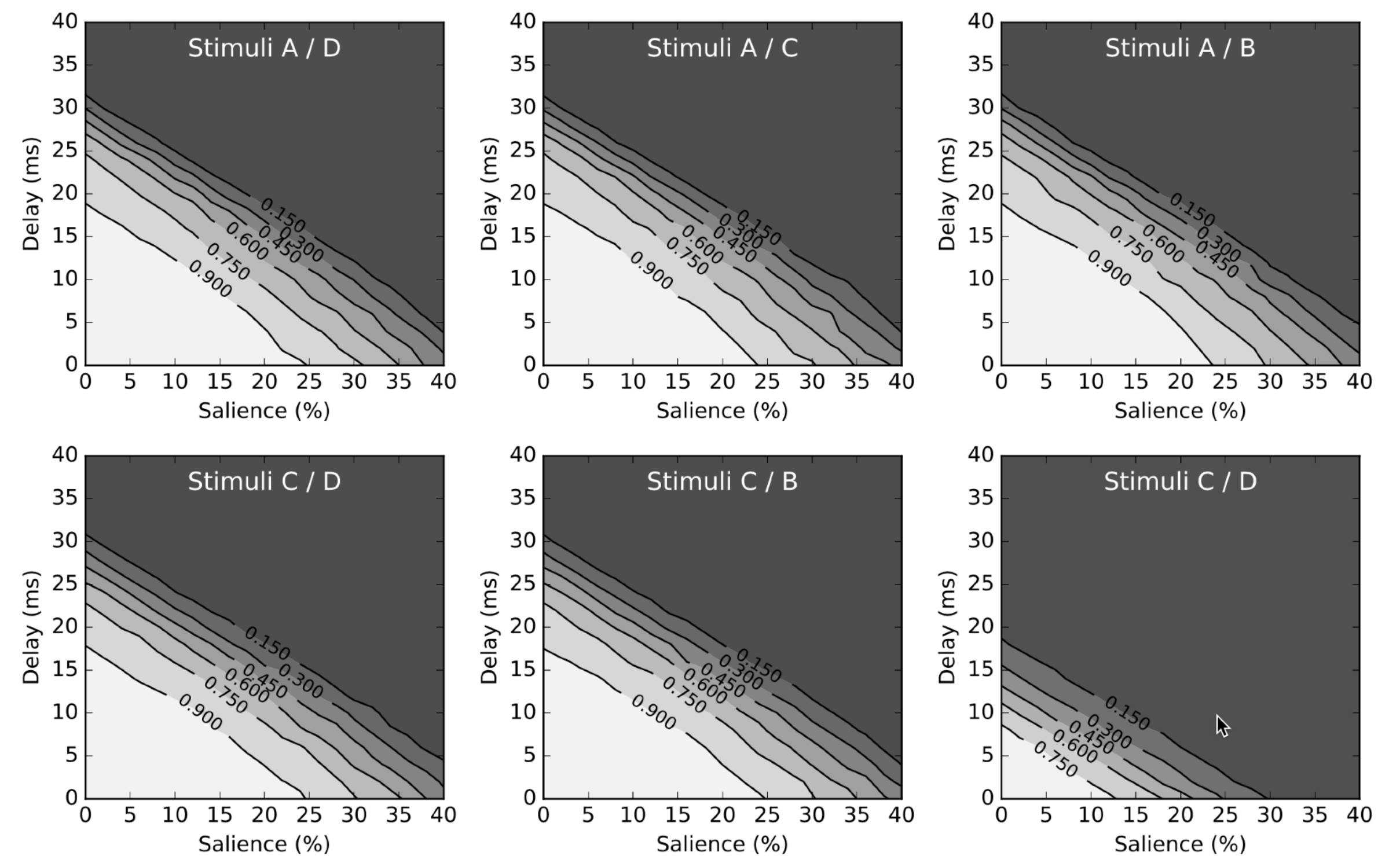
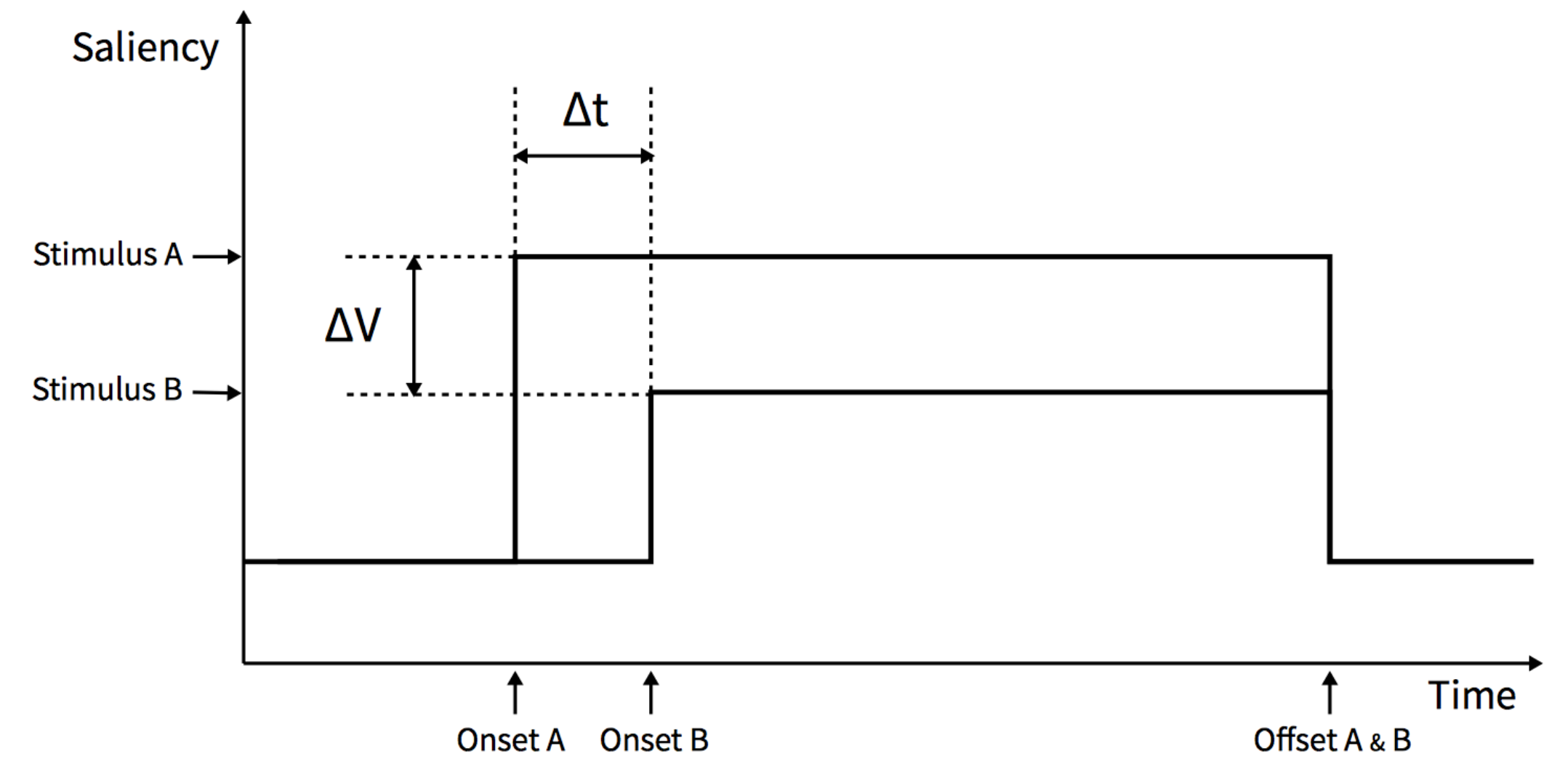
DECISION MAKING

Noise & noise

Four shapes are associated with different reward probabilities (1, 2/3, 1/3, 0). A trial is a time period in which any two of the four possible shapes are presented at two random positions (out of the four possible positions - up, right, down and left) at different time, using different saliency.



The inner dynamic of the model disturbs considerably the final choice such that the strongest or the earliest stimulus can be chosen independently of its value.



Conclusion

Initial exploration thanks to noise - later exploitation thanks to learning bias
A decision results from several competitions

