

New developments in brain imaging, why and how?

Renaud Jolivet, PhD

Colloquium at IJCLab
Orsay, France
18 Apr 2023



Maastricht University



@RenaudJolivet





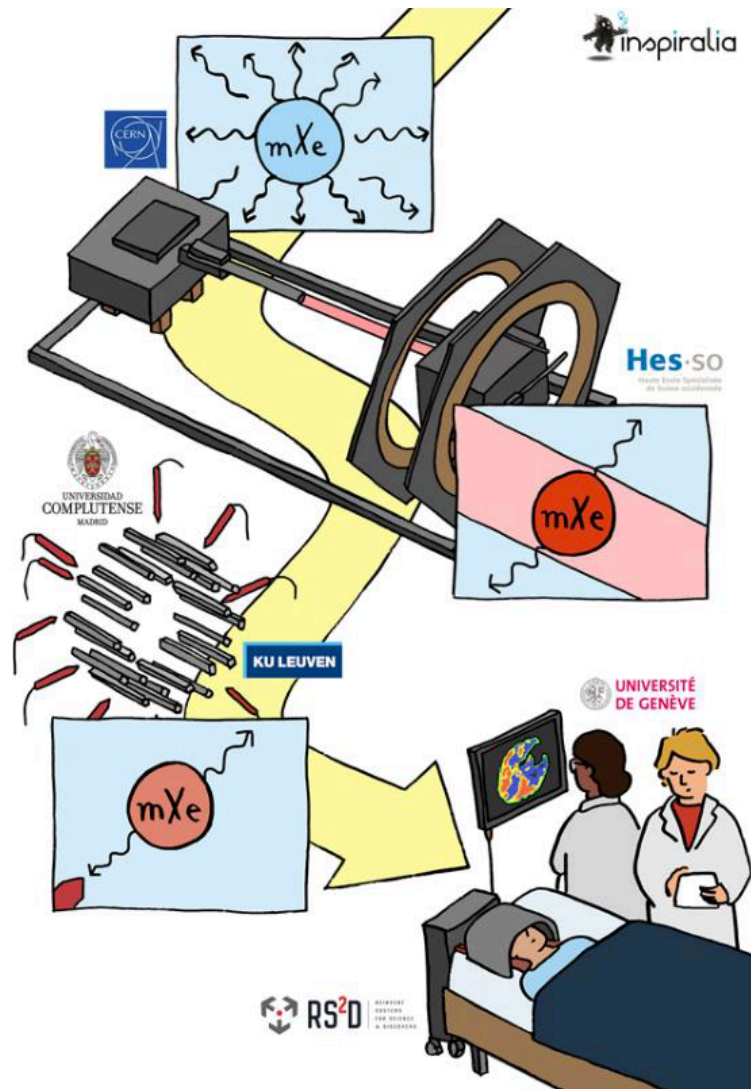
A novel modality to investigate brain activity?

H2020 FET-Open GAMMA-MRI



Started Spring 2021 (about 2 out of 3.5 yrs); ~3.4M€

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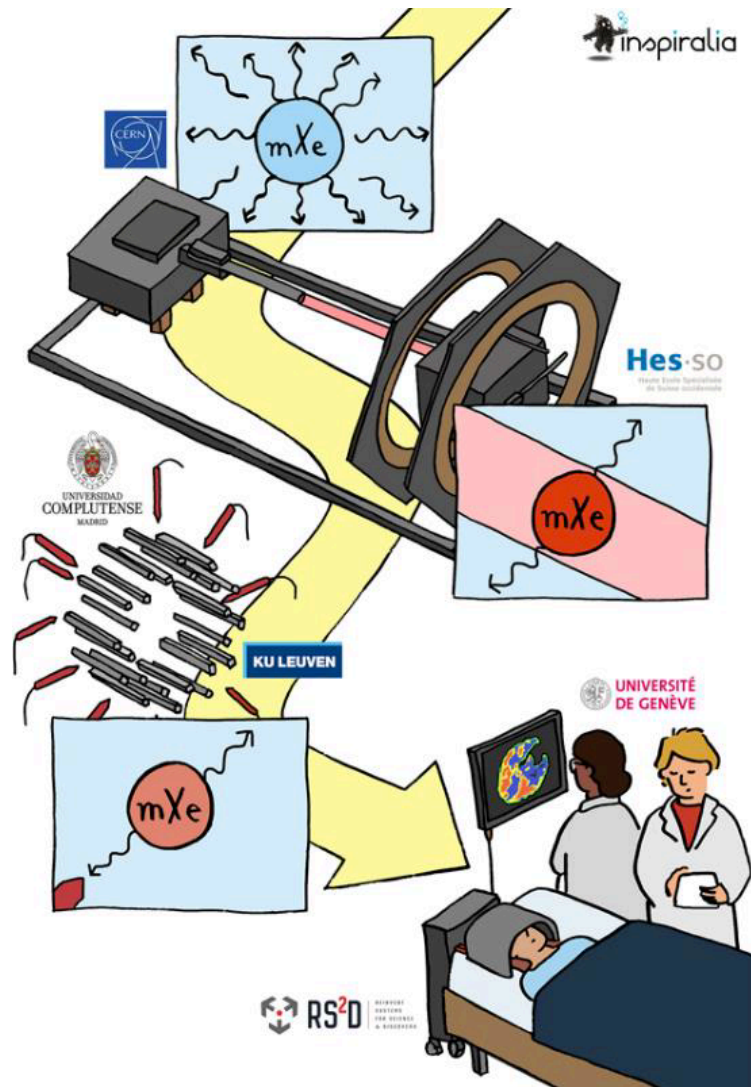
Partners: **Hes·SO**

KU LEUVEN



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1. Production of $^{129,131,133}\text{mXe}$

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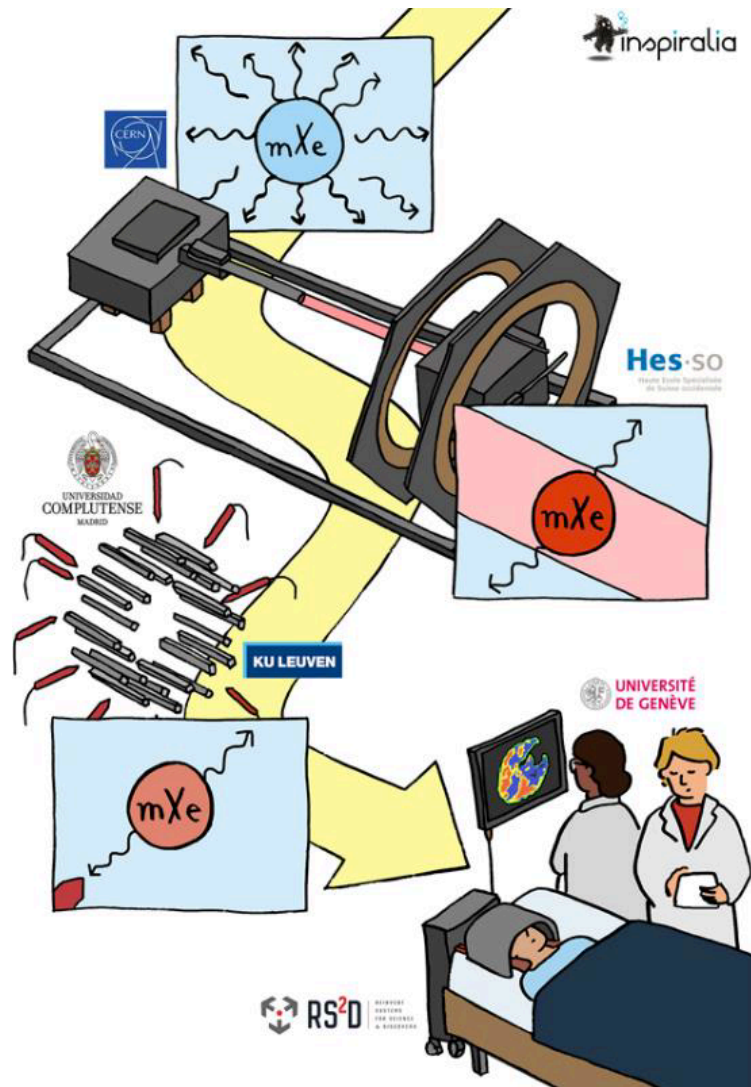
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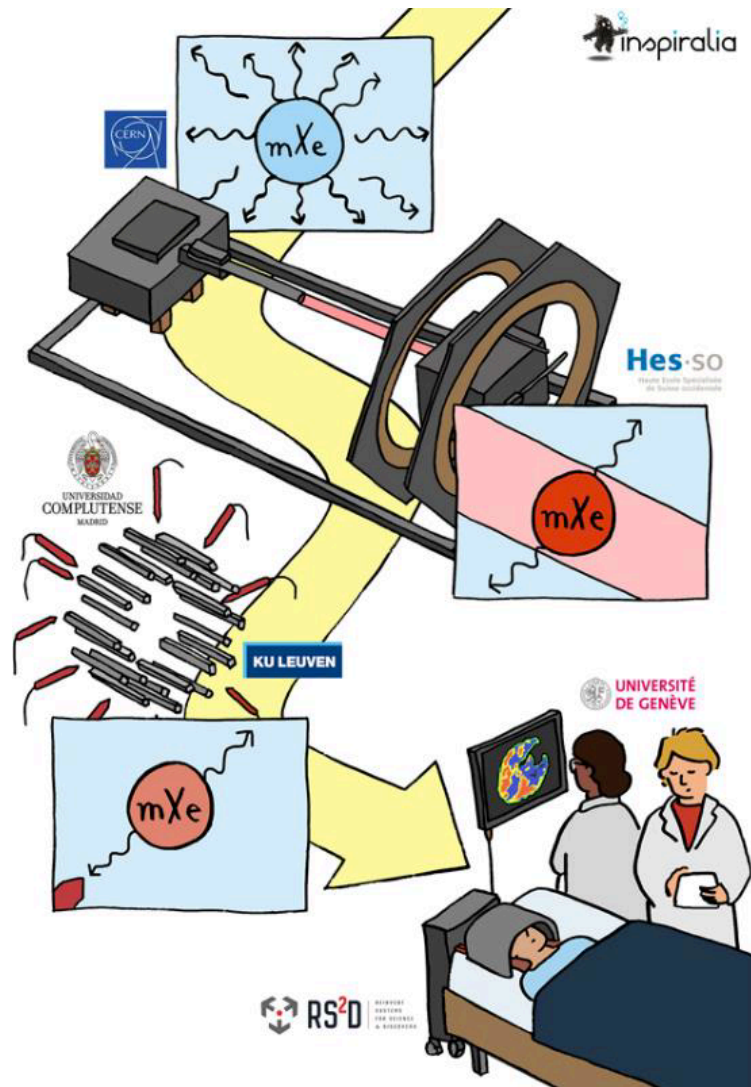
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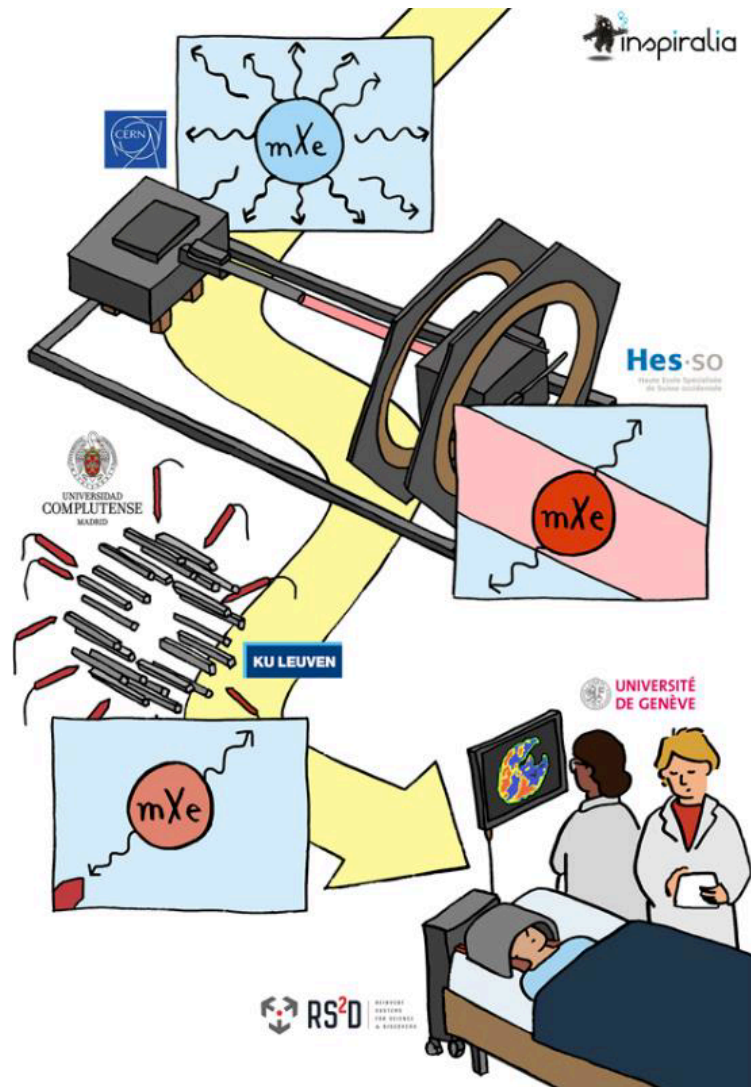
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3. Inhalation by test subject
4. Detection of emitted gammas and image reconstruction

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- Production of $^{129\text{m}}\text{Xe}$ and $^{131\text{m}}\text{Xe}$ via neutron activation of ^{128}Xe and ^{130}Xe at the ILL and MARIA high-flux reactors (paper submitted soon)

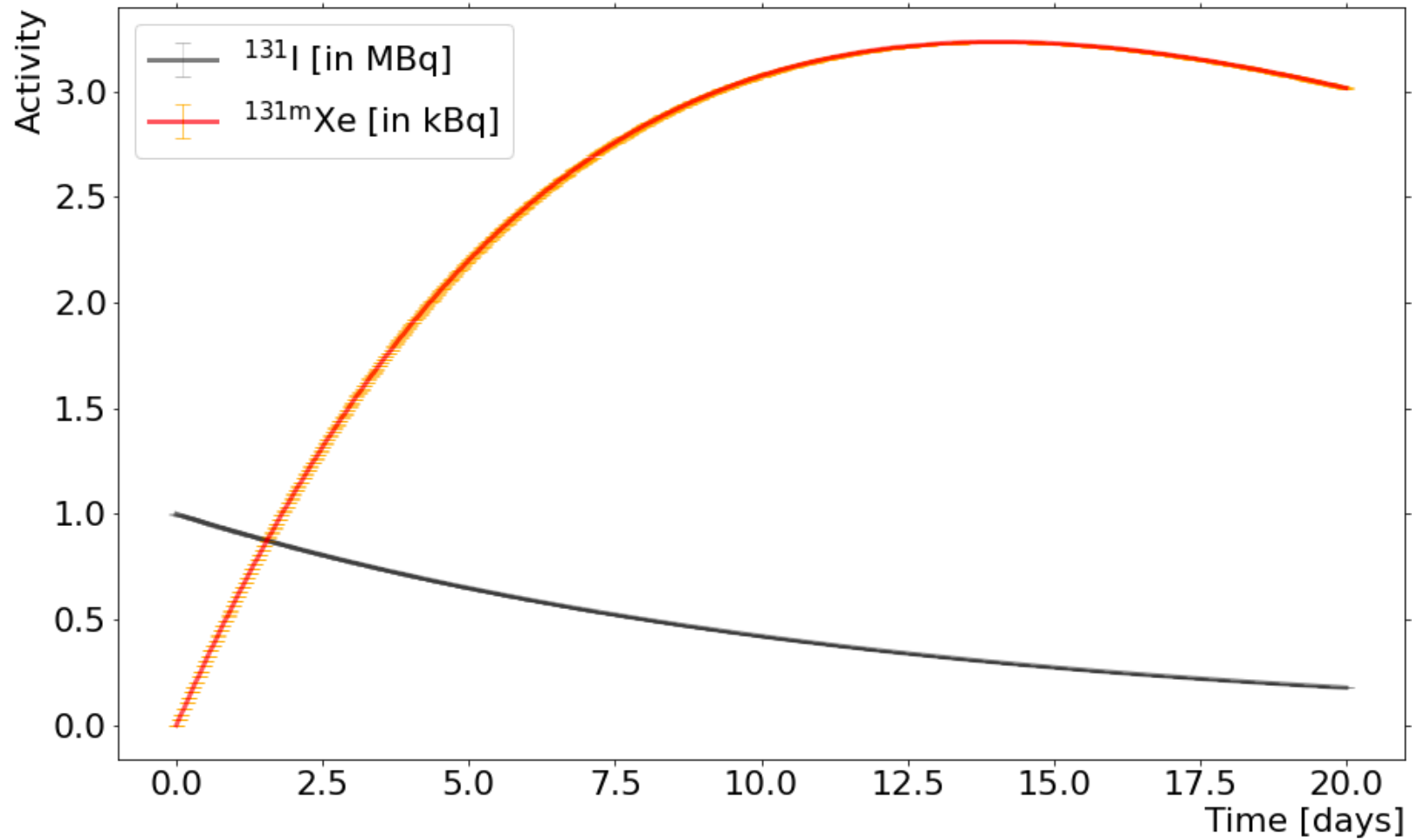
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- From the decay of Na^{131}I

Production of mXe from I (simulations)



Production of mXe from I (experiments)

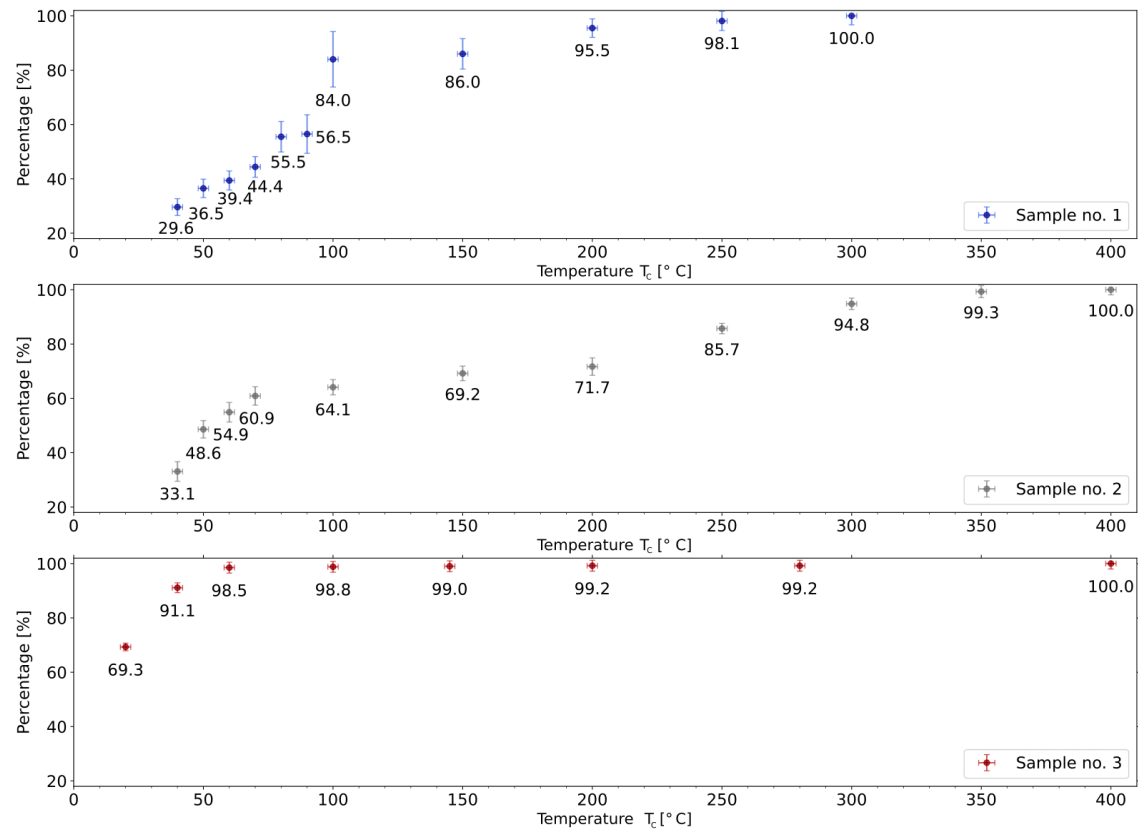
ID	Measured ^{131}I Activity at Delivery [MBq] *	Time T between EOM and Delivery [Days]	^{131}I Transfer Rate ρ	Determined $^{131\text{m}}\text{Xe}$ Activity at EOC (Given ρ and α) [kBq]	Measured $^{131\text{m}}\text{Xe}$ Activity at EOC [kBq] *	Efficiency of $^{131\text{m}}\text{Xe}$ Collection
1	49.0(5)	6	64(1)%	119(4)	99(2)	83(3)%
2	51.1(6)	2	85(2)%	149(5)	131(4)	88(3)%
3	47.5(4)	22	96(2)%	240(7)	204(1)	85(3)%

*—measured with Canberra n-type XtRa detector, model GX6020. EOM—end of manufacturing of ^{131}I capsule. EOC—end of collection of $^{131\text{m}}\text{Xe}$. ρ —the transfer rate of ^{131}I from the capsule to the vial. α —the determined release rate of $^{131\text{m}}\text{Xe}$ at ambient conditions.

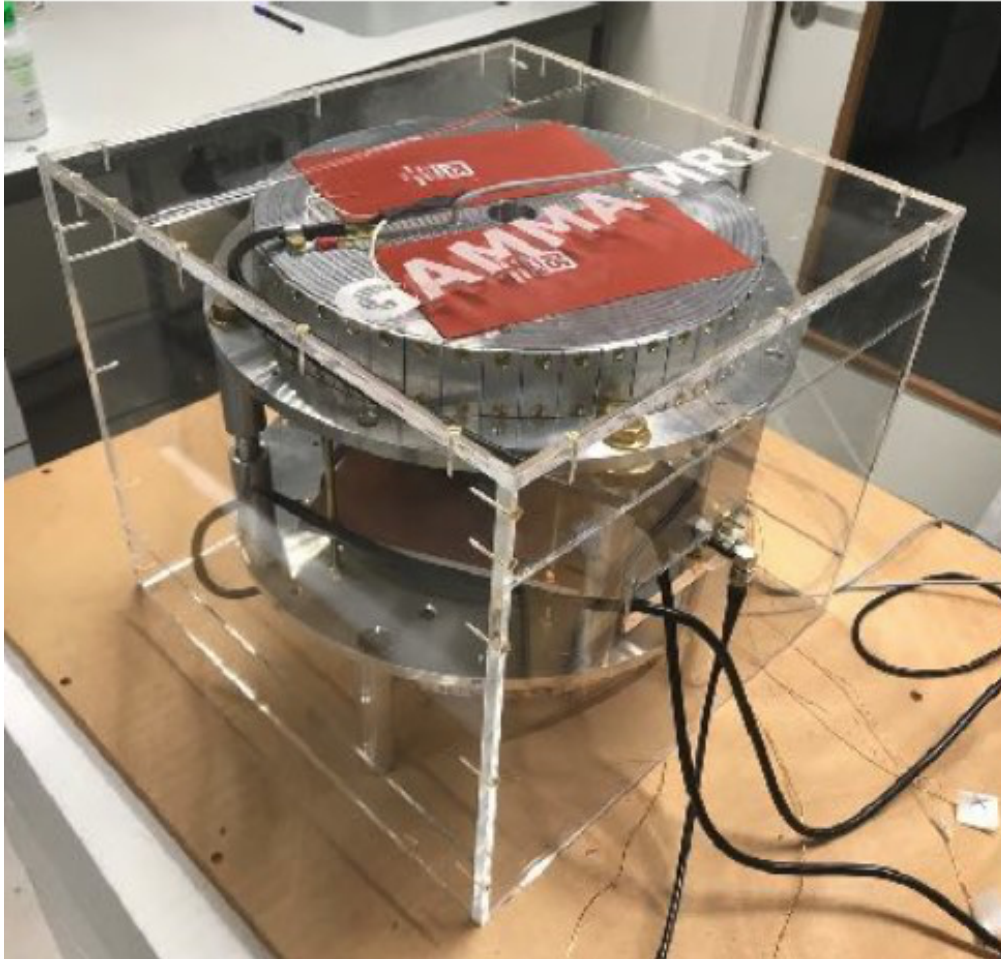
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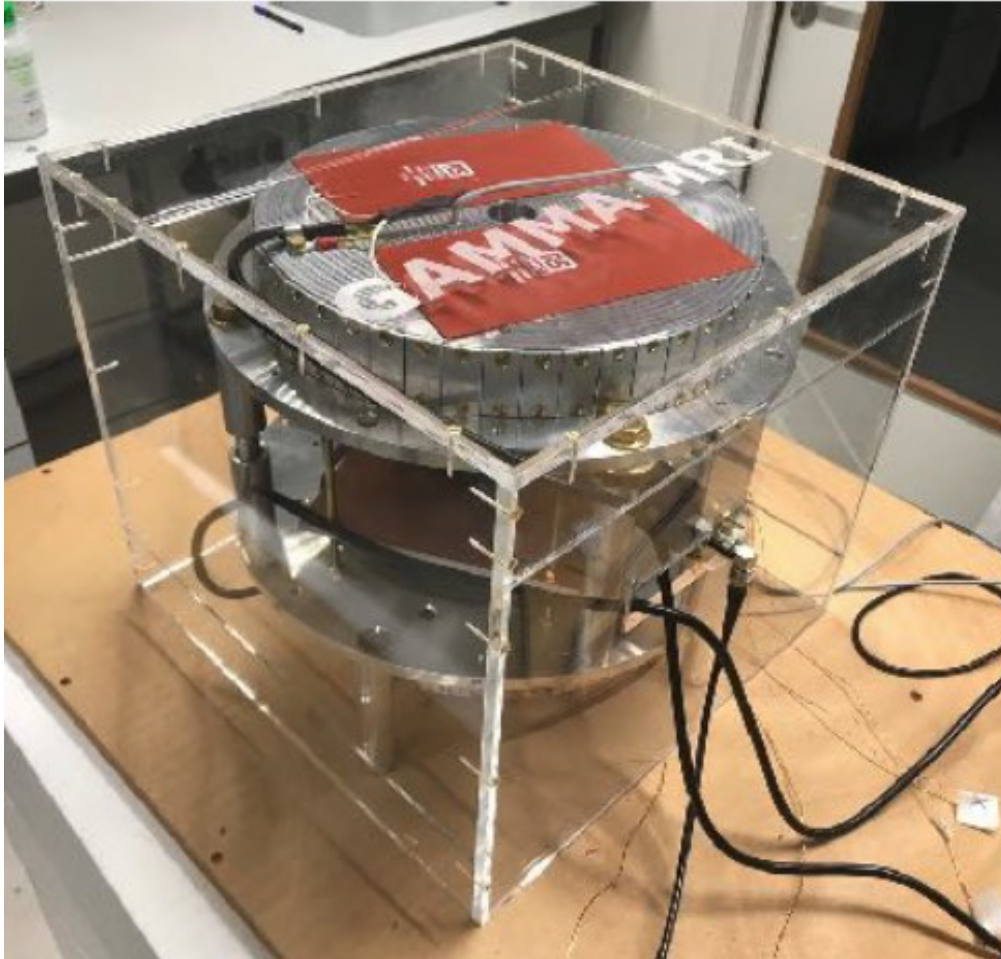
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Where do we stand?

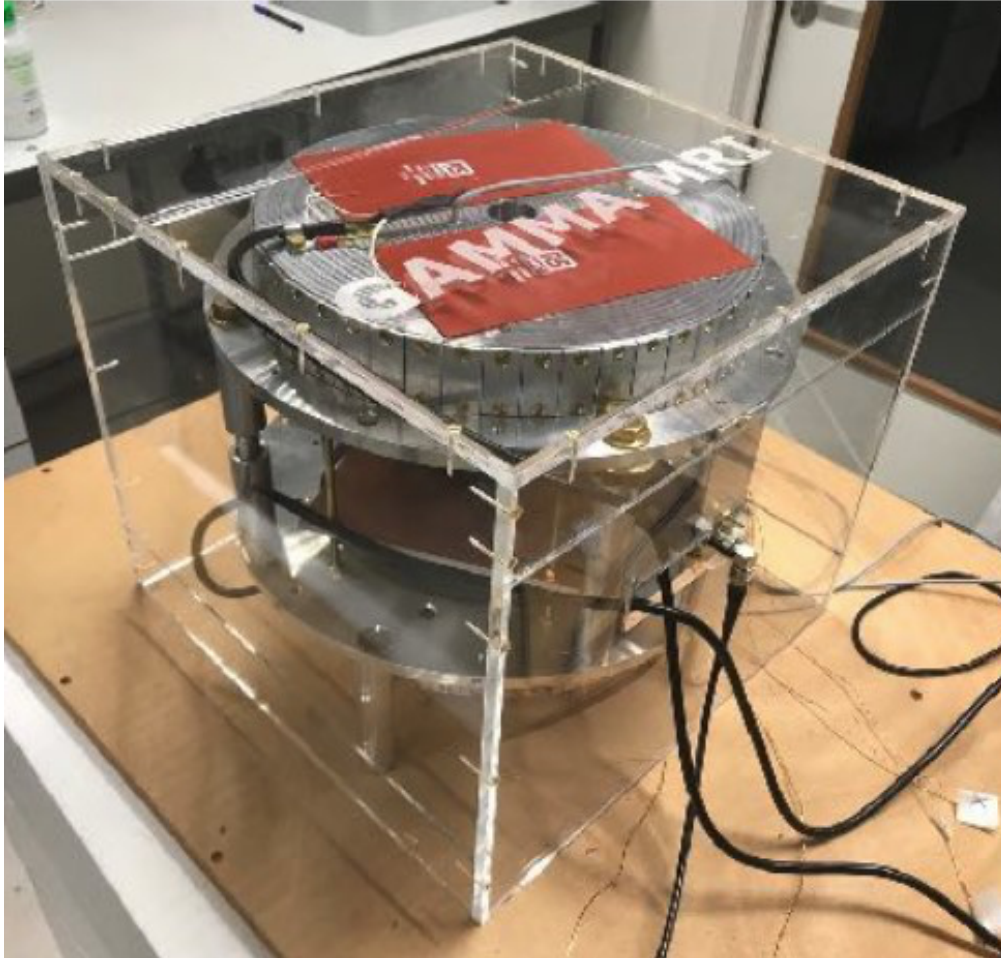


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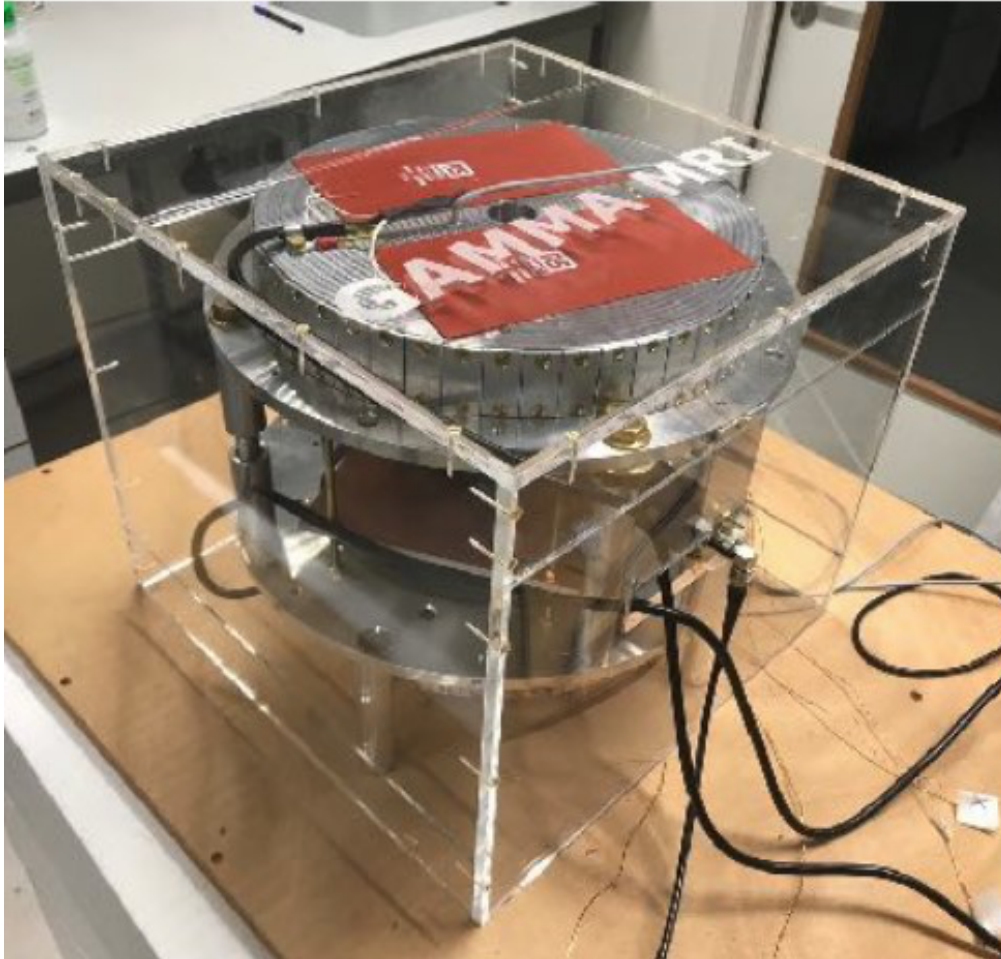
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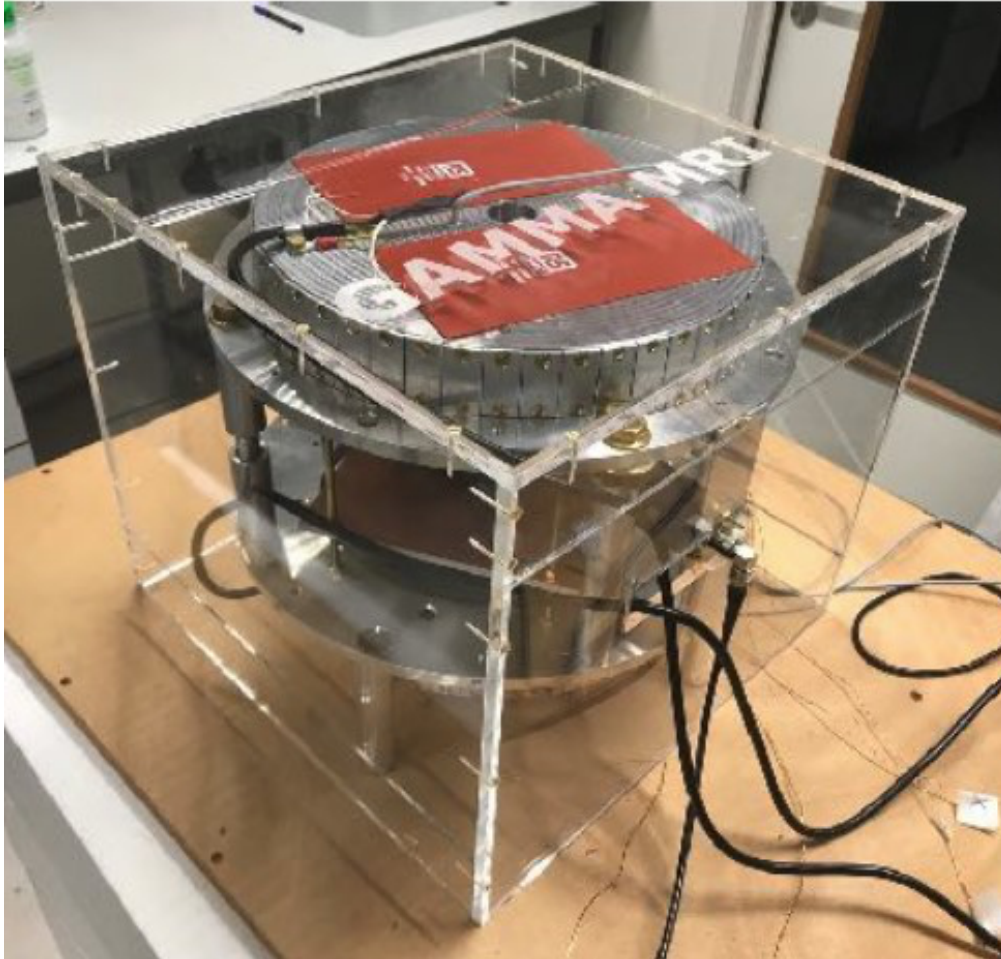
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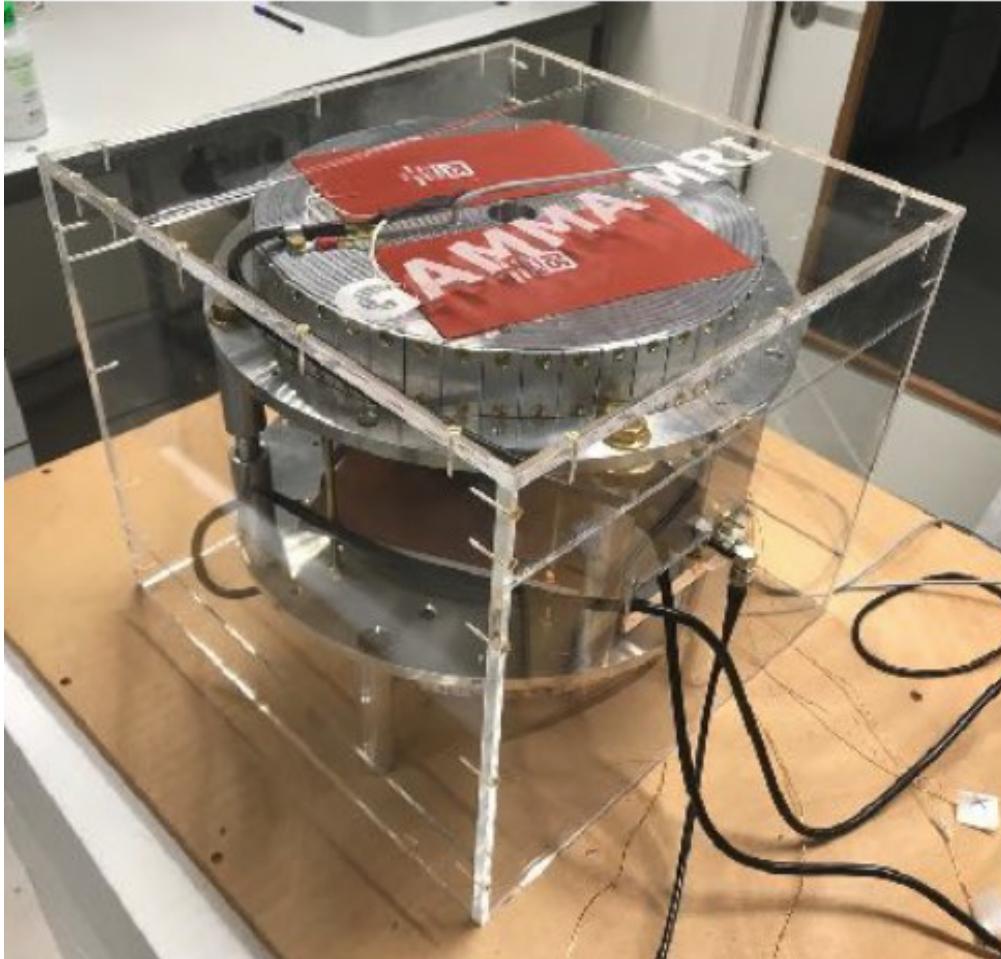
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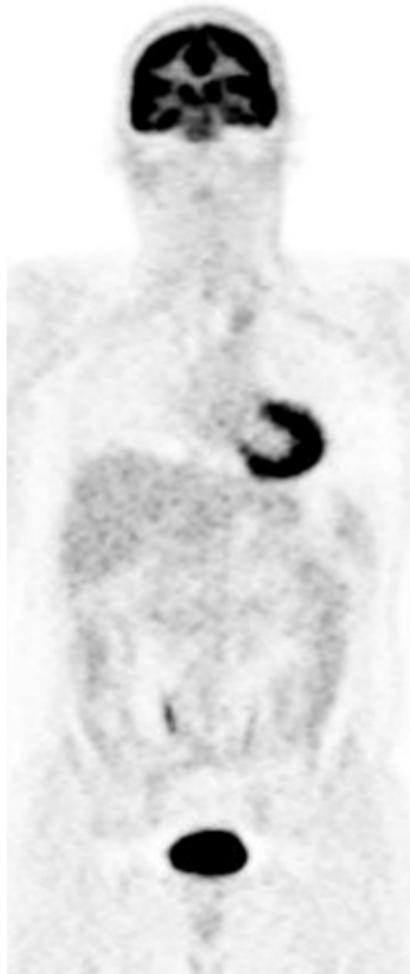
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- Target pathology: ischemic stroke (relatively simple animal model and clinically relevant)

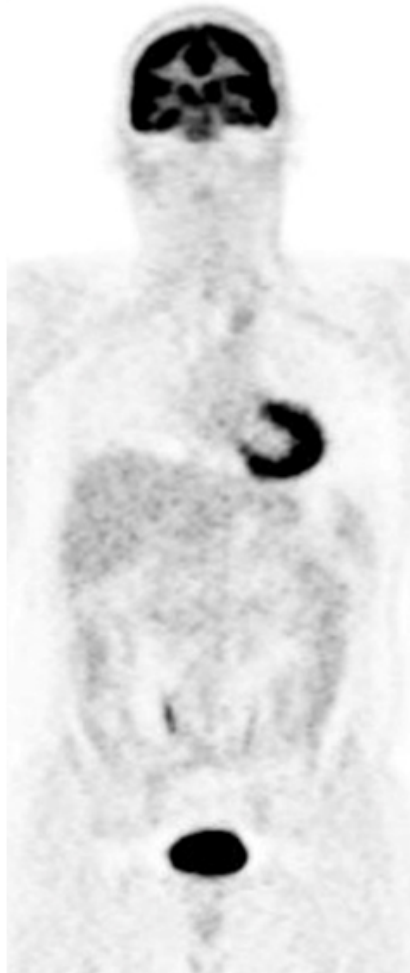
Imaging the brain

From your body's perspective, your brain is rather expensive



^{18}F -fluorodeoxyglucose
~ glucose utilisation
(image courtesy of M. T. Wyss)

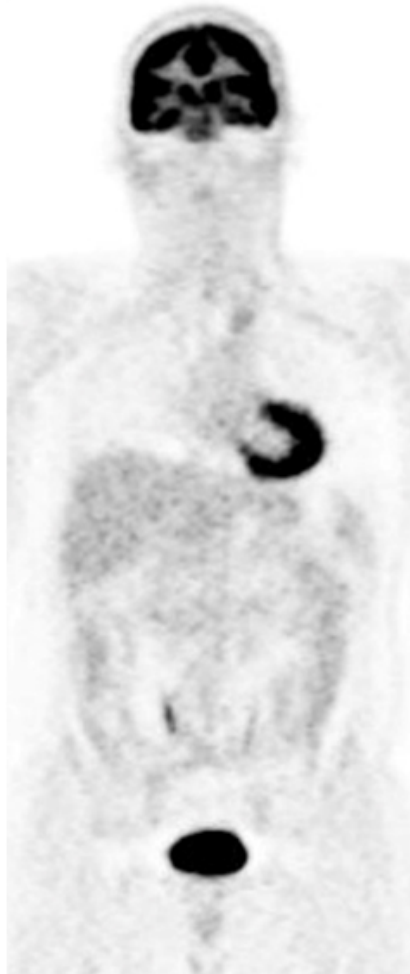
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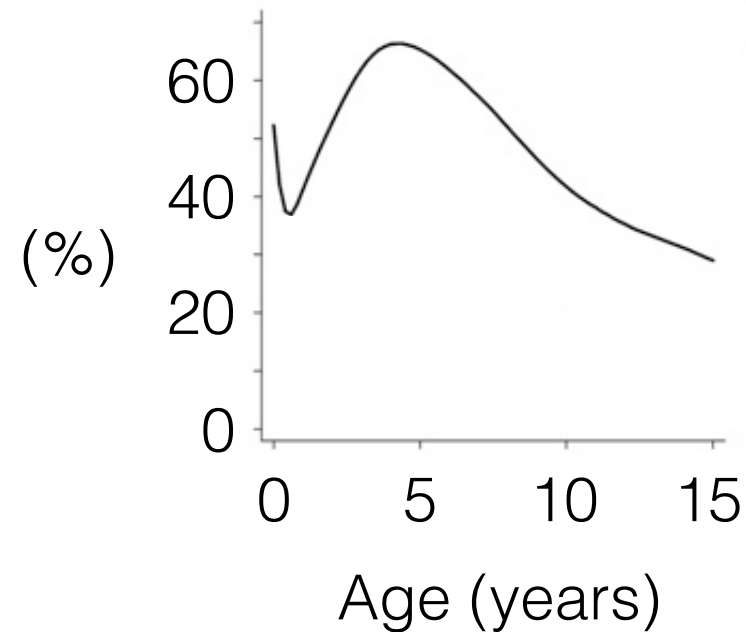
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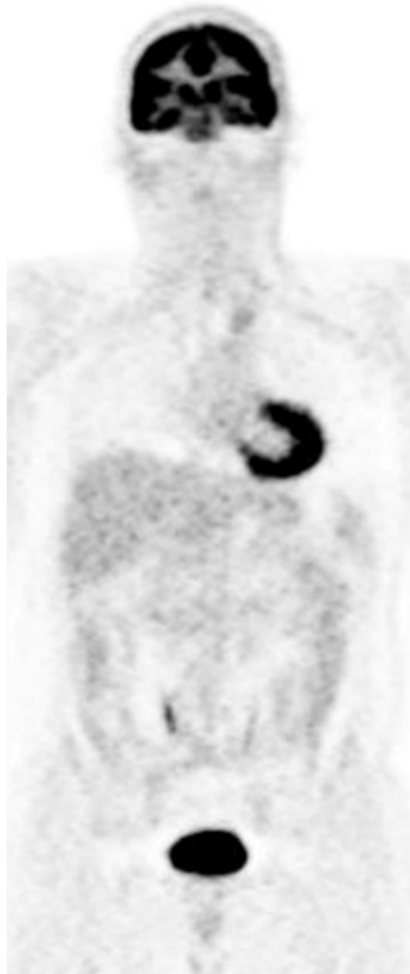


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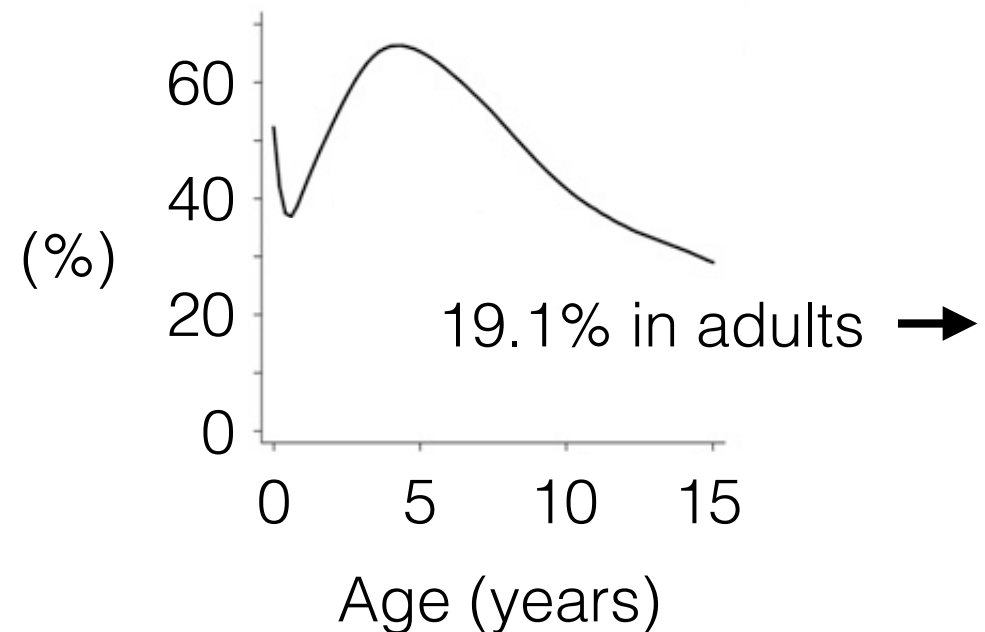


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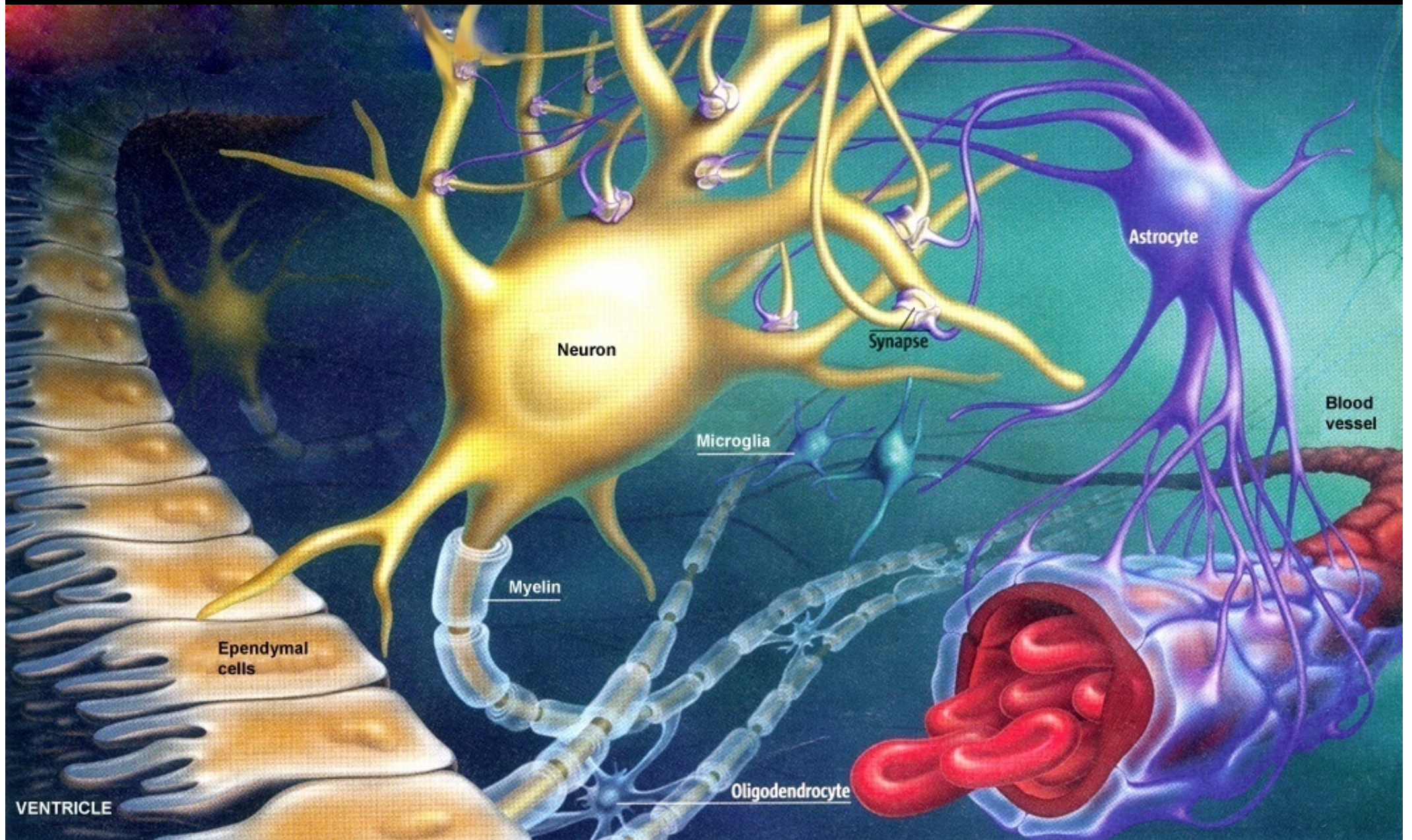


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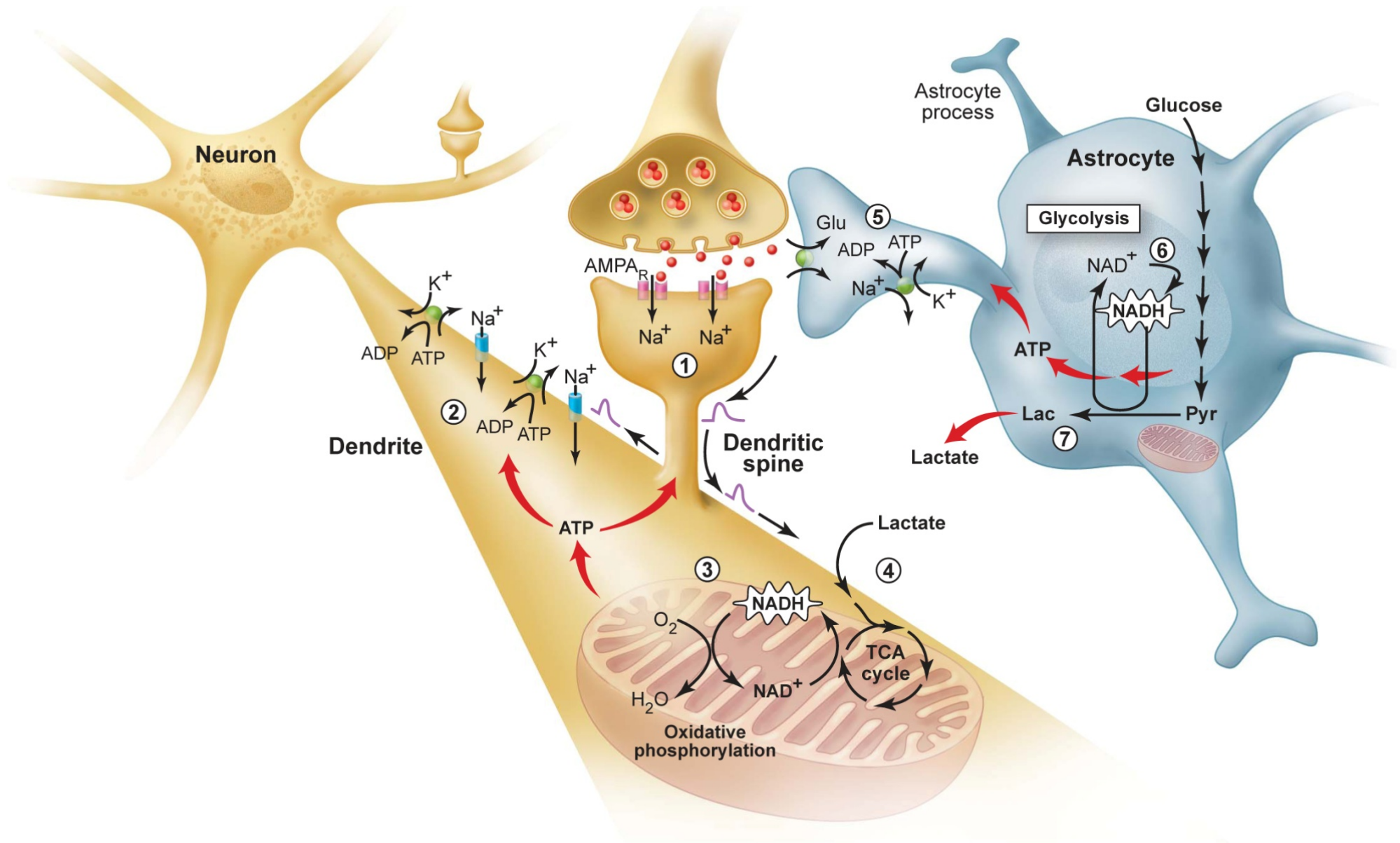
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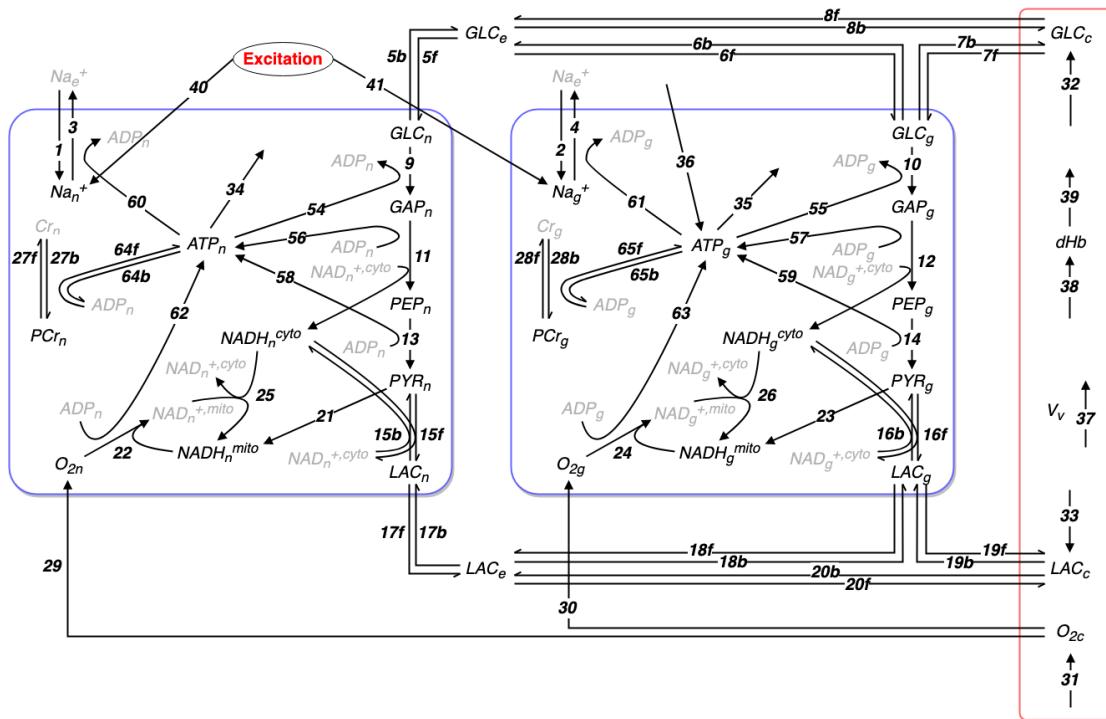




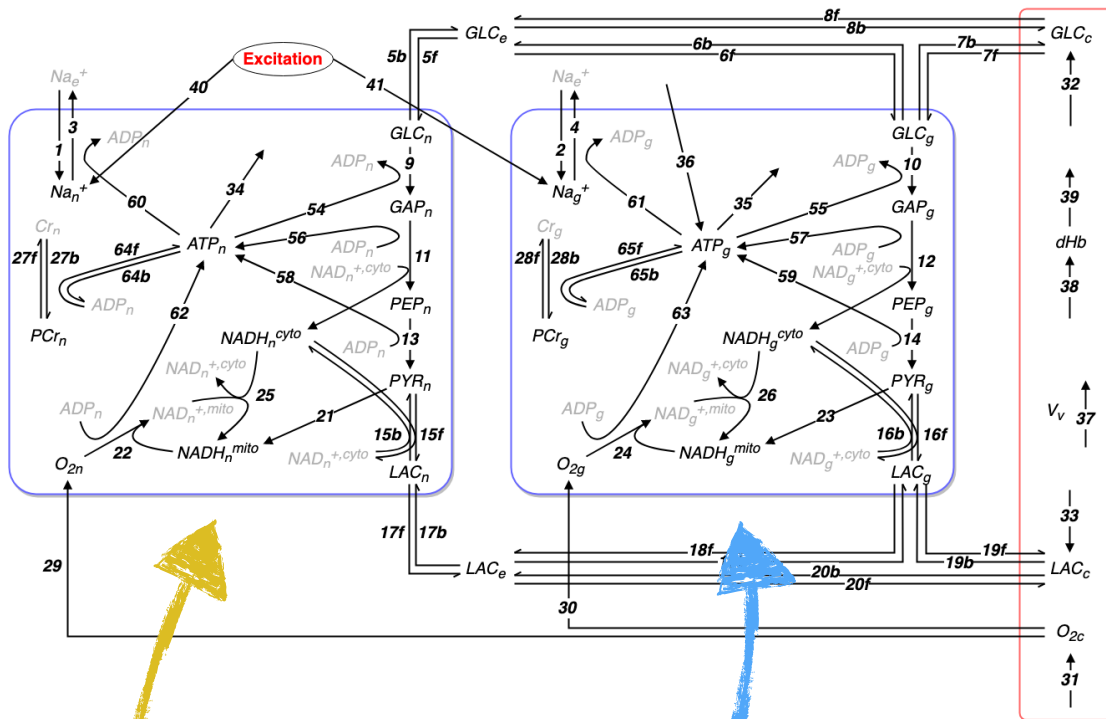
Modelling energy-related processes at synapses: A holistic approach to brain networks



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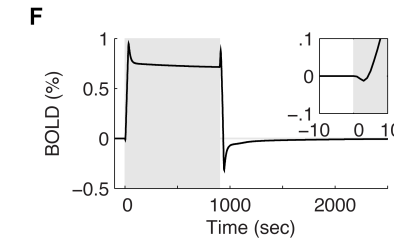
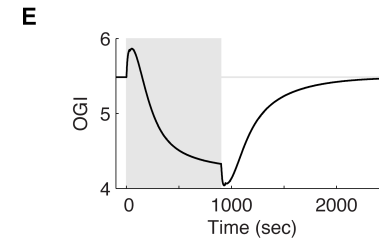
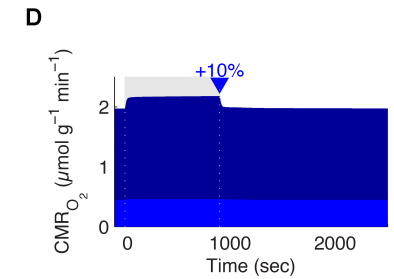
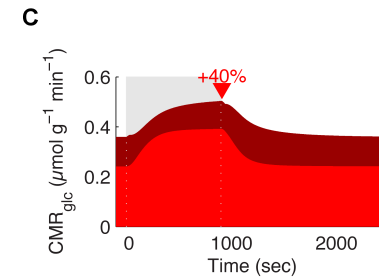
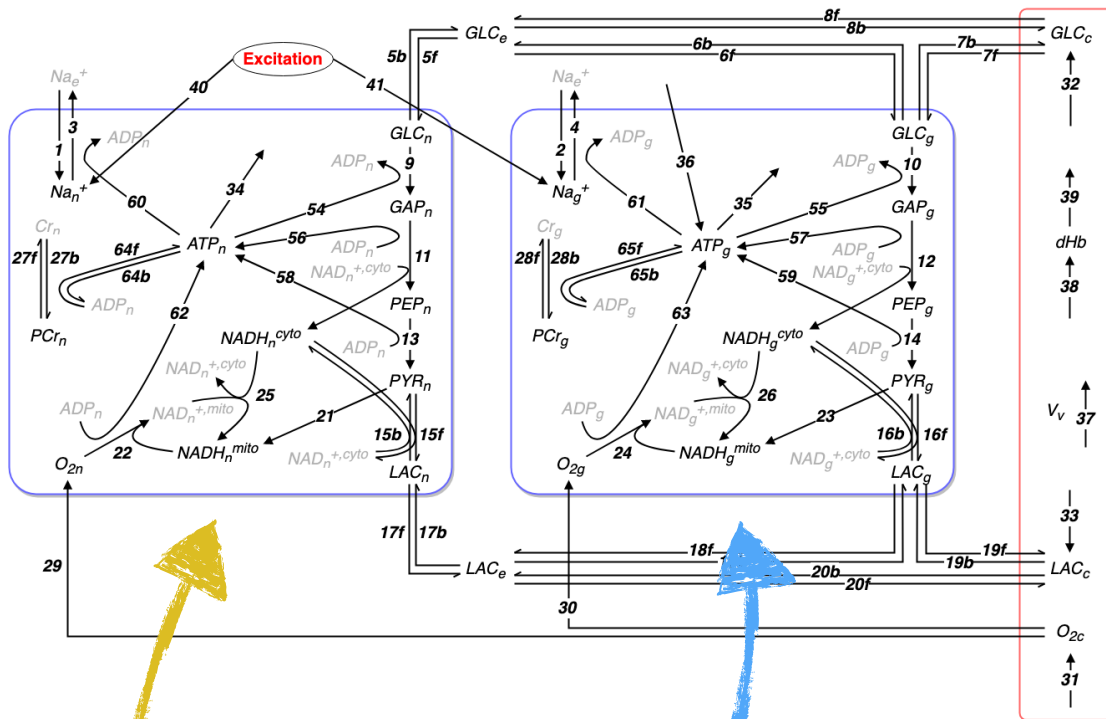


Modelling energy-related processes at synapses: A holistic approach to brain networks



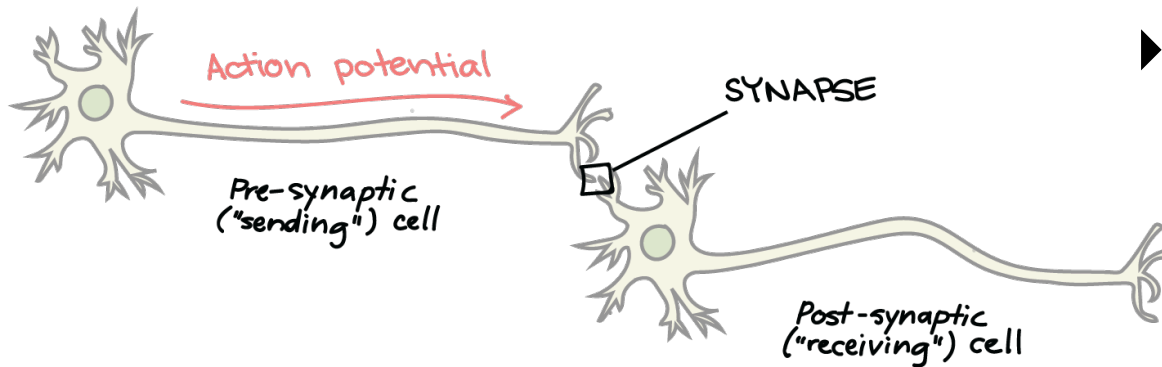
neurons glial cells (astrocytes) blood vessels

Modelling energy-related processes at synapses: A holistic approach to brain networks



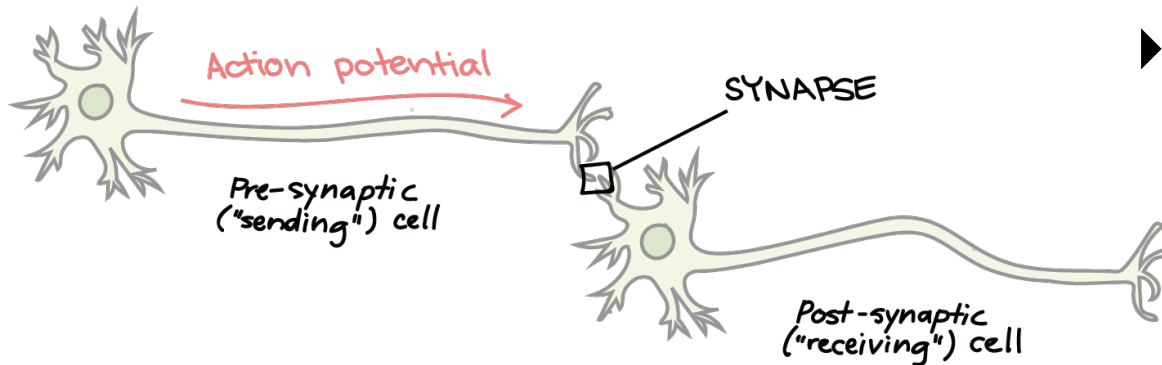
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Synaptic function is energetically expensive but not particularly reliable

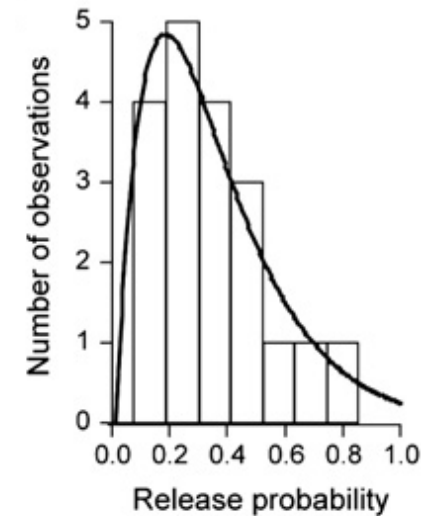


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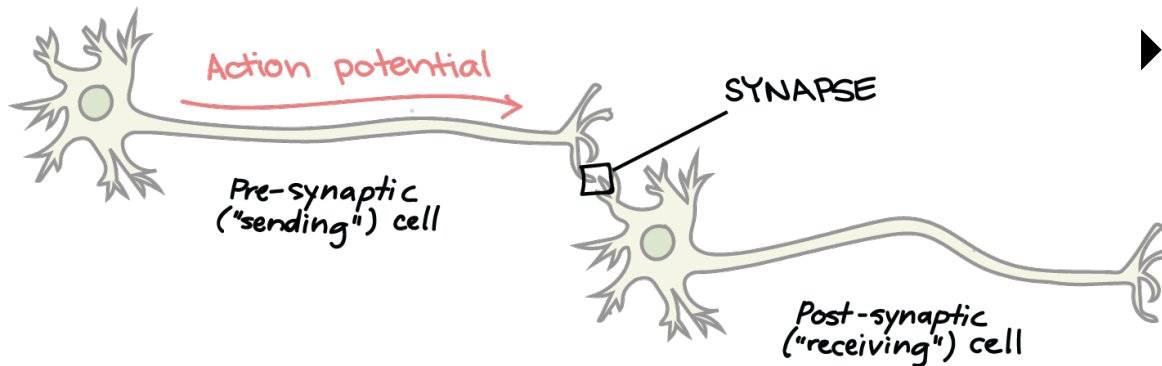


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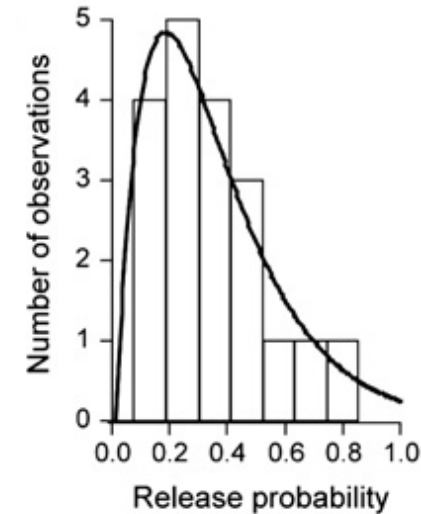
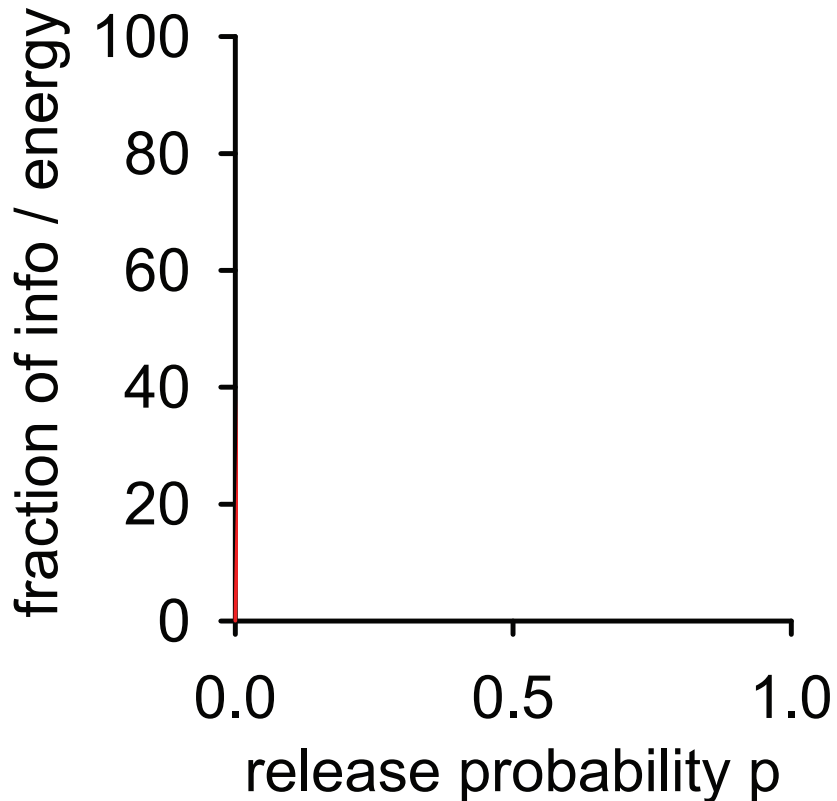


Branco et al., *Neuron* 2008

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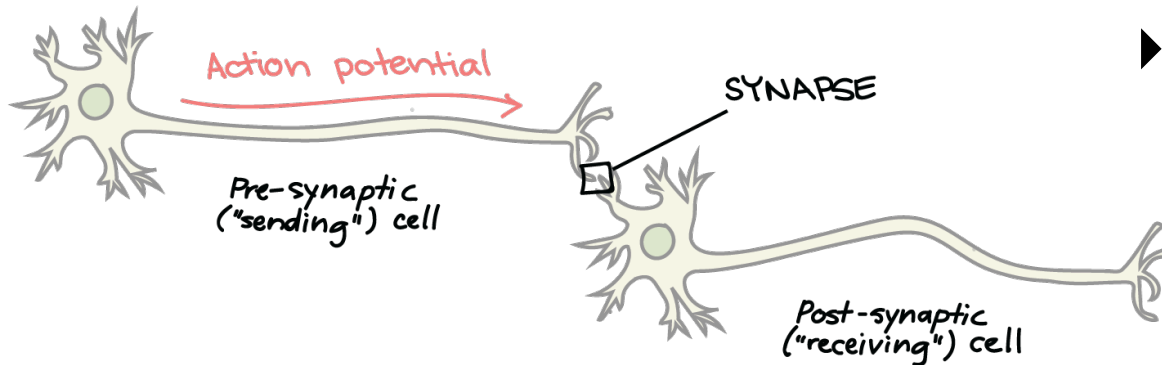


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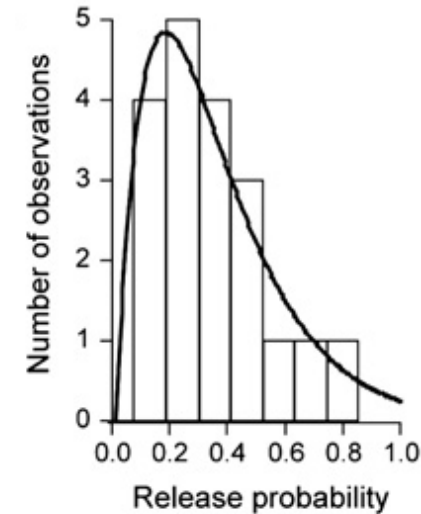
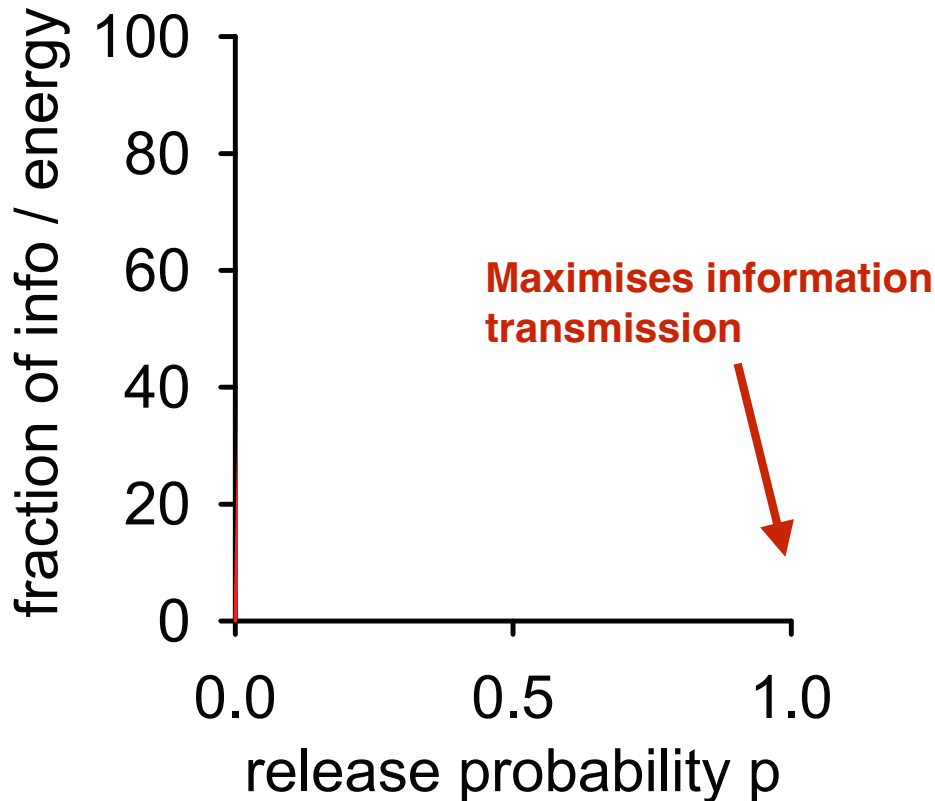


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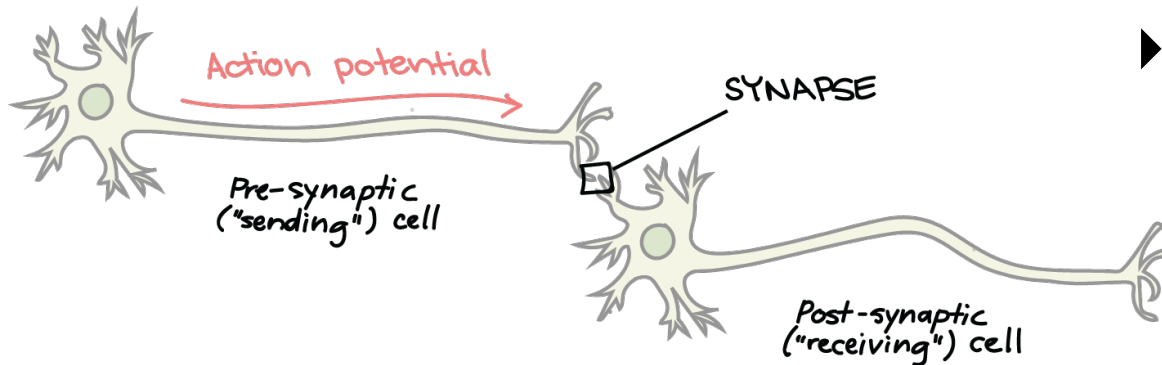


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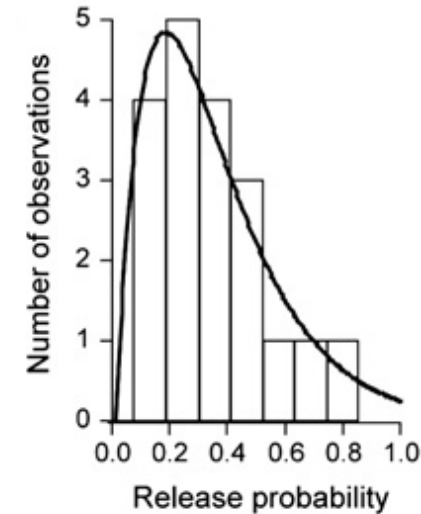
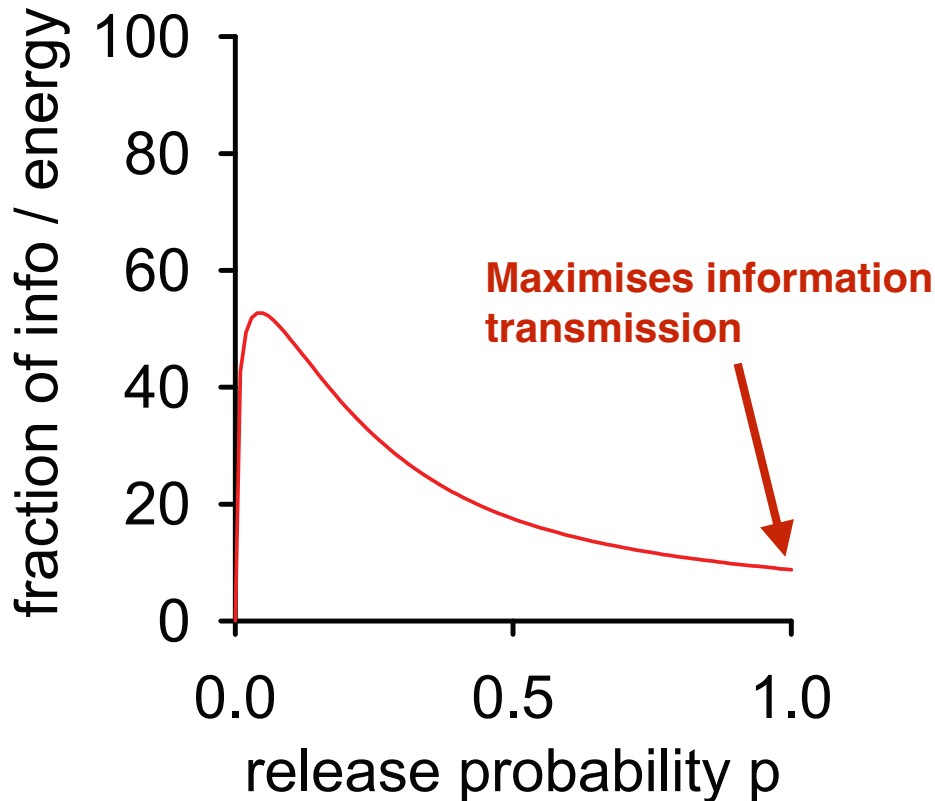


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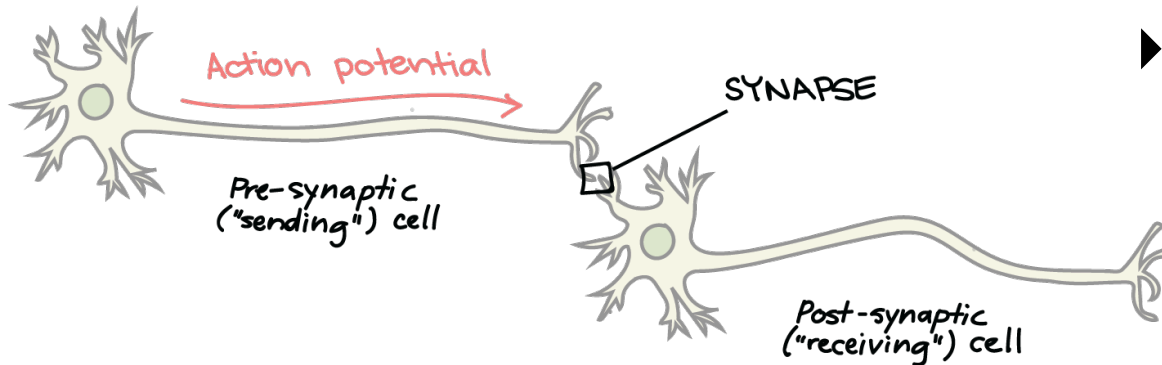


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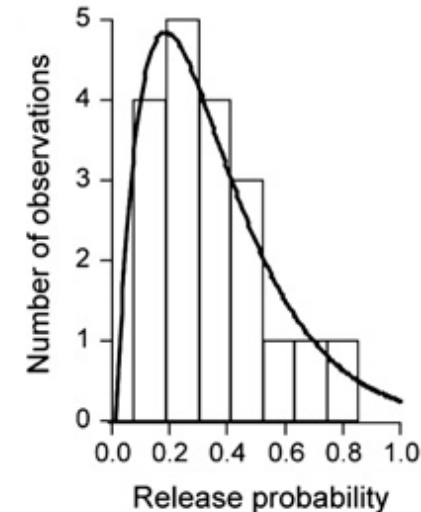
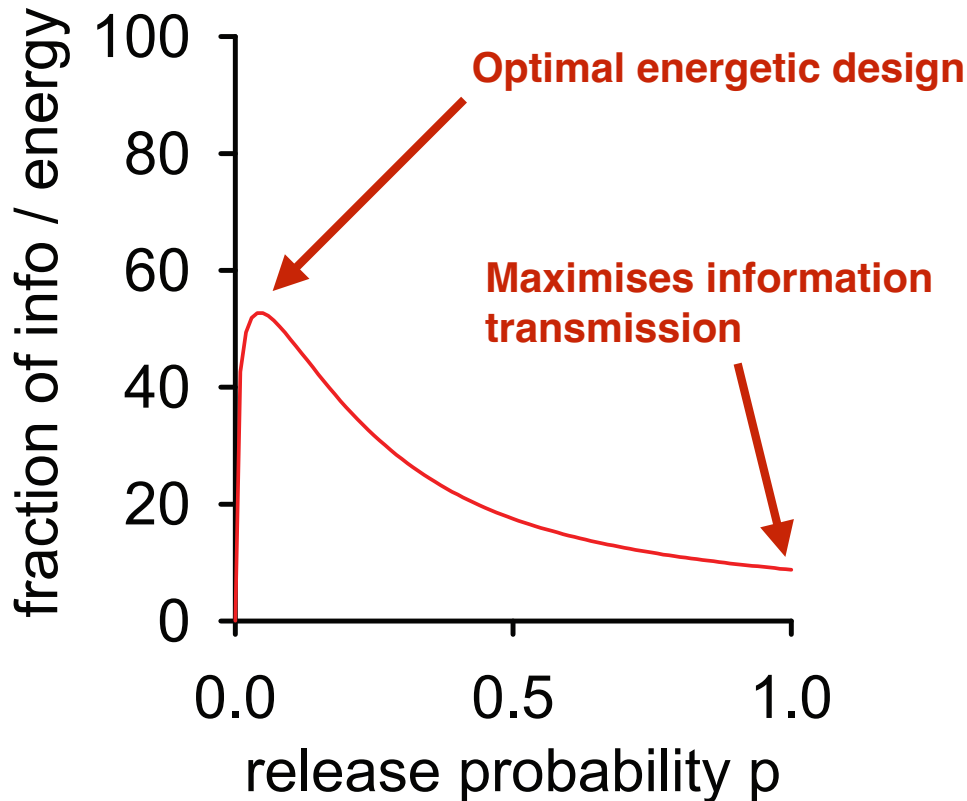


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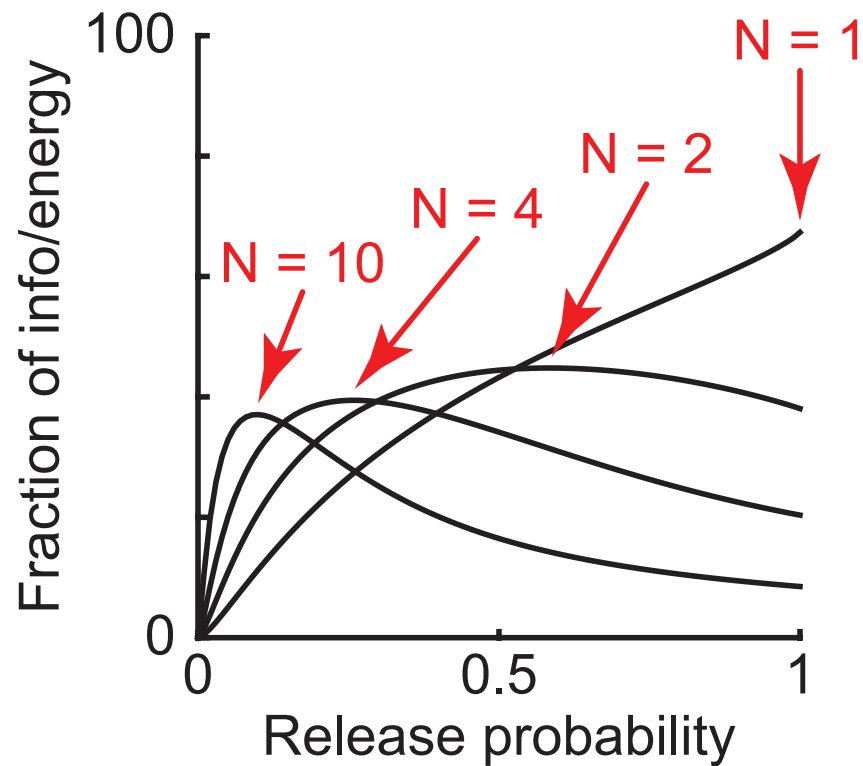


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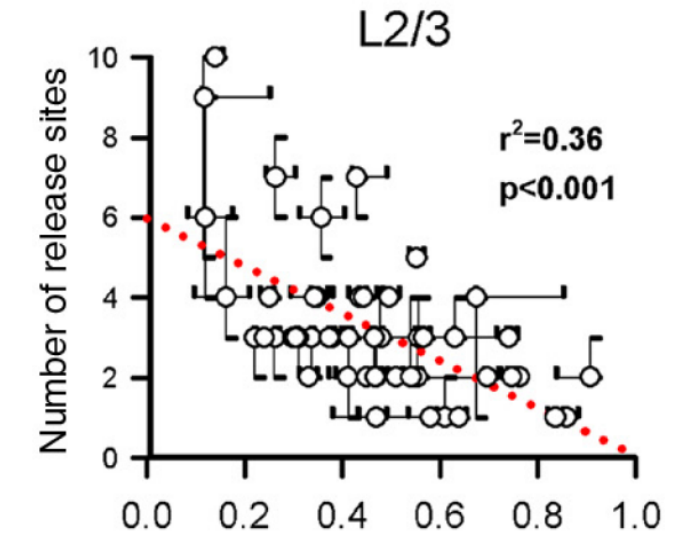
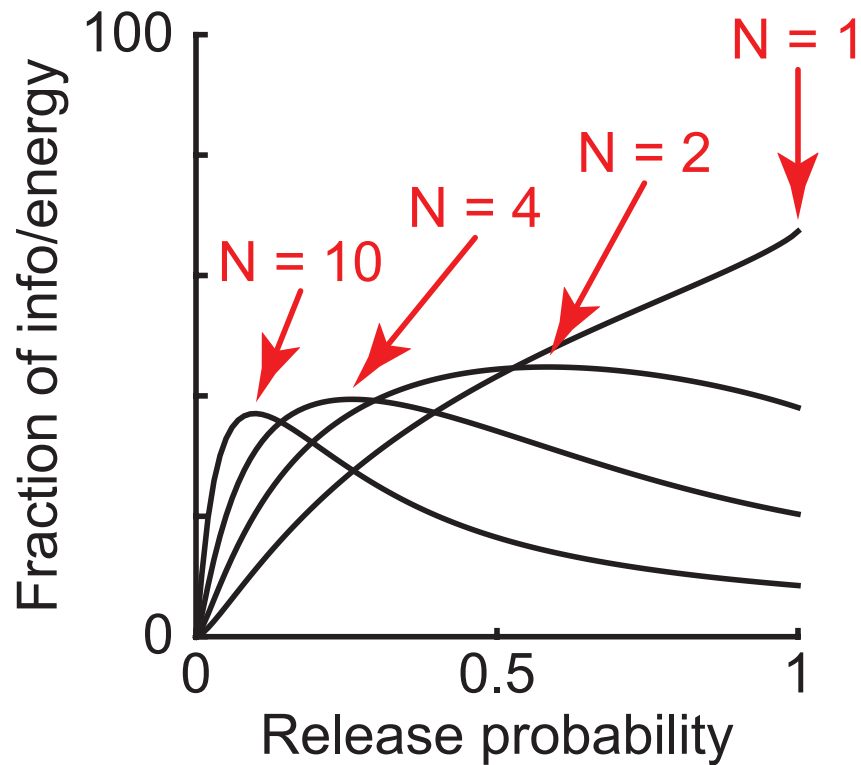
- ▶ This configuration can be explained by representing the optimal energetic design.

Harris et al., *Neuron* 2012

Optimal energetic design of CNS synapses requires failures of presynaptic release

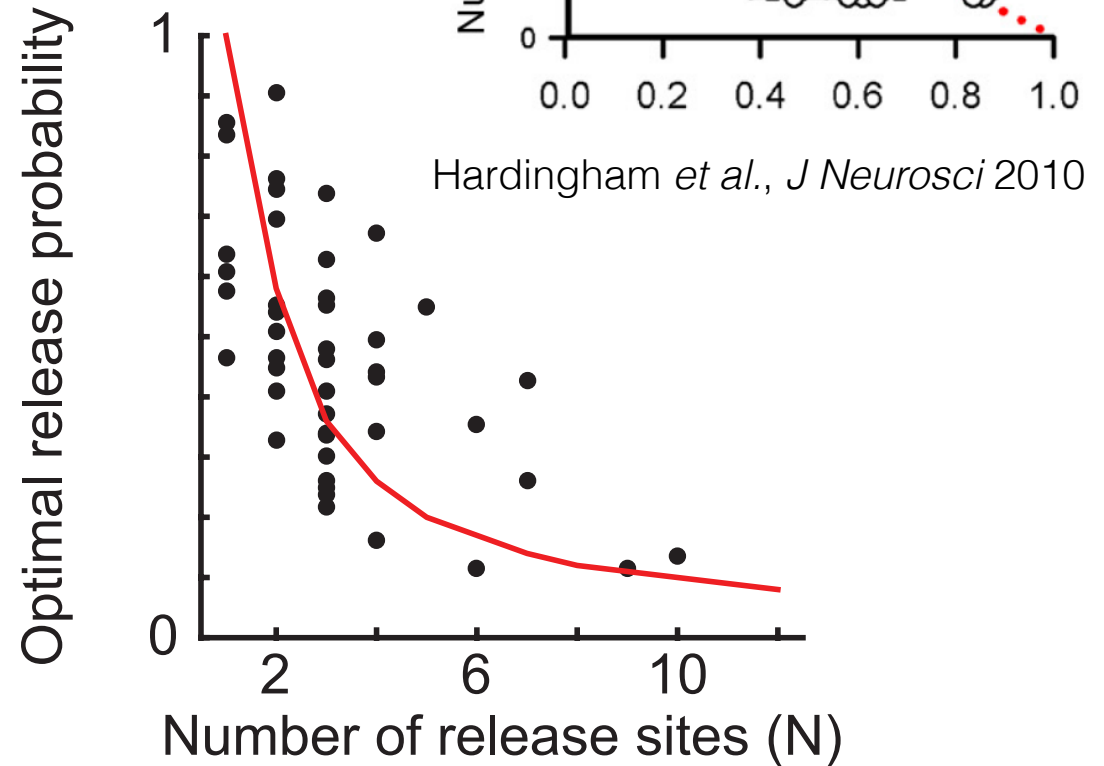
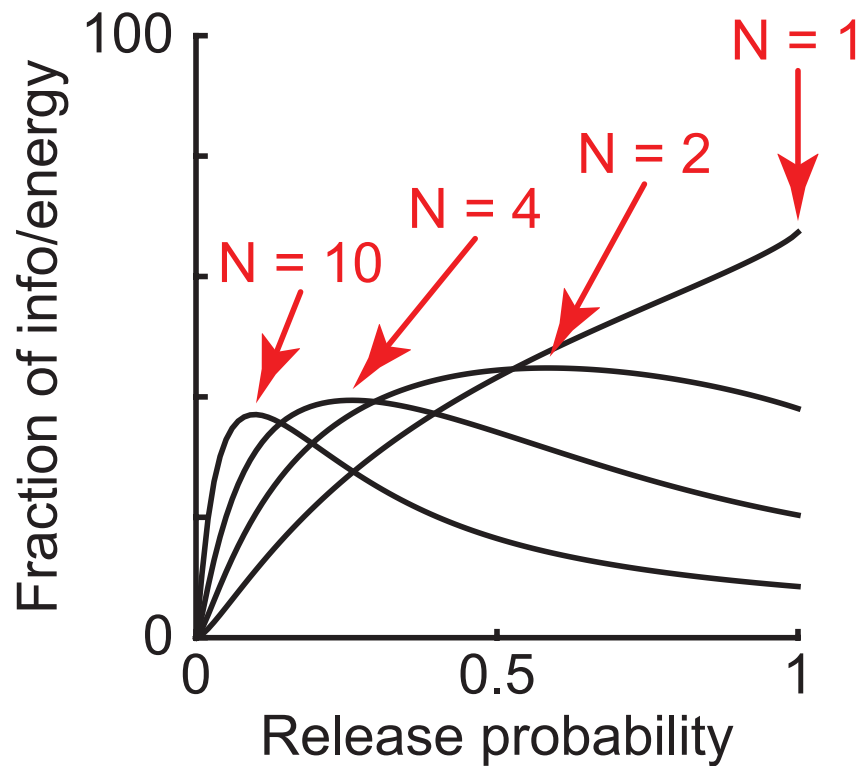


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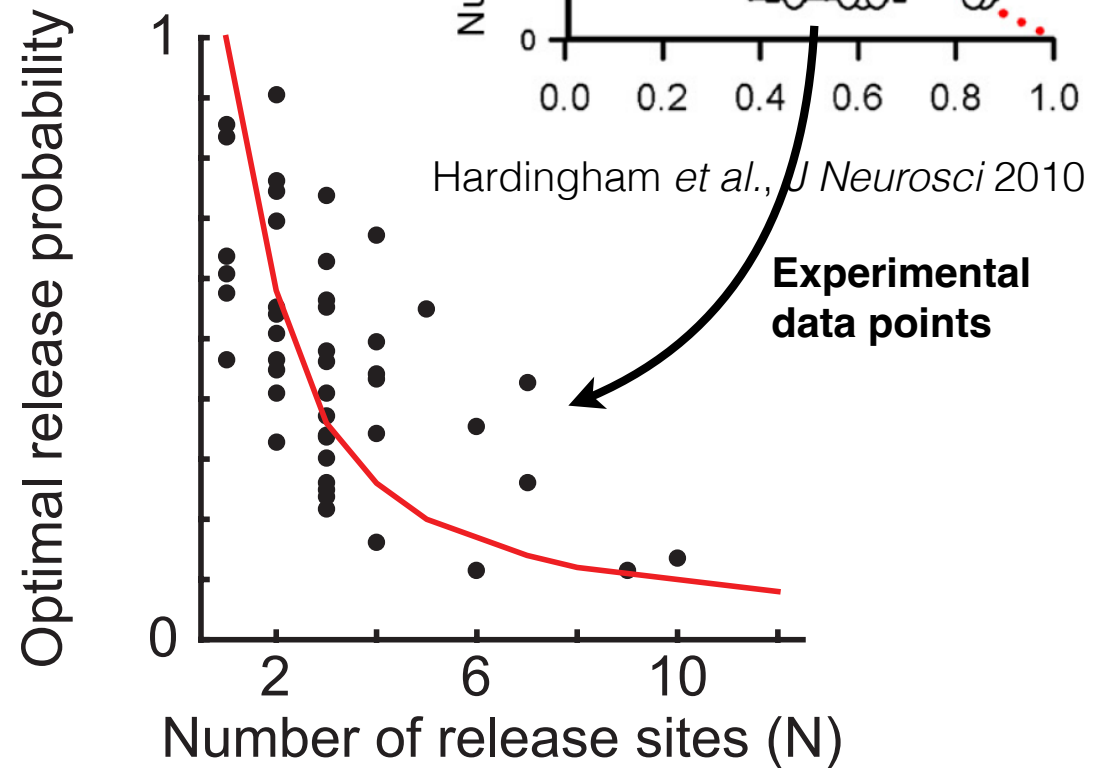
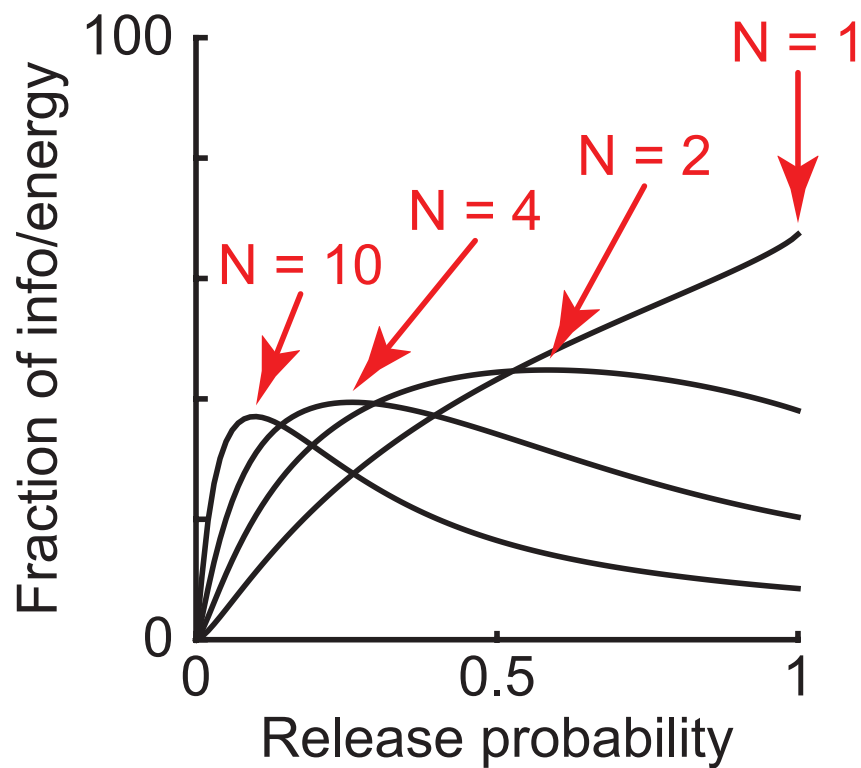


Hardingham *et al.*, *J Neurosci* 2010

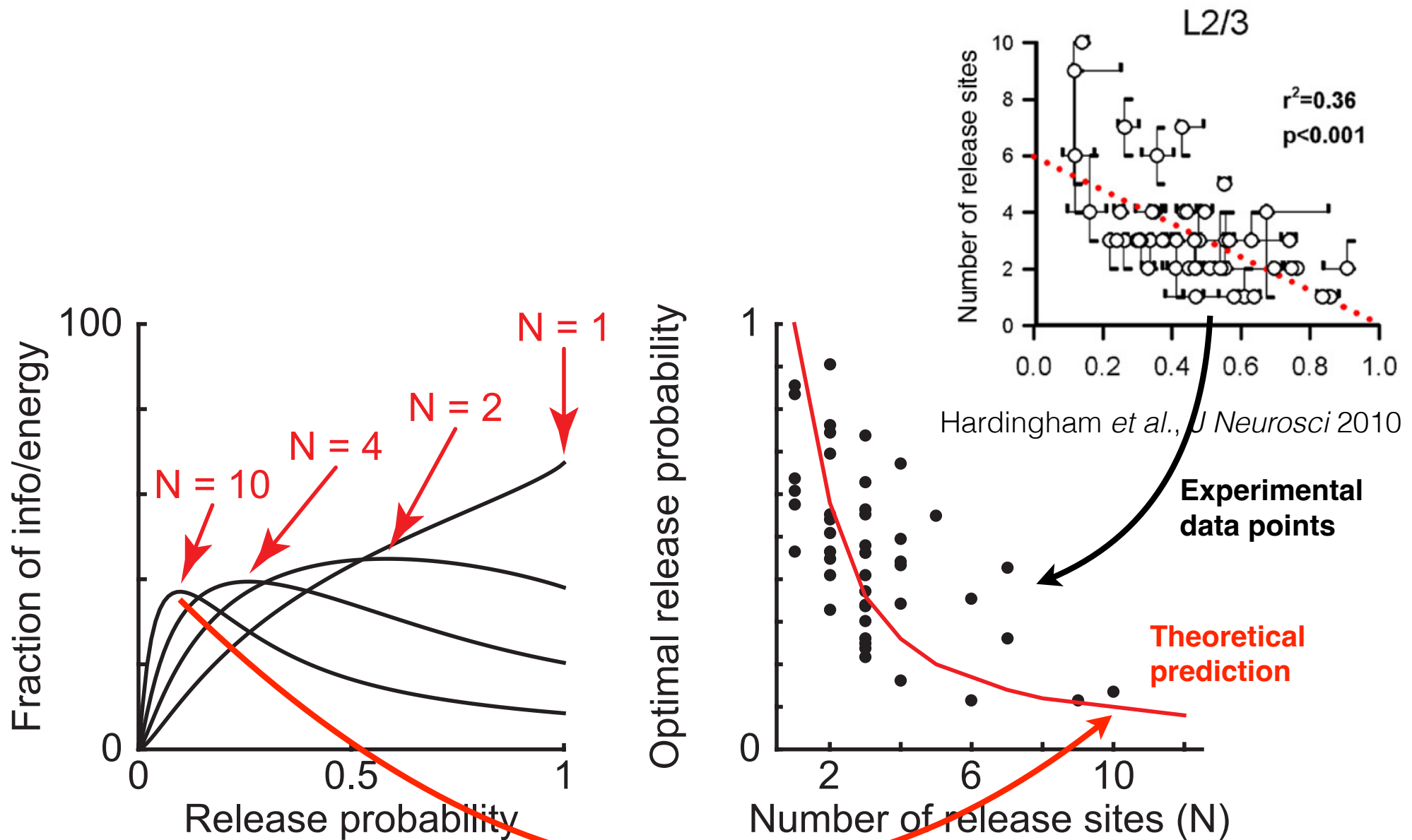
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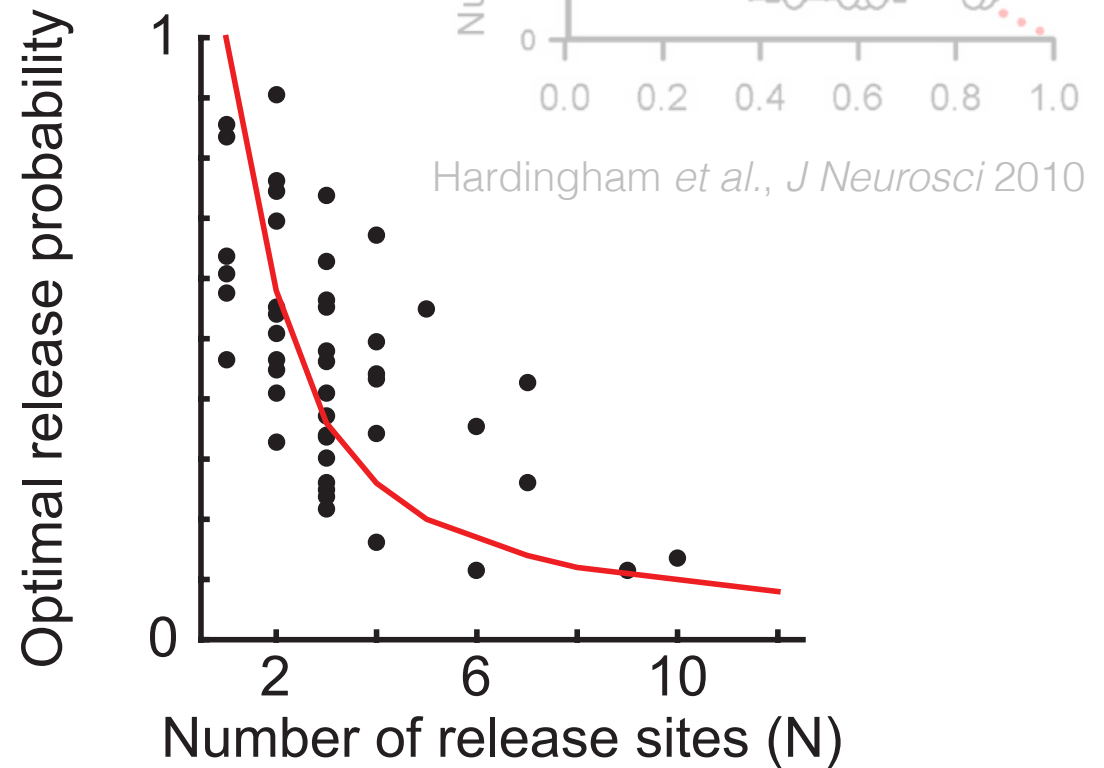
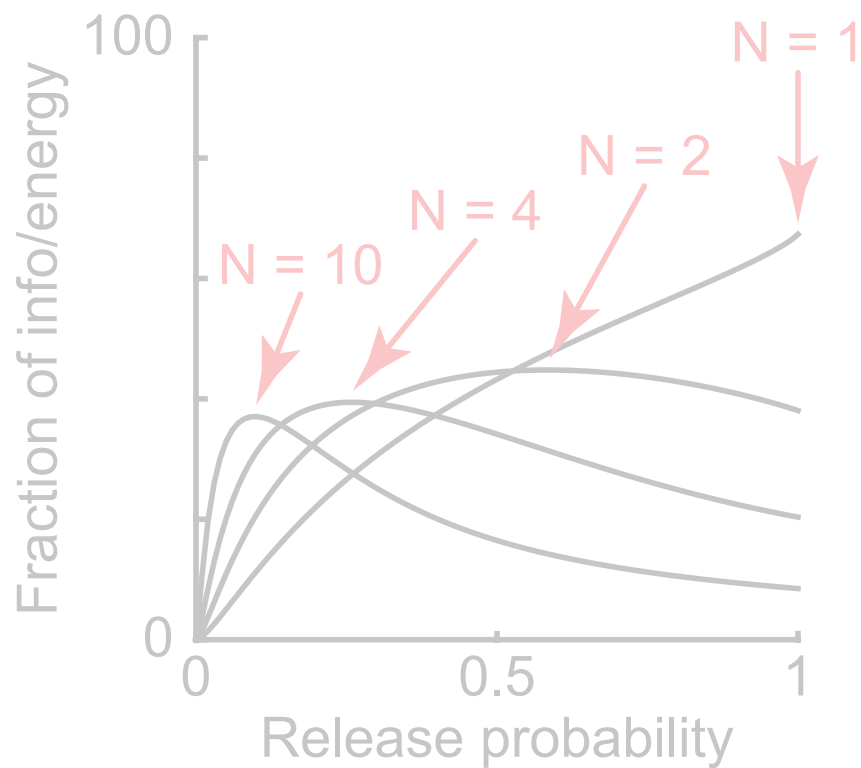
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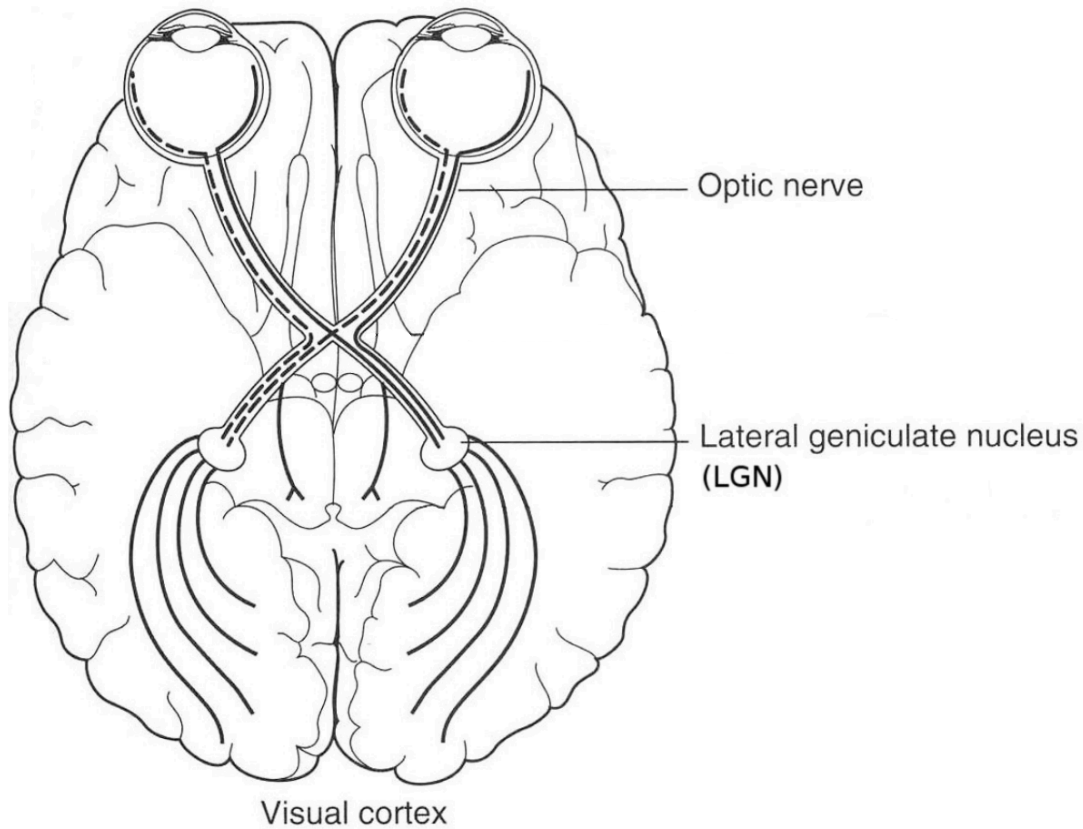
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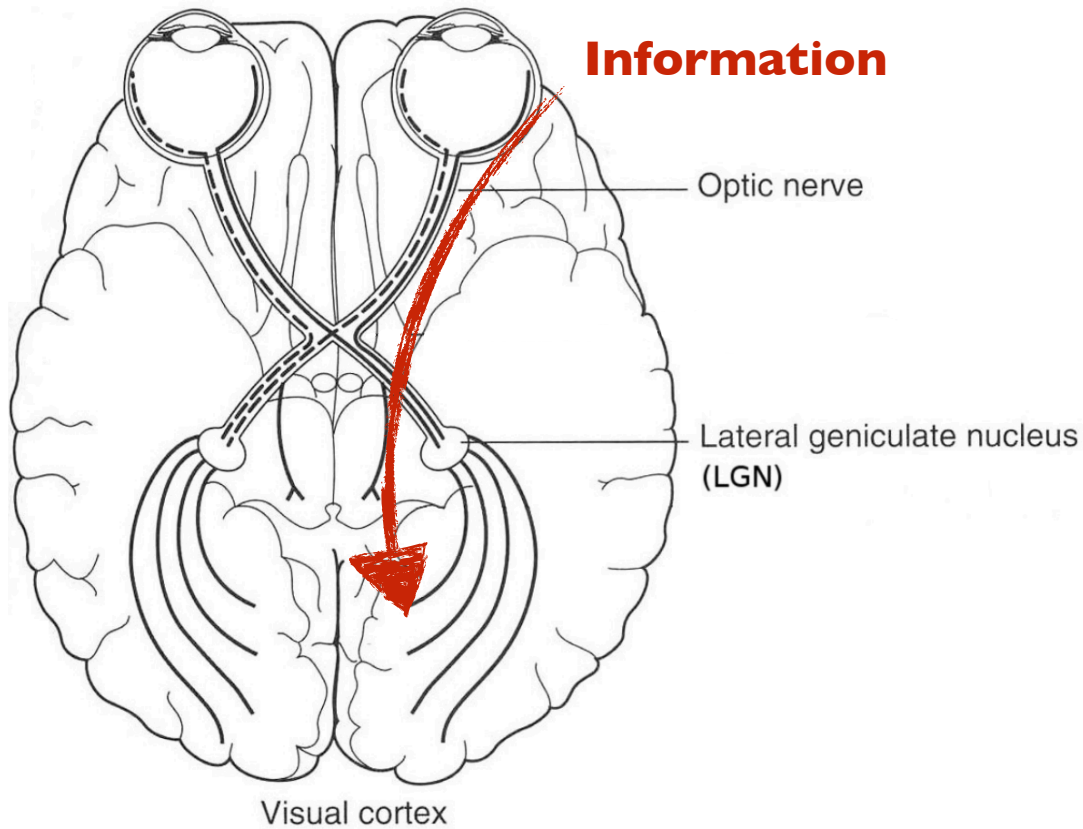


Information flow in the visual pathway



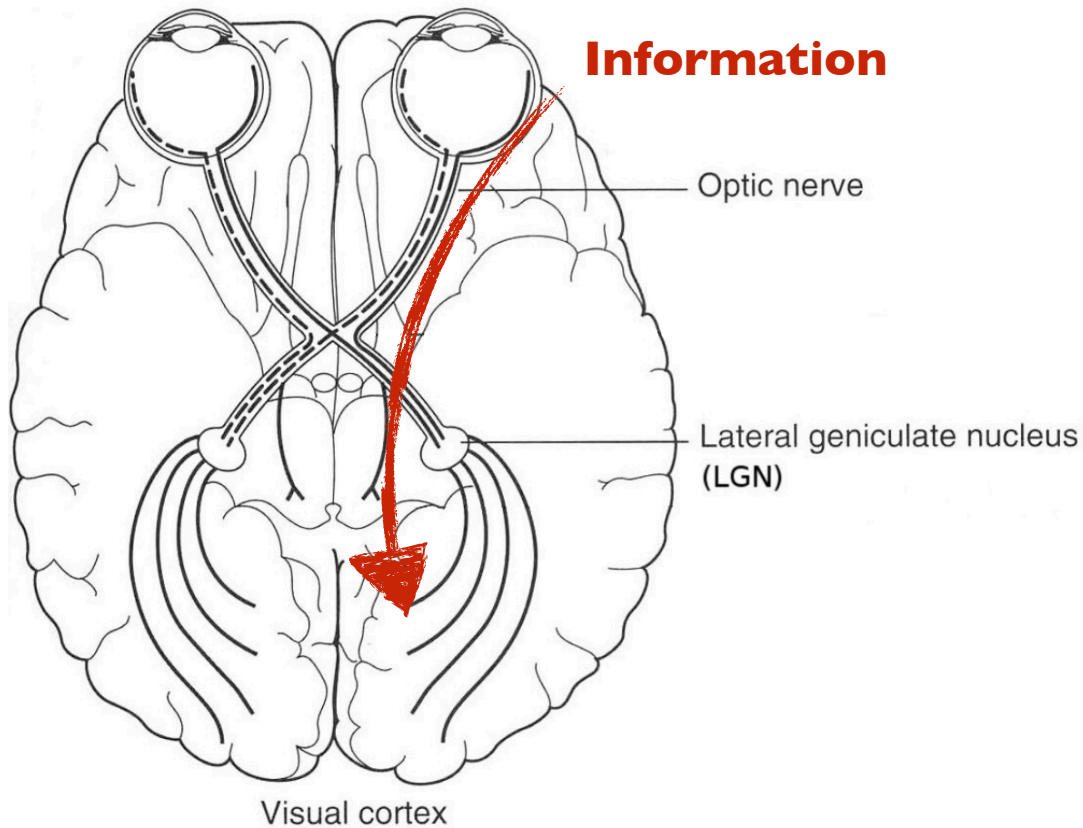
Goldstein, *Sensation and Perception (4th Ed.)*, 1996

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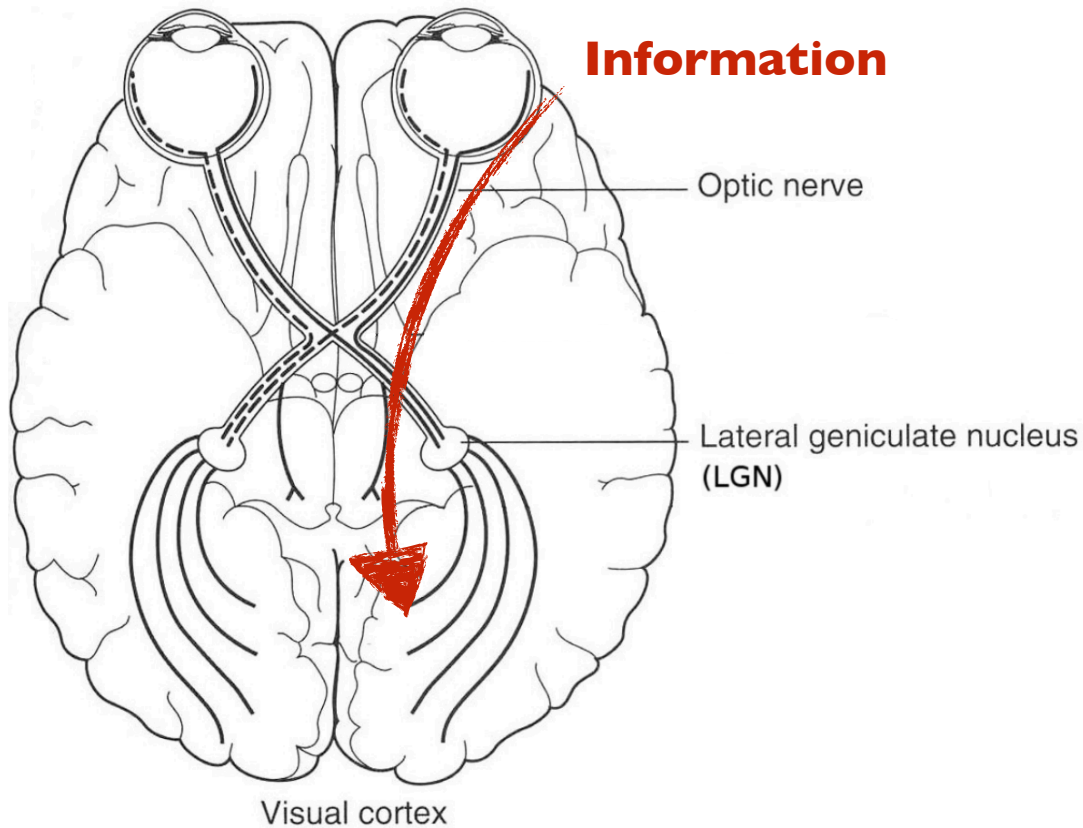
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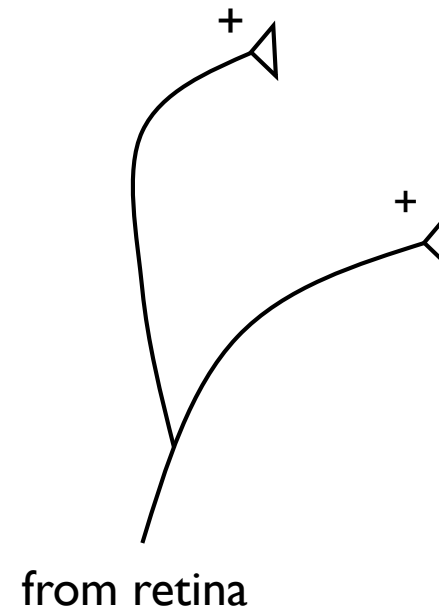
How do information flow and energy consumption compare at those synapses?

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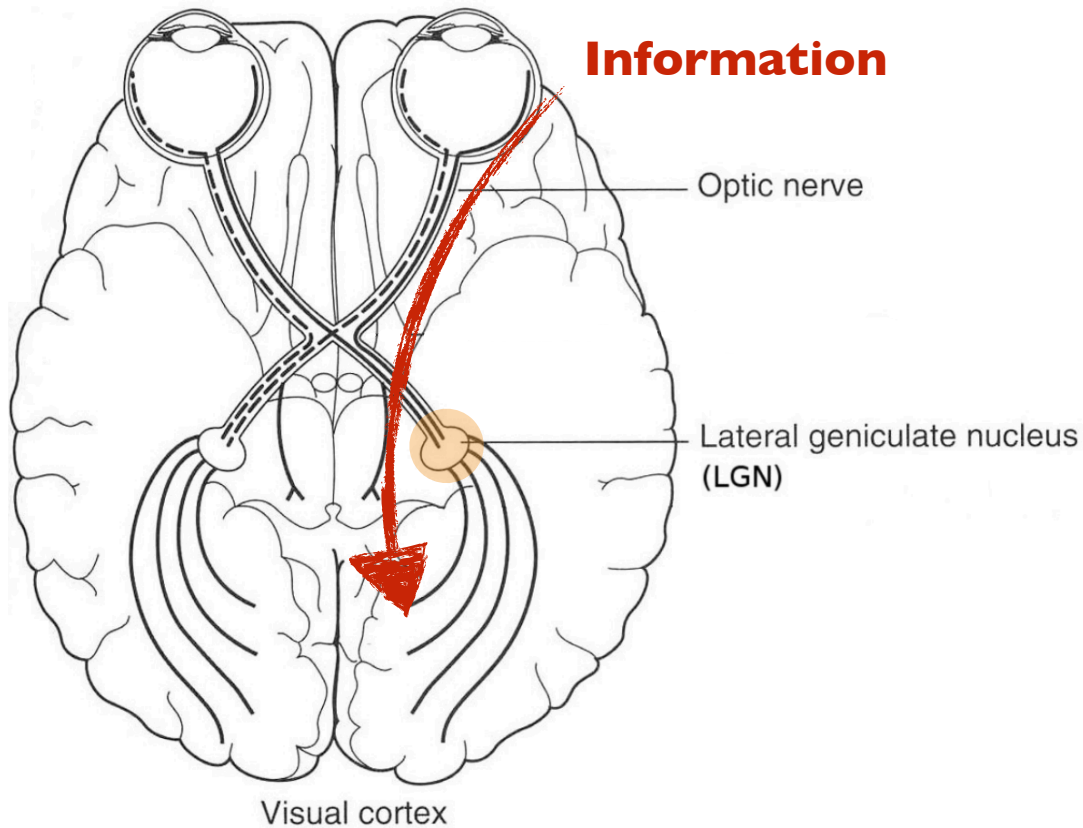


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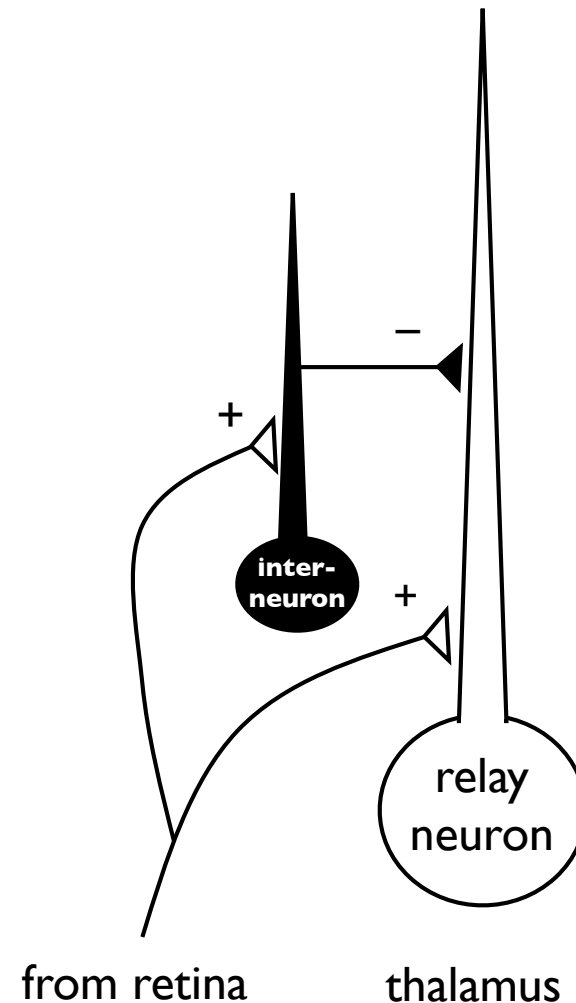


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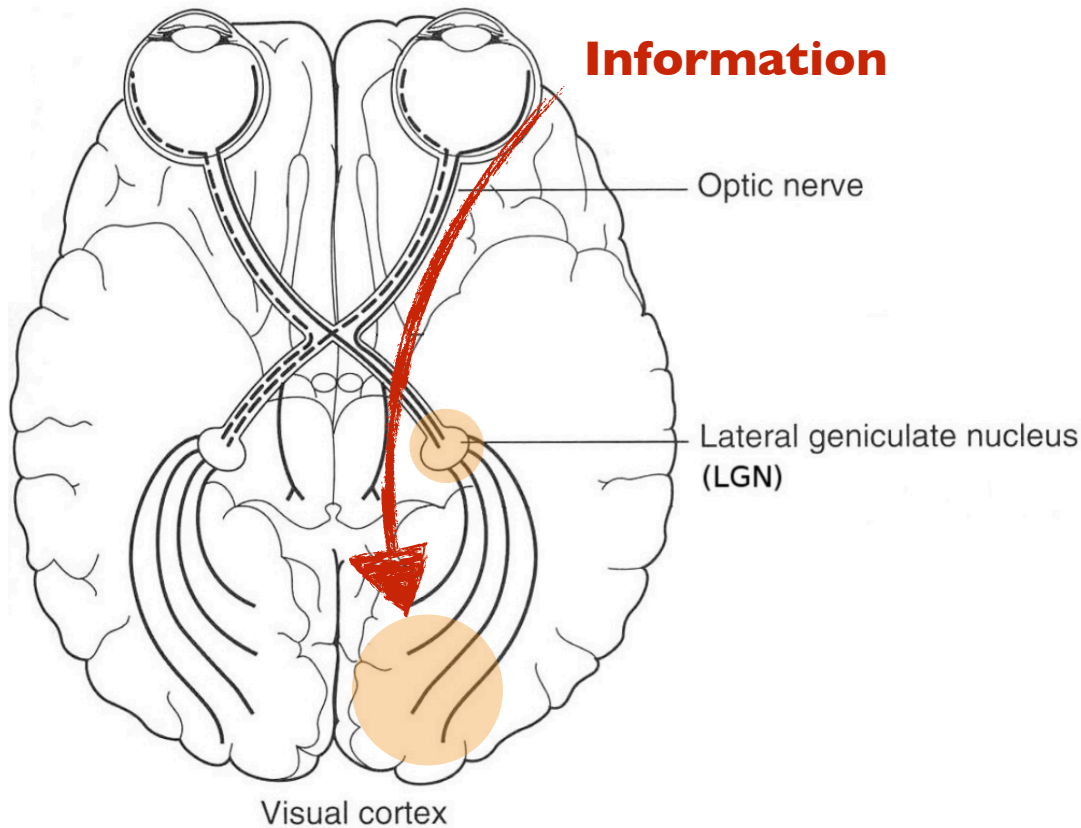


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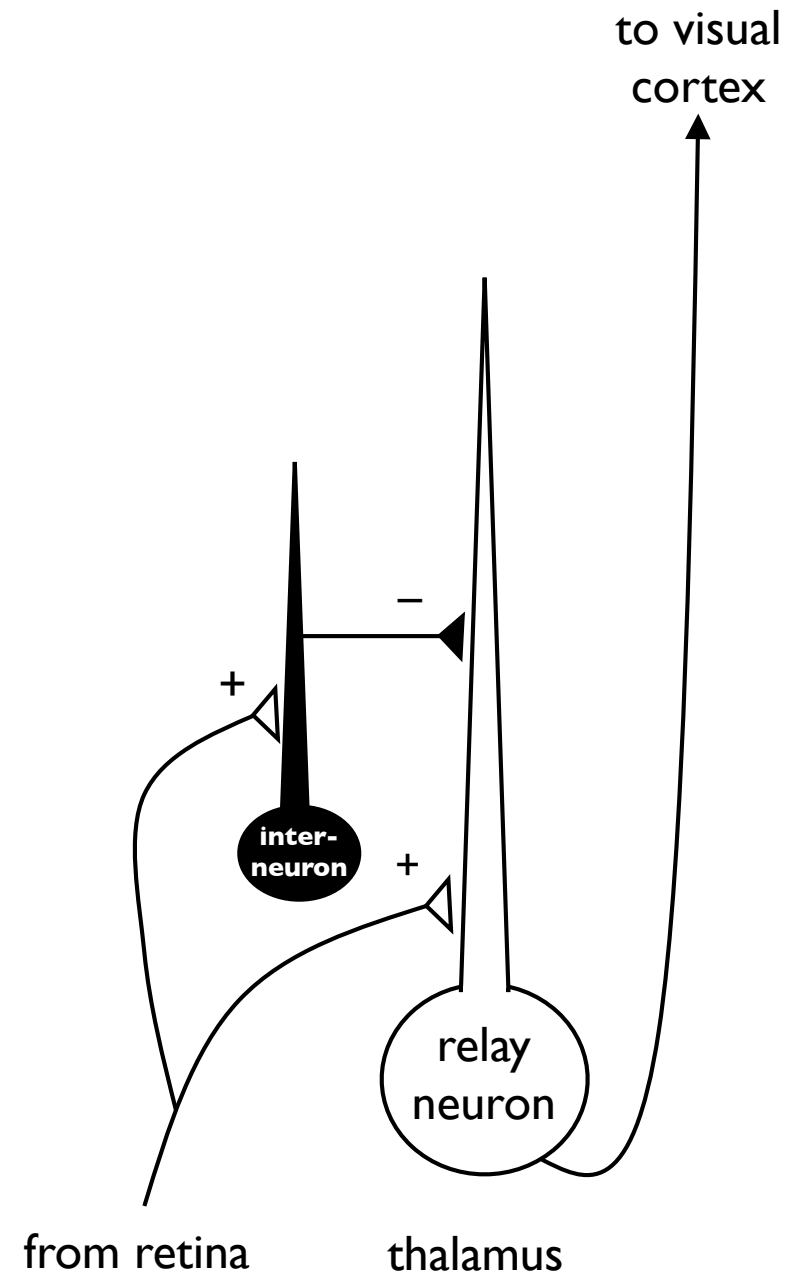


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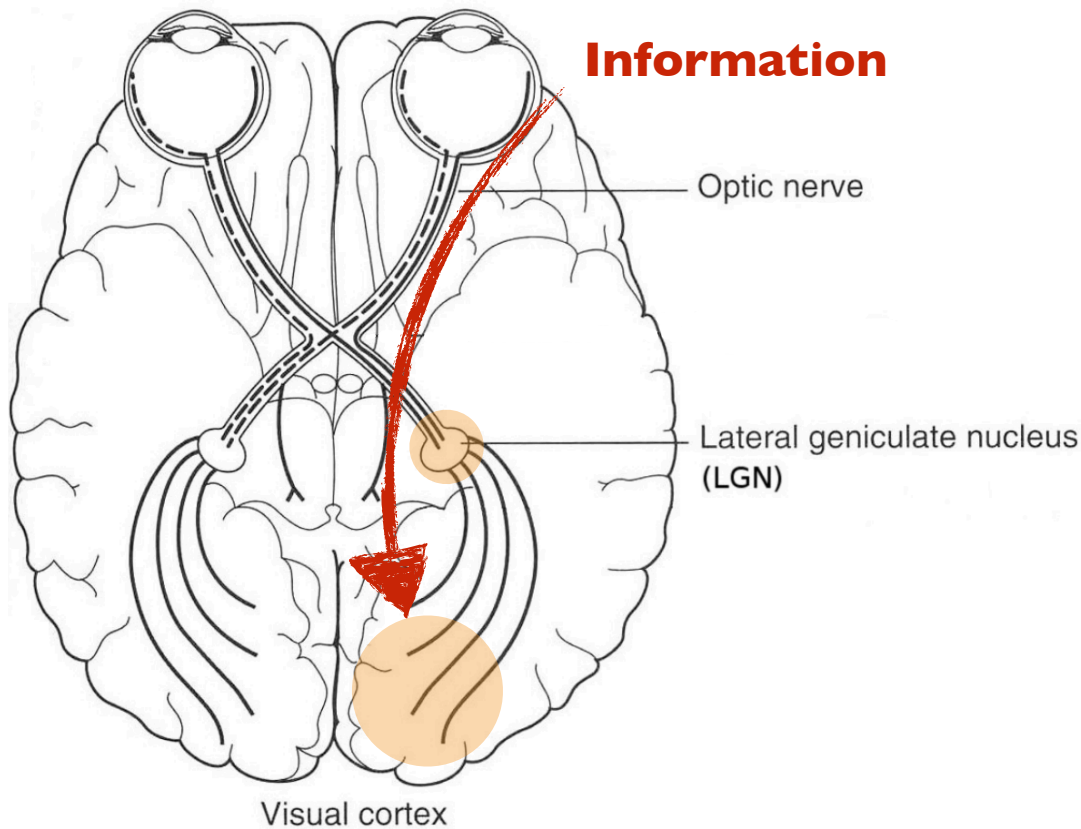


Goldstein, *Sensation and Perception* (4th Ed.), 1996

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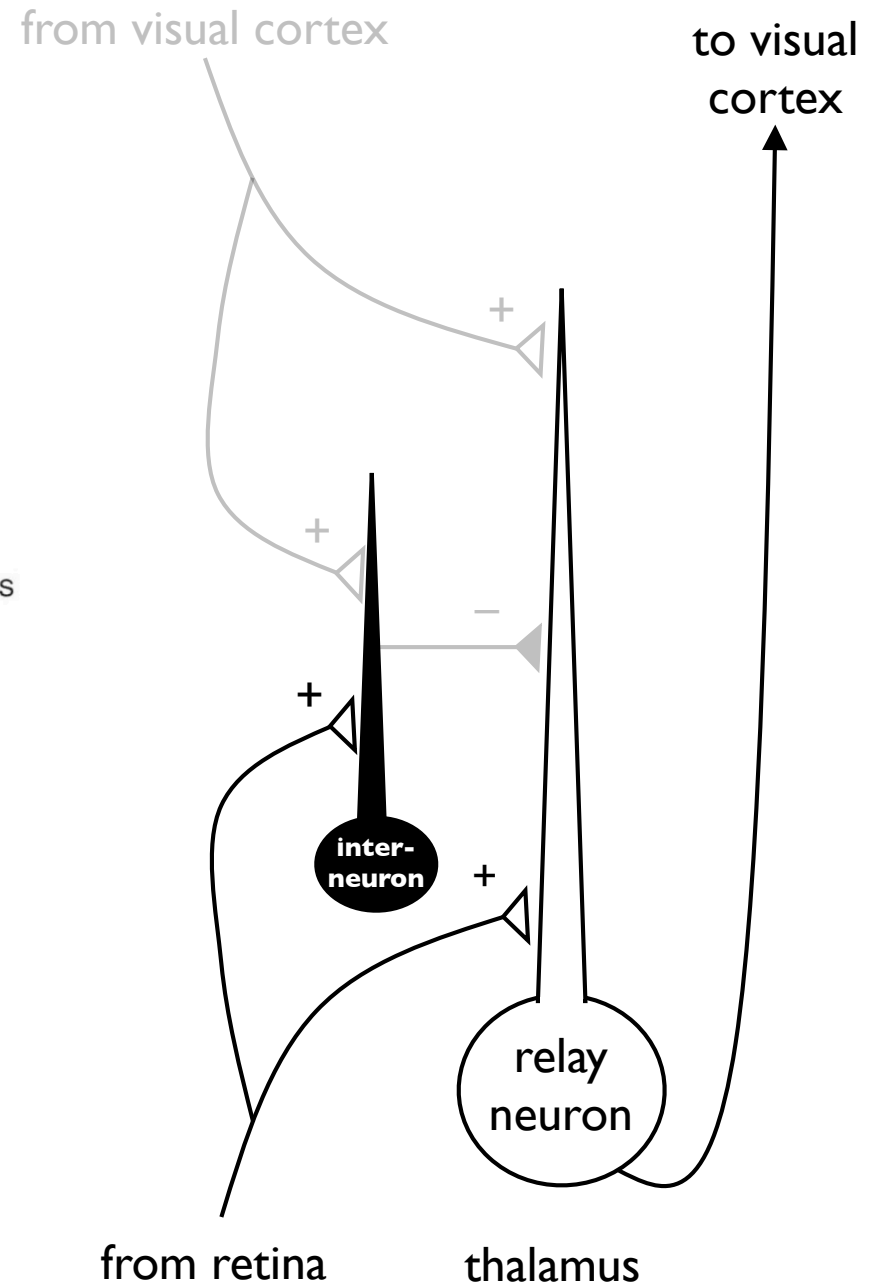


Information flow in the visual pathway

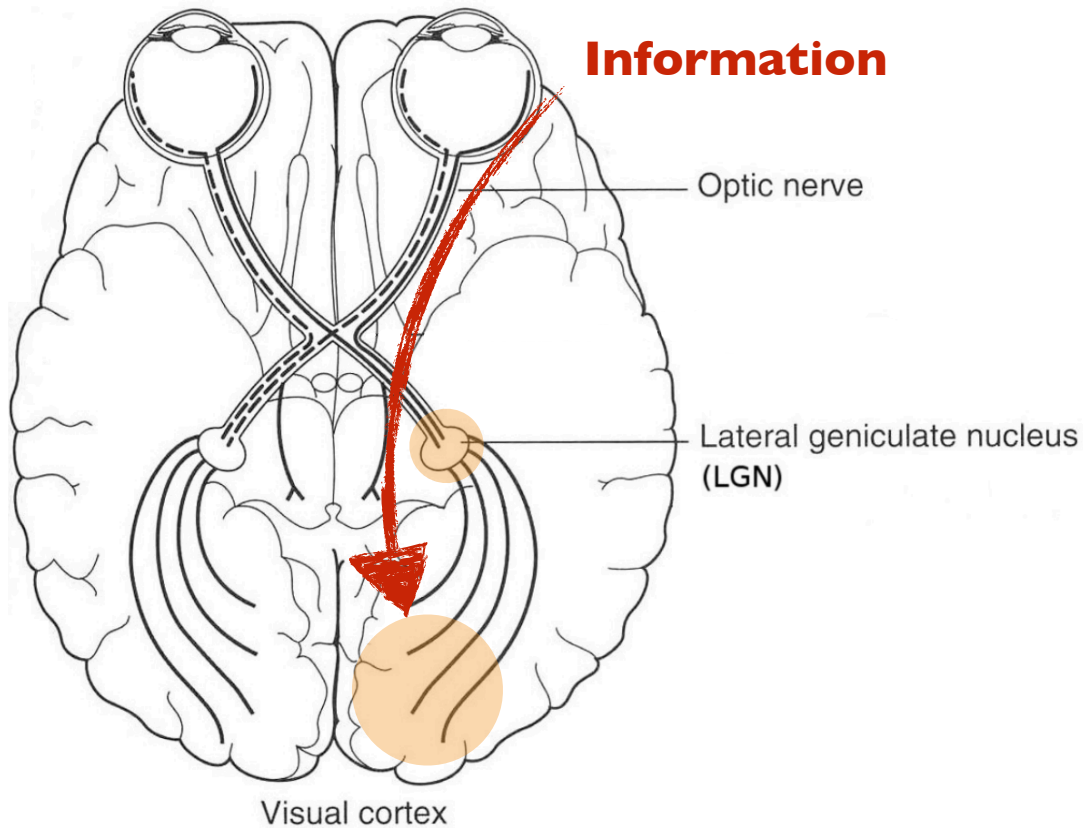


Goldstein, *Sensation and Perception* (4th Ed.), 1996

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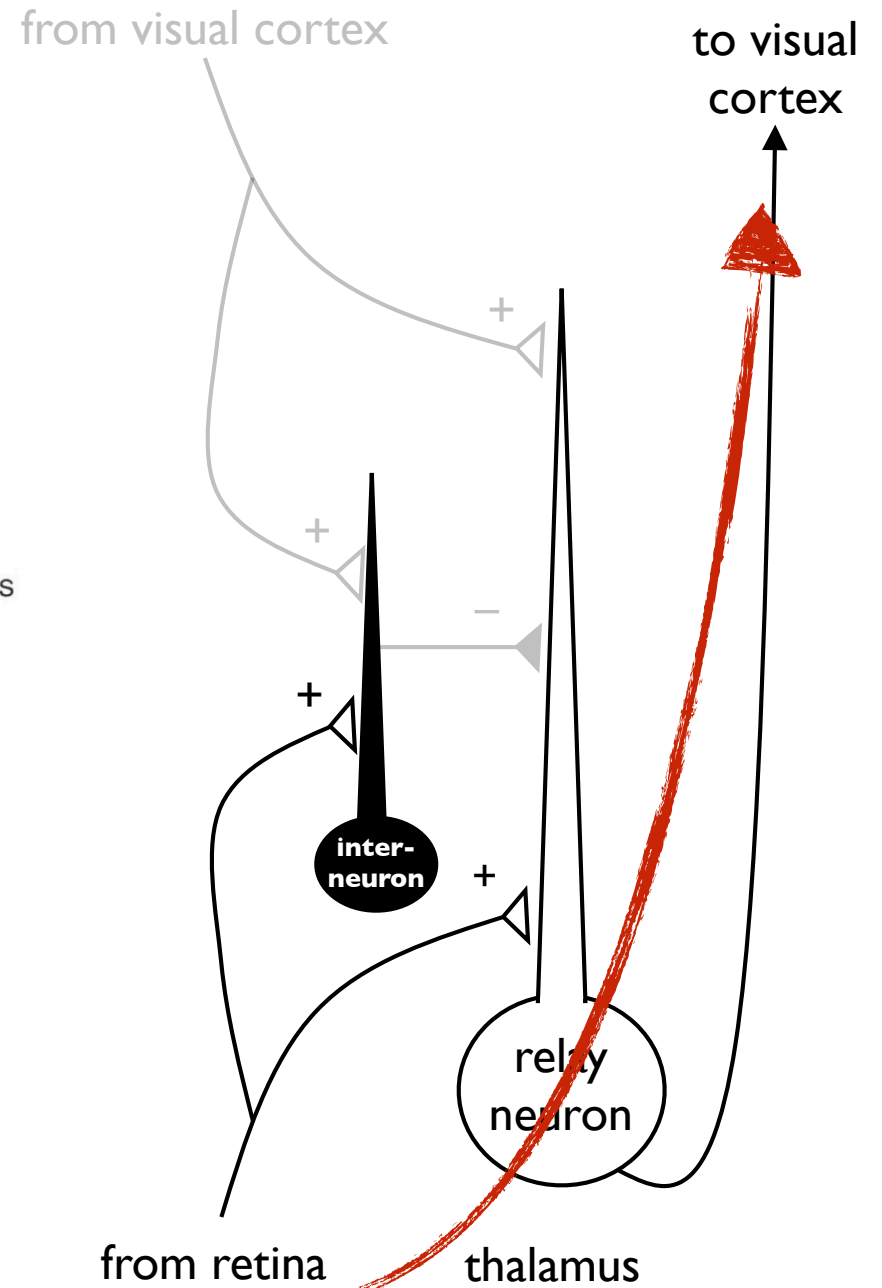


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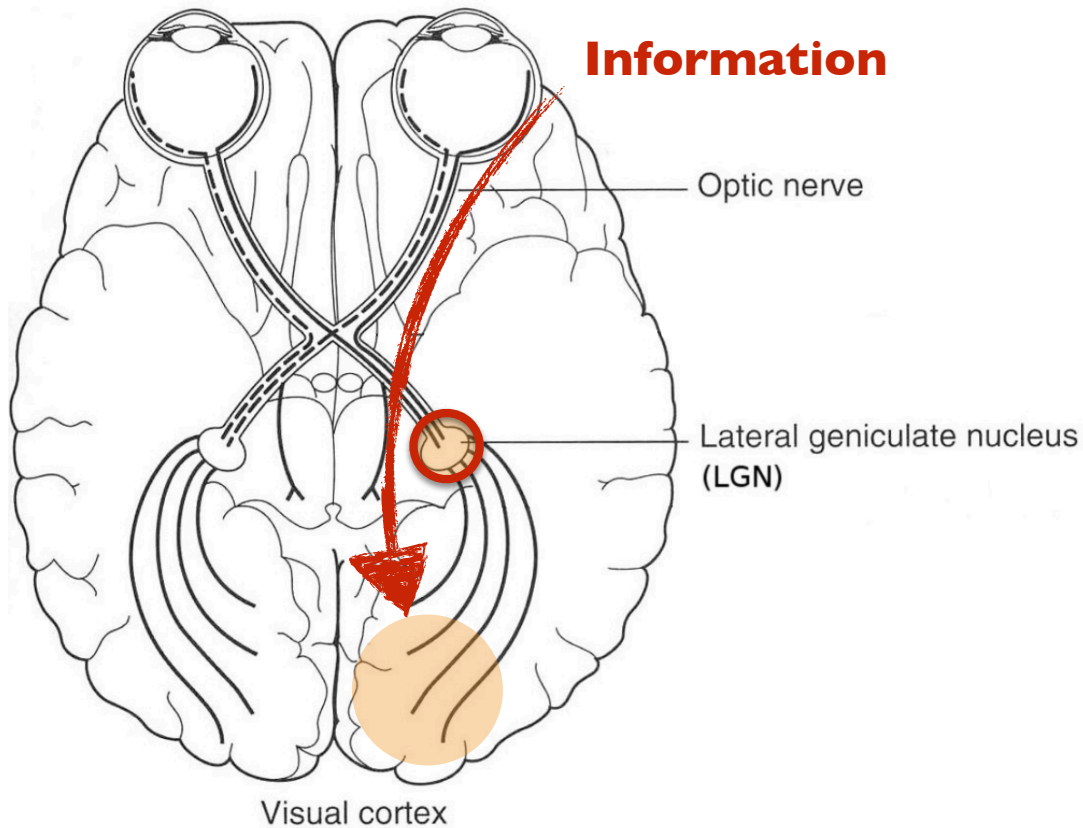


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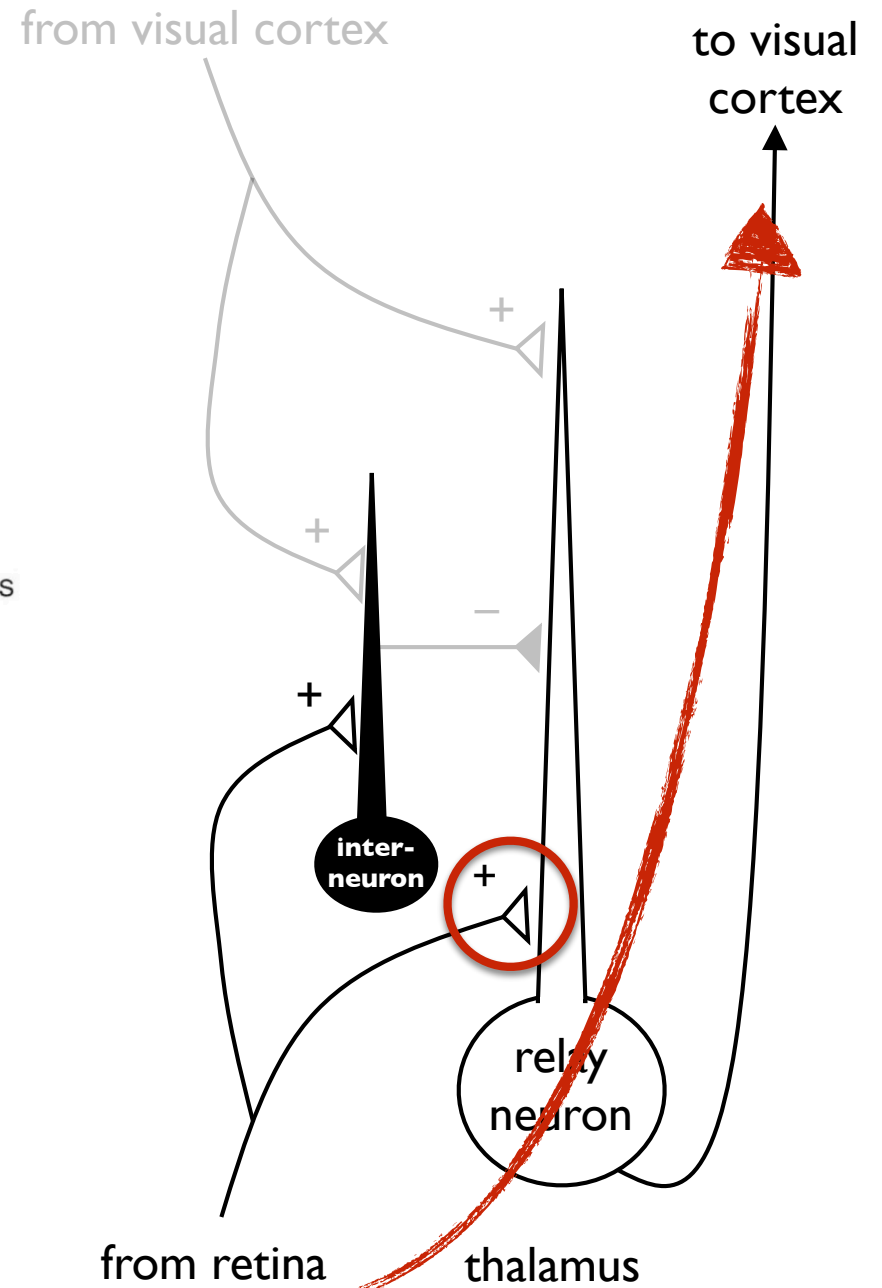


Information flow in the visual pathway

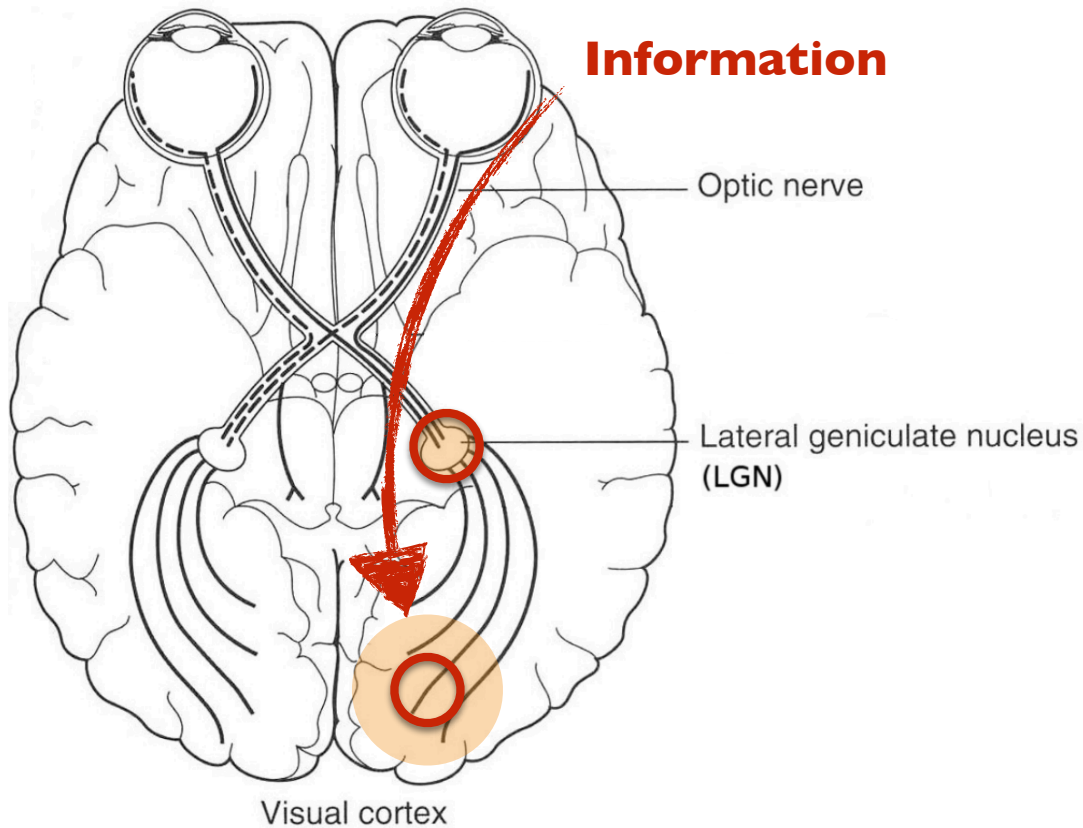


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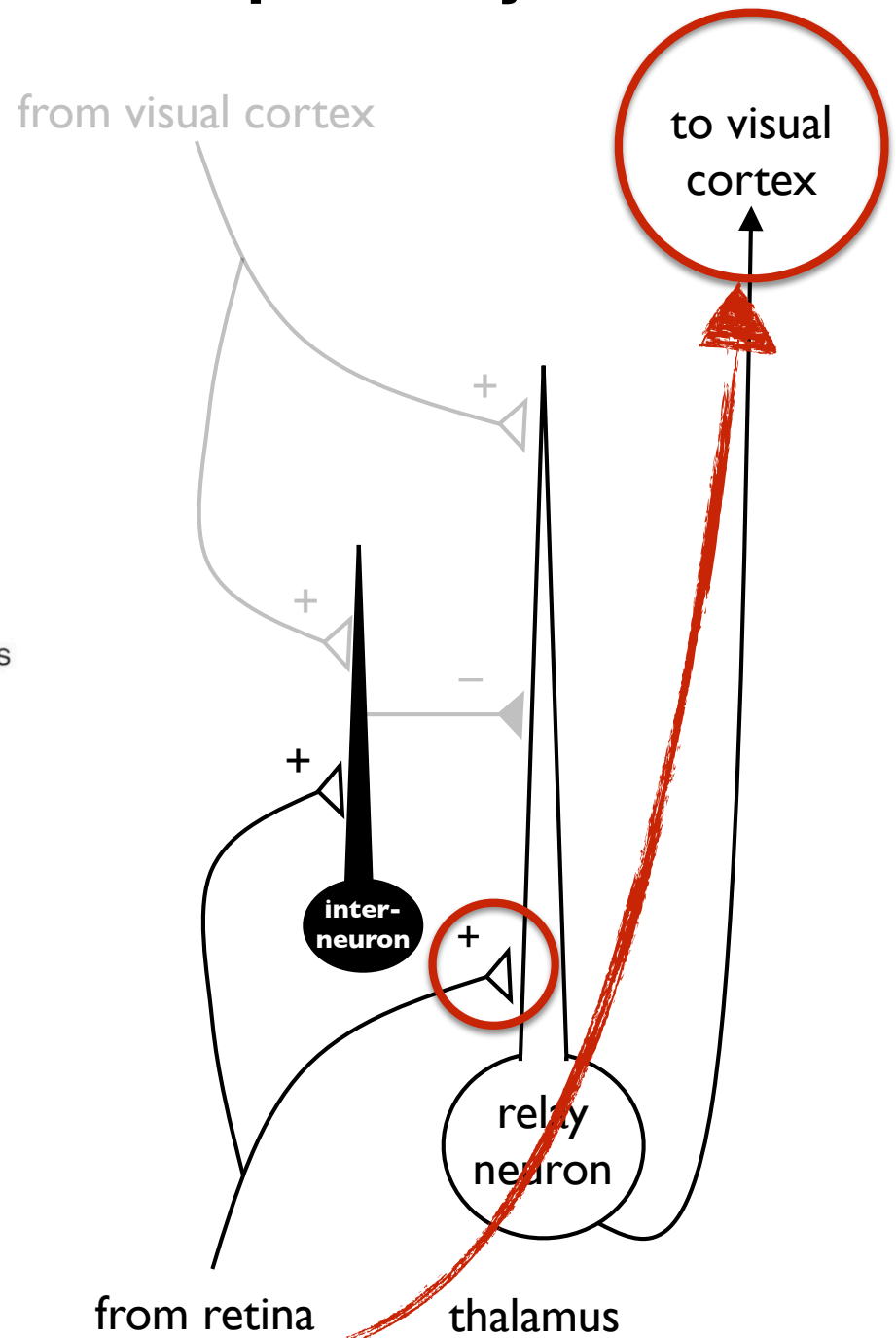


Information flow in the visual pathway

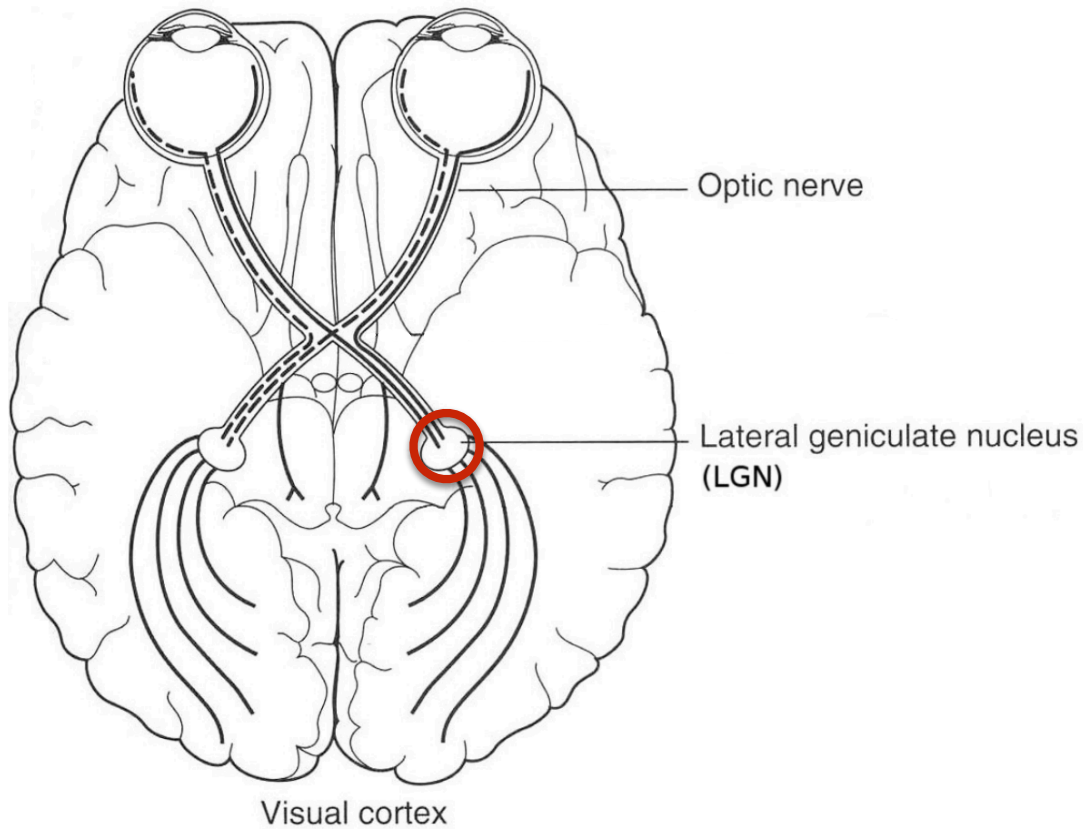


Goldstein, *Sensation and Perception* (4th Ed.), 1996

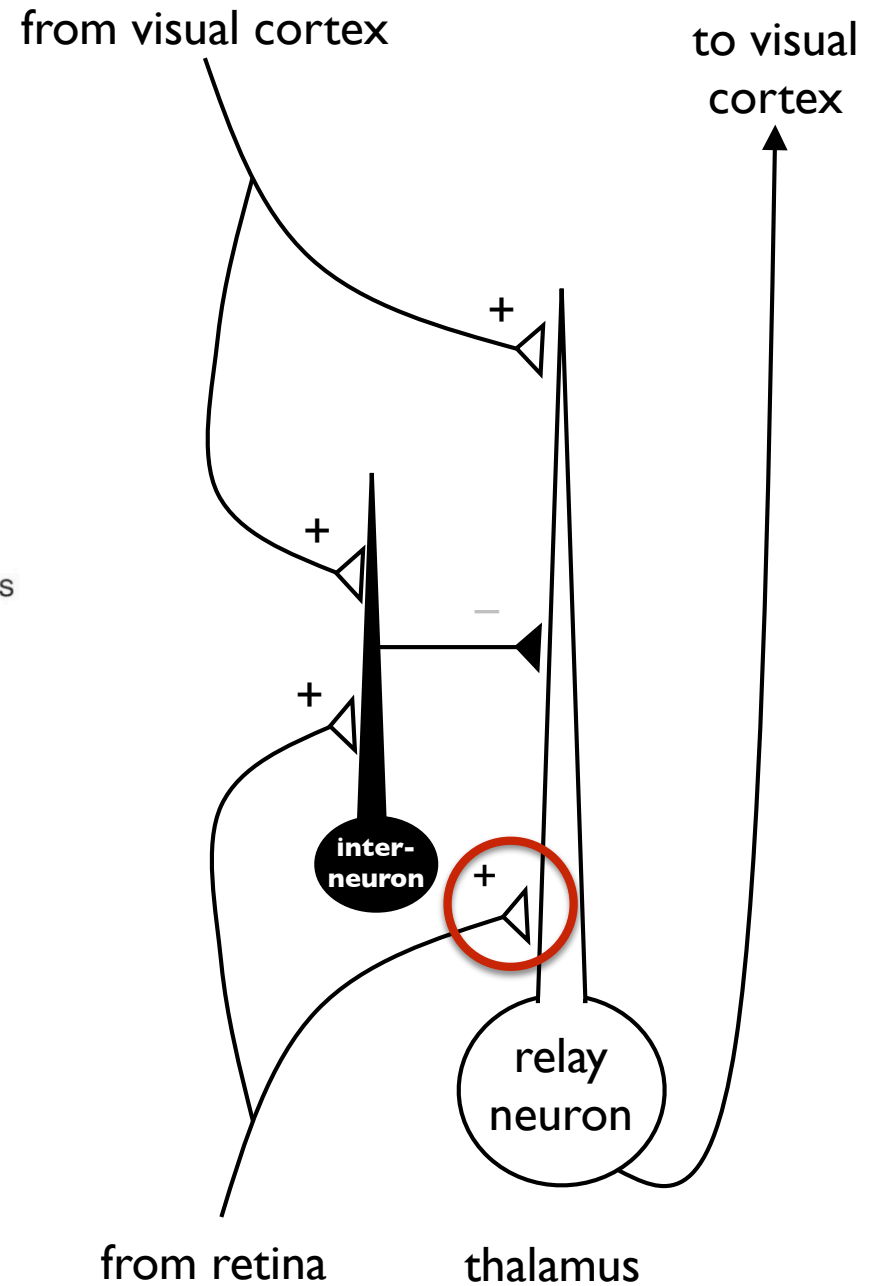
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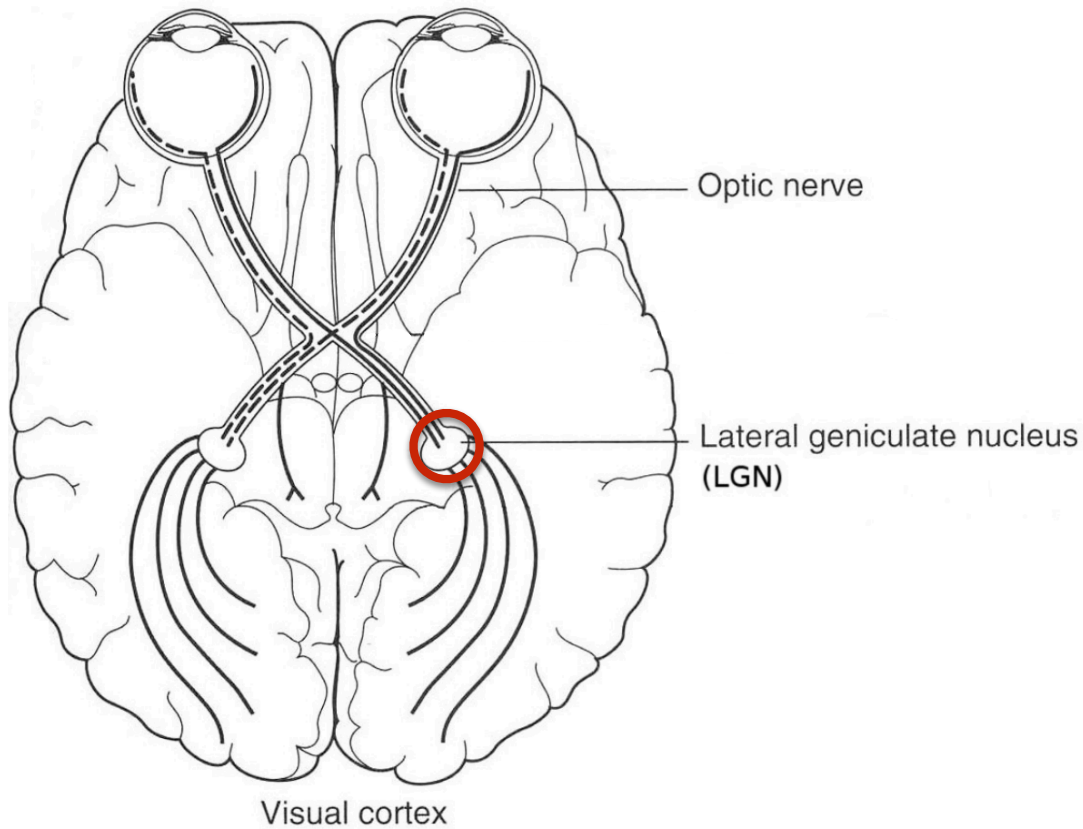
Information flow in the visual pathway



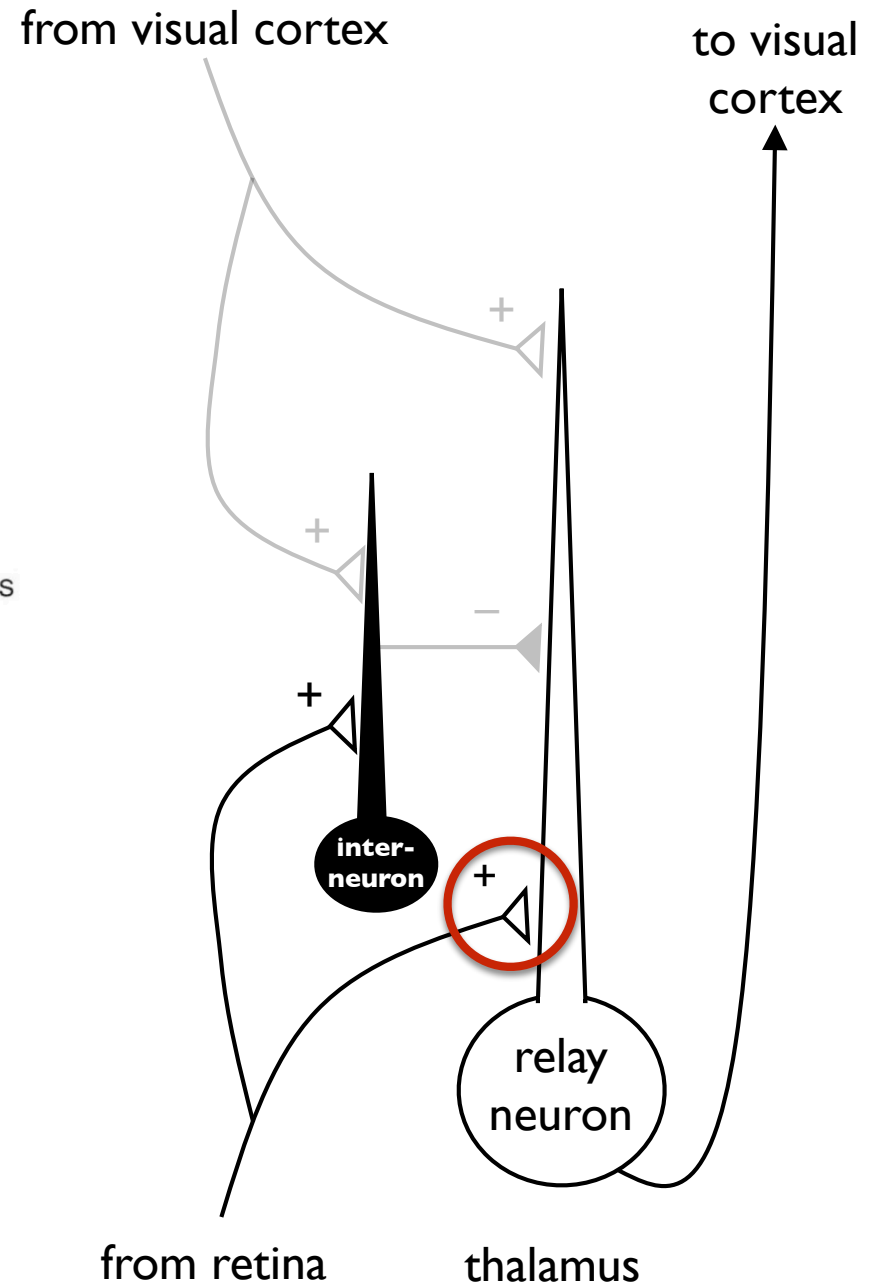
Goldstein, *Sensation and Perception (4th Ed.)*, 1996



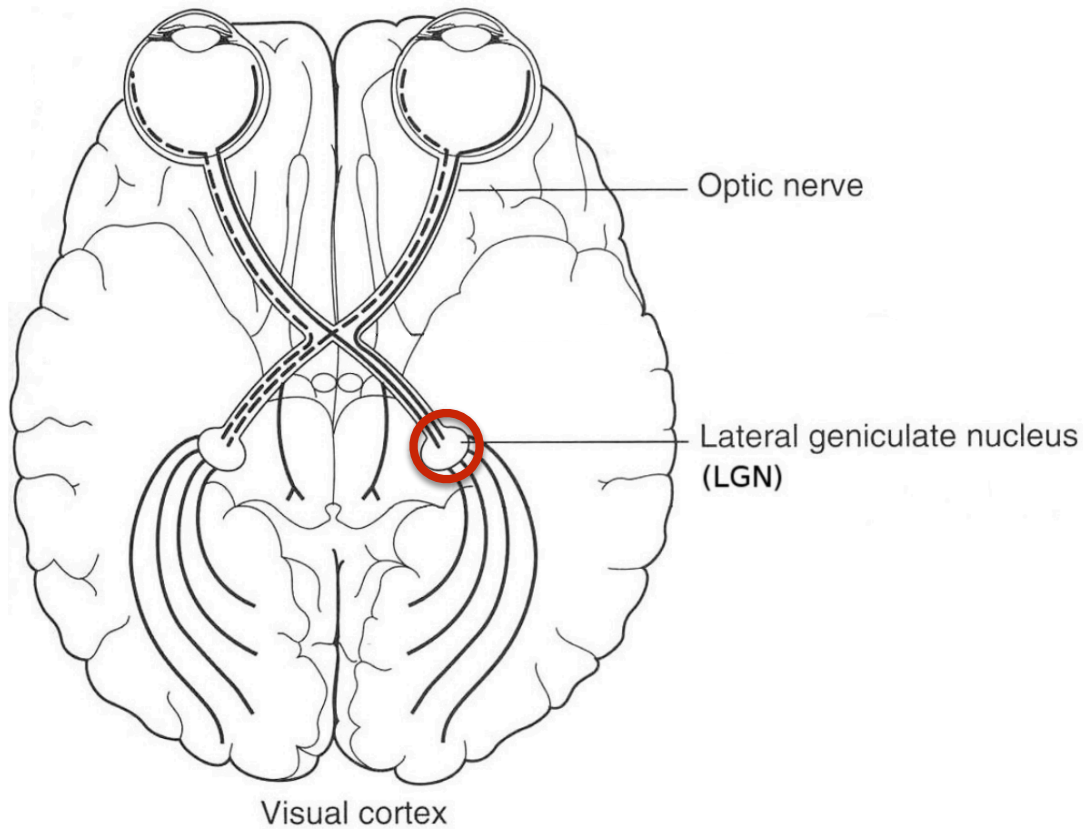
Information flow in the visual pathway



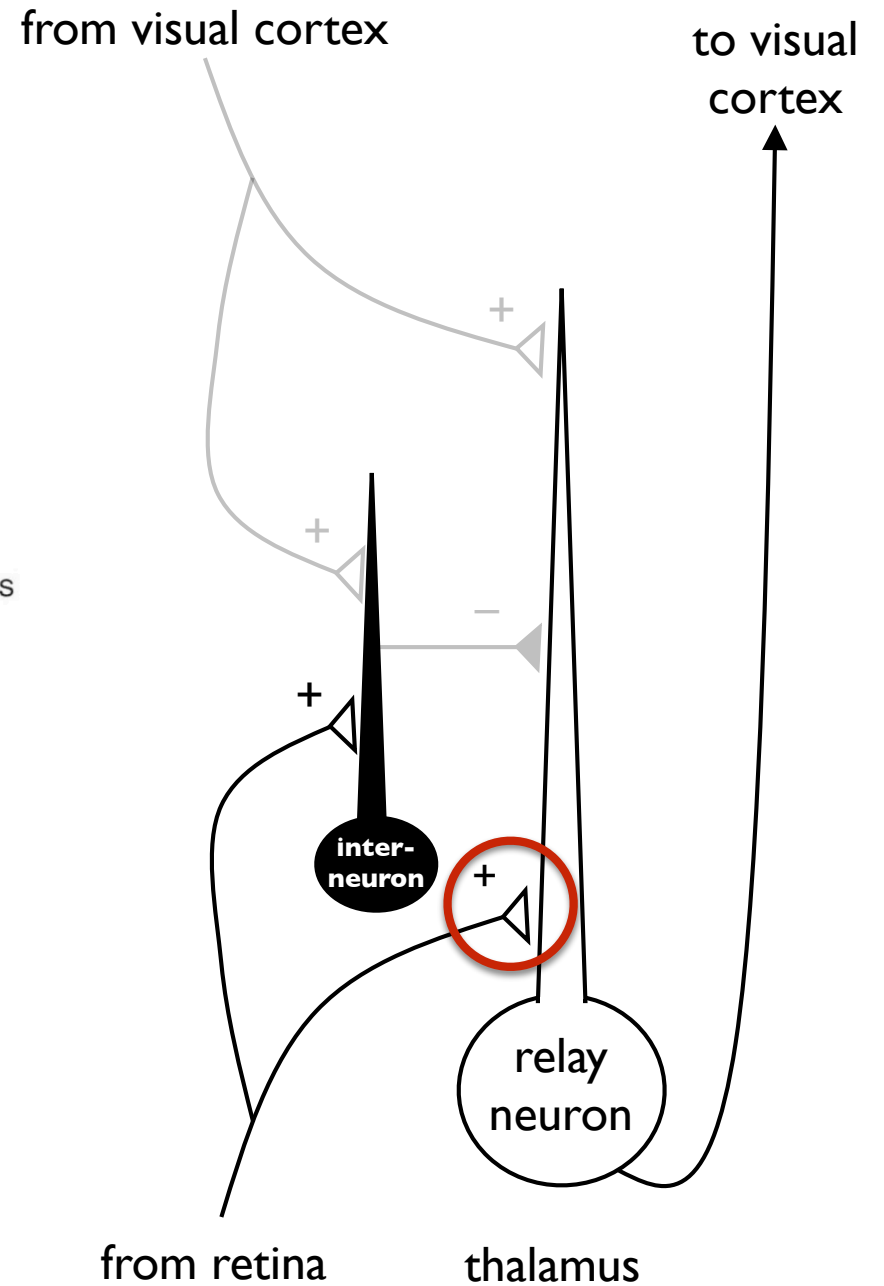
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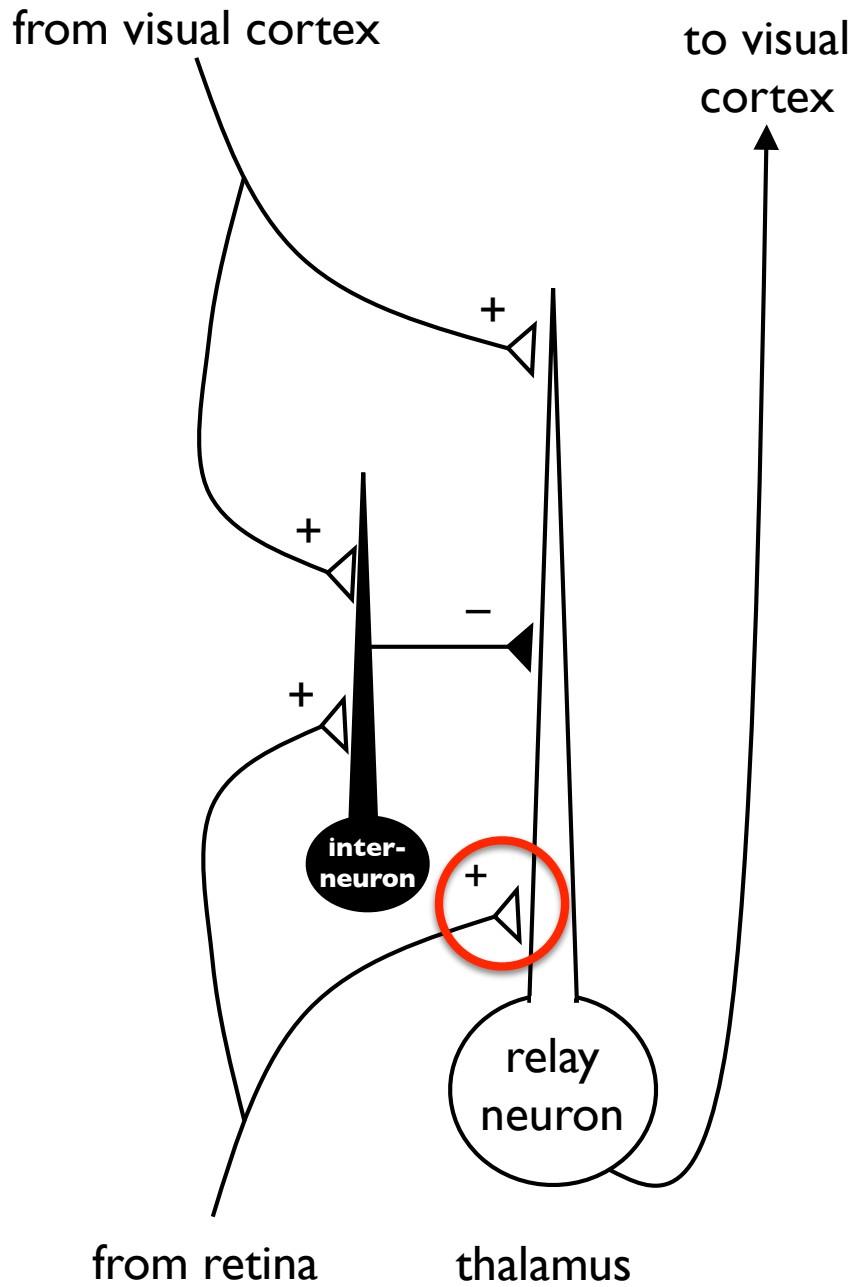
Information flow in the visual pathway



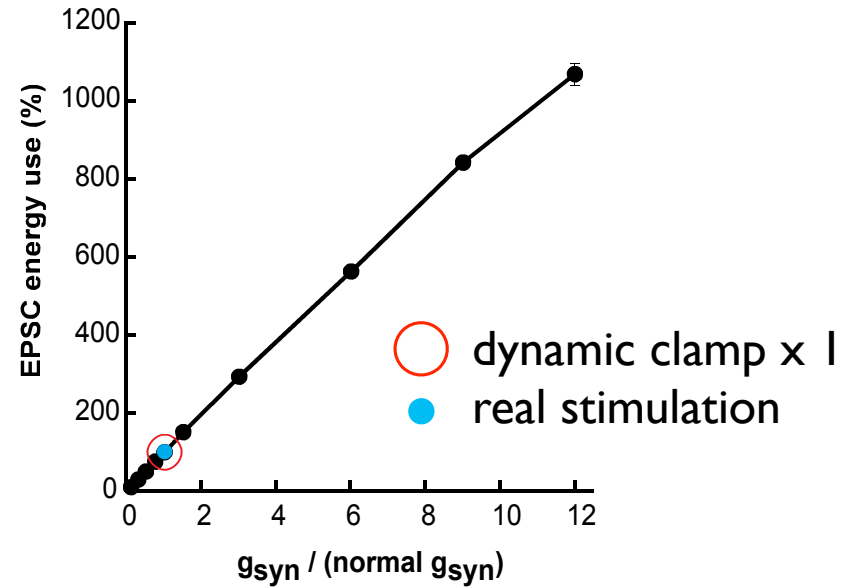
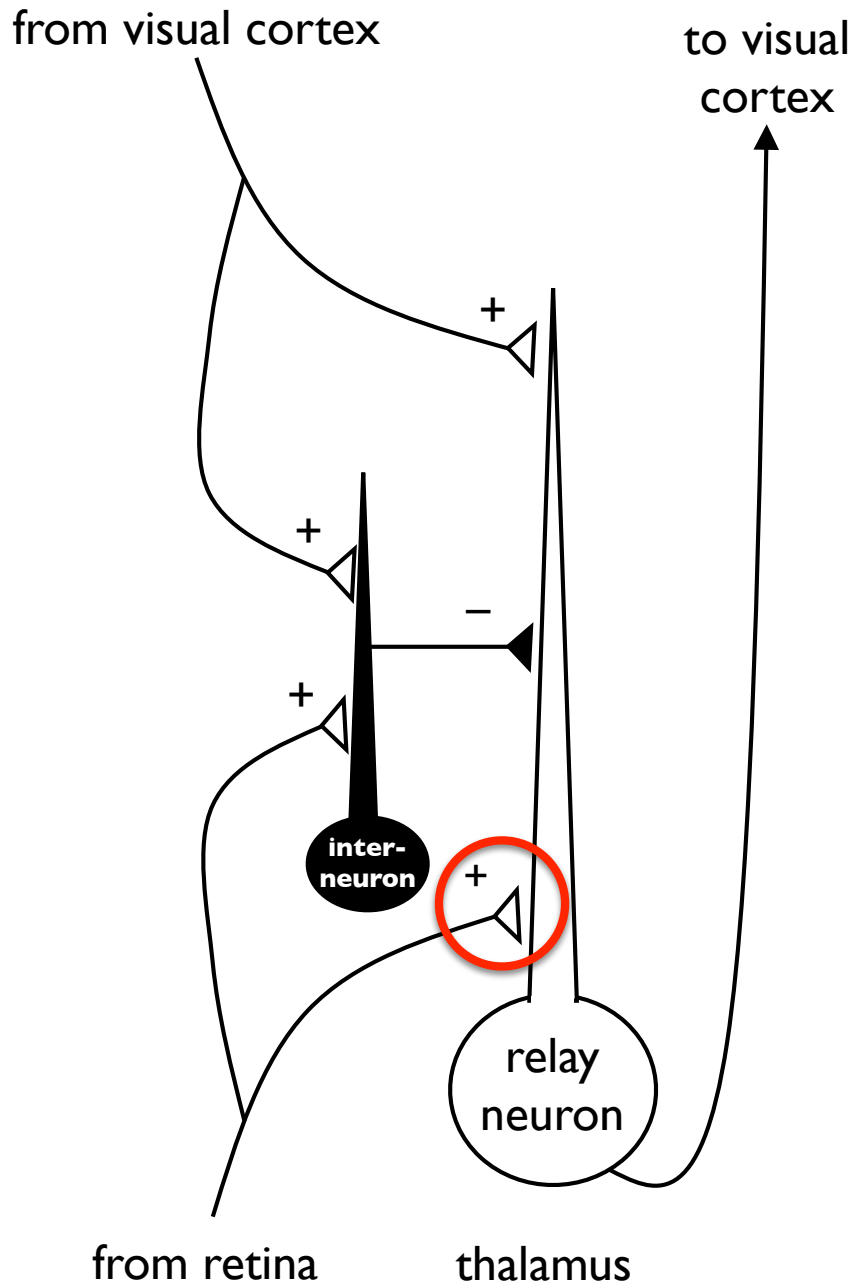
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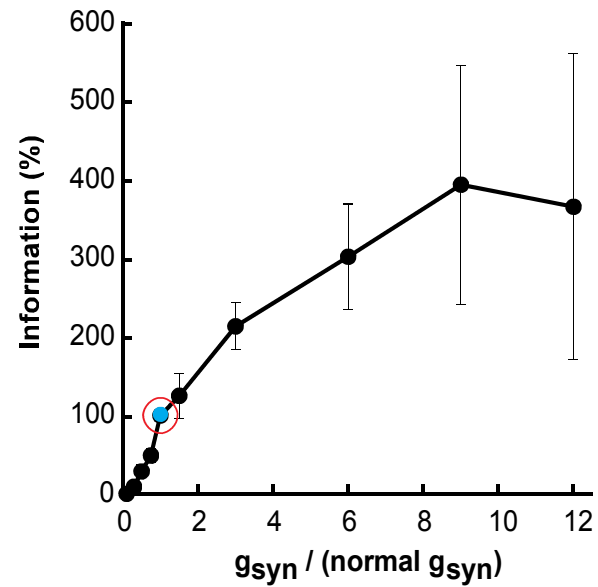
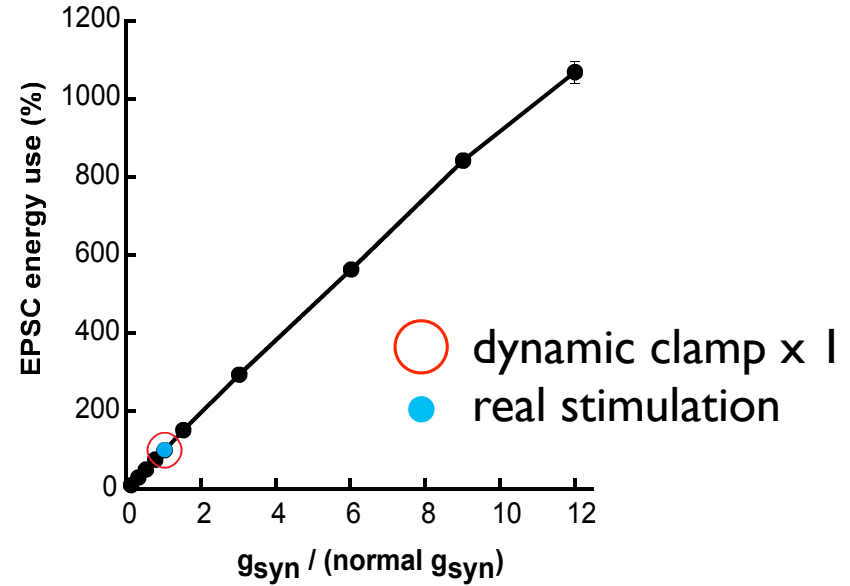
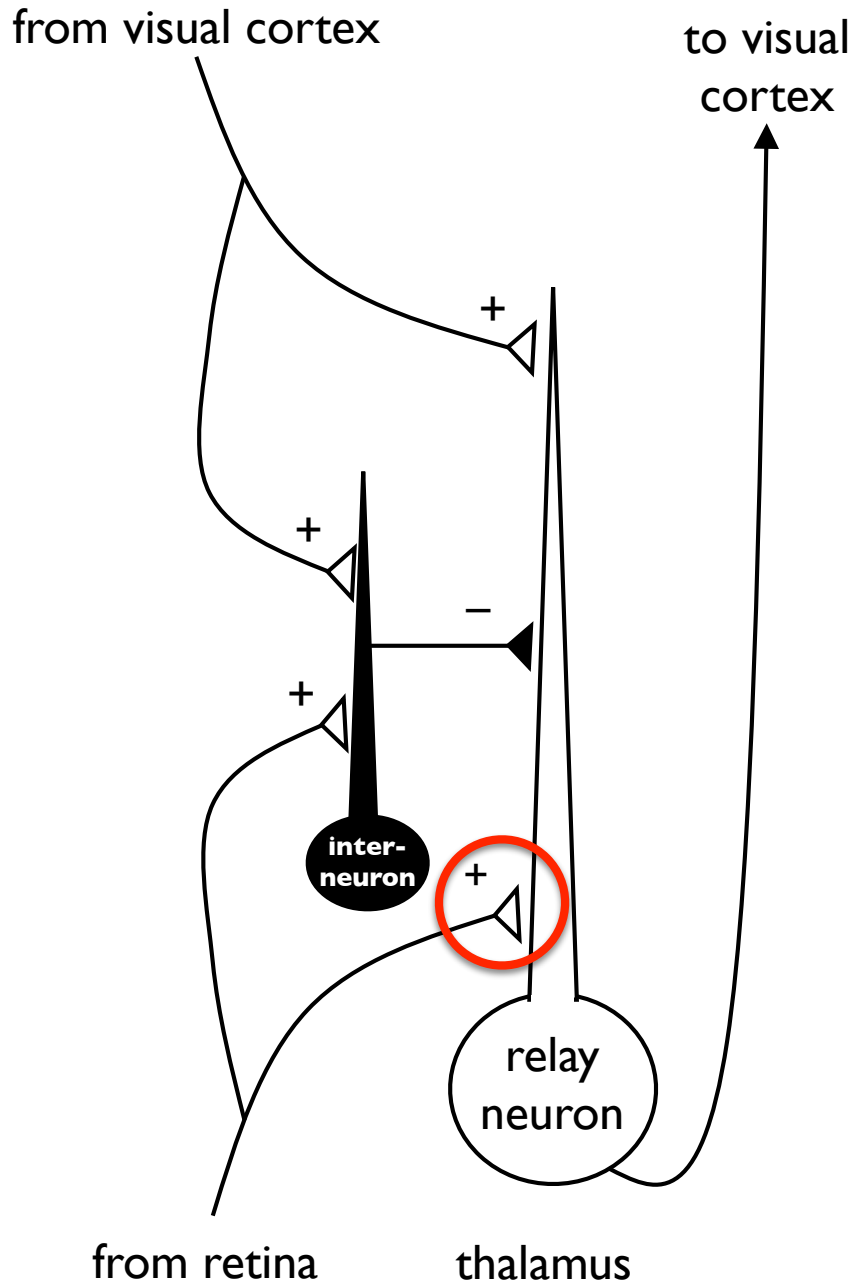
Information vs energetics in the visual pathway



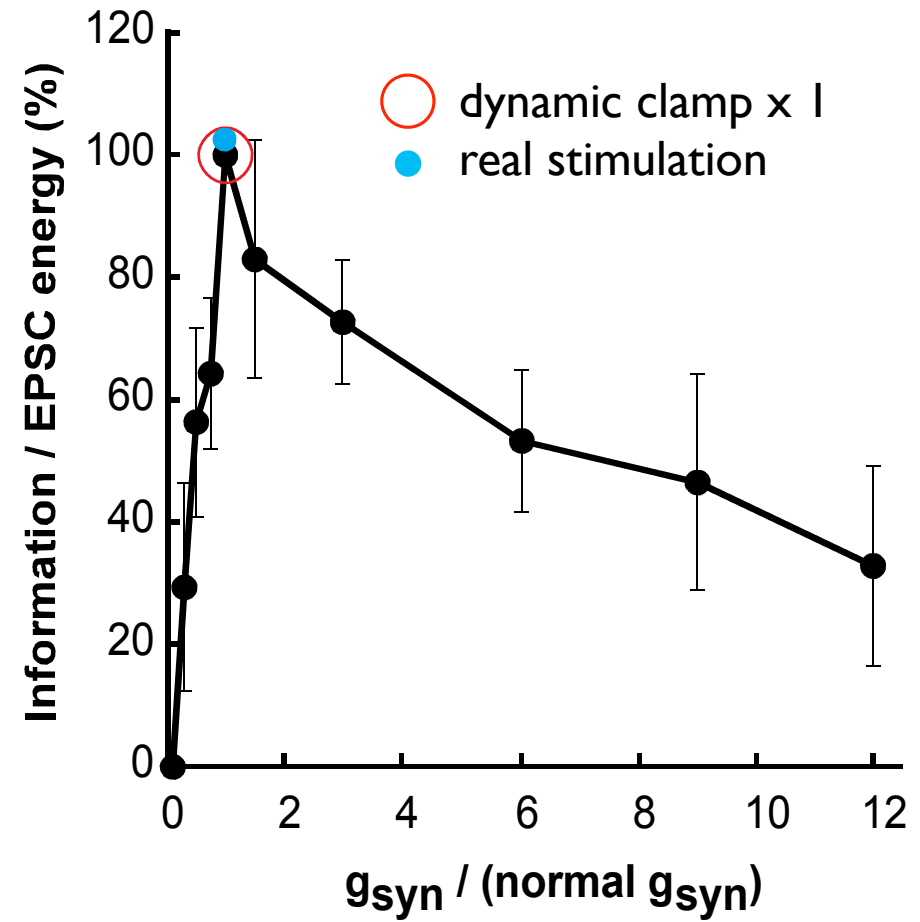
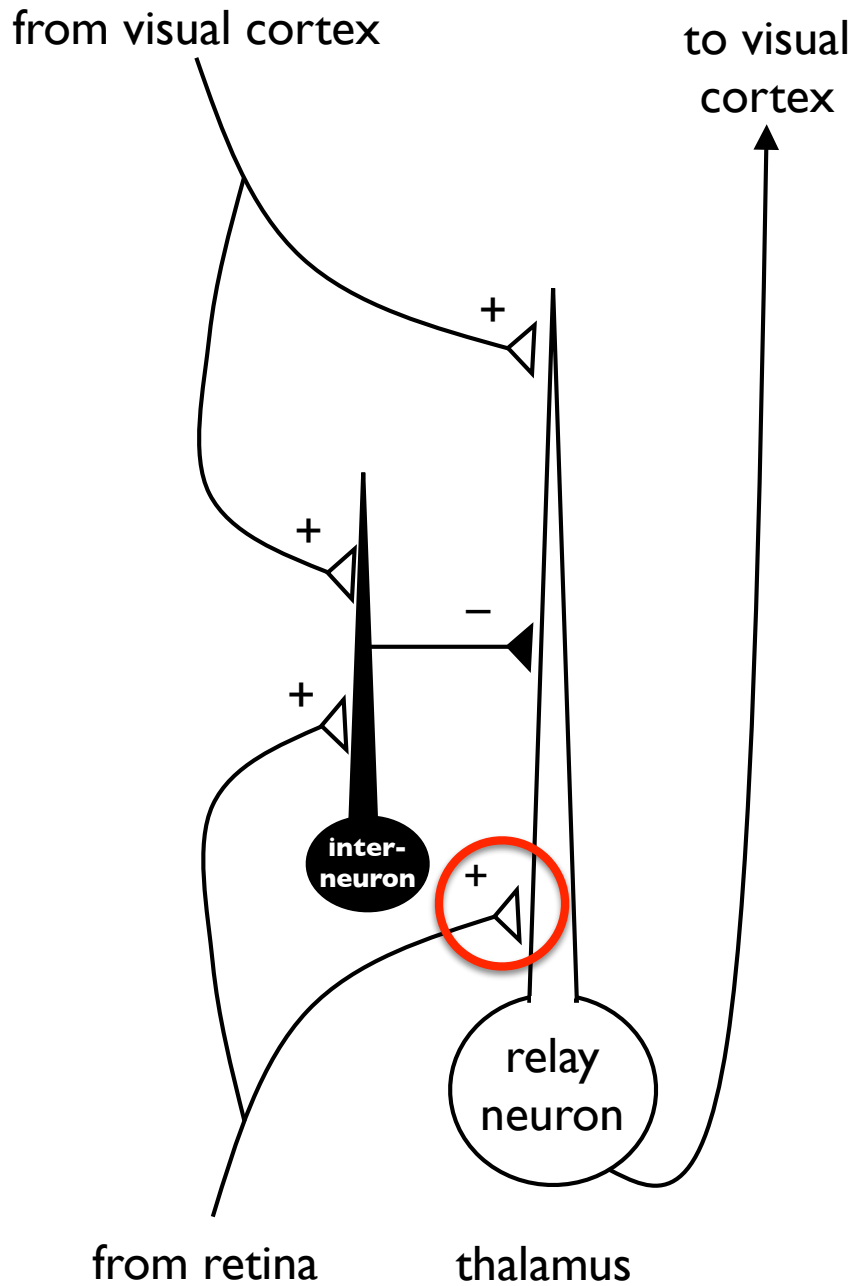
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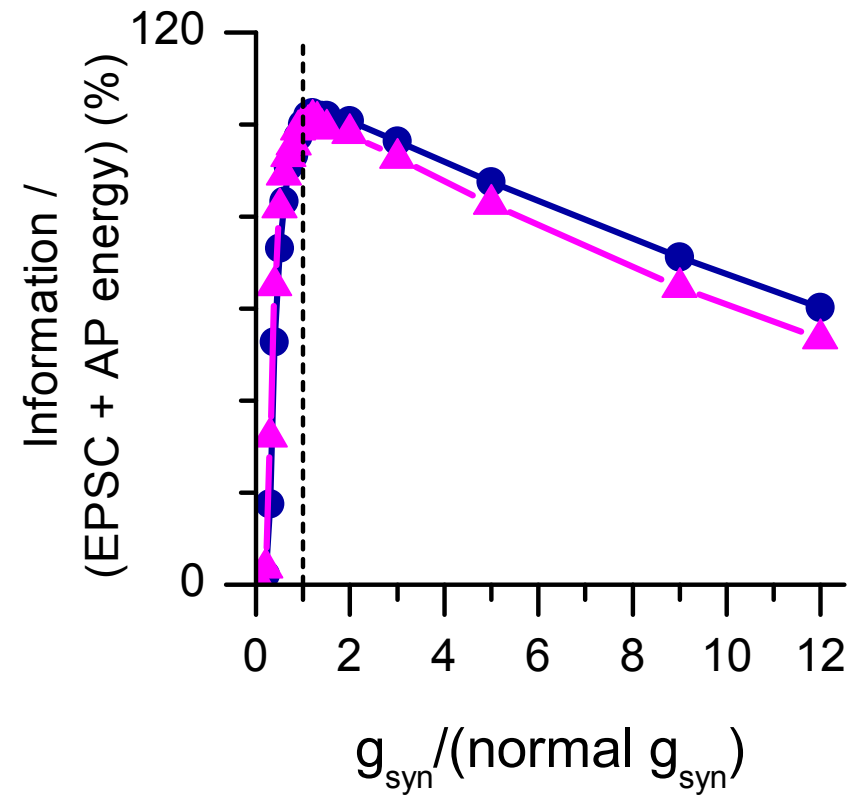
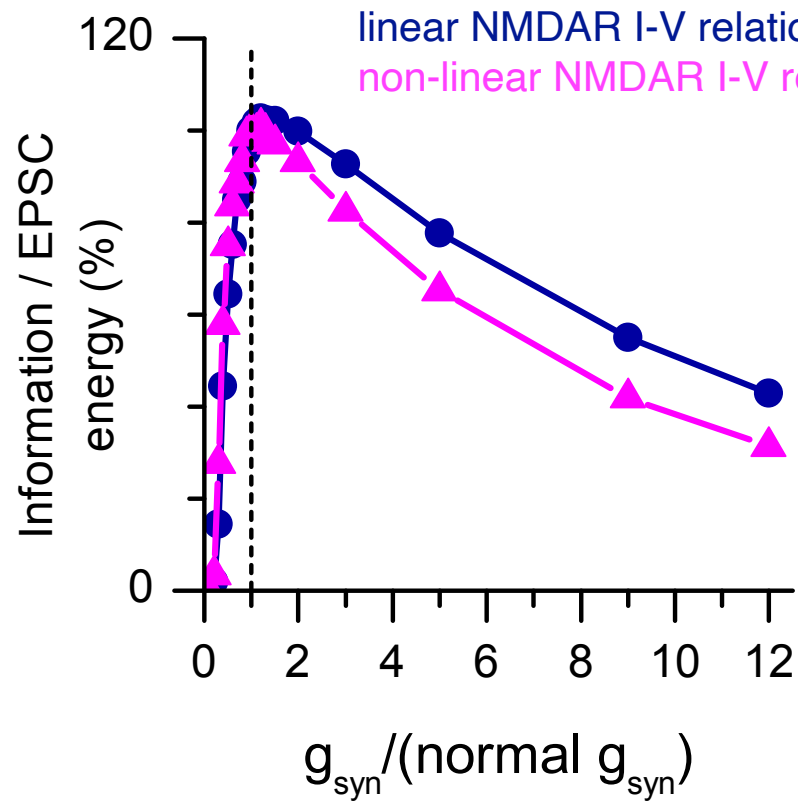
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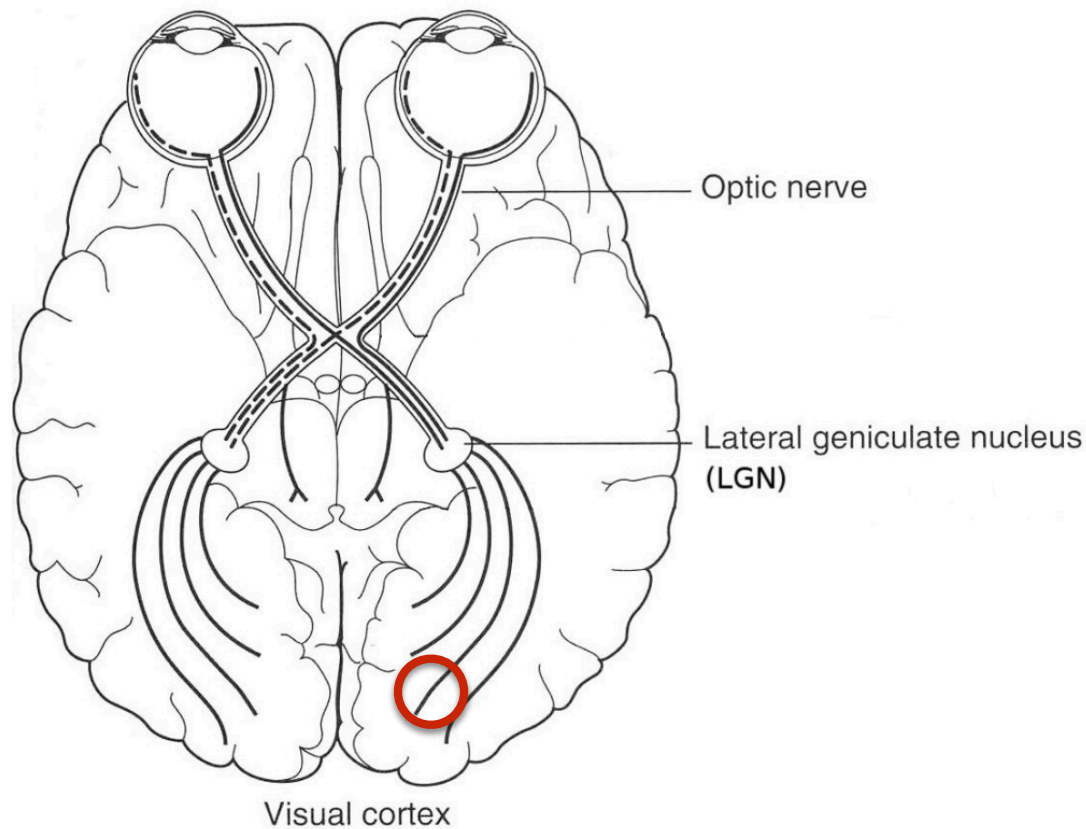
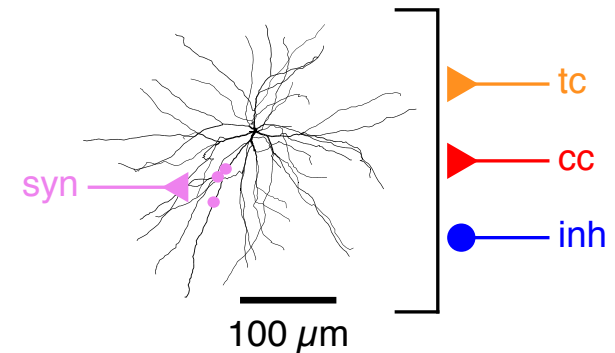


All these results can be reproduced in an Hodgkin-Huxley model of LGN cells

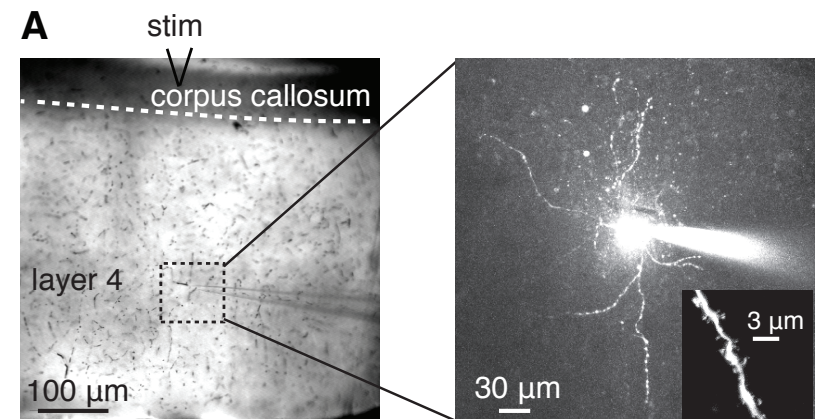


What happens at the next synapse in the visual pathway?

Multicompartment simulations
(layer 4 spiny stellate cells)

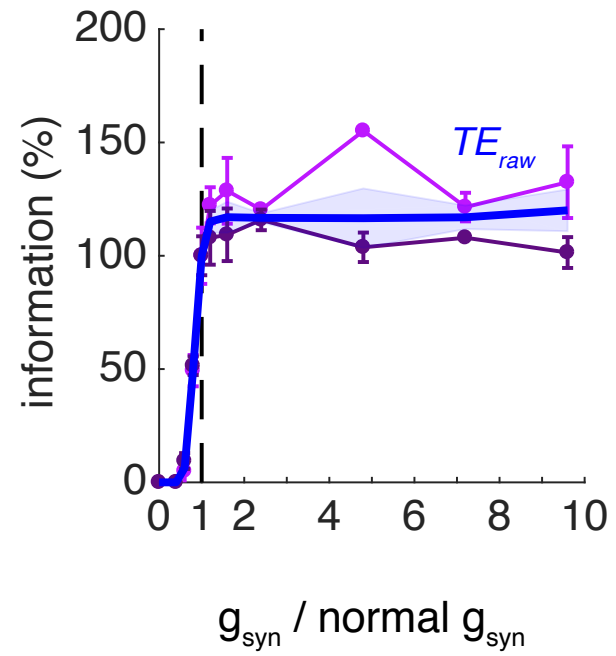


Electrophysiology experiments
(layer 4 spiny stellate cells)

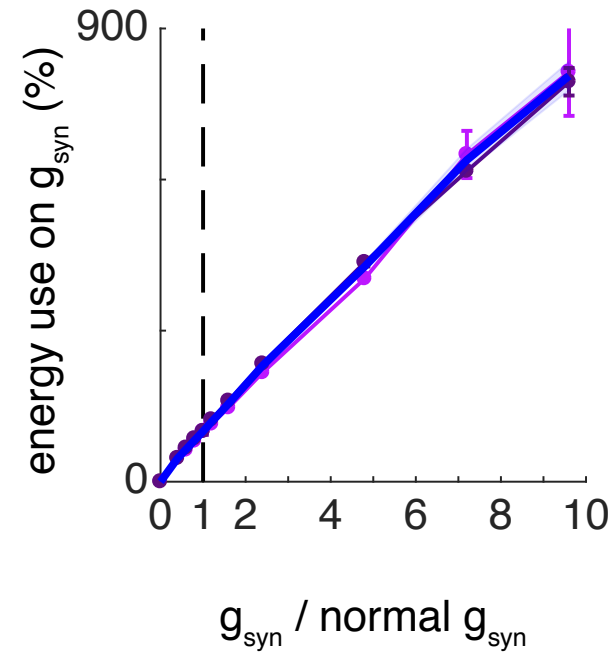
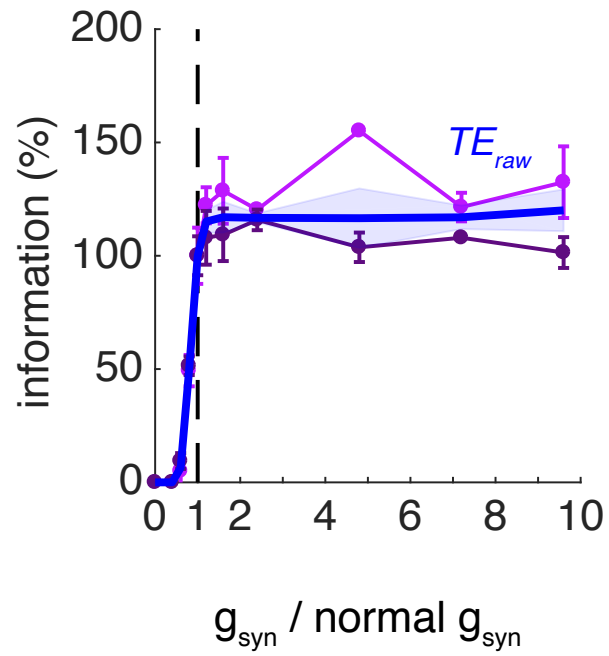


Goldstein, *Sensation and Perception (4th Ed.)*, 1996

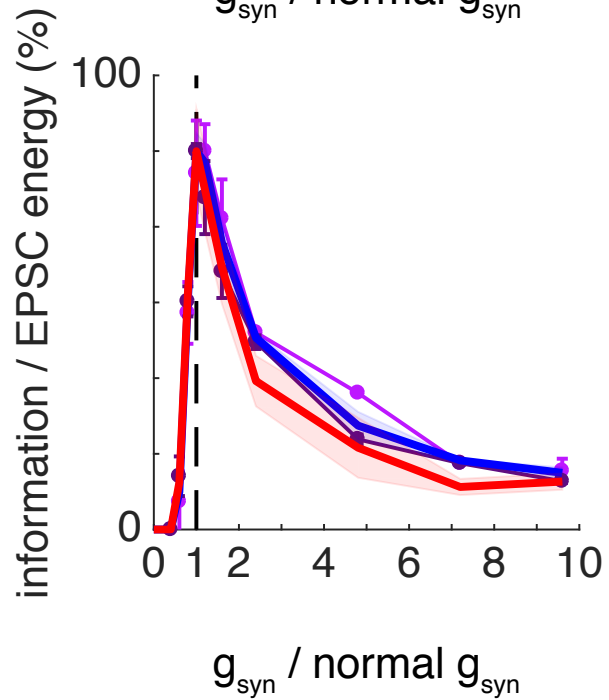
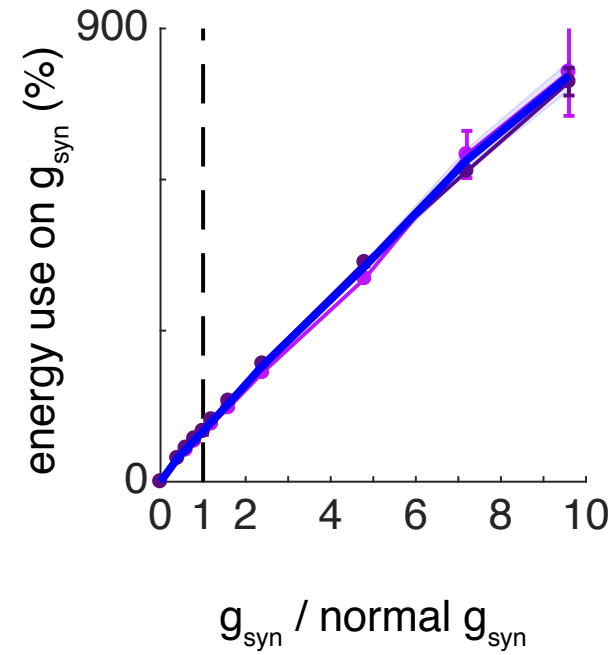
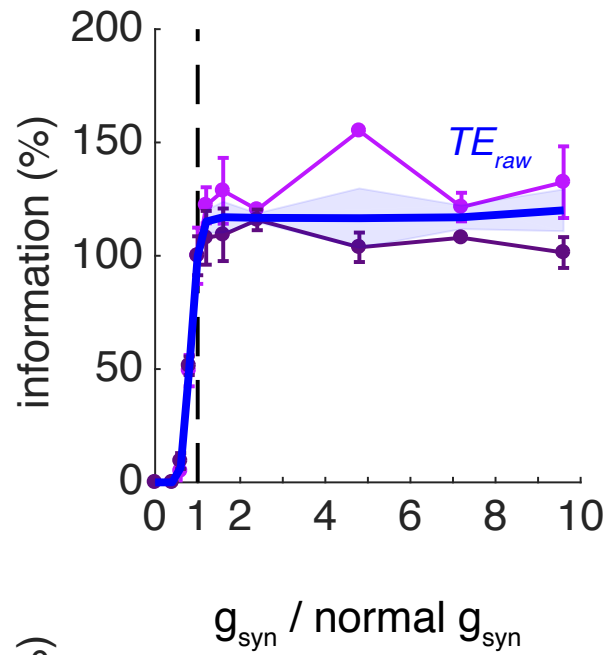
NEURON simulations



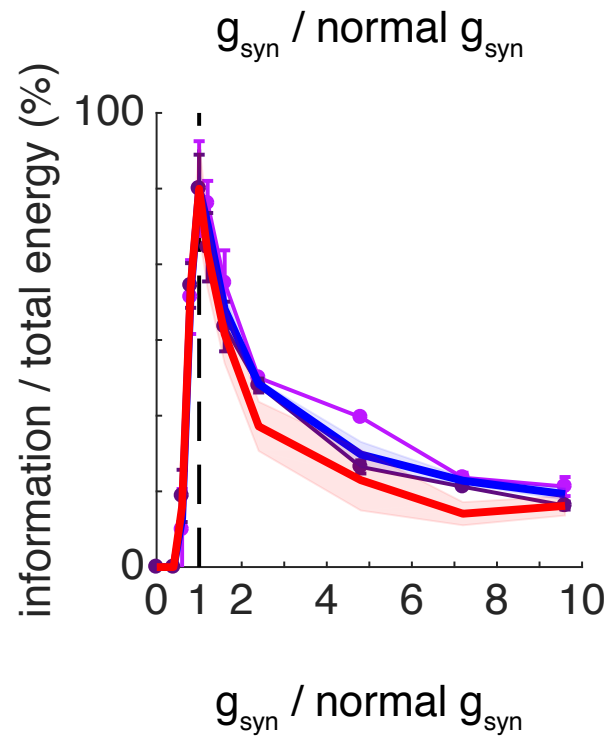
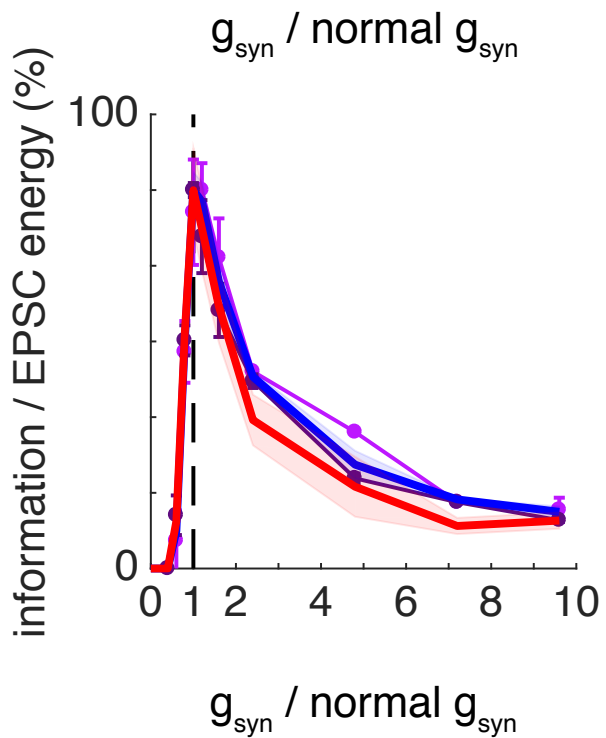
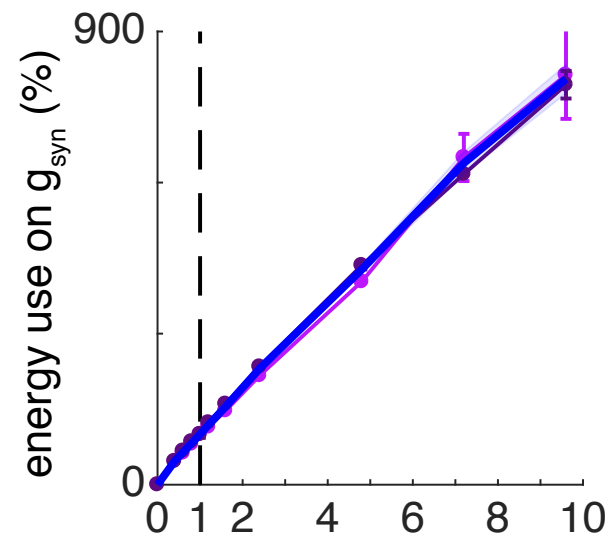
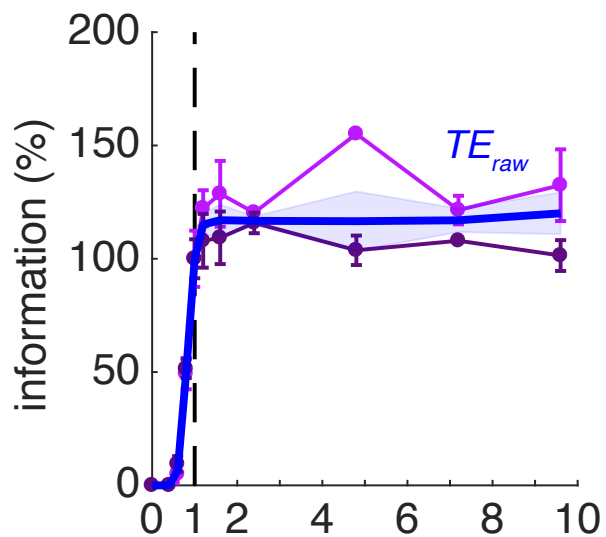
NEURON simulations



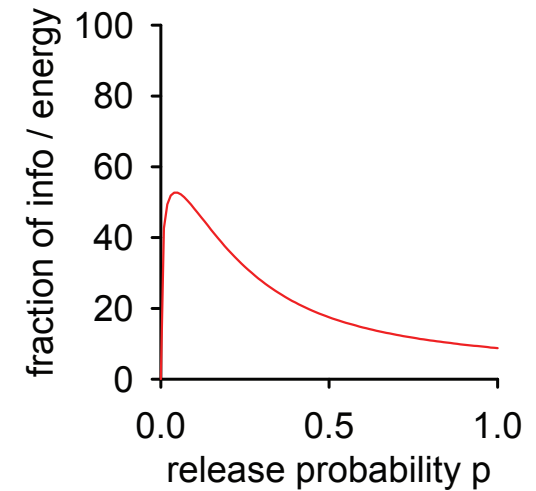
NEURON simulations



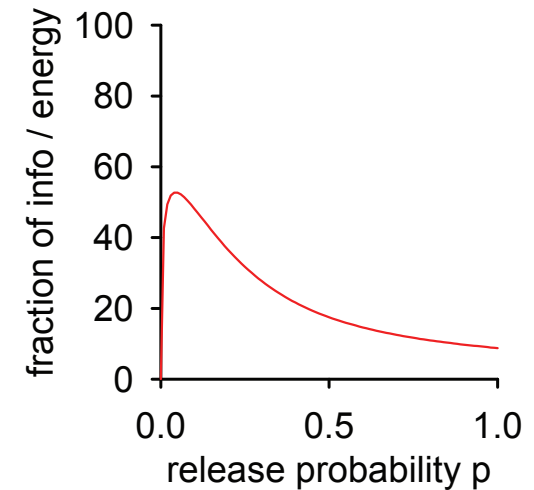
NEURON simulations



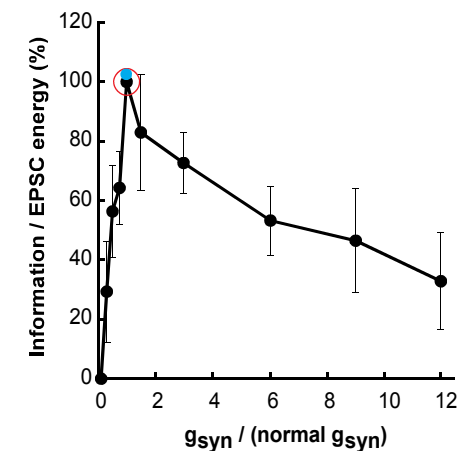
- ▶ Low release probability (presynaptic side) can be explained as a way to maximise not information transfer (bits/sec) but information over concomitant energy consumption (bits/ATP).



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- ▶ 'Imperfect' action potential transmission at relay synapses in the visual pathway (postsynaptic side, i.e. number of receptors inserted in the membrane) can be explained as a way to maximise not information transfer (bits/sec) but information over concomitant energy consumption (bits/ATP).



How is learning in neural networks affected by energetic constraints?

- ▶ Network of Hawkes neurones with reset after spiking;

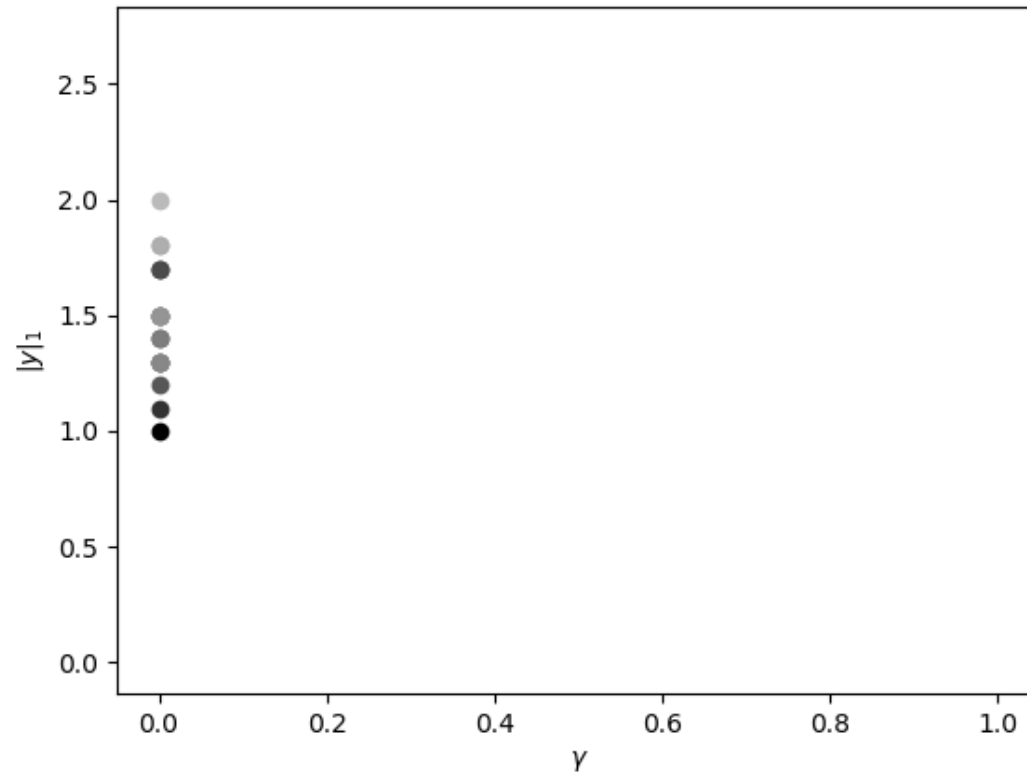
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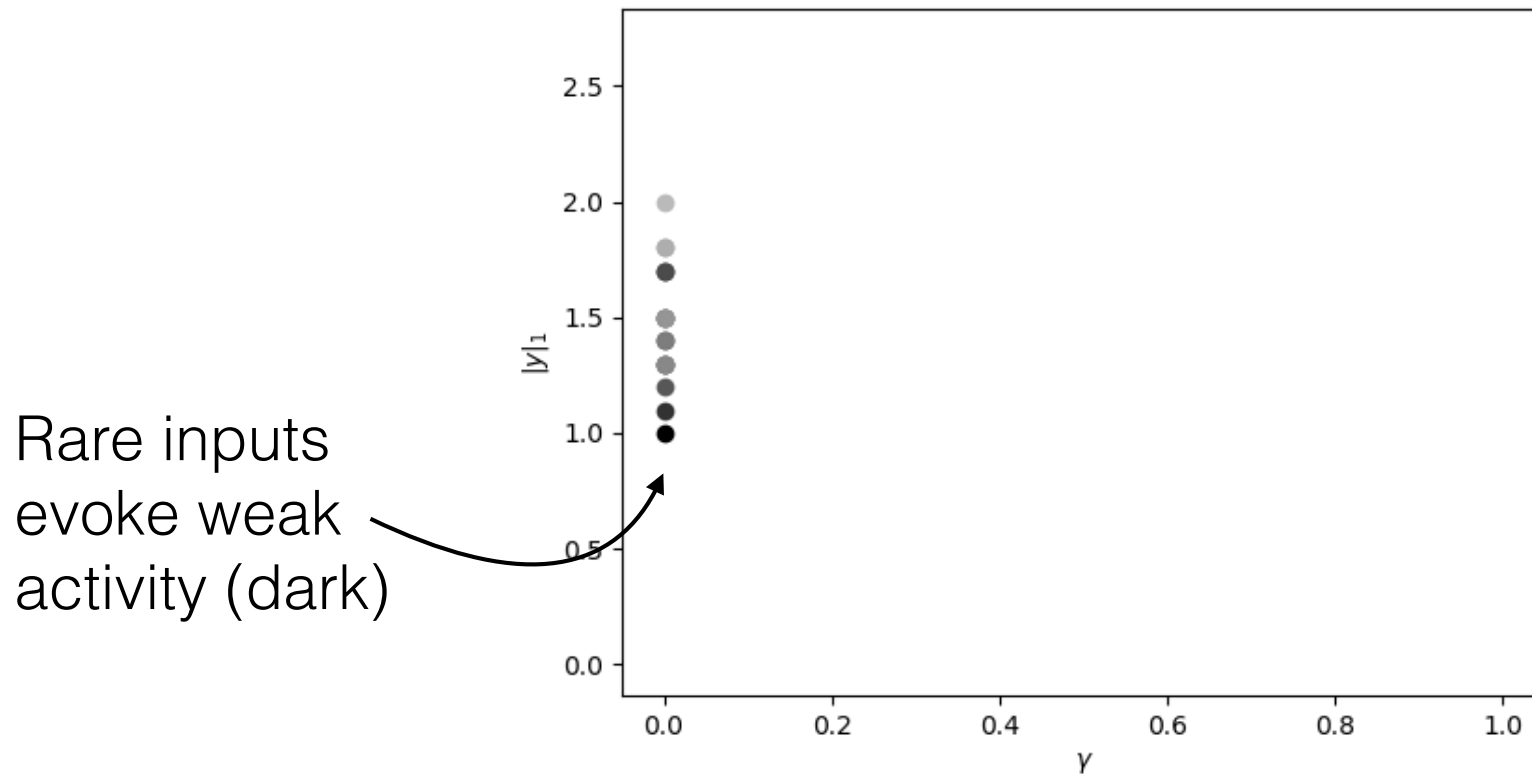
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- ▶ Network of Hawkes neurones with reset after spiking;
- ▶ Maximise Mutual Information (MI) between inputs and outputs, with an additional “energy” term (E): $f = MI - \gamma \cdot E$;
- ▶ Derive learning rules as a gradient descent optimising this function f .

How is learning in neural networks affected by energetic constraints?



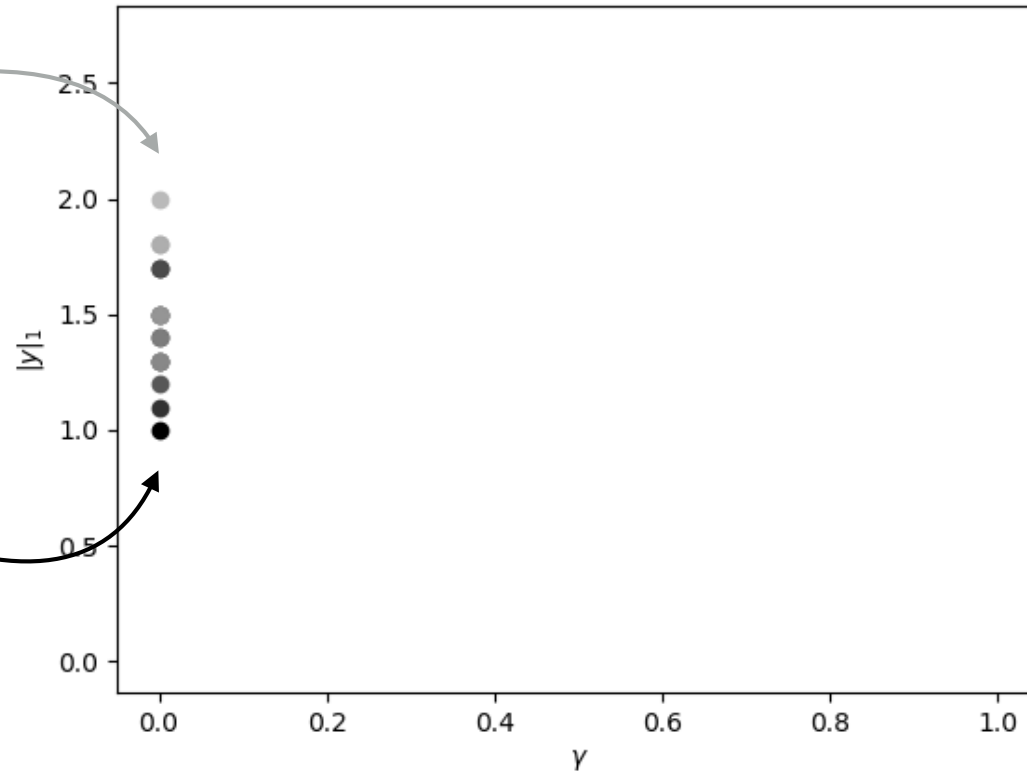
How is learning in neural networks affected by energetic constraints?



How is learning in neural networks affected by energetic constraints?

Frequent inputs
evoke strong
activity (light)

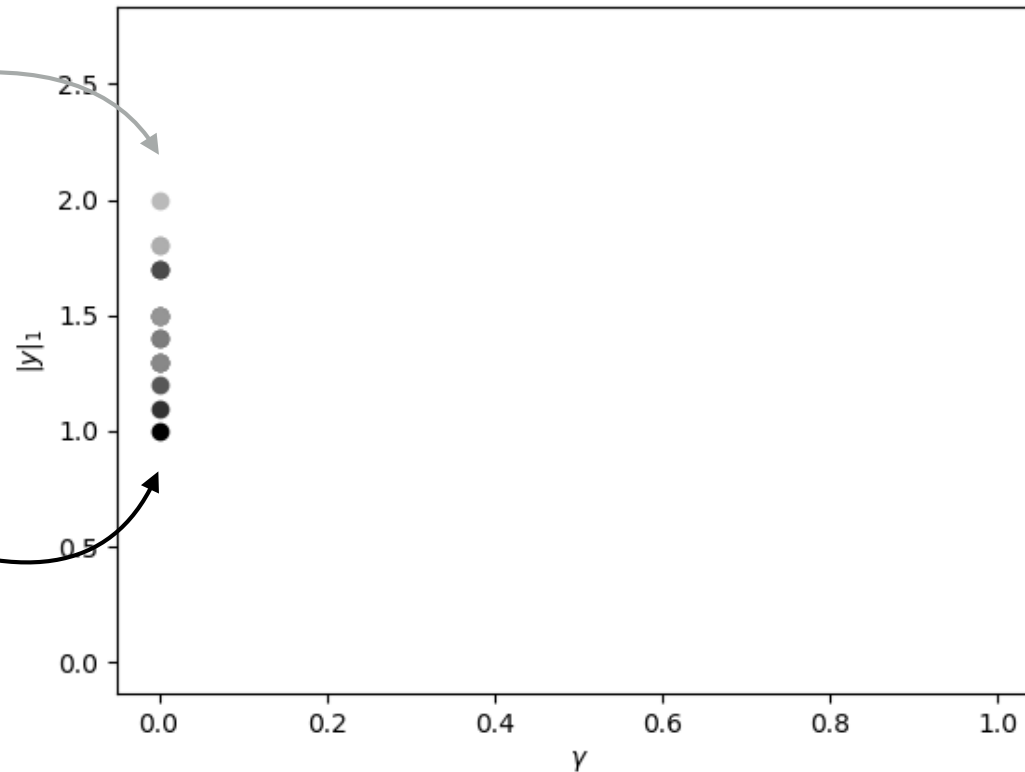
Rare inputs
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Increasing energetic
constraint

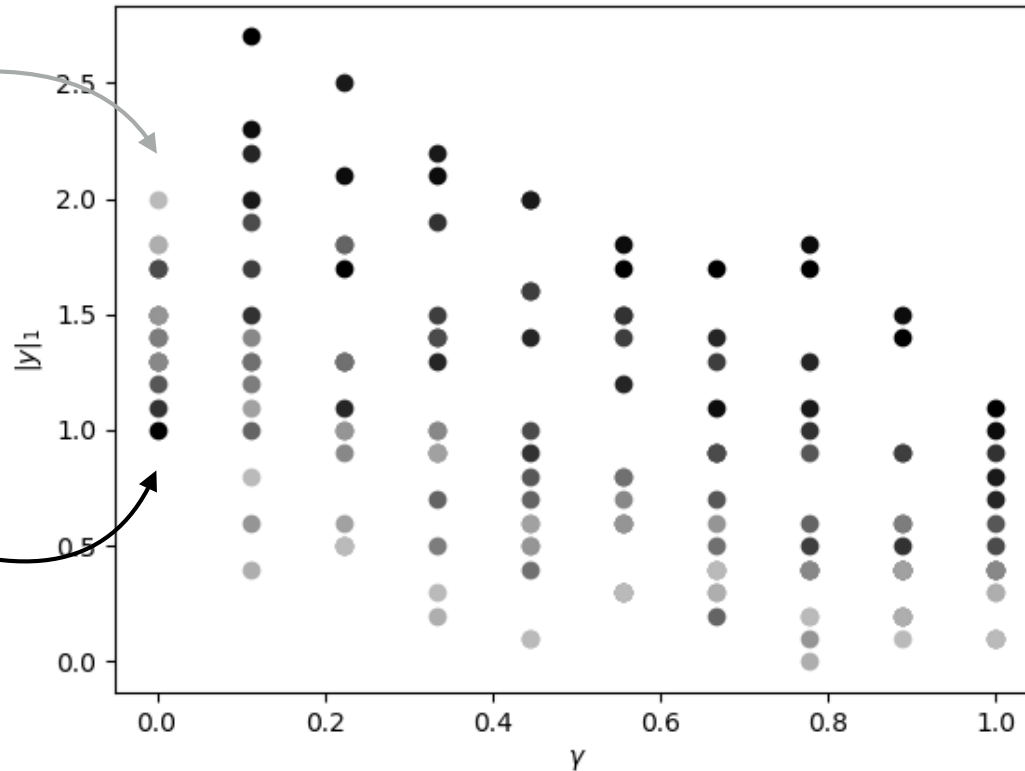


The quality of inference decreases by $\sim 1/3$

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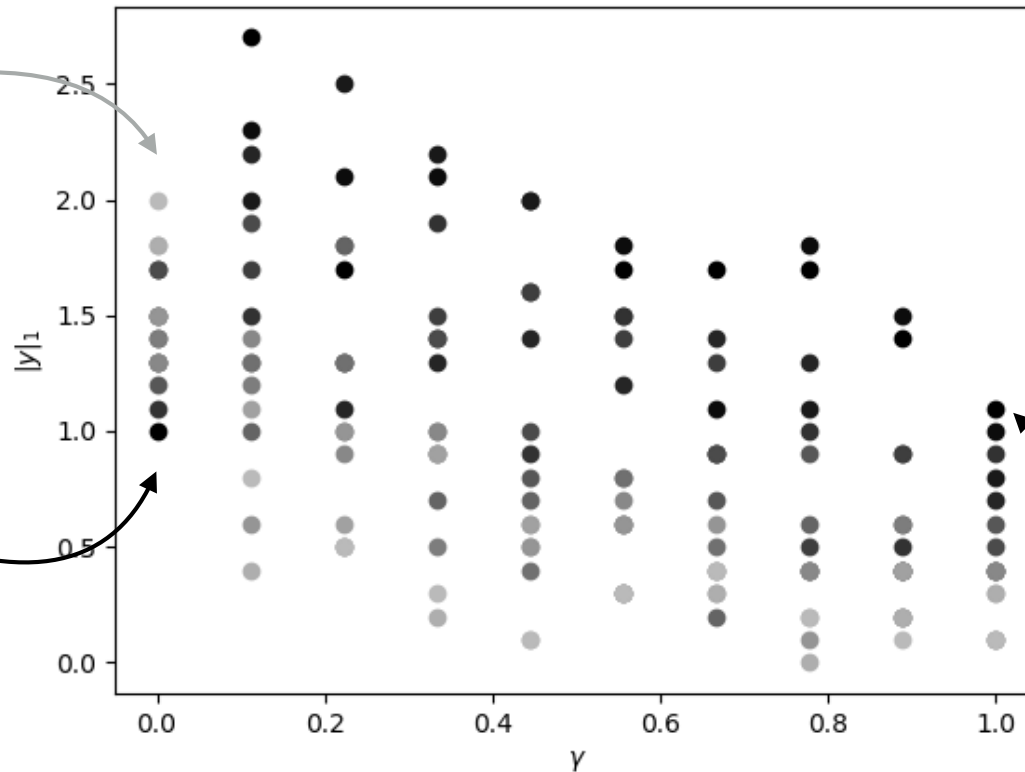


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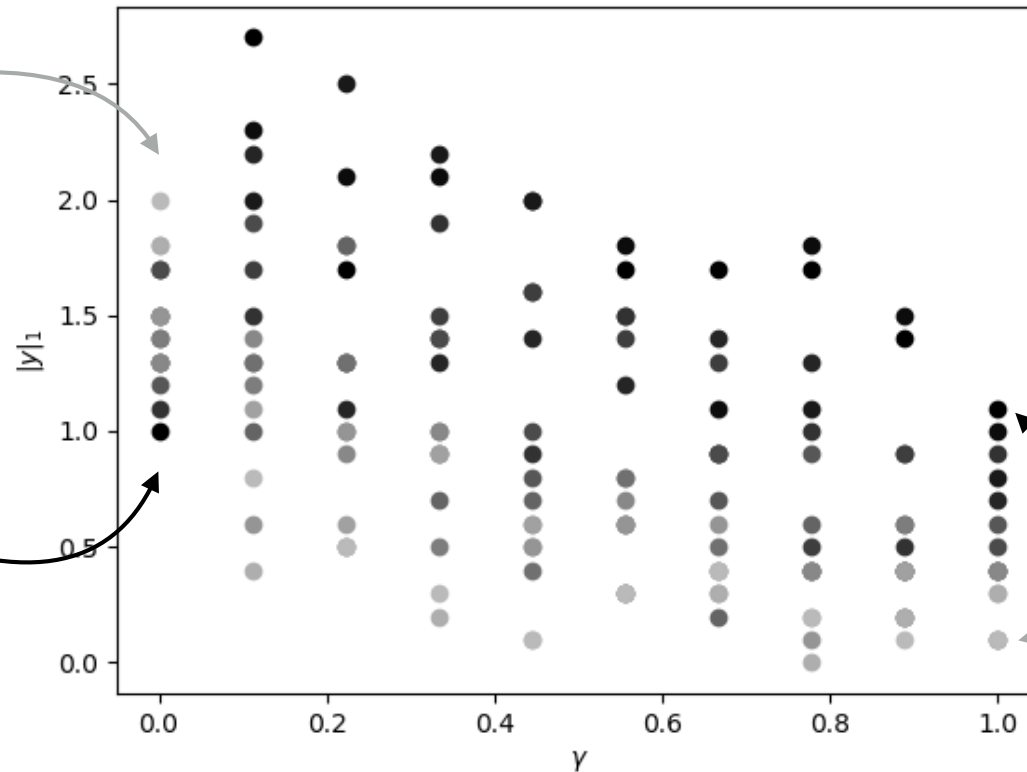


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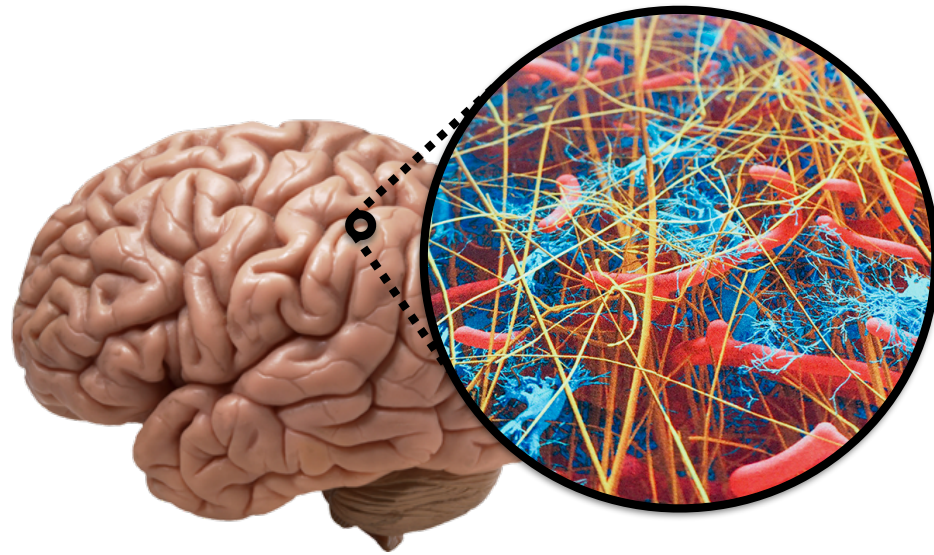
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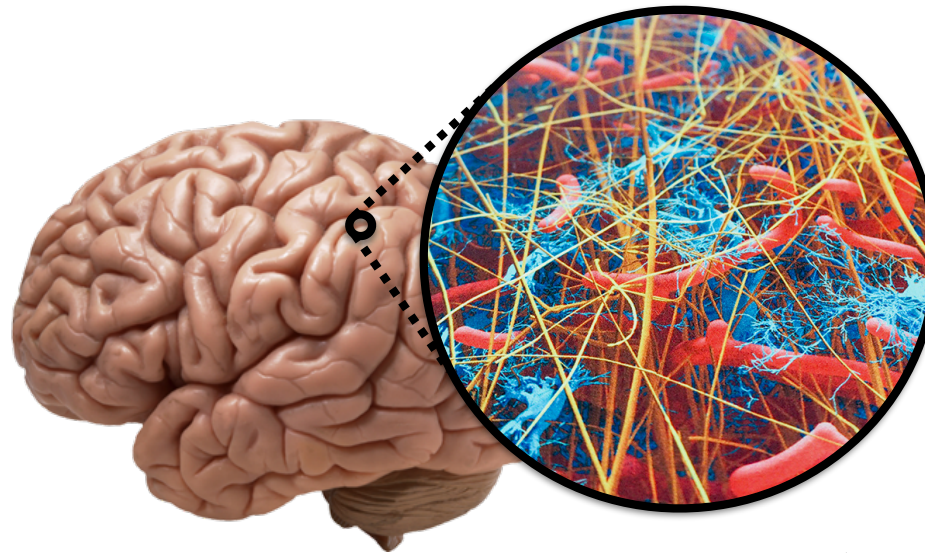
- ▶ It is possible to derive learning rules that are reminiscent of synaptic learning rules observed biologically;
- ▶ But they are three-factor rules, i.e. they include the pre- and post-synaptic activities, and a third global term.



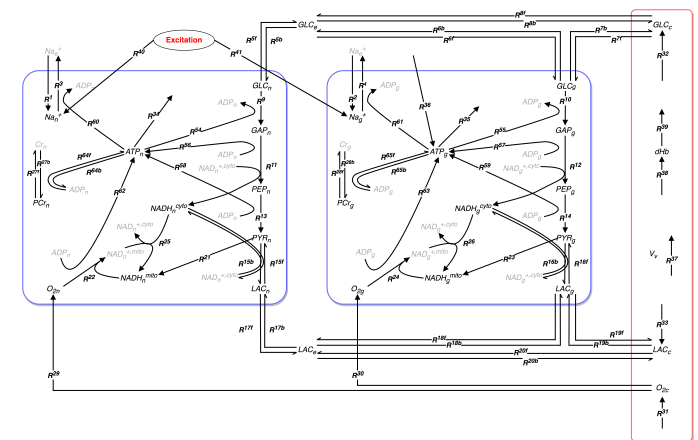
Your brain
~20 W



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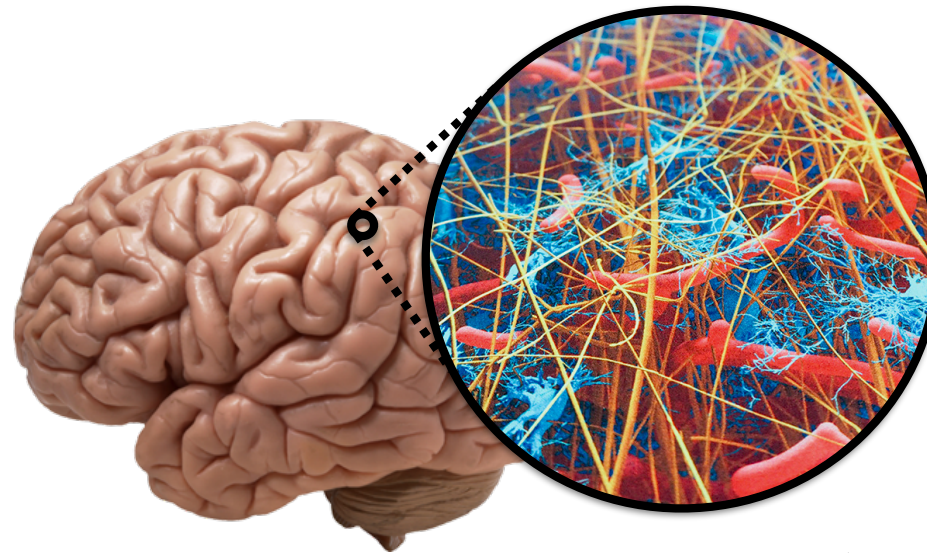


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~20 W

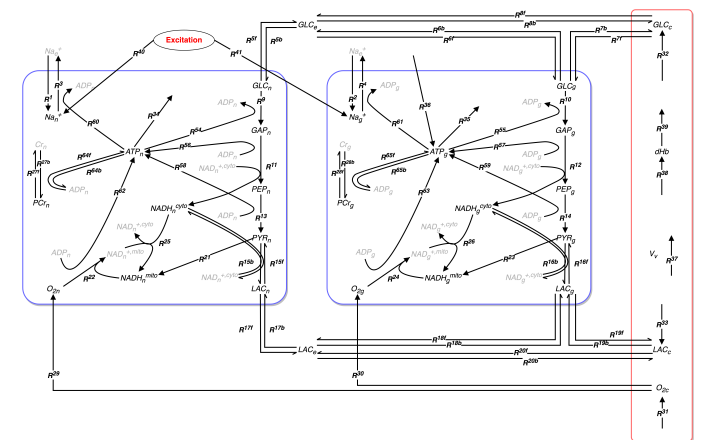
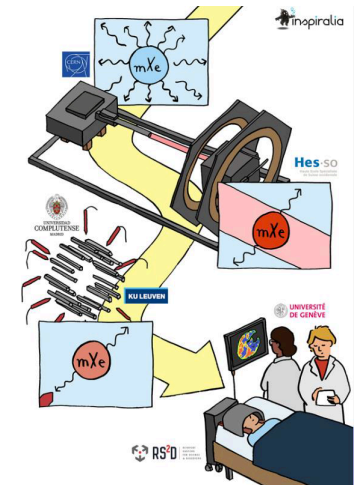


Computational studies of intra- and inter-cellular pathways involved in brain energy metabolism

Developing a new clinical imaging modality (GAMMA-MRI)

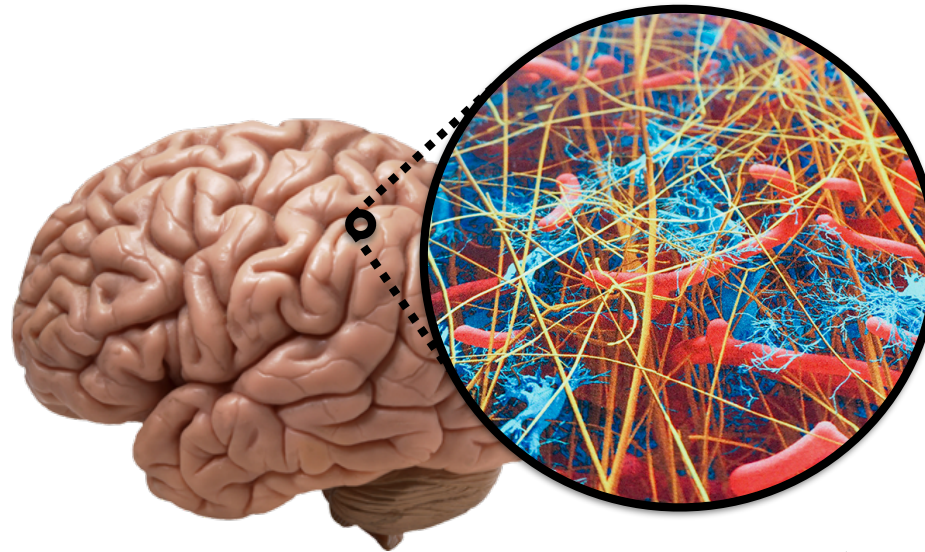
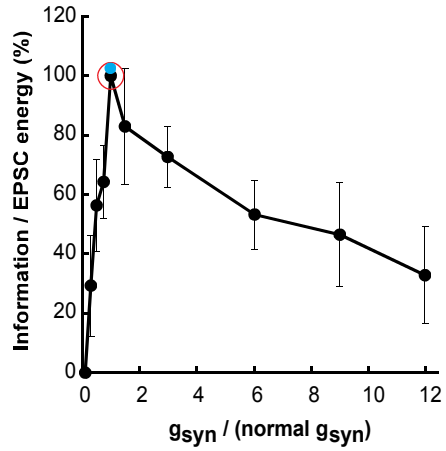


Your brain
~20 W



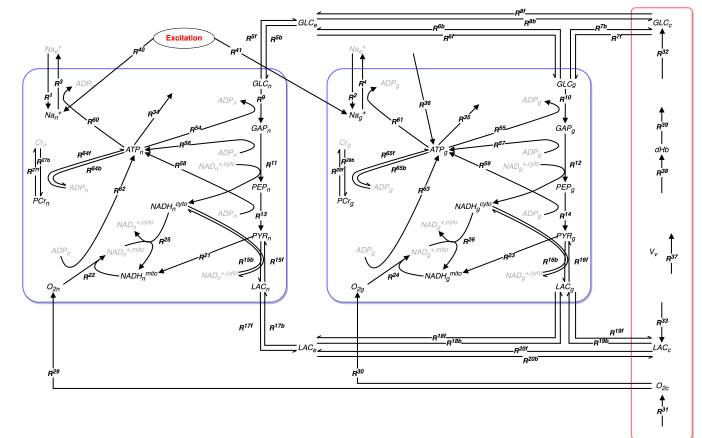
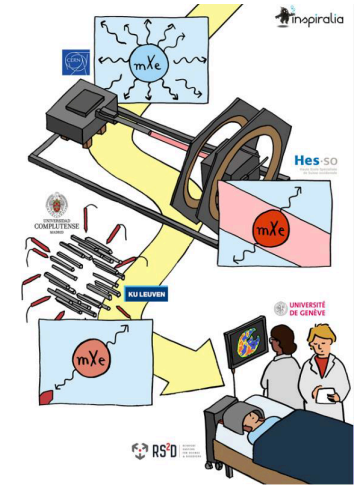
Computational studies of intra- and inter-cellular pathways involved in brain energy metabolism

Computational studies of the trade-offs between information flow, learning and energy consumption at synapses and in networks



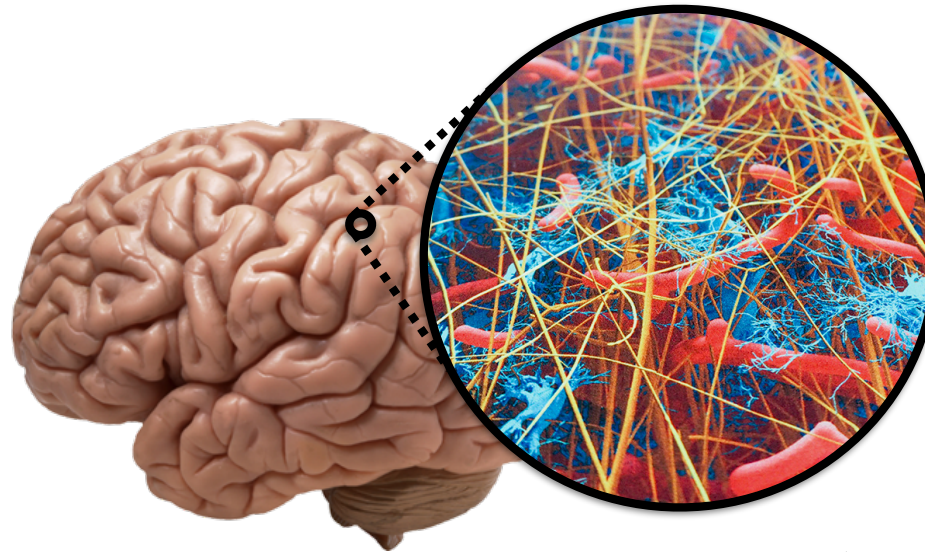
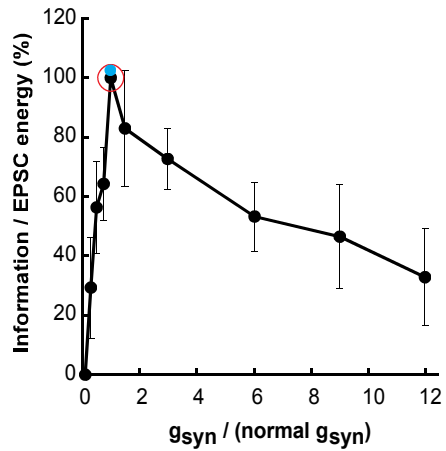
Your brain
~20 W

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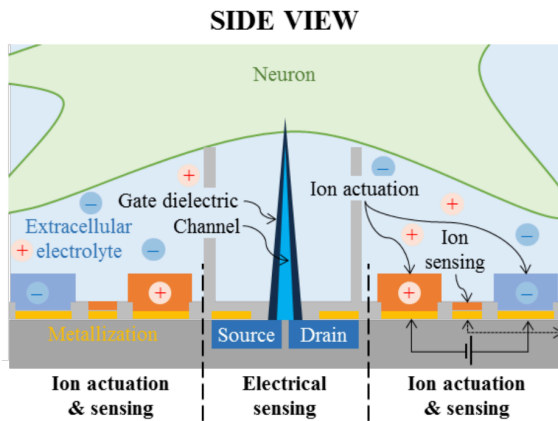


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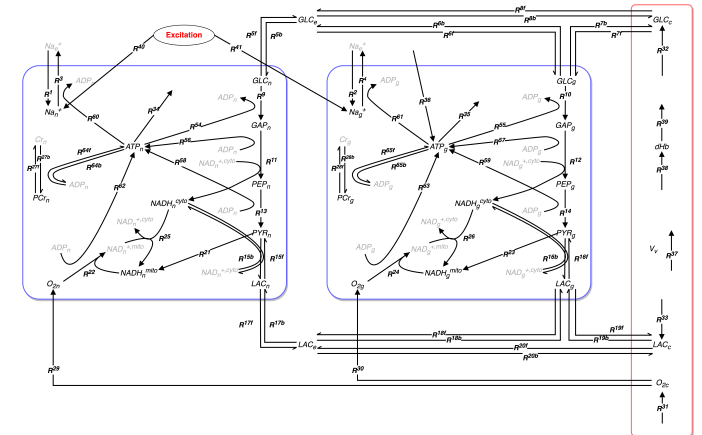
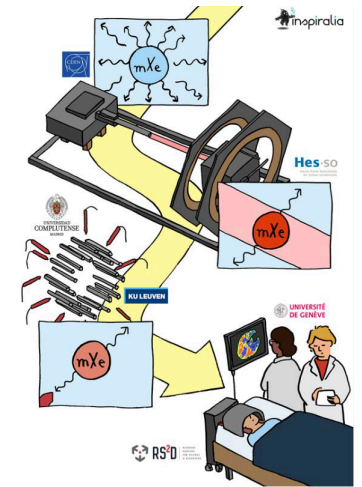


Your brain
~20 W



Developing a new type of neural interface (IN-FET)

Developing a new clinical imaging modality (GAMMA-MRI)



Computational studies of intra- and inter-cellular pathways involved in brain energy metabolism

Acknowledgements



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IN-FET

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Merlyne De Souza (Sheffield)
Siegfried Karg (IBM)
Patrick Ruch (IBM)
Jannis Meents (MCS)

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Pierre Magistretti (KAUST)
Kaylene Young (U. Tasmania)



Thank you for your attention!

