Computational Neuroscience Course

An Introduction to Computational Neuroscience

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University of Science and Technology of China

Sep 8 2021

Course website

https://github.com/Wenlab/Computation-Neuro-Course/tree/Fall2021

Computational-Neuroscience-Course

This repository serves as an ongoing effort to create a systems and computational neuroscience course. I hope to develop a two-semester course for USTC biophysics students. The first semester will cover some basic materials, and the second semester will introduce more advanced topics for undergraduate and graduate students.

When: Wednesday 9:45 am - 11:25 am, Fall 2021
Where: 东区第二教学楼2504
Teacher: 温泉 qwen@ustc.edu.cn
Teaching Fellow: 徐畅 xuchangustc216@mail.ustc.edu.cn 沈宣宇sxy0704@mail.ustc.edu.cn 蒋朋岑 twilight_79@mail.ustc.edu.cn

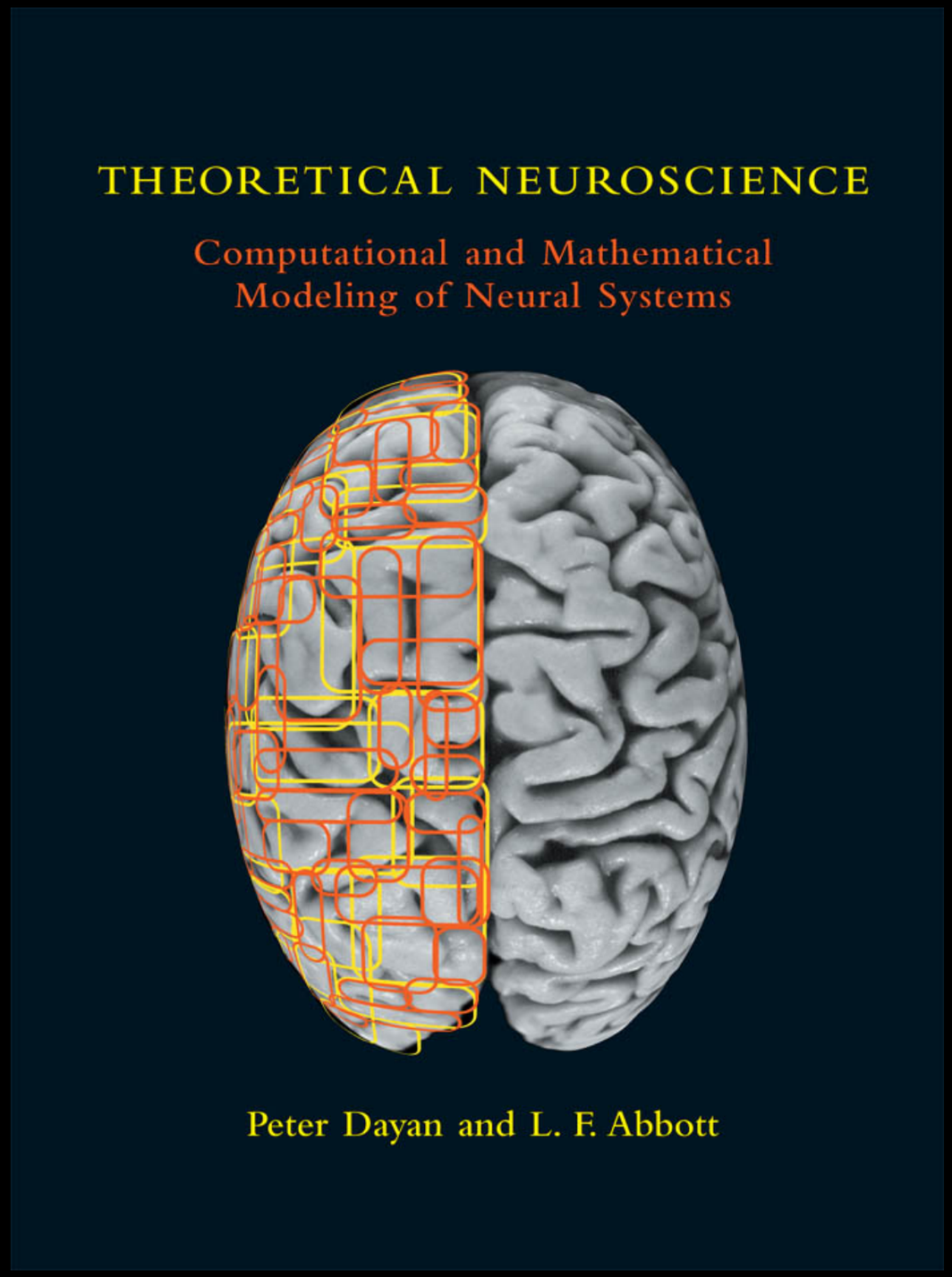
Recommended Textbooks:

- Theoretical Neuroscience: Computational and Mathematical Modeling the Neural System
- Principles of Neural Design

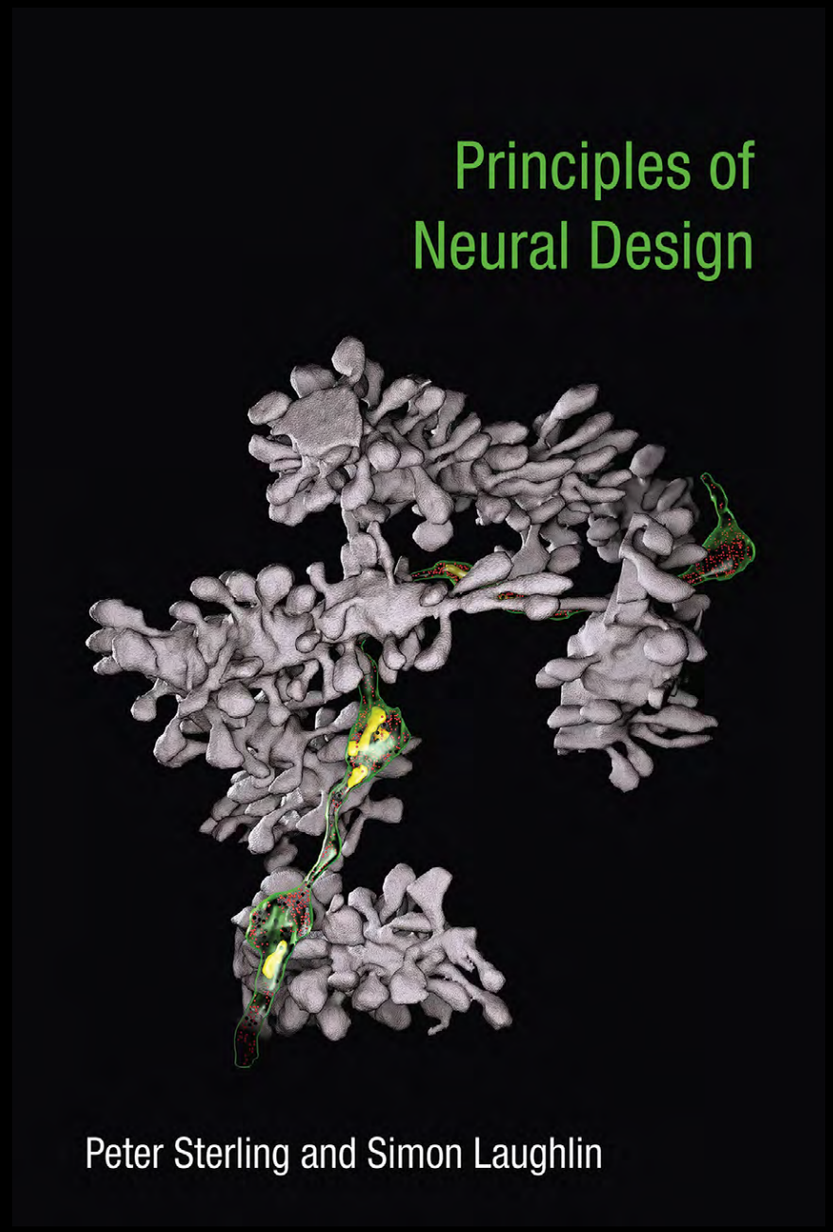
Course Performance Evaluation:

- Homework: 70%
- Final: 30%

Recommended textbooks



How questions



Why questions

A brief pre-history

Theoretical Neurophysiology

1907 Lapique:
integrate-and-fire model

1952 Hodgkin-Huxley:
theory of action potential

1960's Rall:
cable theory of dendrites

1970's Wilson-Cowan:
firing-rate population models

1980's: Biophysics of neurons &
synapses, network dynamics

Psychology & Computer Science

1949 Hebb:
learning rules

1960's Rosenblatt, Minsky:
perceptrons

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perceptrons

1970's signal detection theory

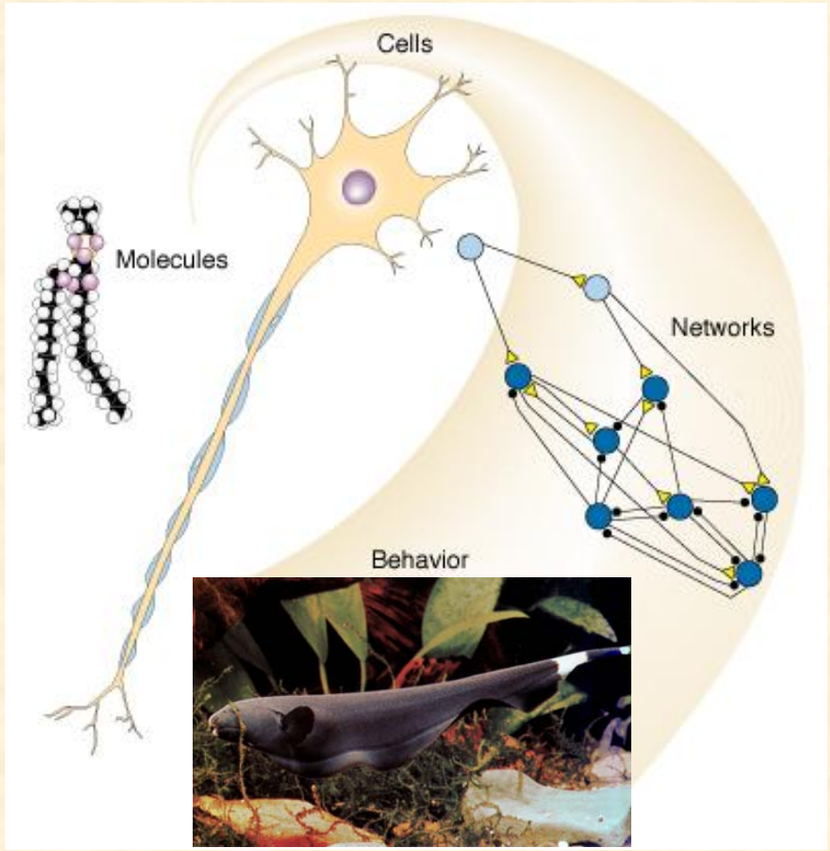
1980's Hopfield:
associative memory model

Sejnowski, Koch, Churchland, Computational neuroscience. Science *1988* 241: 1299-1306
Methods in Computational Neuroscience Summer School, Marine Biological Laboratory

adapted from Xiaojing Wang's slide

Principles of Neuroscience ?

Multiscale Organization of the Nervous System



Organism	1 m
System	10 cm
Map	1 cm
Column	1 mm
Neuron	10 μm
Synapse	1 μm
Molecule	10 Å

Delcomyn 1998

"To pile speculation on speculation, I would say that the next stage could be hierarchy or specialization of function, or both…. with increasing complication at each stage, we go on up the hierarchy of sciences. We expect to encounter fascinating and, I believe, very fundamental questions at each stage in fitting together less complicated pieces into the more complicated system and understanding the basically new types of behavior which can result."

P. W. Anderson, 1972
condensed matter physicist

More is different

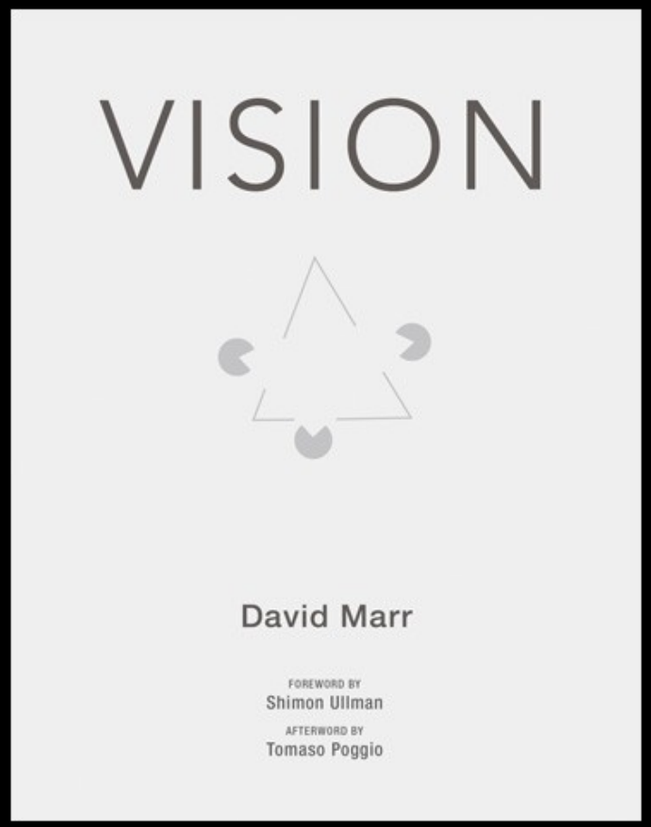
Fitzgerald: The rich are **different** from us.

Hemingway: Yes, they have **more** money.

a conversation somewhere in Paris in 1920s

David Marr
1945-1980

Henry Markram
1962 -



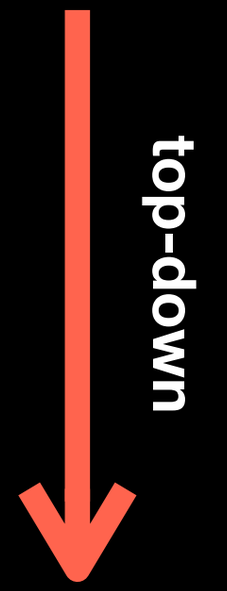
blue brain project

David Marr's three level theory

- **Computational level**: Identify the computational problem and task that the brain solves.

- **Algorithmic level**: Find the mathematical procedures that solve the problem.

- **Implementation level**: How the algorithms are realized by the nervous system.



Henry Markram's three level theory

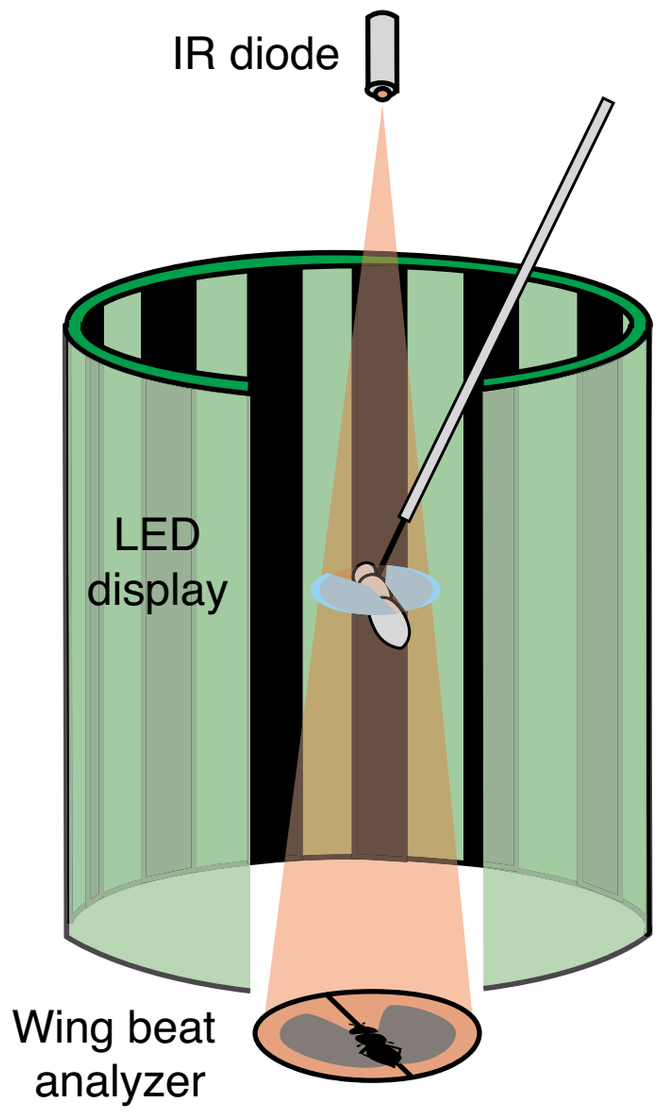
- **Systems level**: describe how population neural dynamics and behaviors emerge from ensembles of neurons.

- **Cellular level**: develop biophysically accurate models to describe input-output relationships of different cell types.

- **Structure level**: identify how neurons are statistically connected to each other in a circuit.

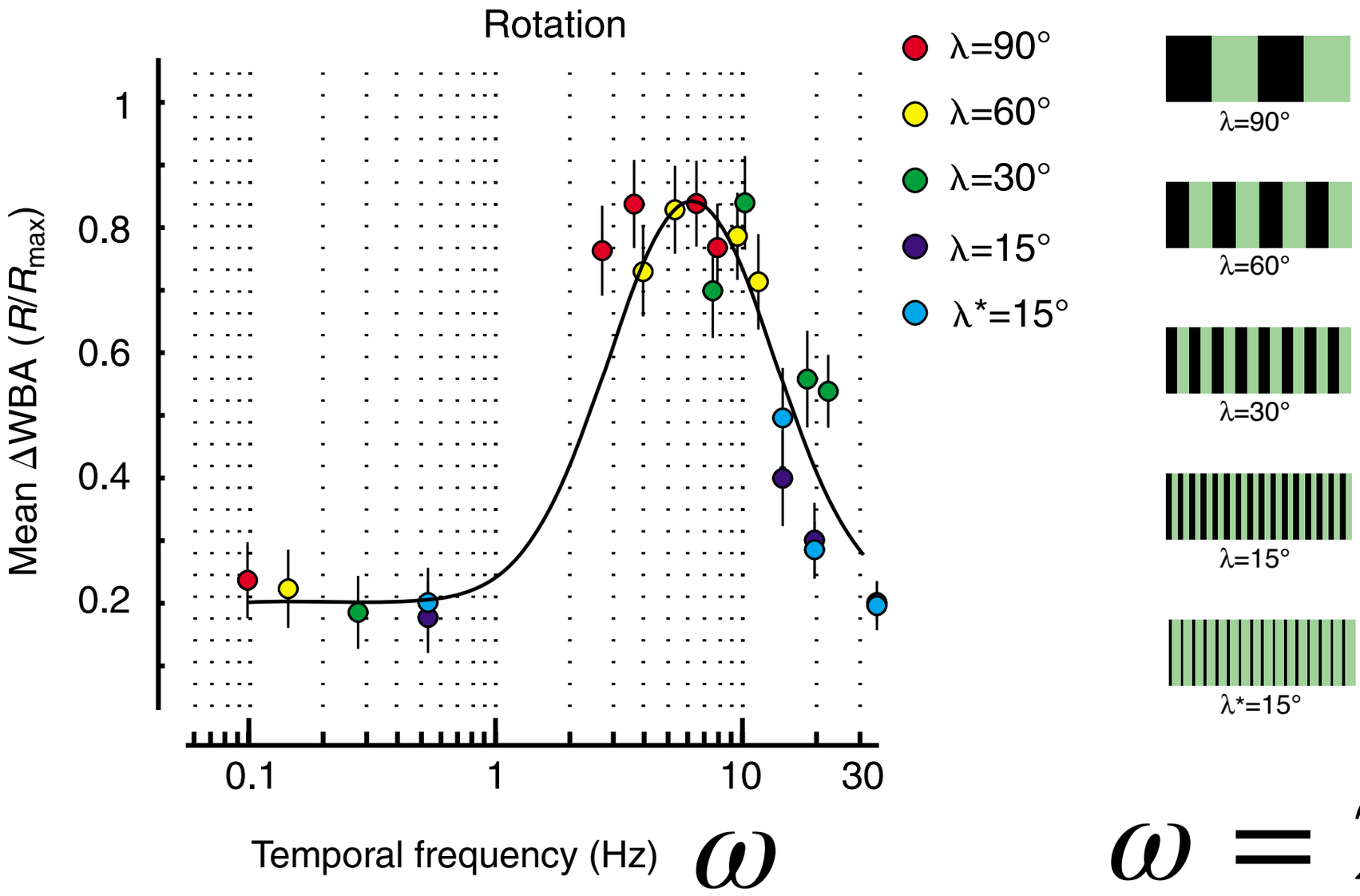
Motion detection, an example

Optomotor response in fly



Duistermars B et. al., Journal of Experimental Biology 2007

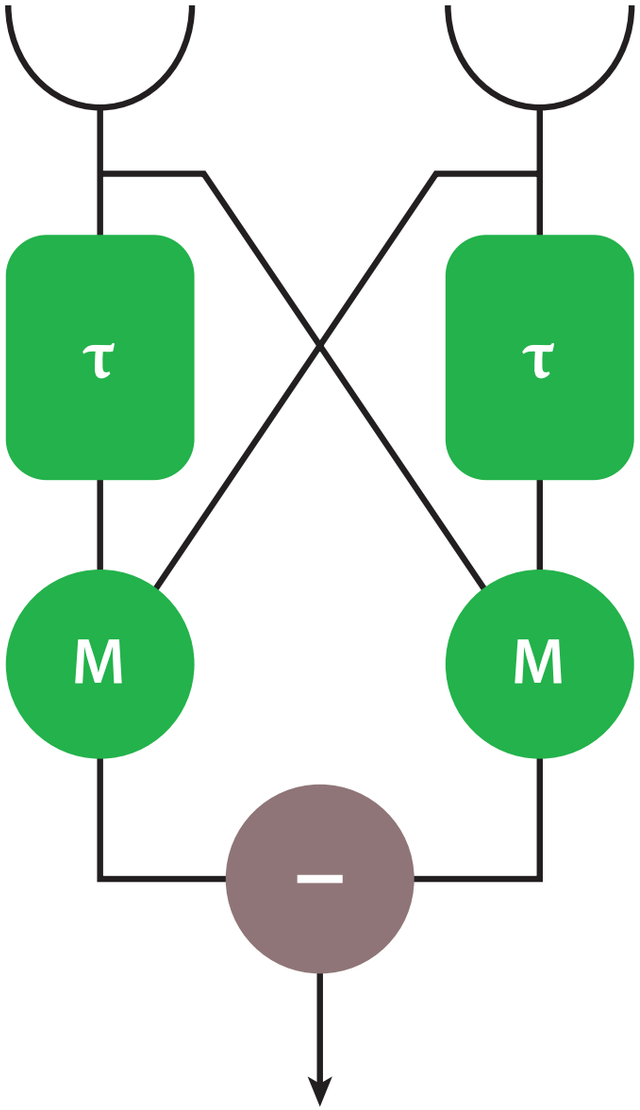
Optomotor response in fly



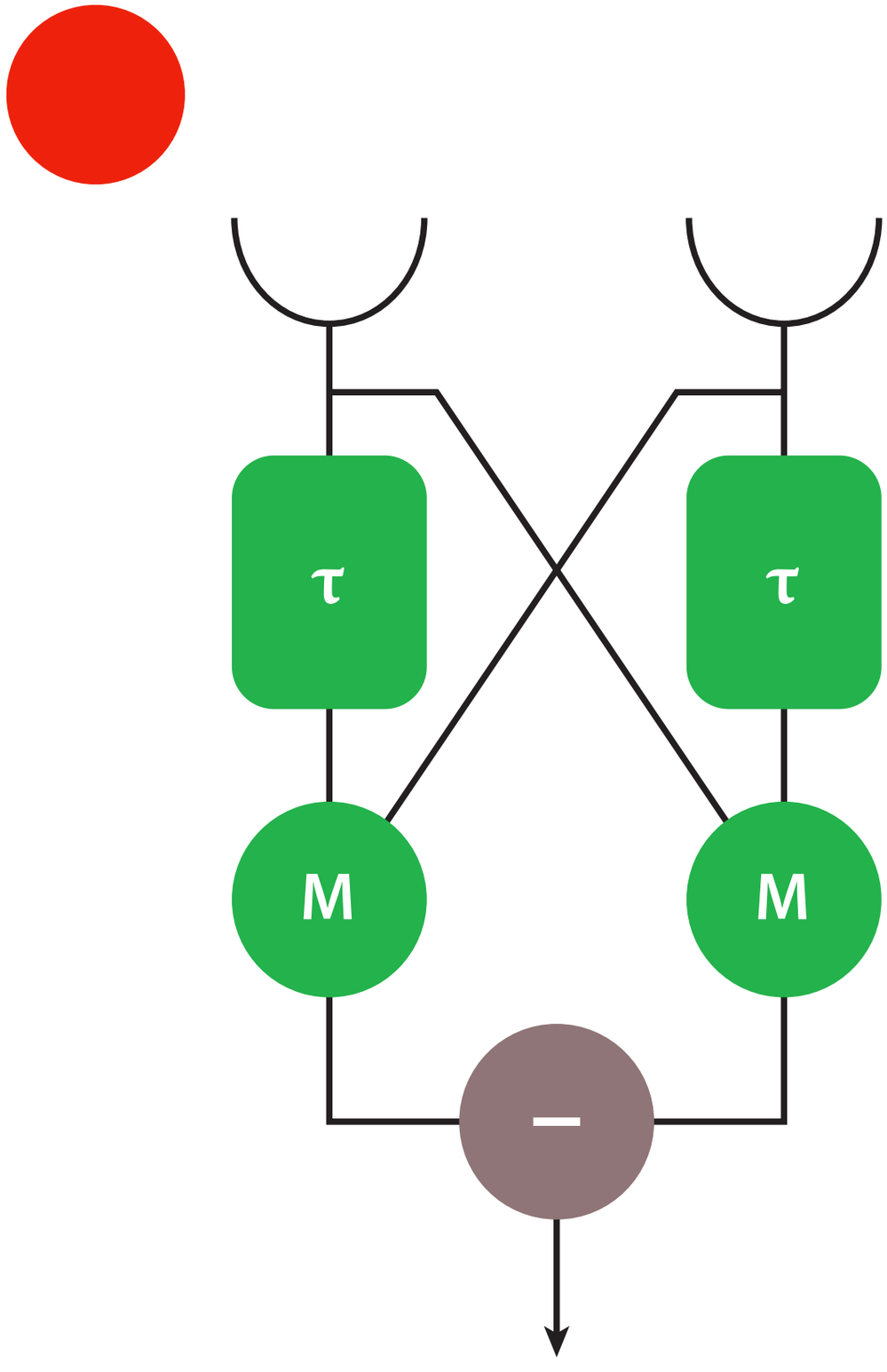
$$\omega = 2\pi v/\lambda$$

Duistermars B et. al., Journal of Experimental Biology 2007

Hassenstein-Reichardt Detector Model



Werner Reichardt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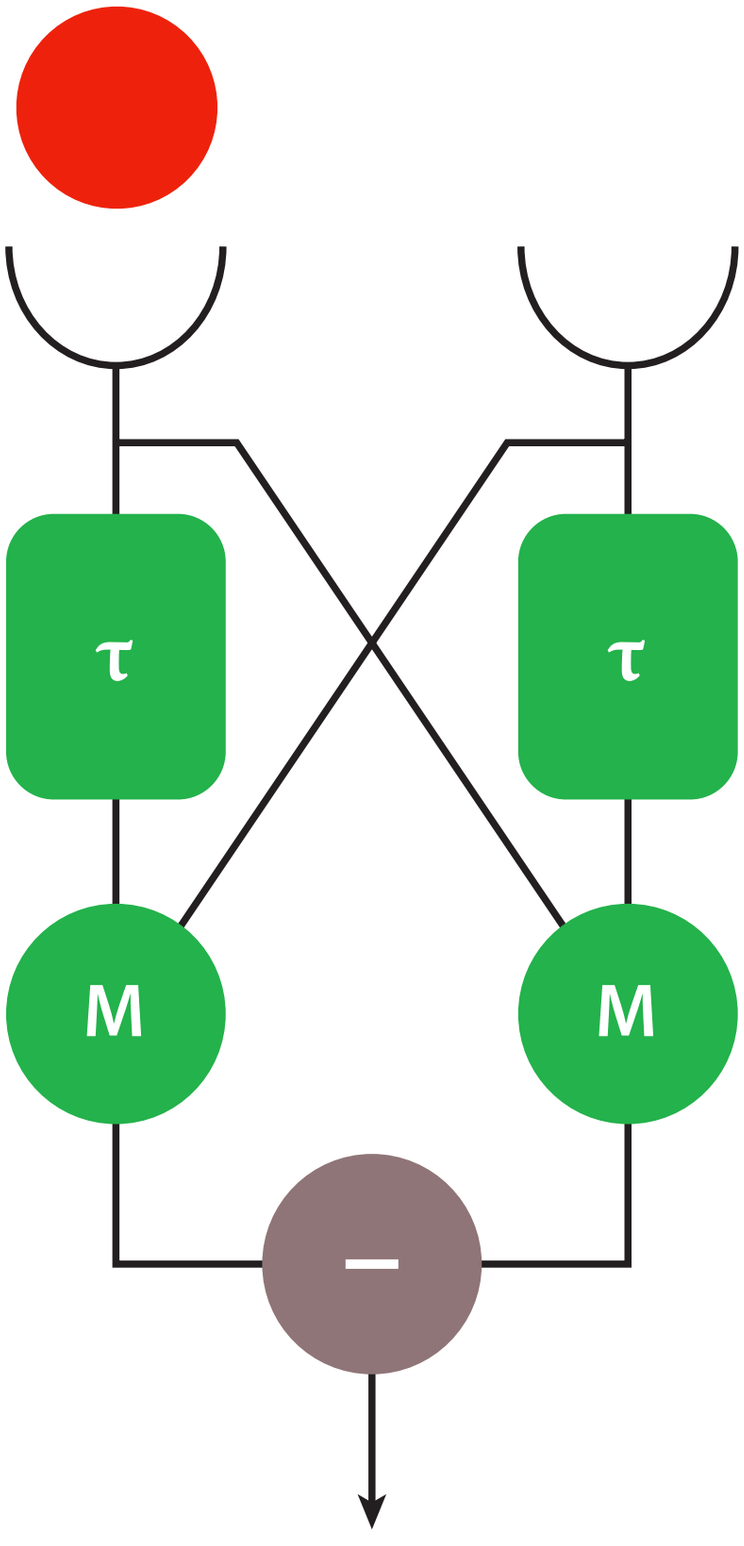
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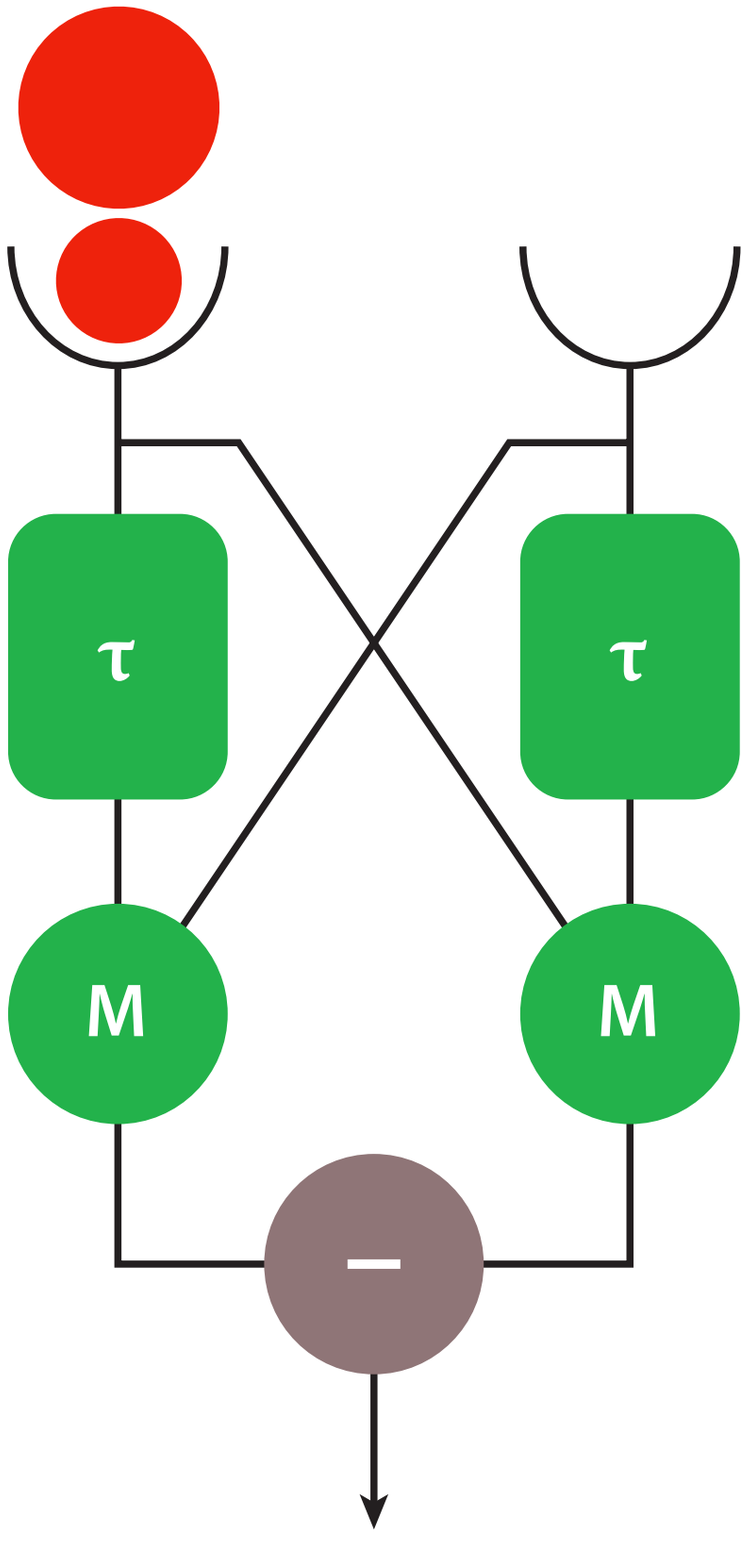
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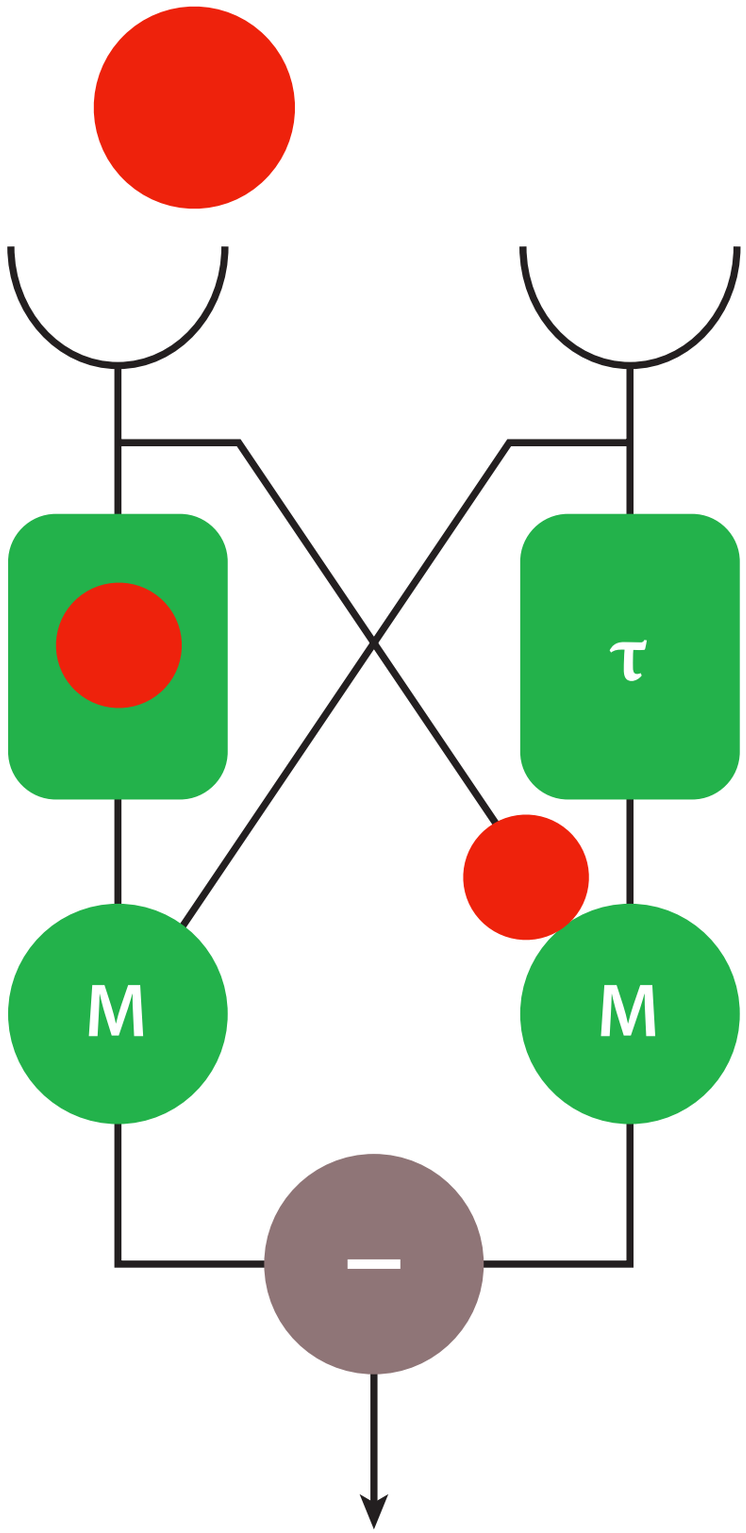
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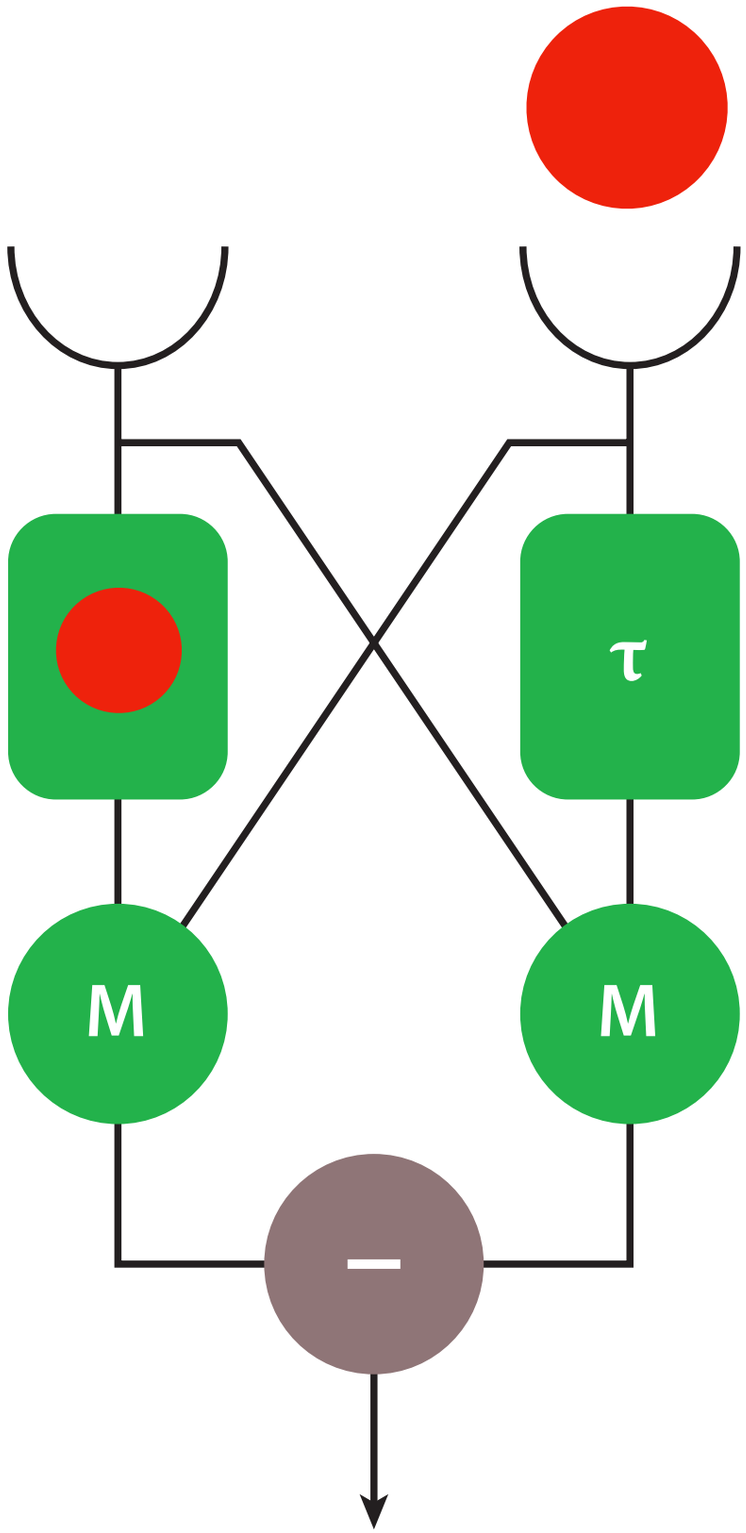
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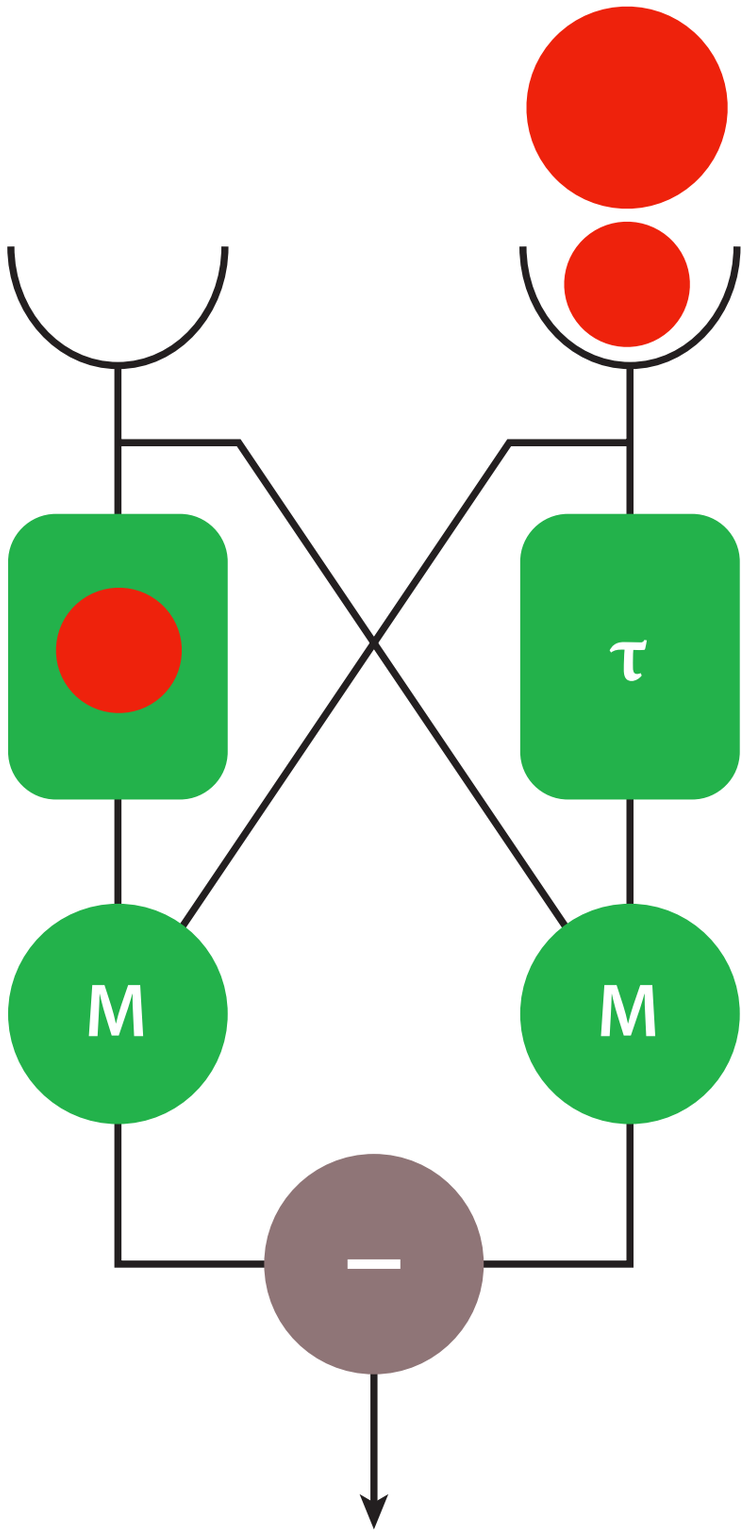
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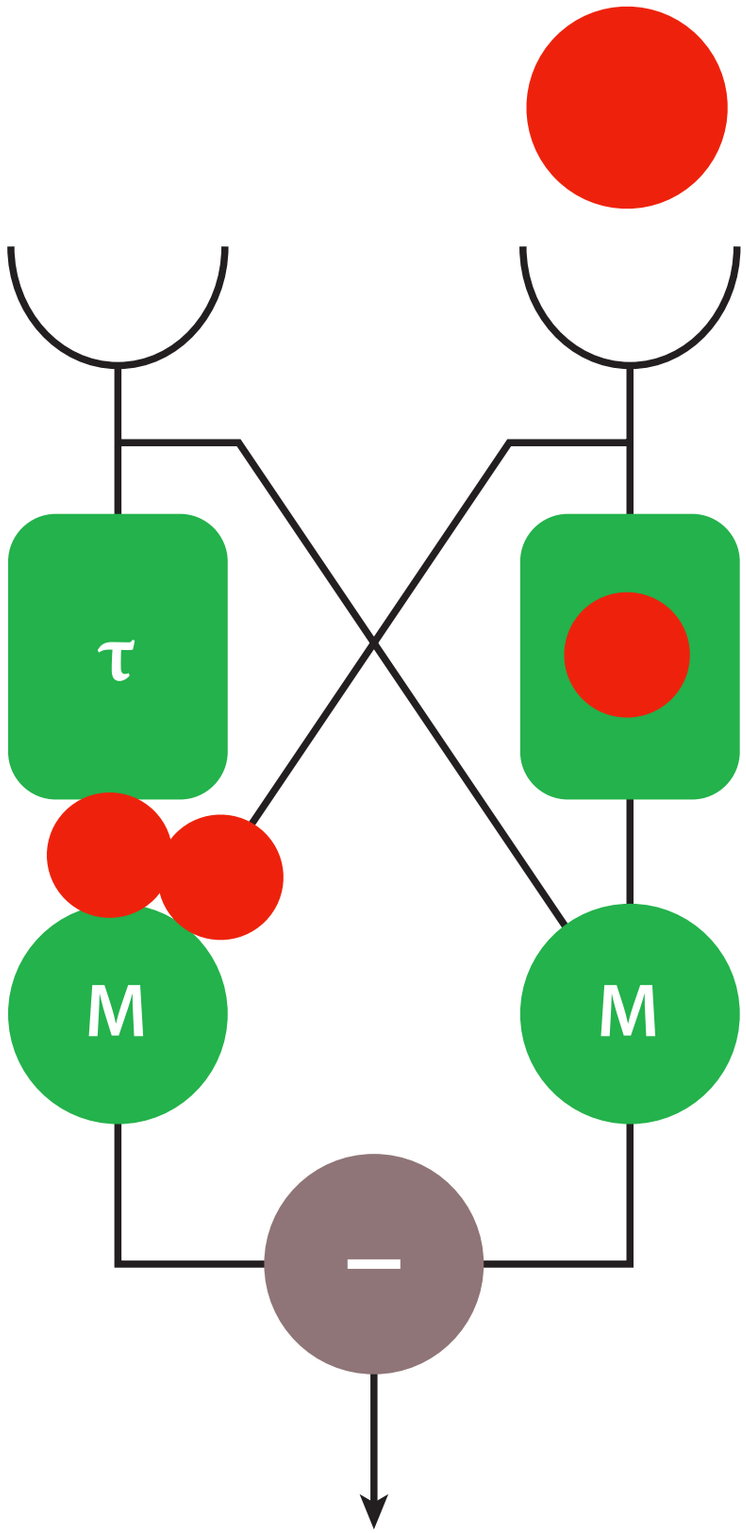
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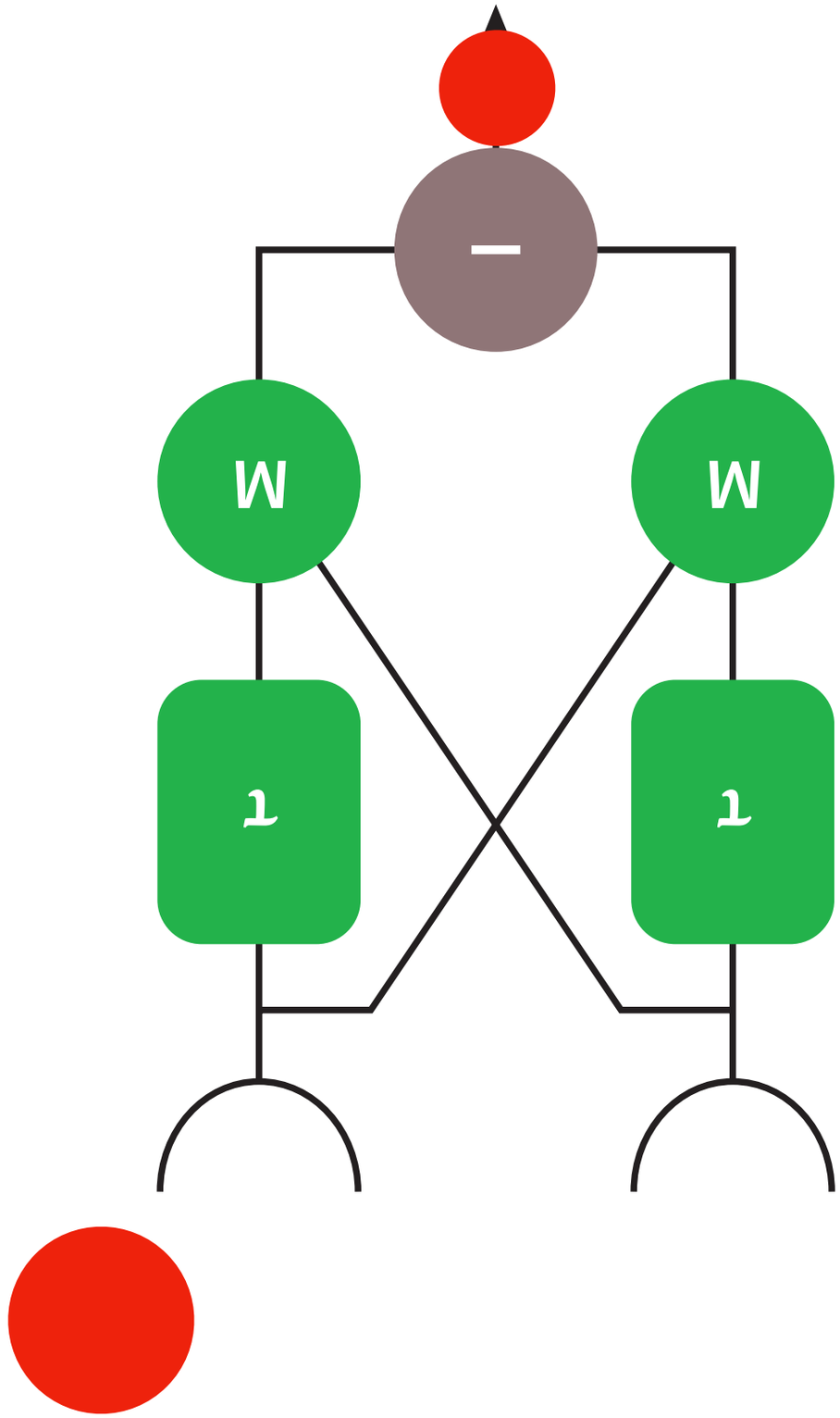
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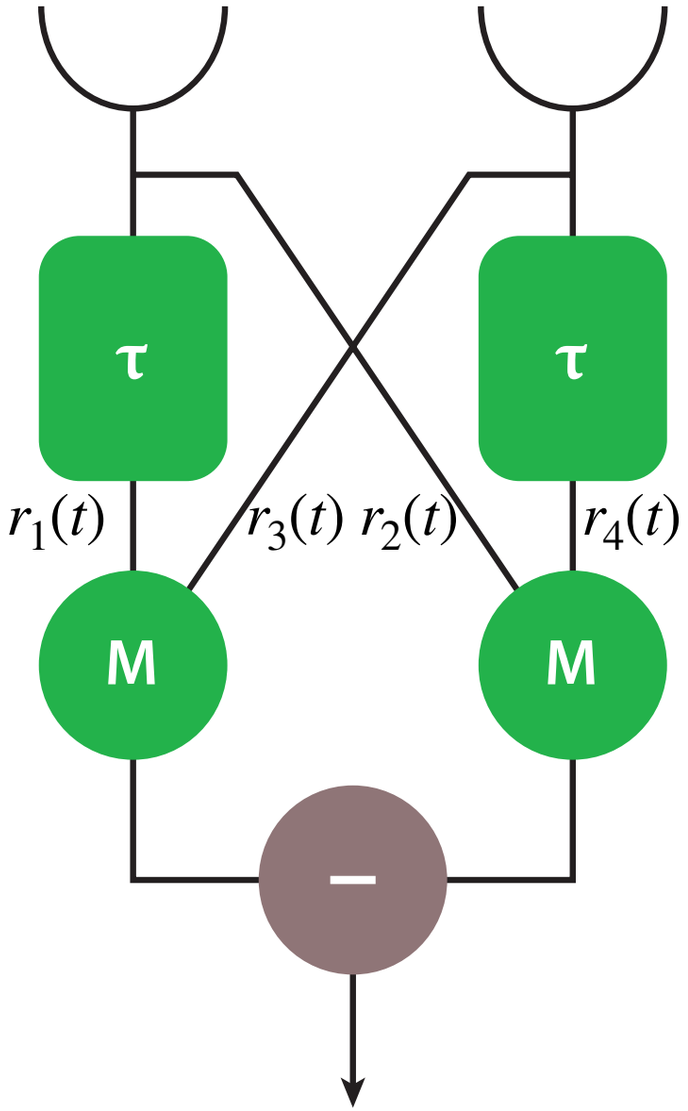
Hassenstein-Reichardt Detector Model



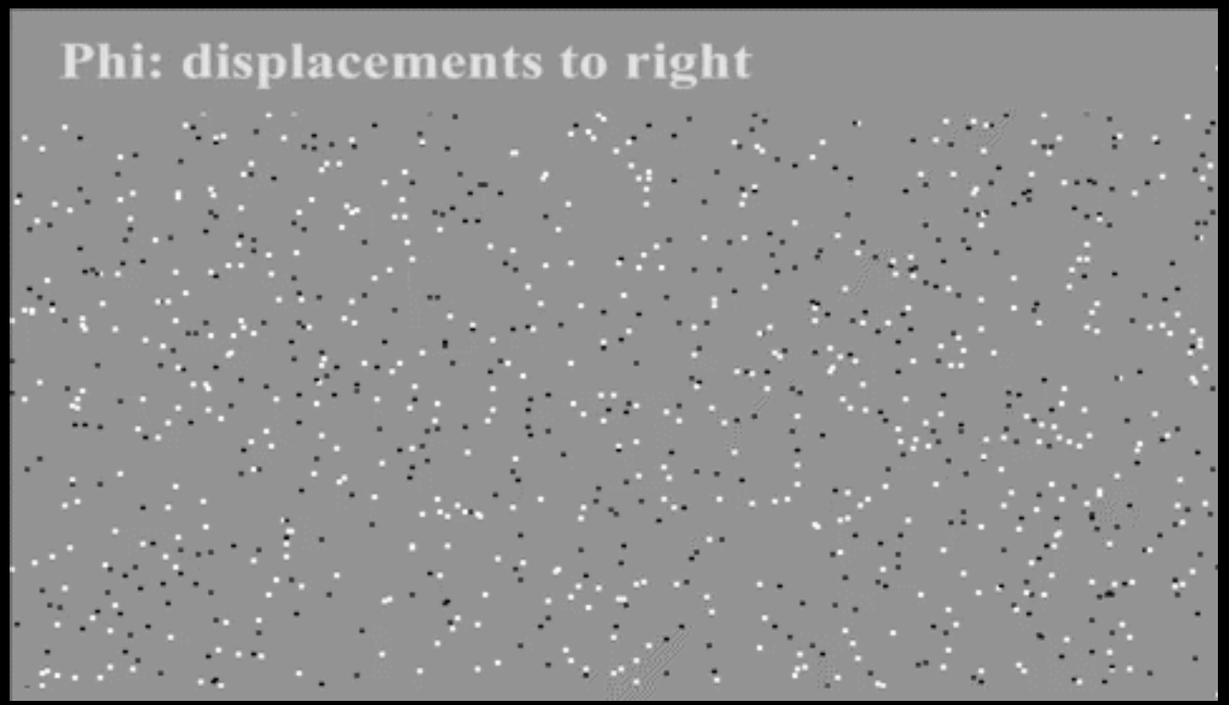
$$r_1(t) = \int_0^\infty s_1(t-\tau)D(\tau)d\tau;\ r_2(t) = \int_0^\infty s_1(t-\tau)\delta(\tau)d\tau$$

$$r_3(t) = \int_0^\infty s_2(t-\tau)\delta(\tau)d\tau;\ r_4(t) = \int_0^\infty s_2(t-\tau)D(\tau)d\tau;$$

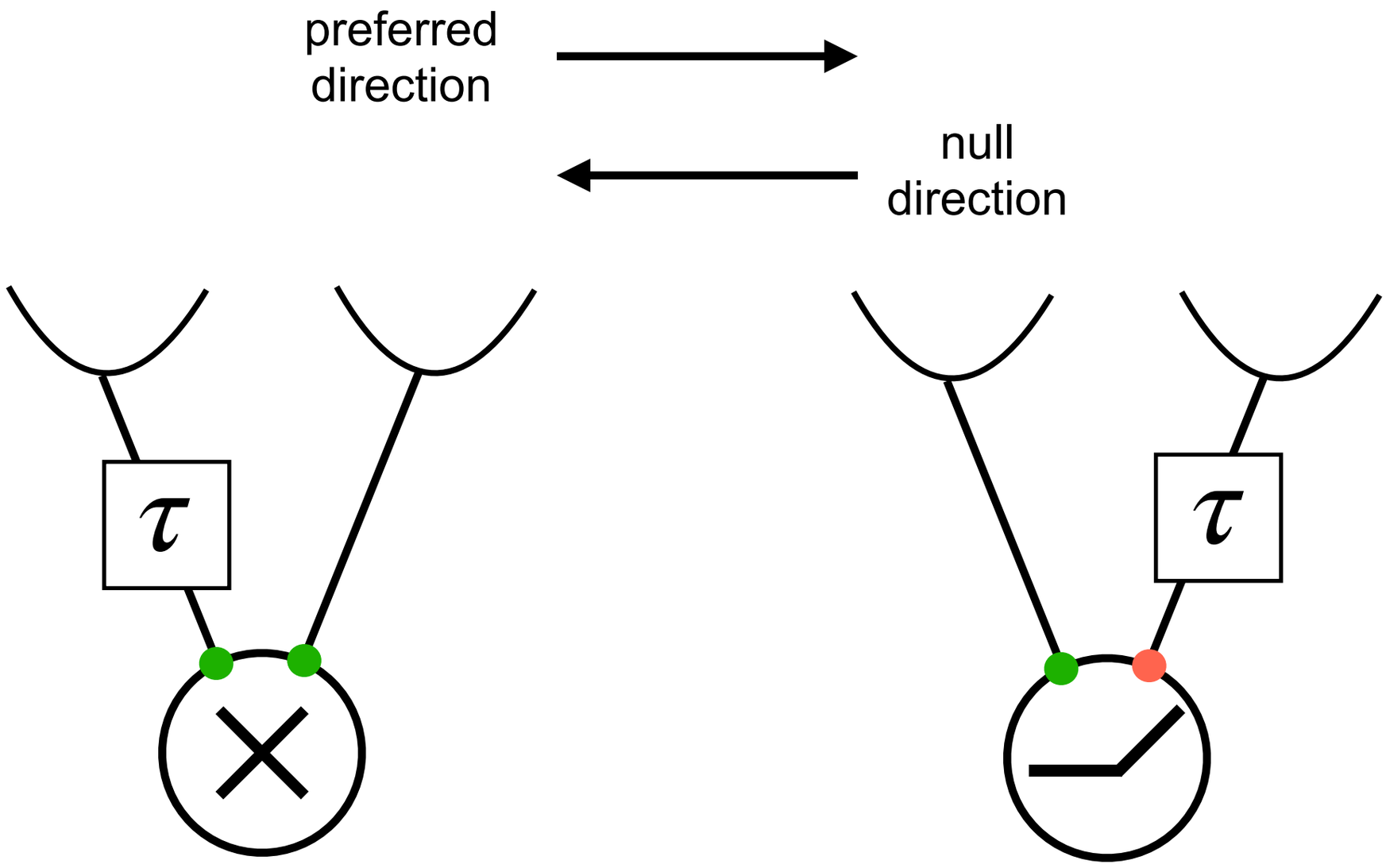
$$R(t) = r_1(t)r_3(t) - r_2(t)r_4(t)$$

$$D(\tau) = \frac{1}{\tau_0}\exp(-\tau/\tau_0)$$

$$\langle R \rangle = \frac{\omega\tau_0}{\omega^2\tau_0^2 + 1}$$

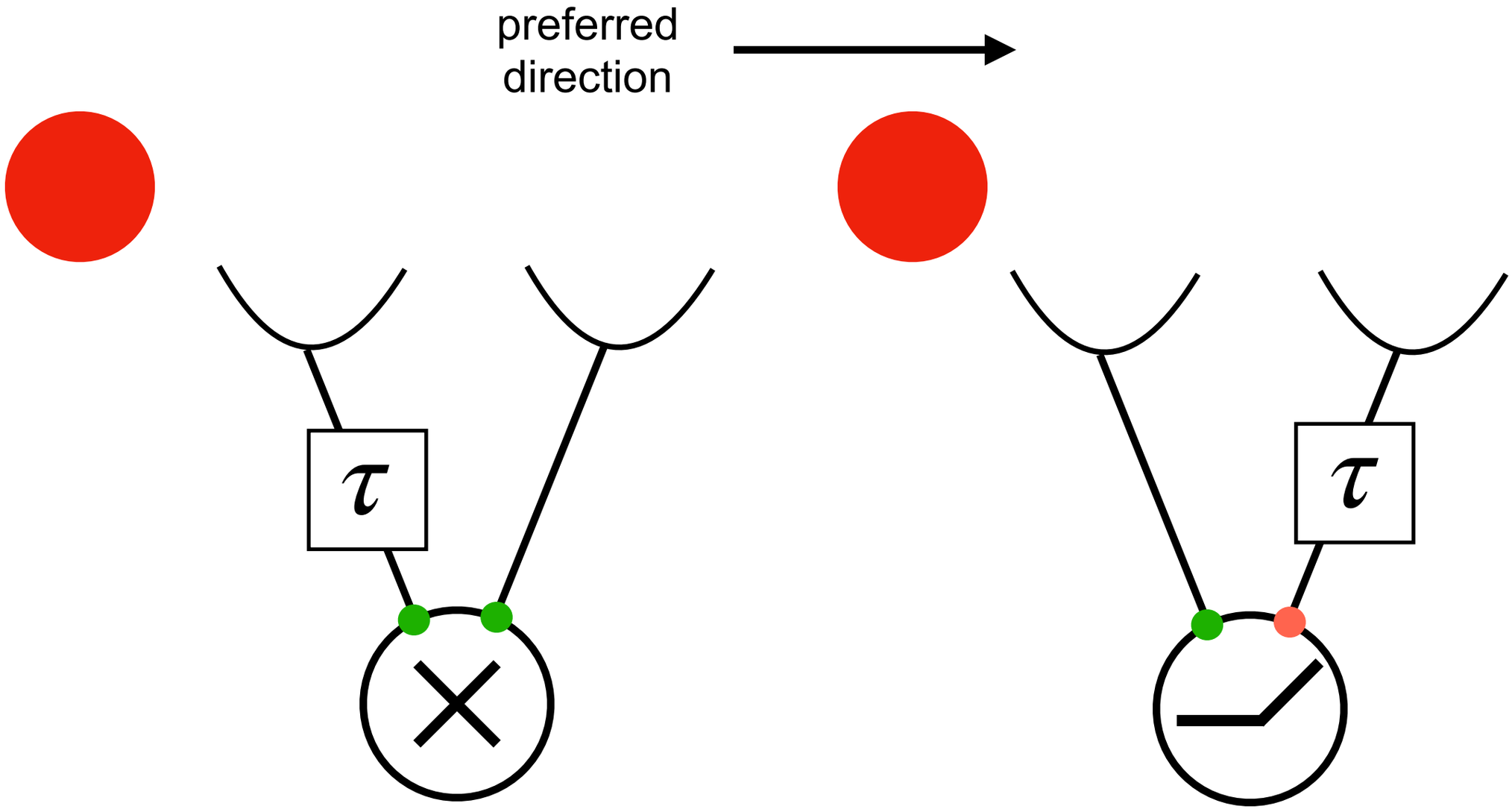


adapted from Damon Clark's slide



Reichardt model

barlow-levick model



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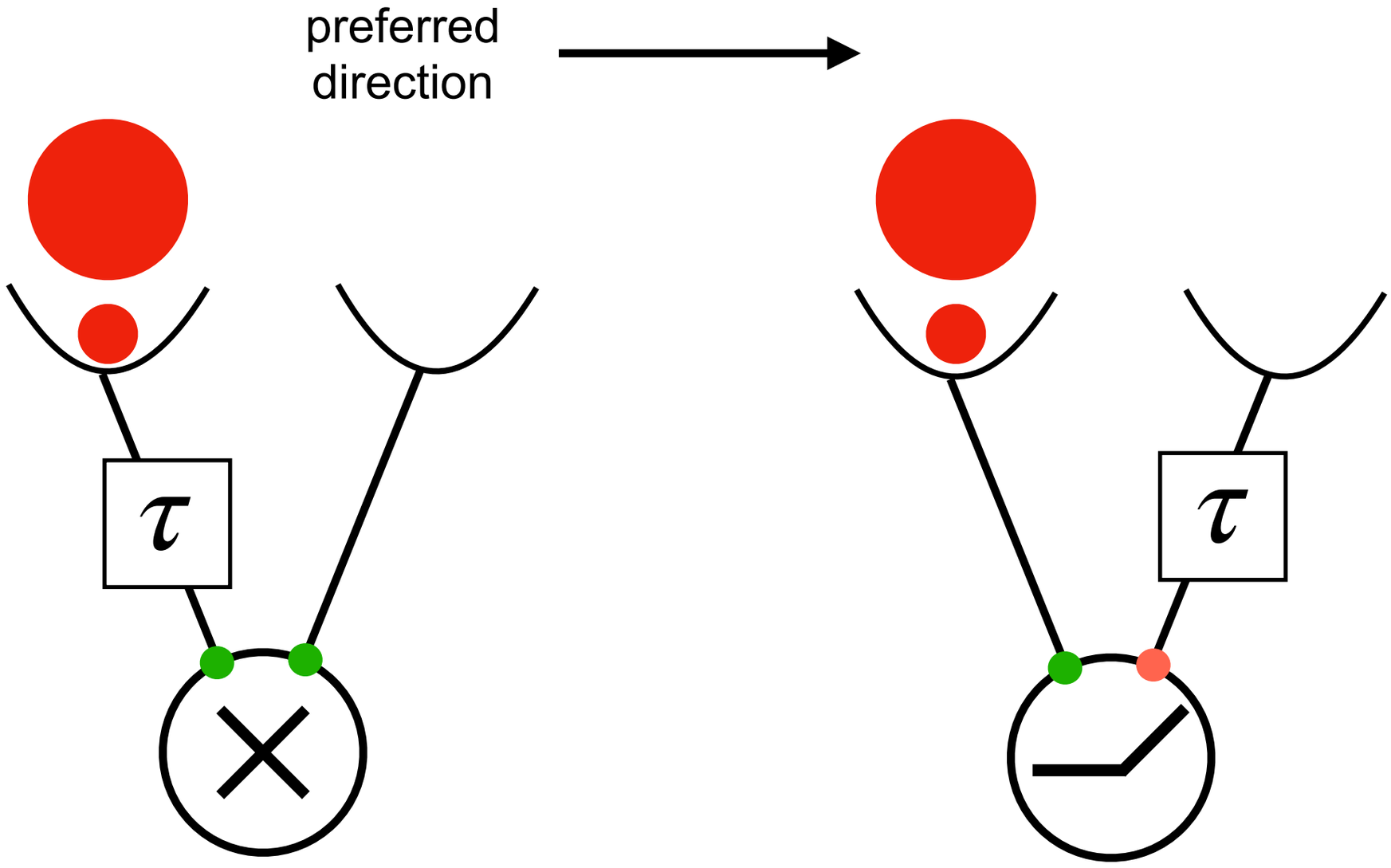

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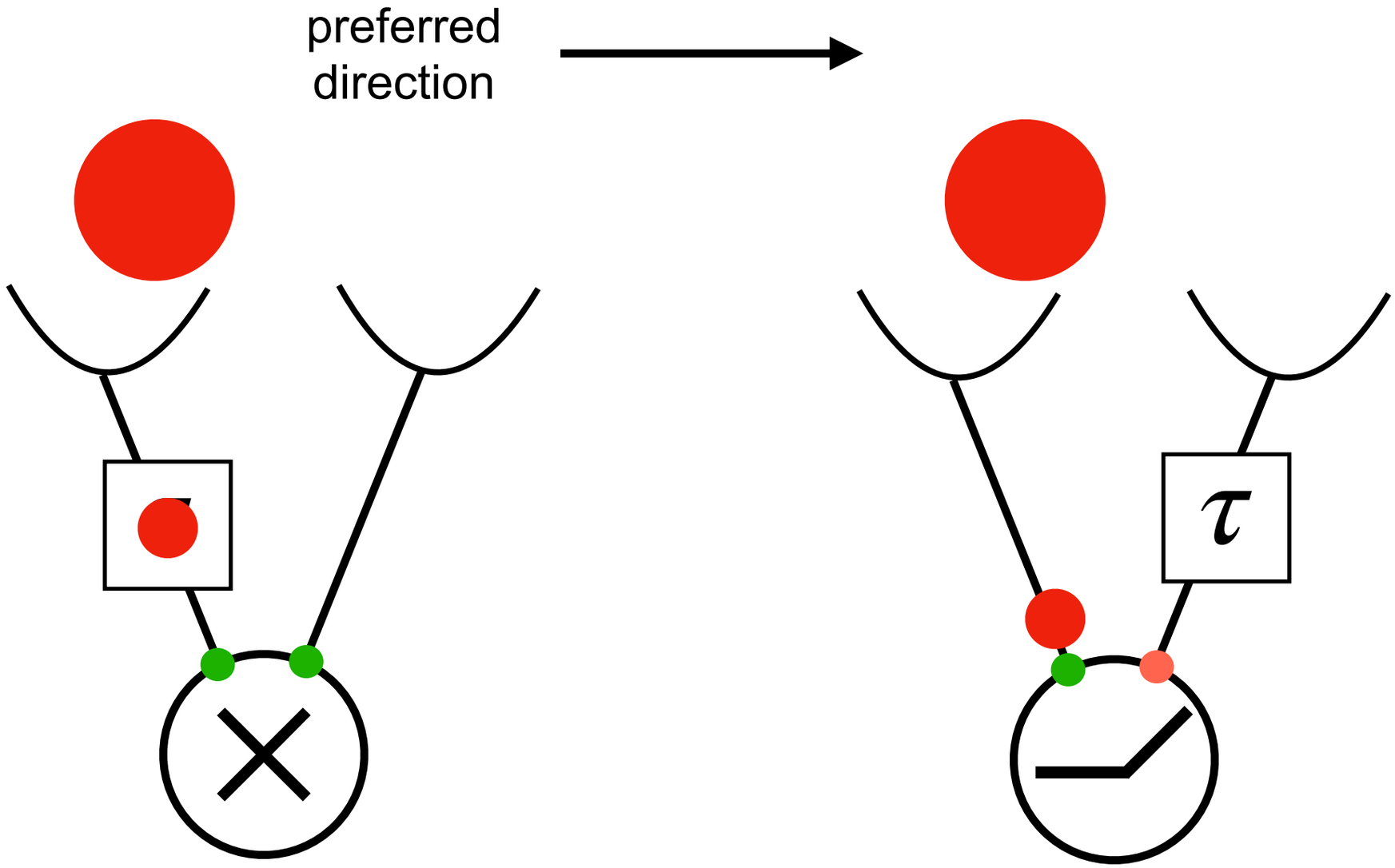

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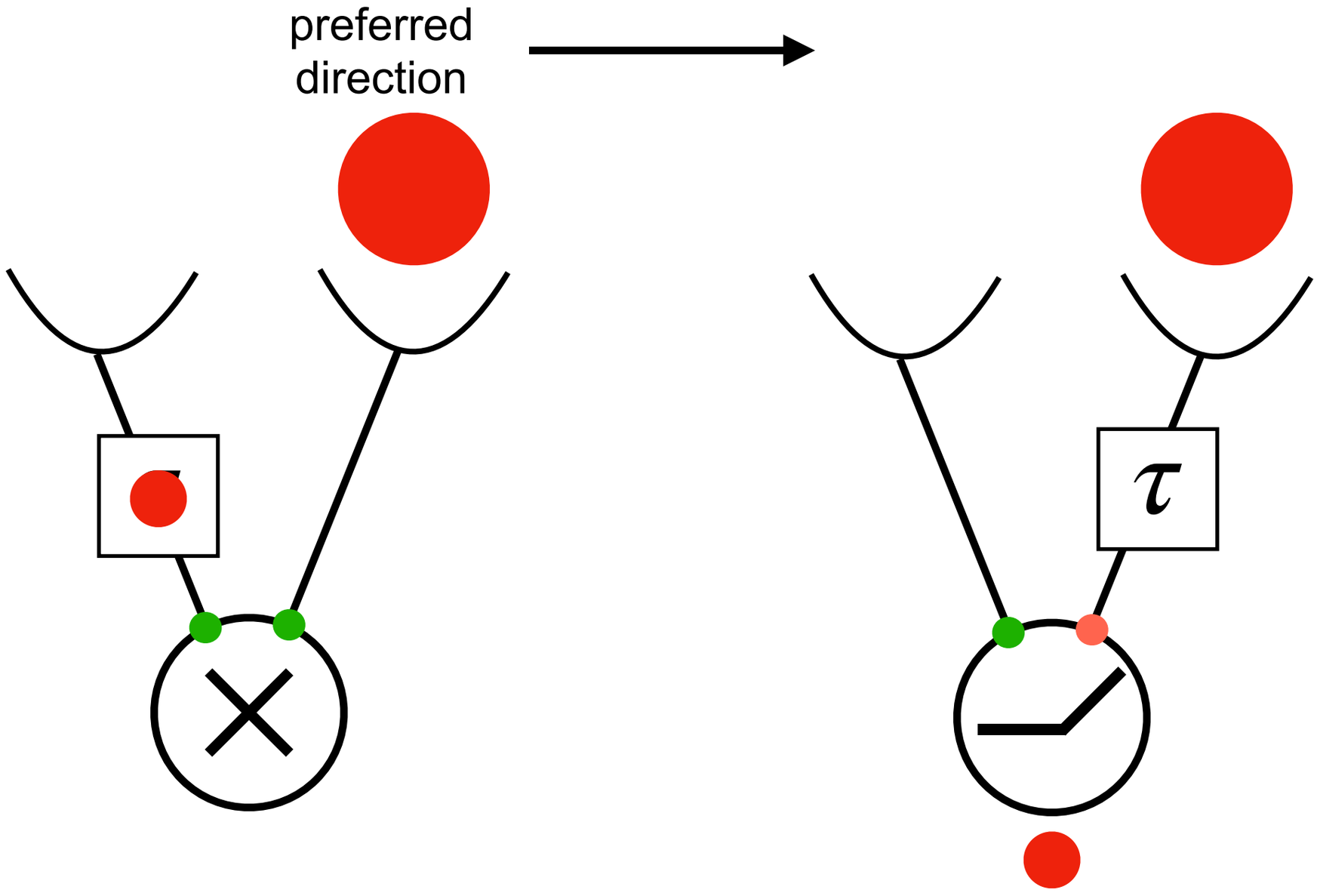
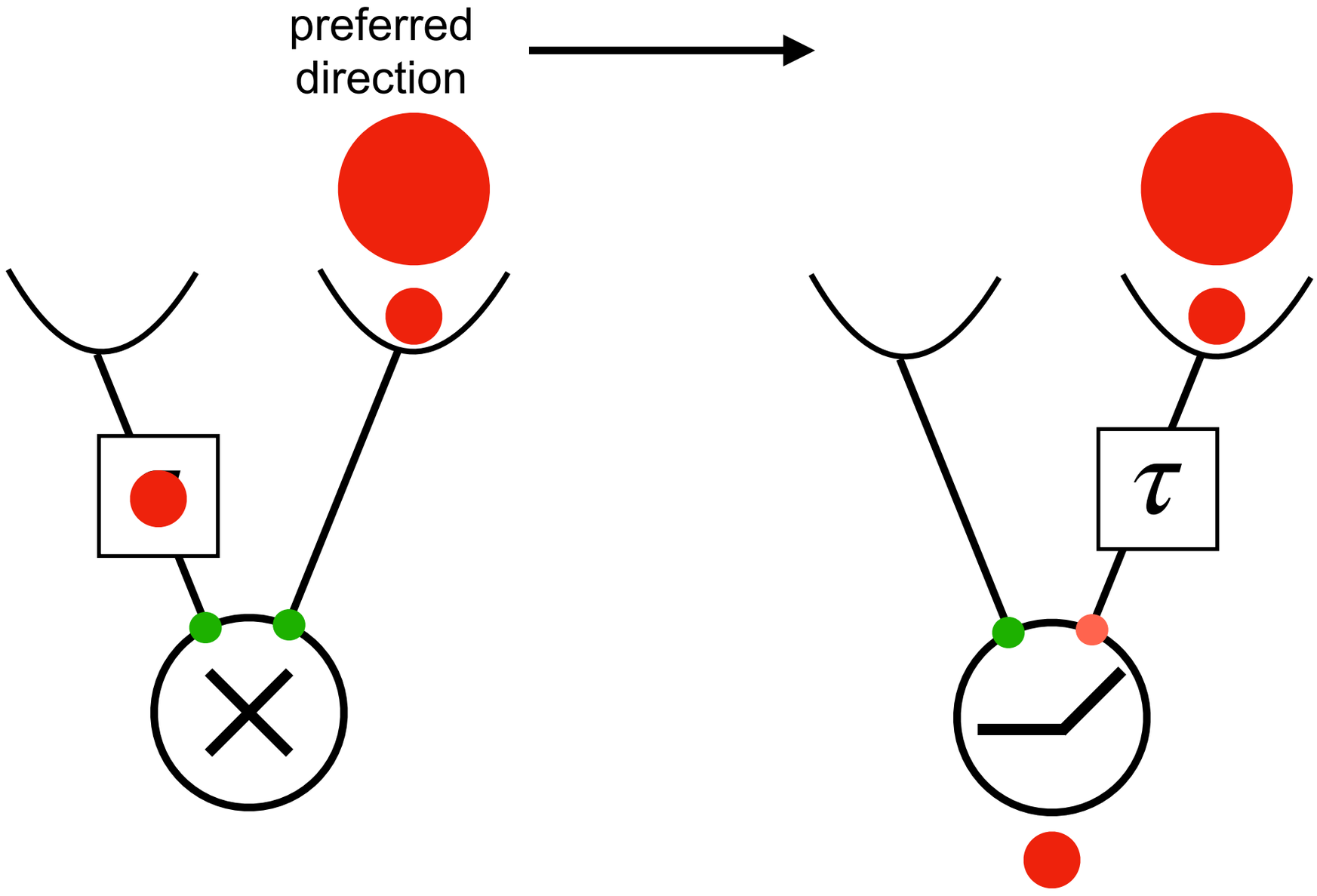


Reichardt model **barlow-levick model**



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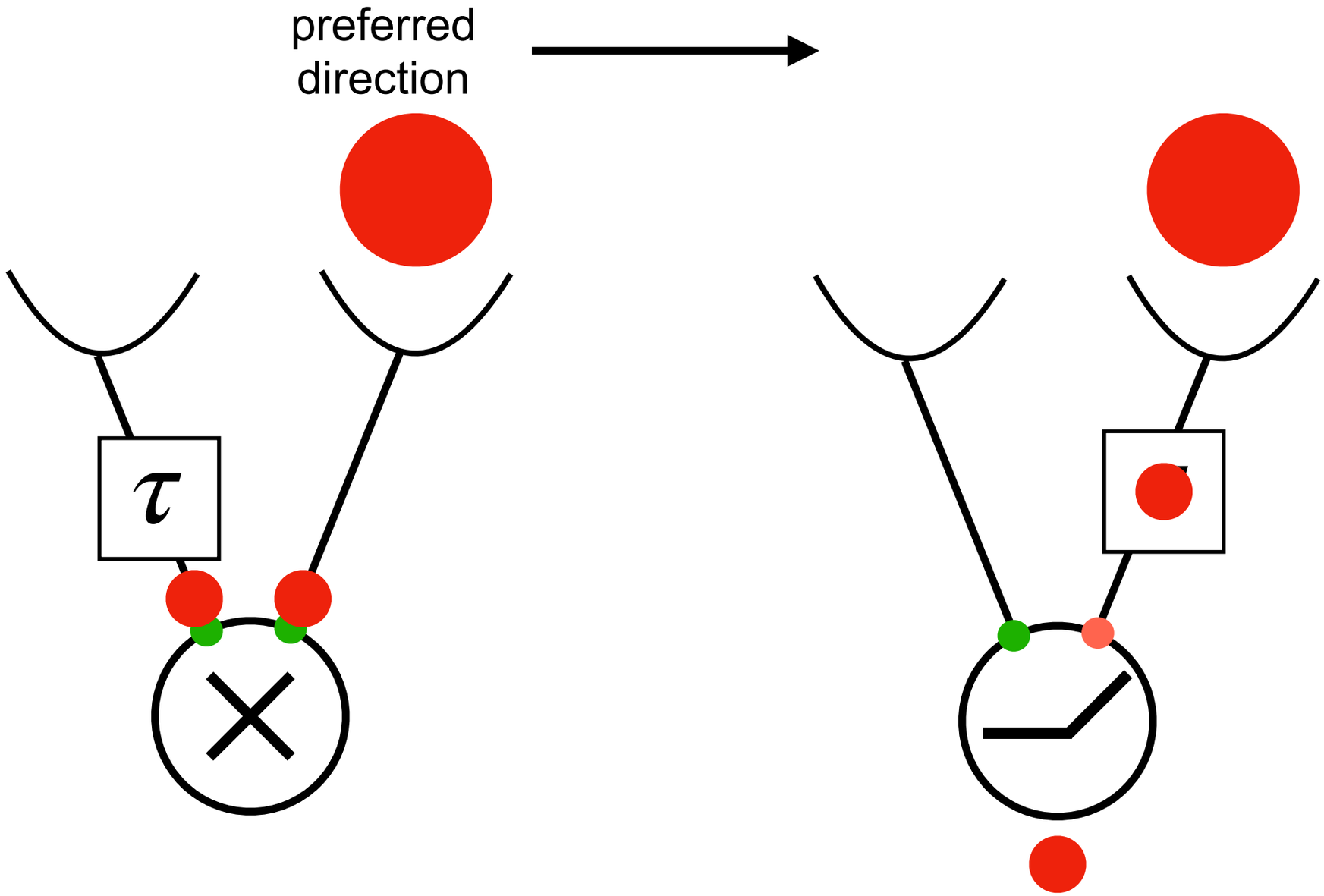
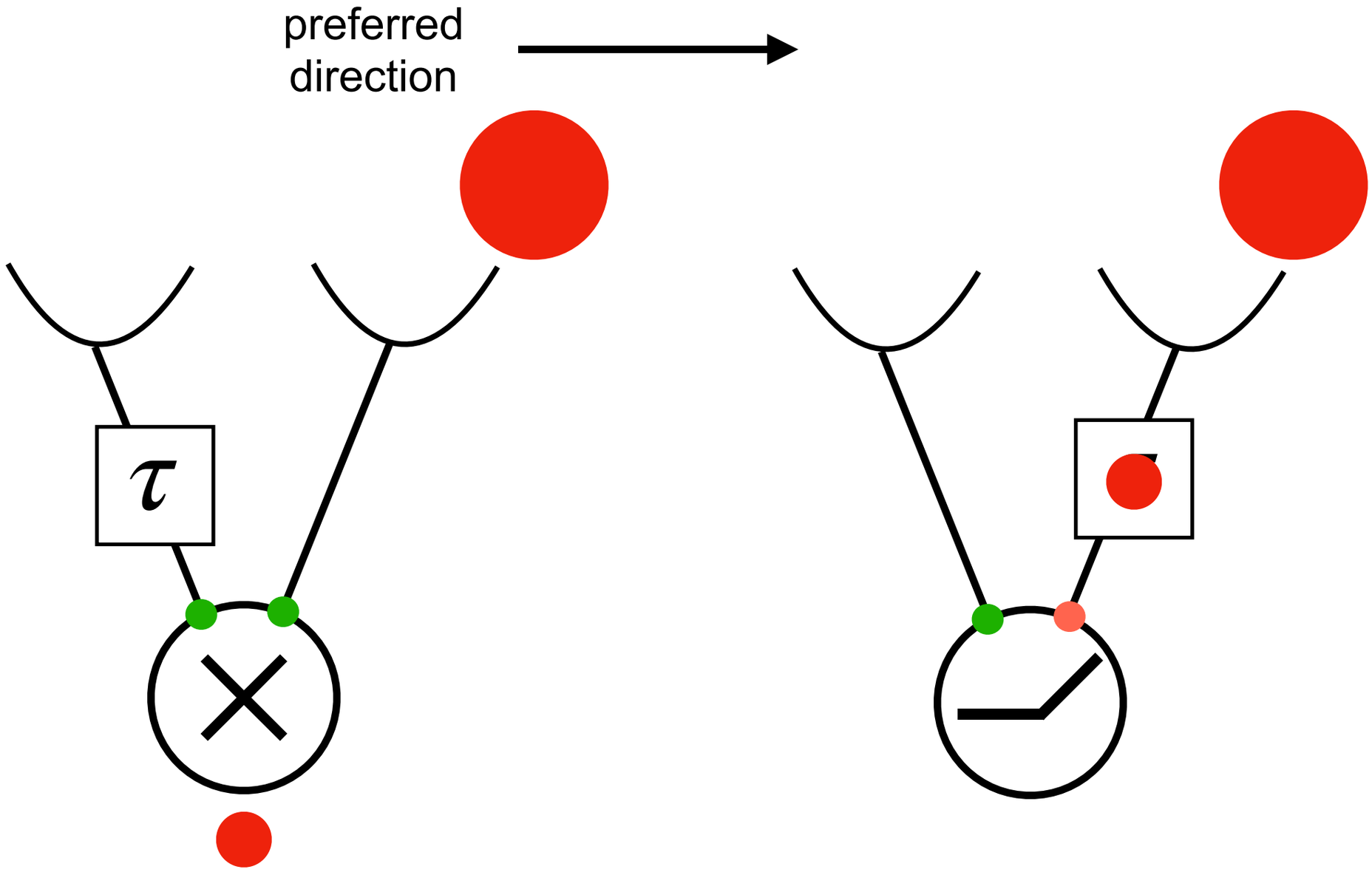


Reichardt model

barlow-levick model



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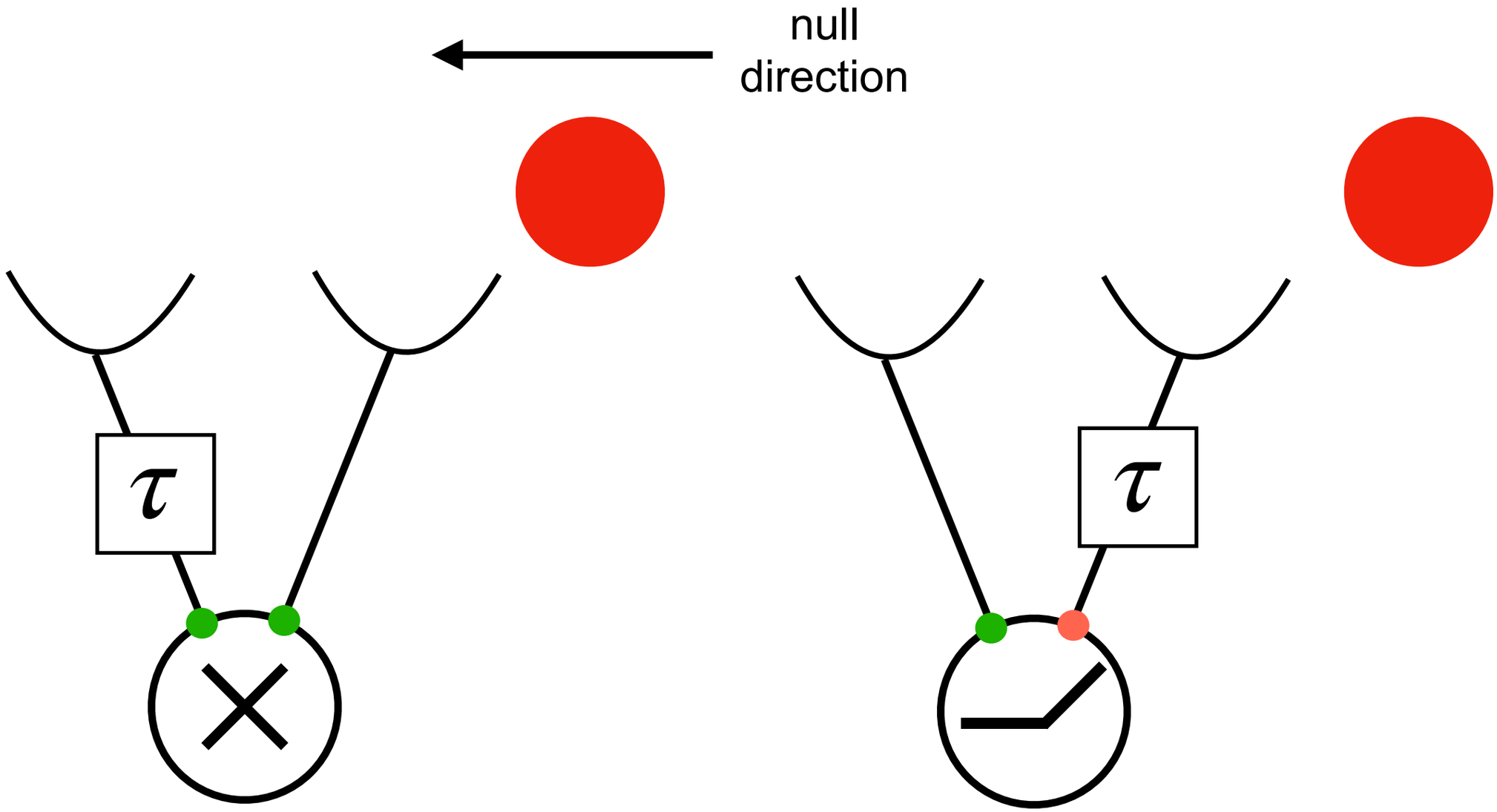
barlow-levick model



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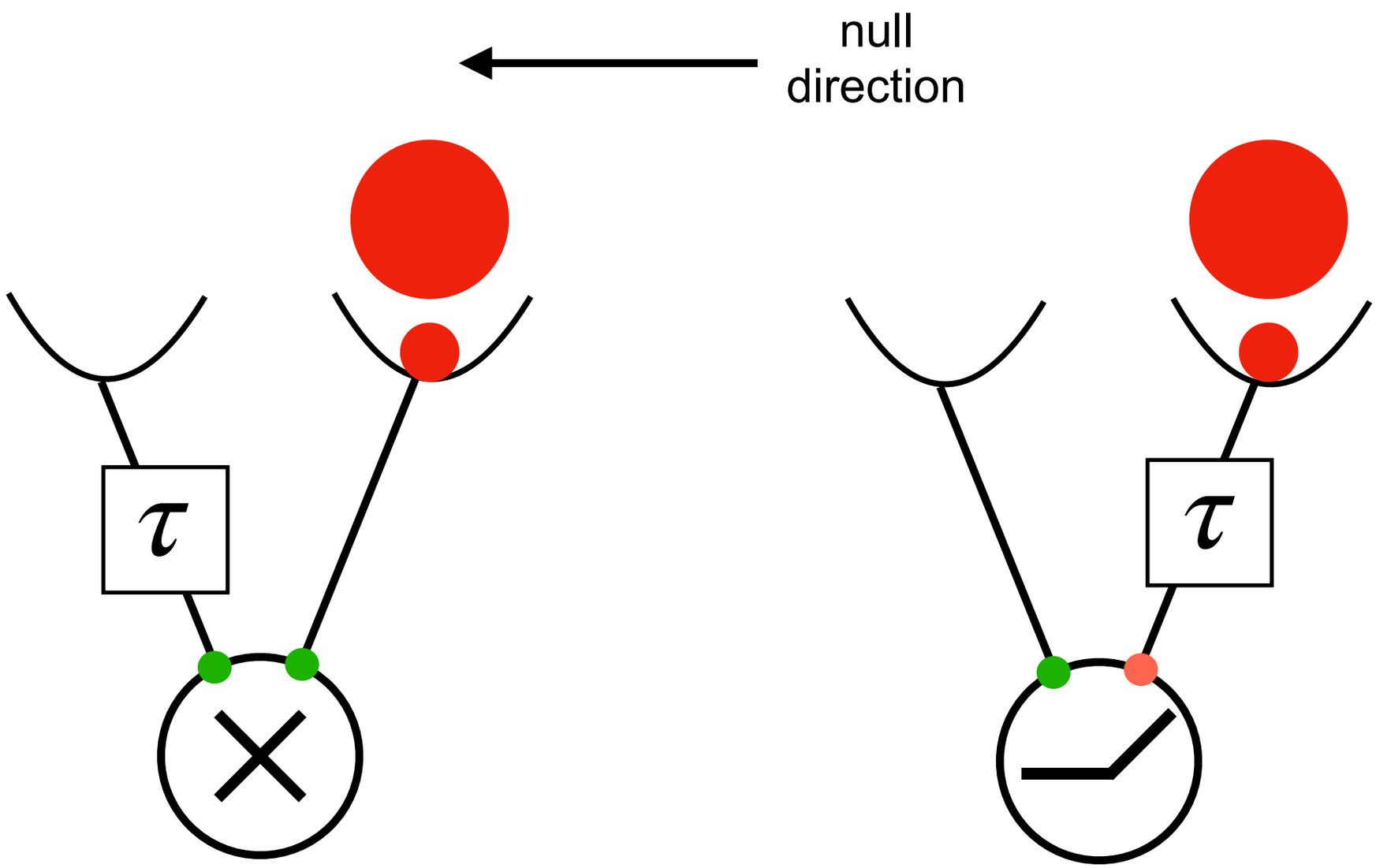
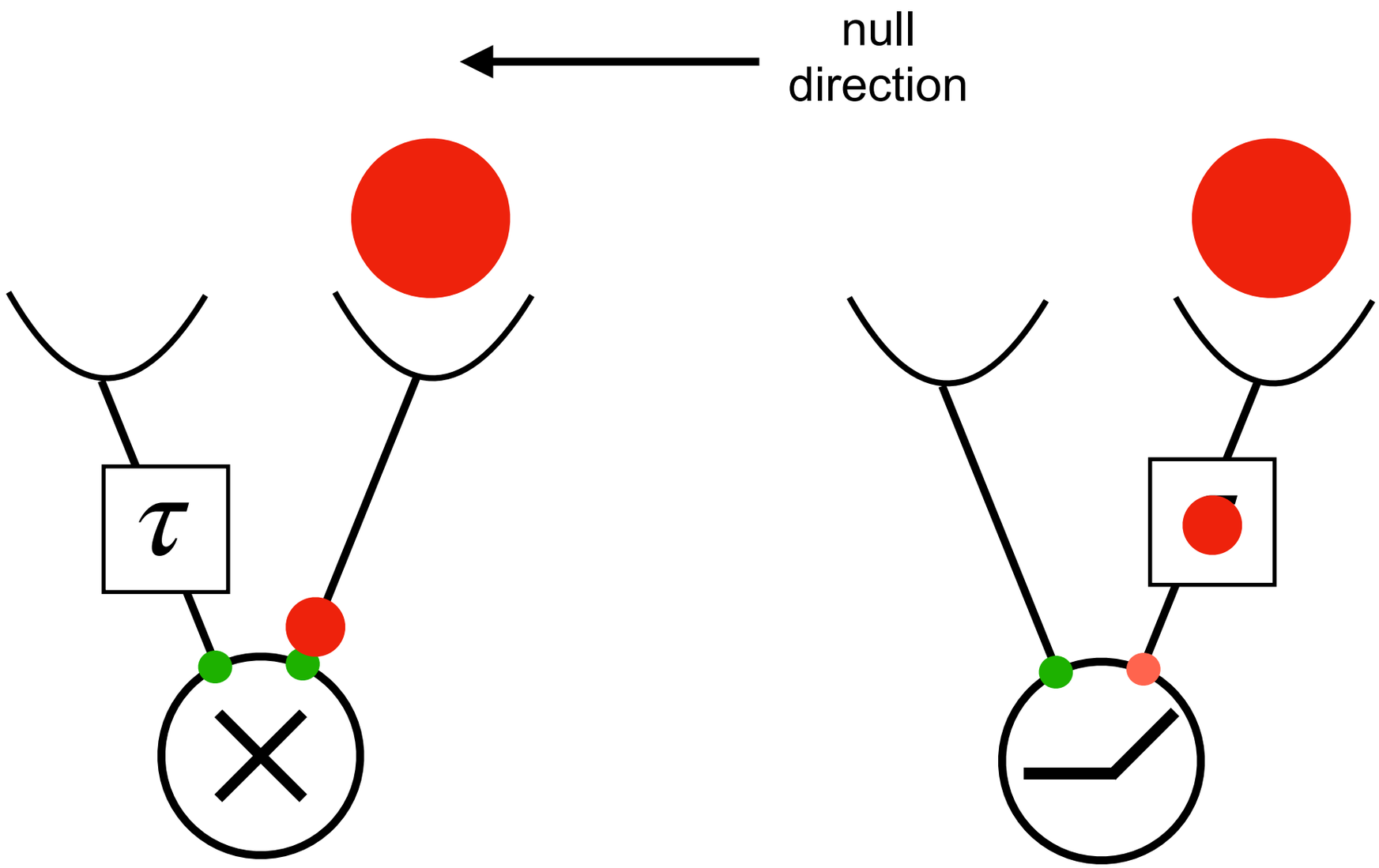


Reichardt model

barlow-levick model



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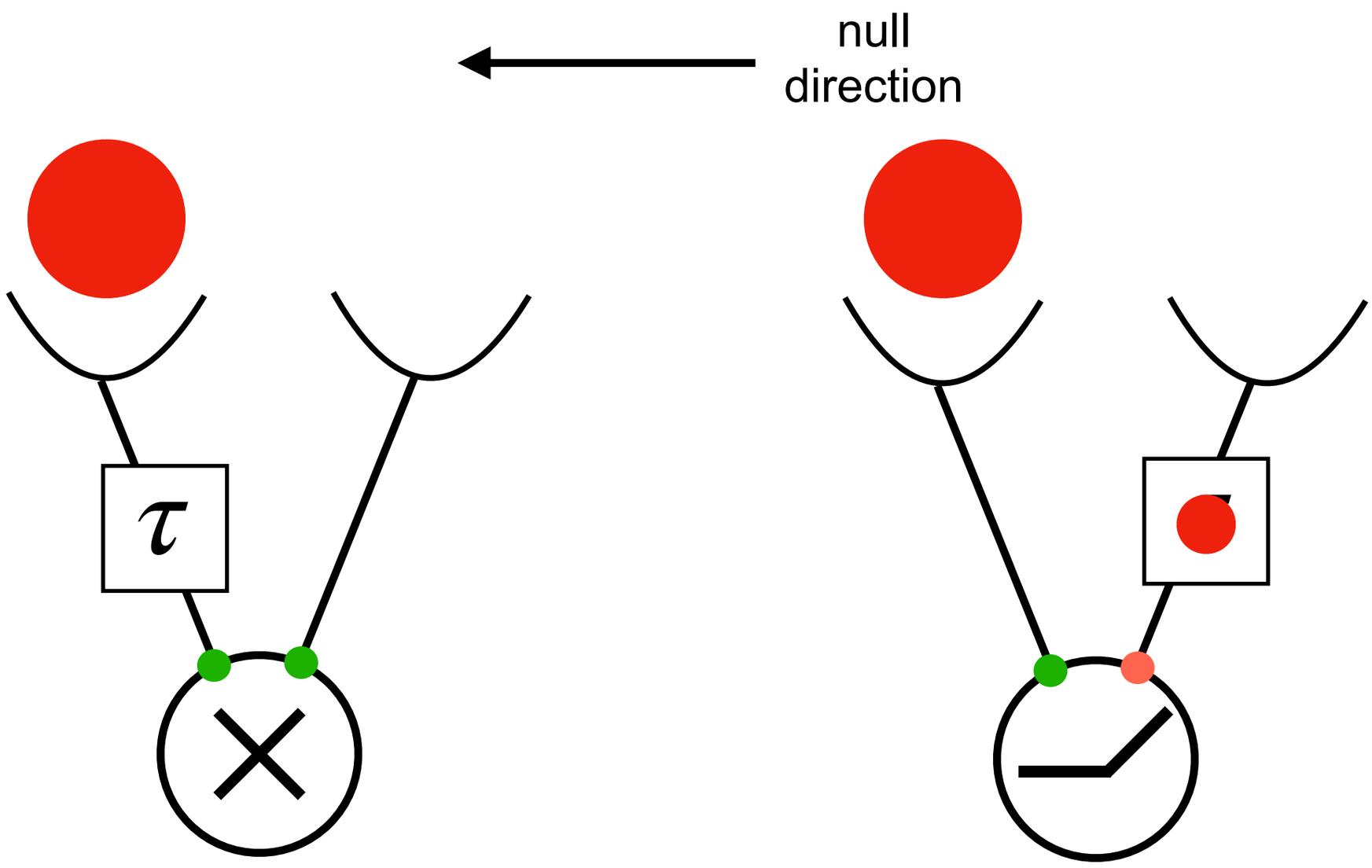

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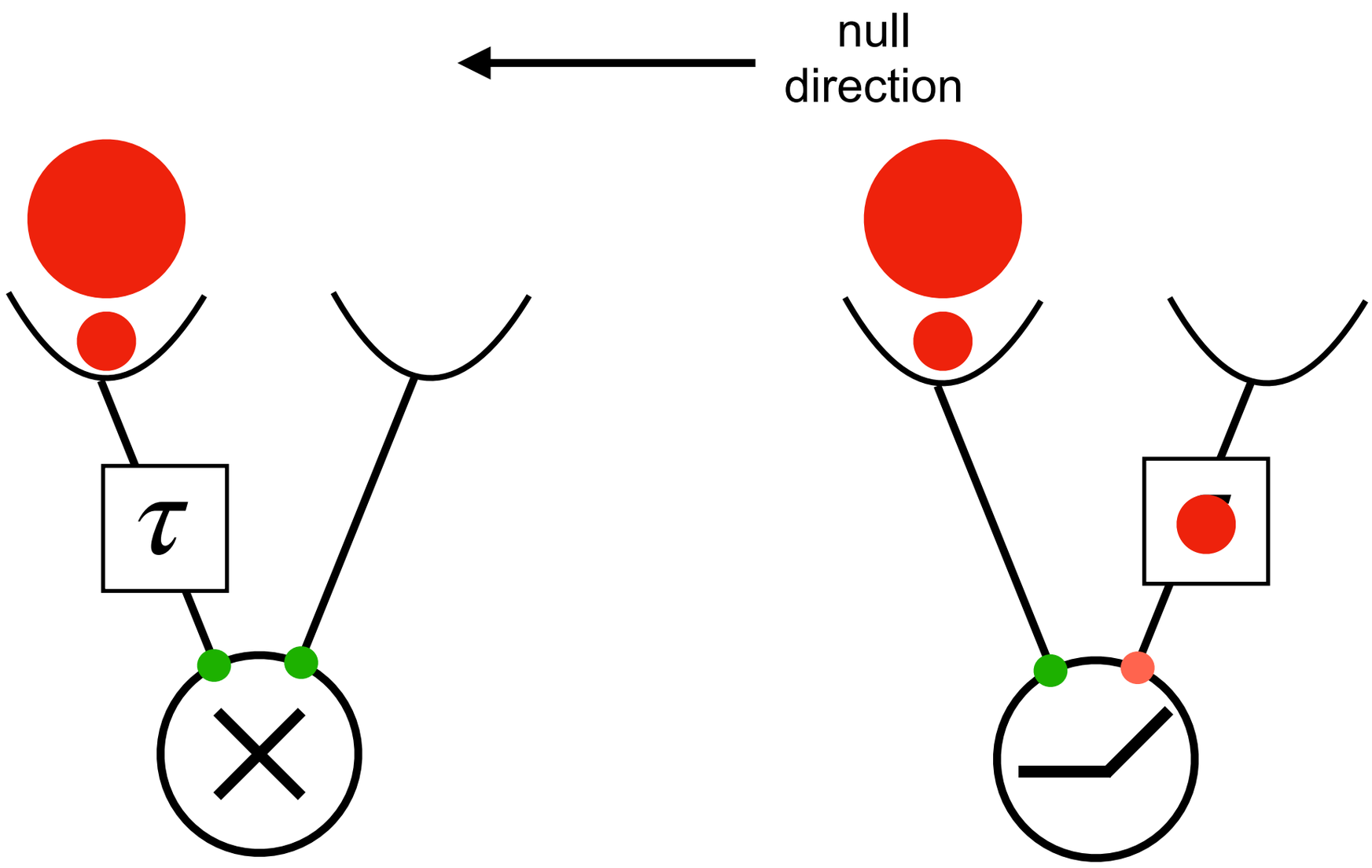

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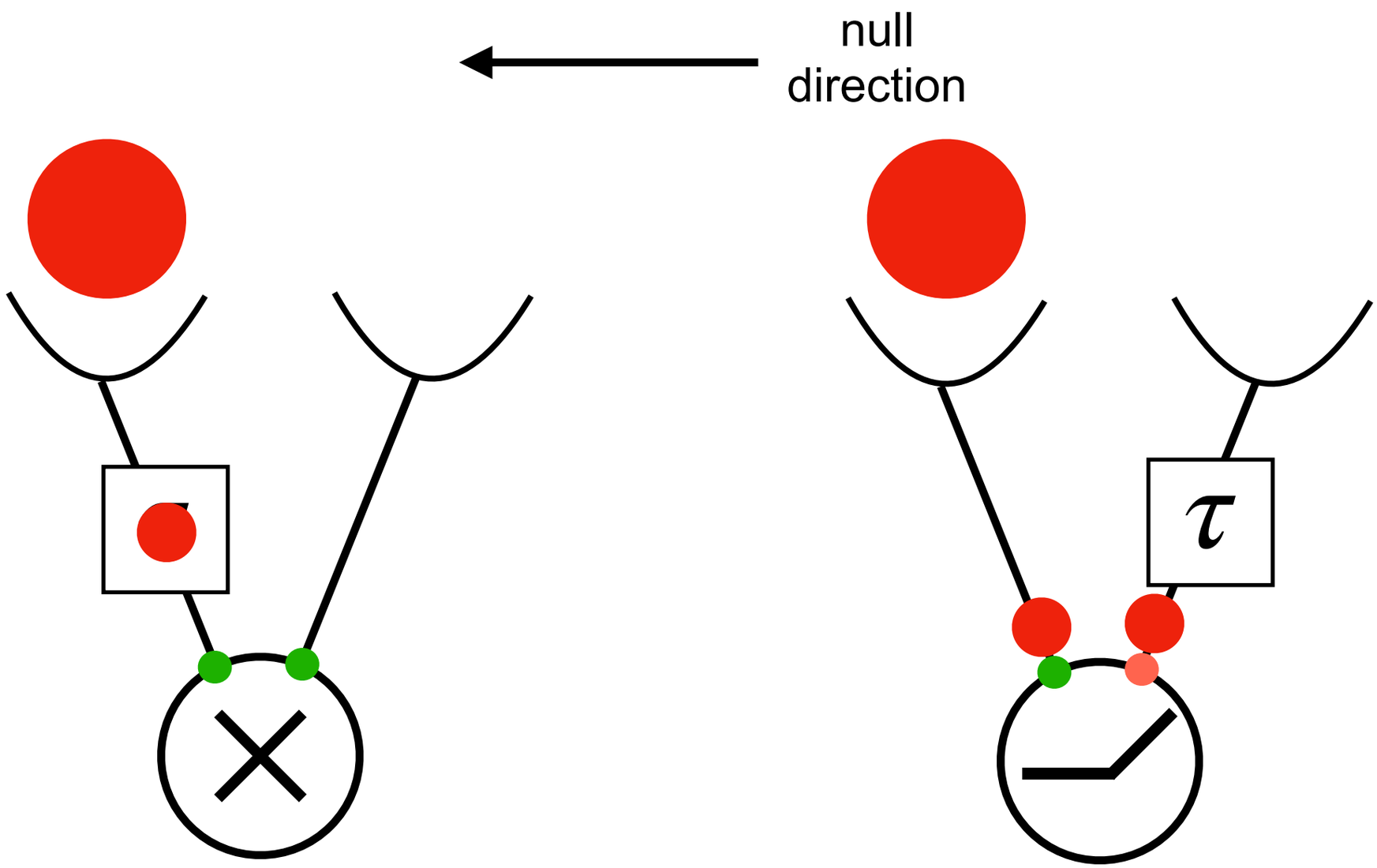

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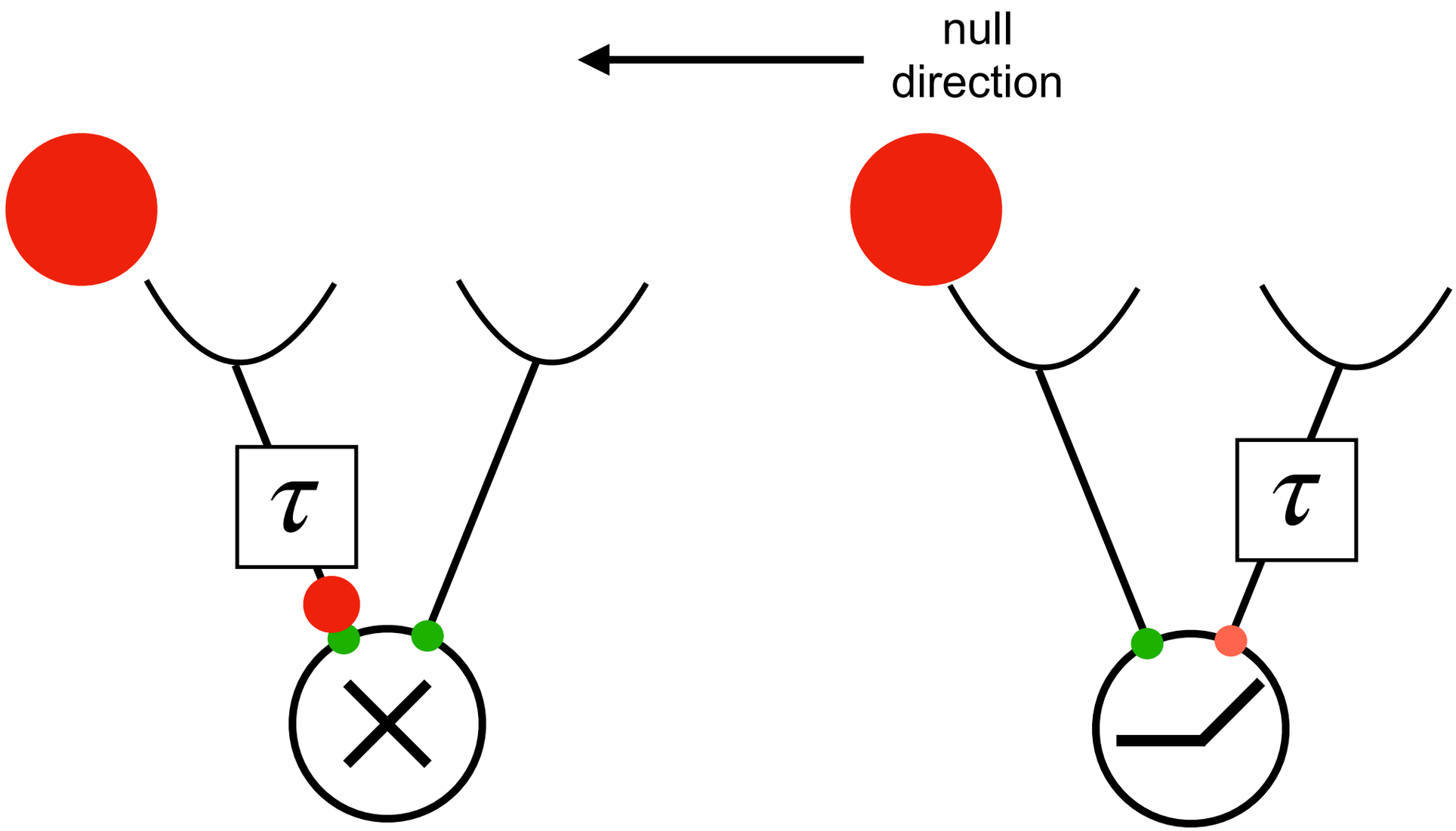

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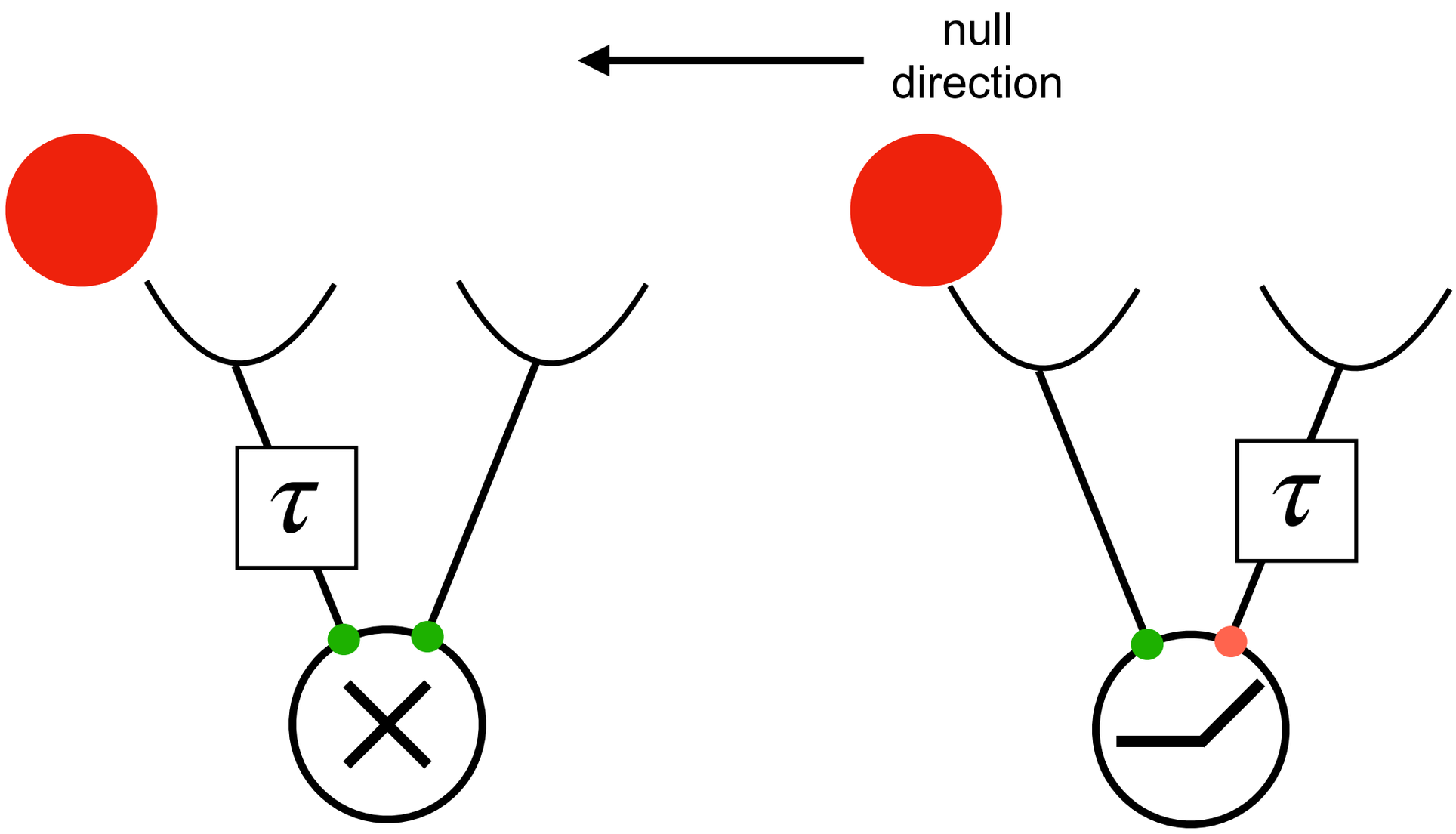

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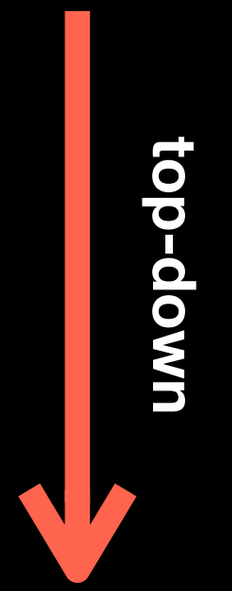
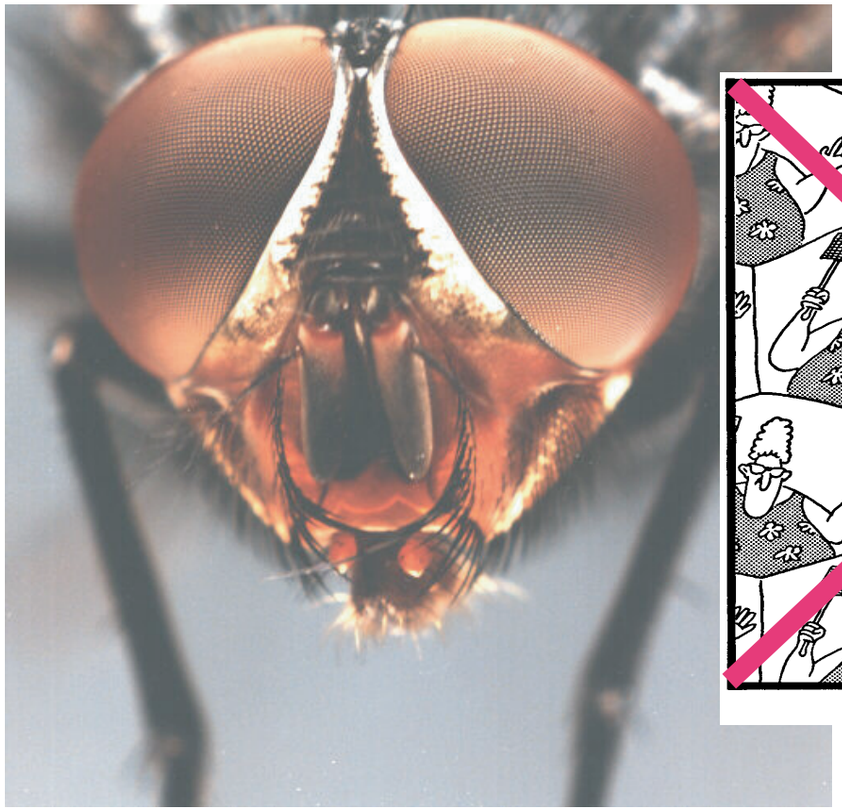
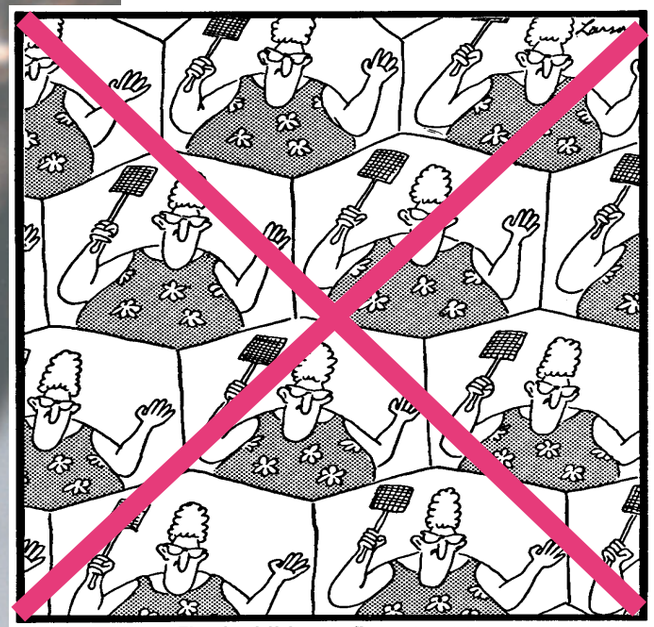


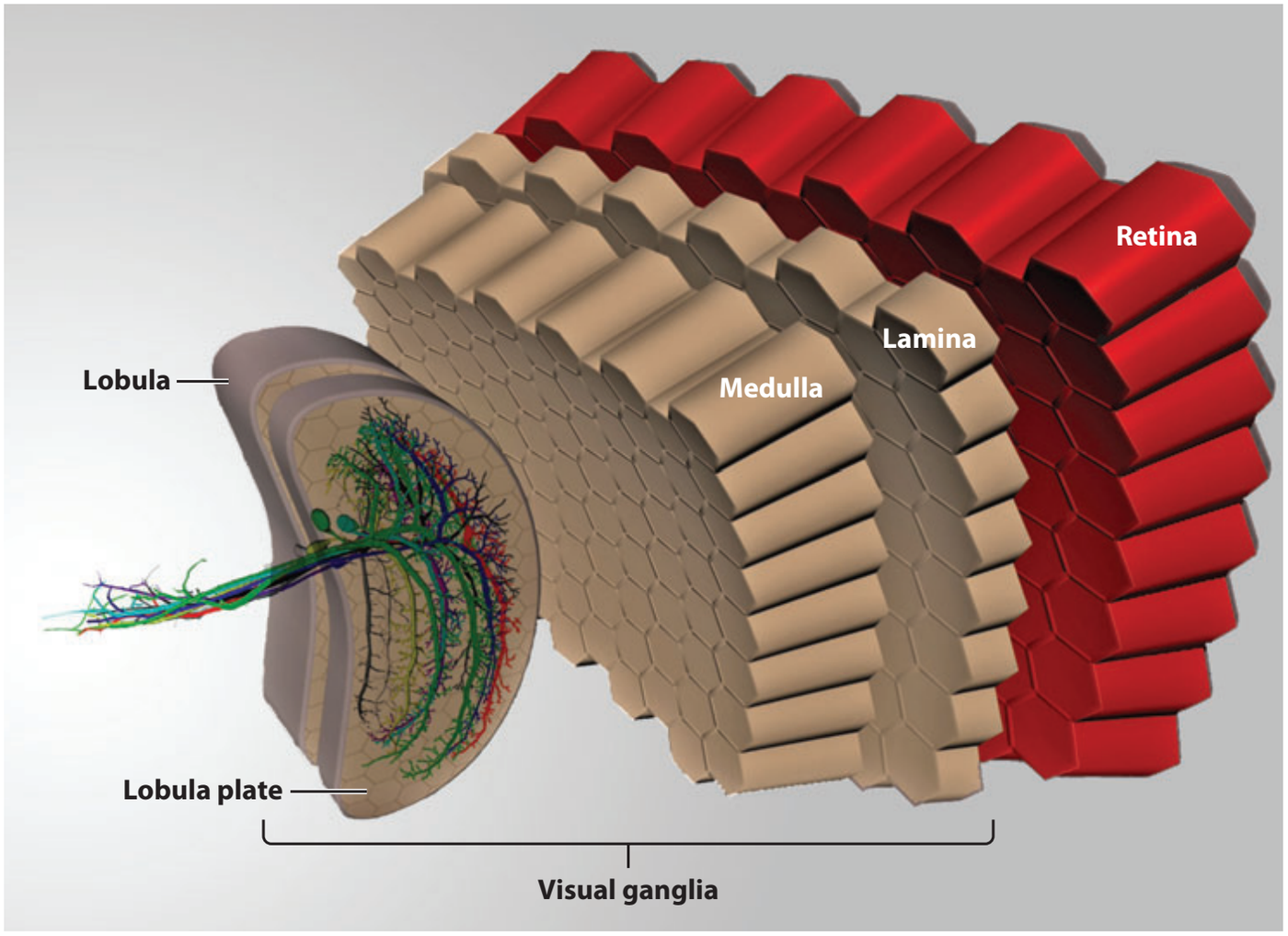
The Fly Visual System





The last thing a fly ever sees

The Fly Visual System



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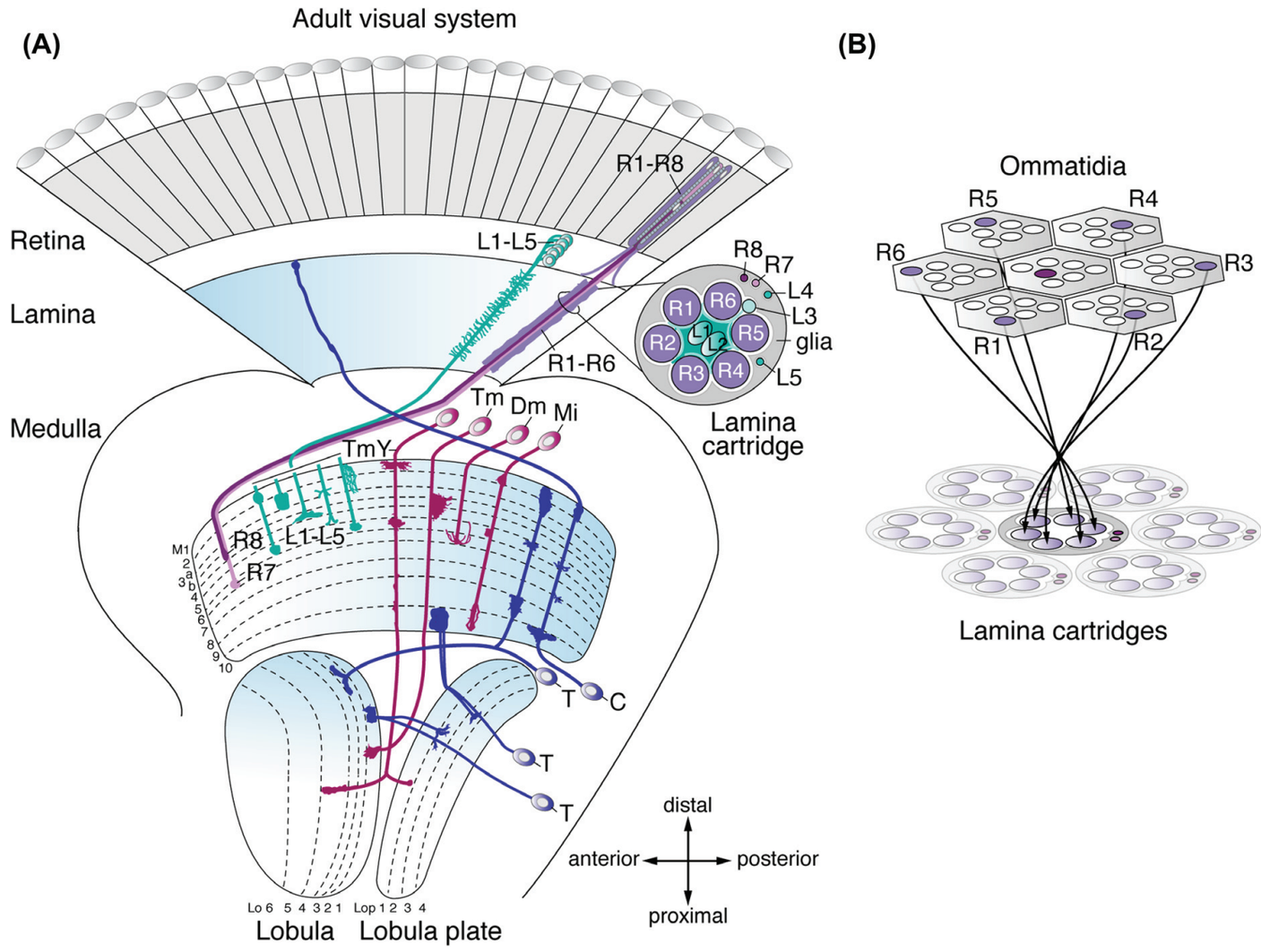
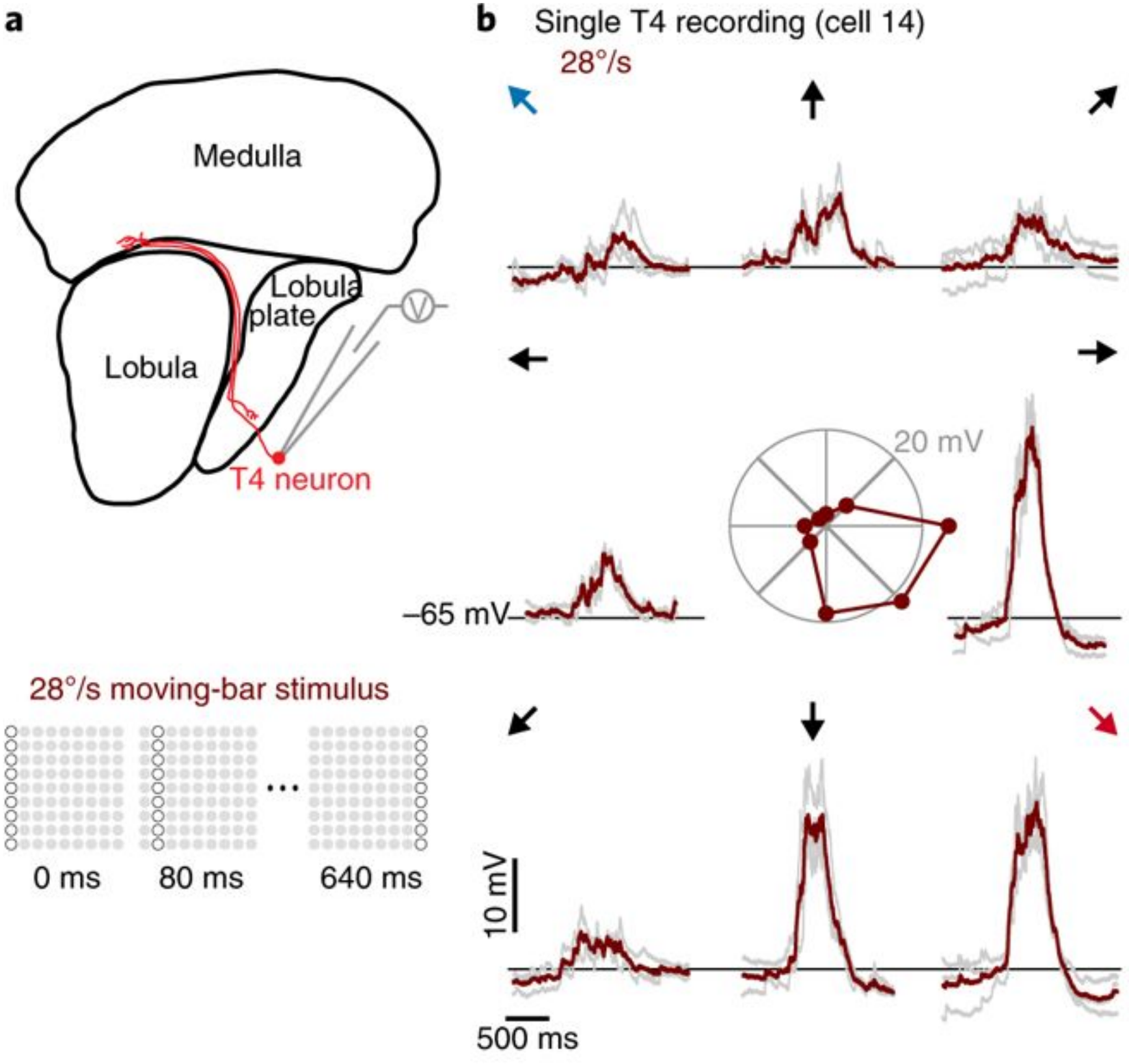
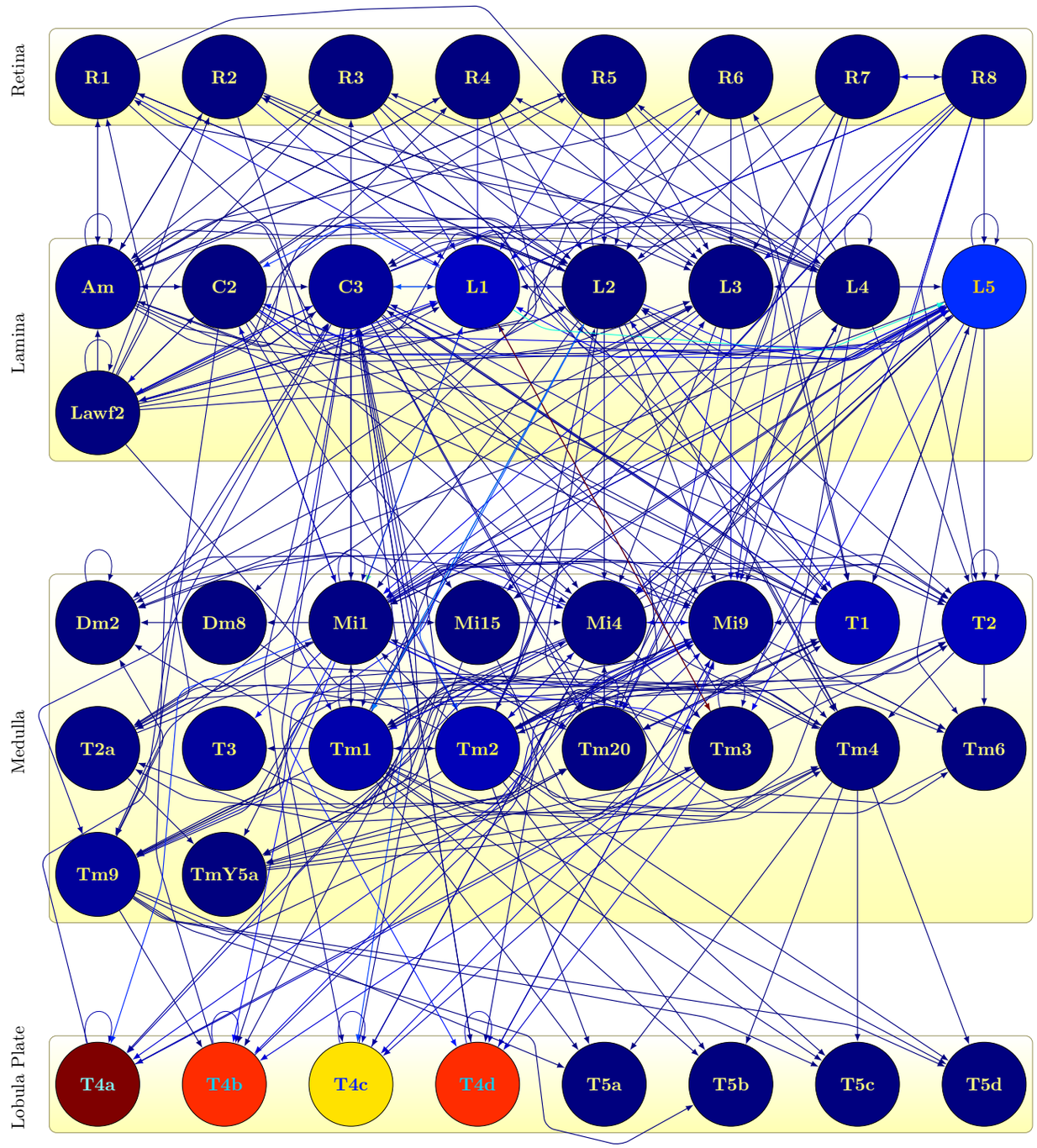




Gruntman, Romani and Reiser et. al., Nature Neuroscience 2018



Takemura et. al., elife 2017

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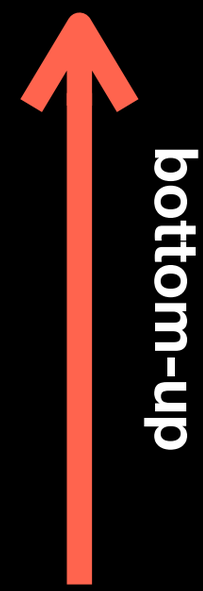
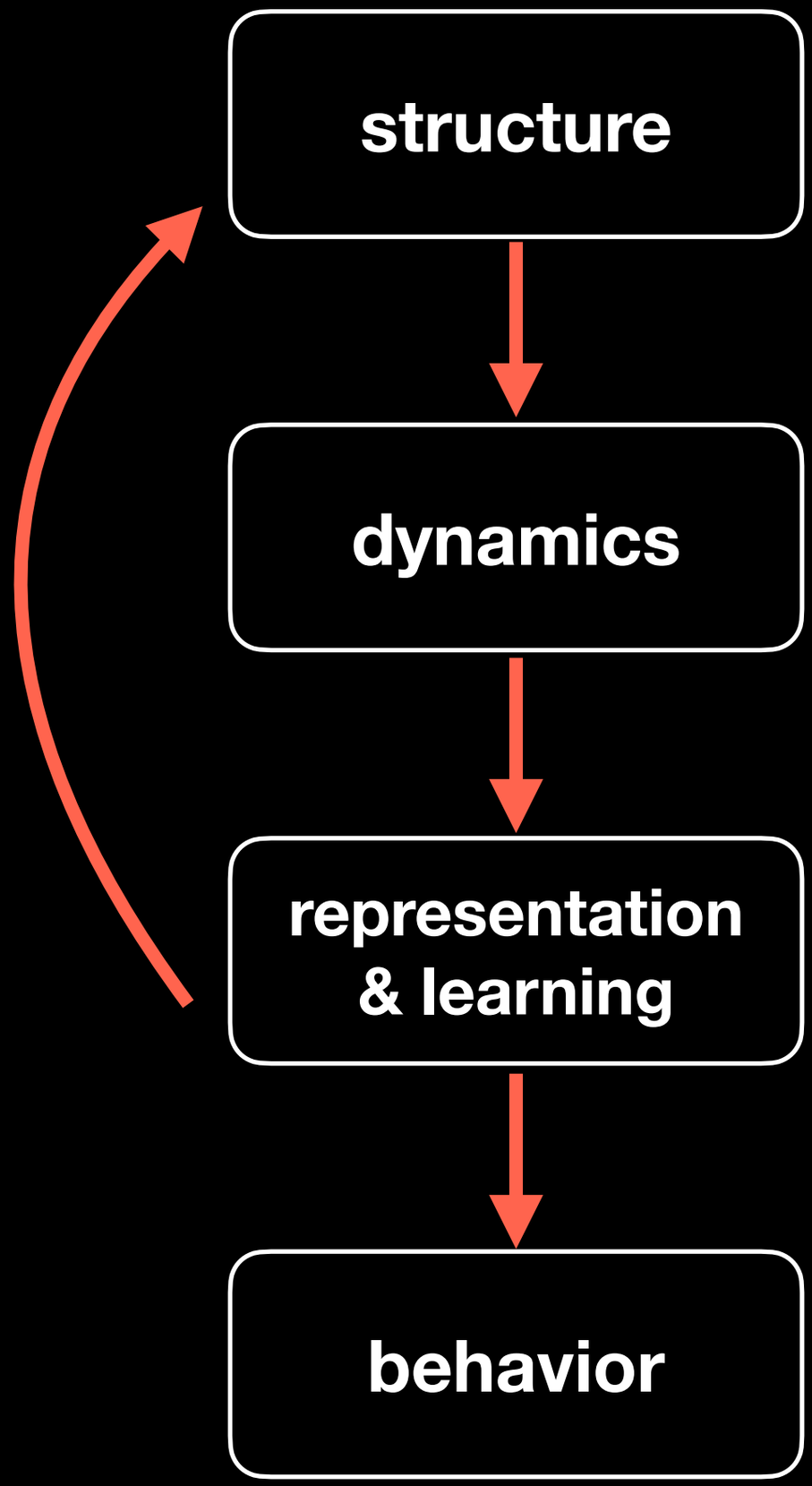


2021 *Fall Course Program*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& learning
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