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Understanding information transfer in the brain: from single cell to network

Open Source Brain, 9-11 September 2019

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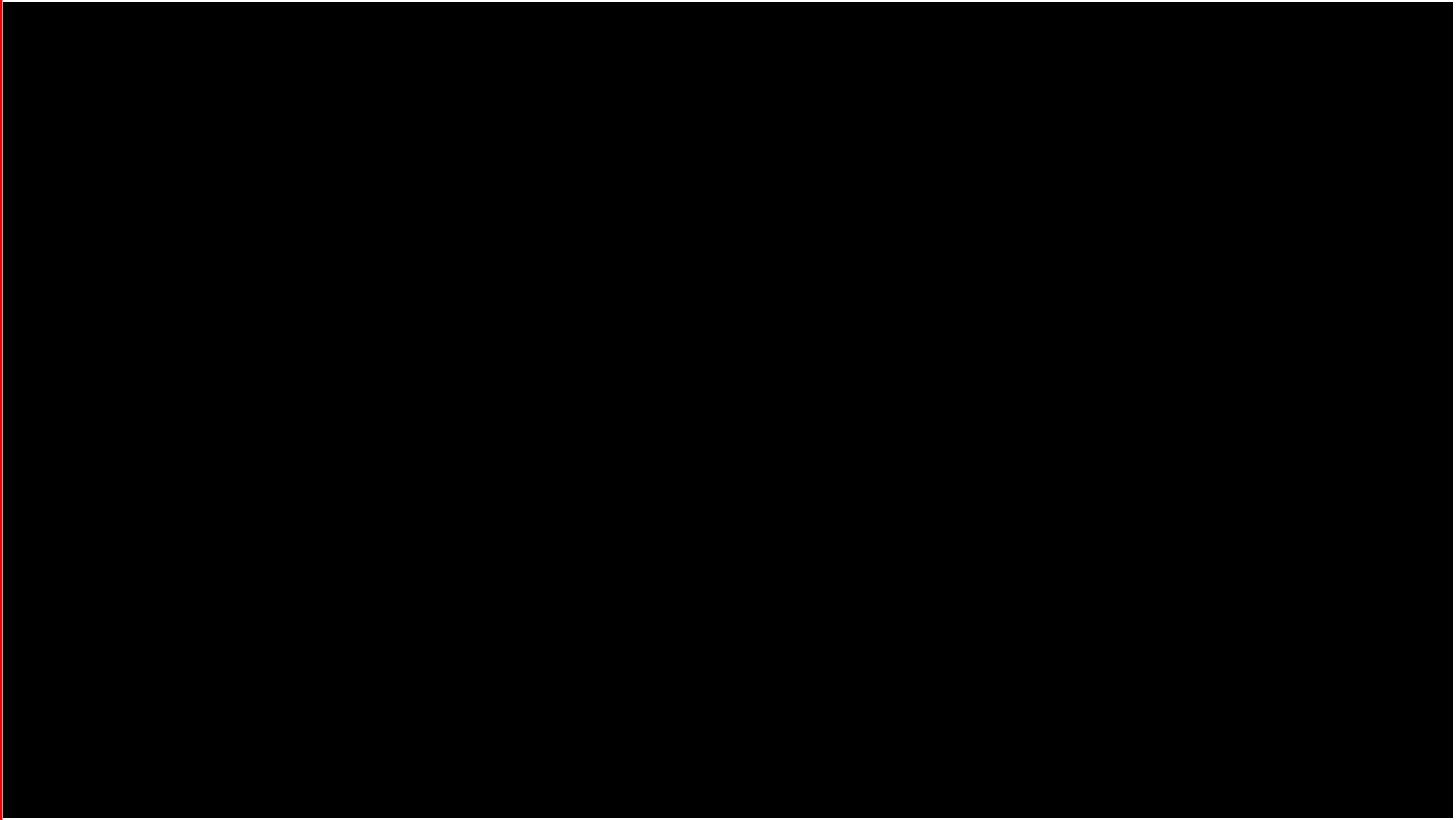
Active Sensing

Suppose you enter a room with the lights switched off, and you have to find the light switch. What will you do?

Sensory perception: how do we represent the environment?
Active sensing: what is the interaction 'action - perception'?

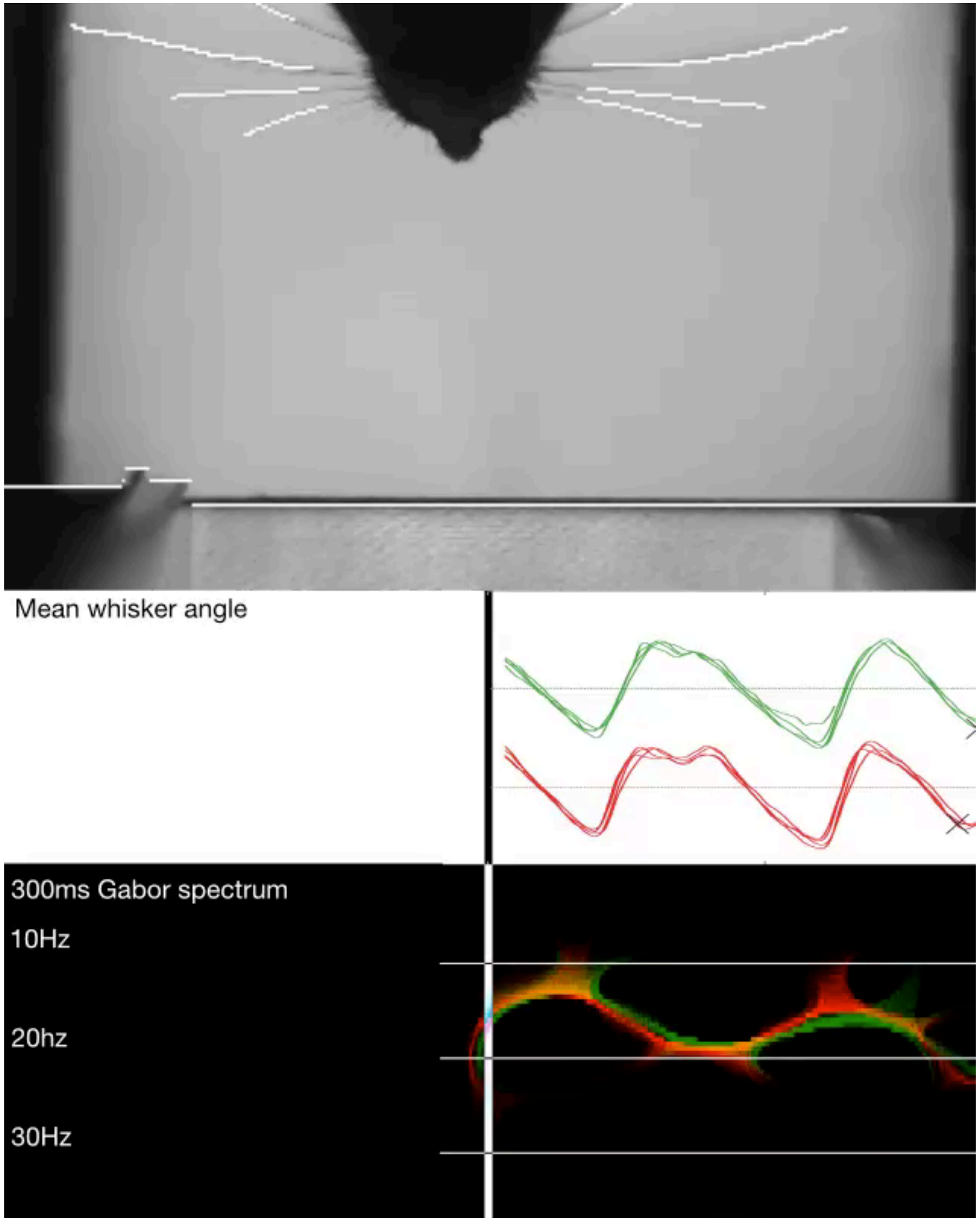
We need active sensing to optimise perception.

Rodents use their whiskers as we our fingers (video Prescott lab)



Rodent whisker system

- Easy to observe
- Very similar to other sensory systems, even in other animals
- Control neural activity (optogenetics)
- Active sense: Mice control whisker position to target predicted position object (Voigts et al. (2015))



Input into the brain

- When a whisker touches an object, the **curvature** changes

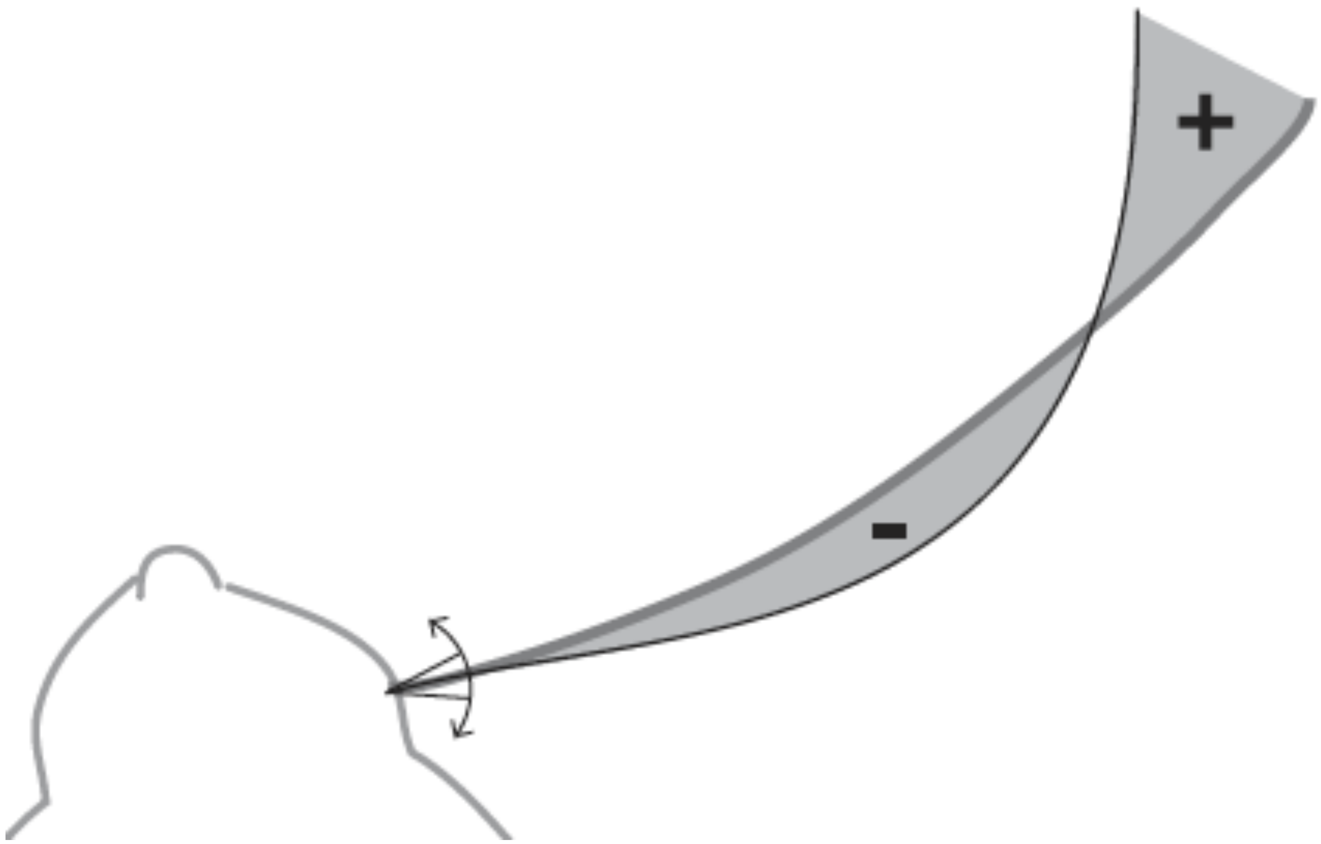


Image: Voigts et al., J. NPhys. 2008

Input into the brain

- When a rat touches an object, the **curvature** of a whisker changes

- **Mechanoreceptors** in the skin respond to this

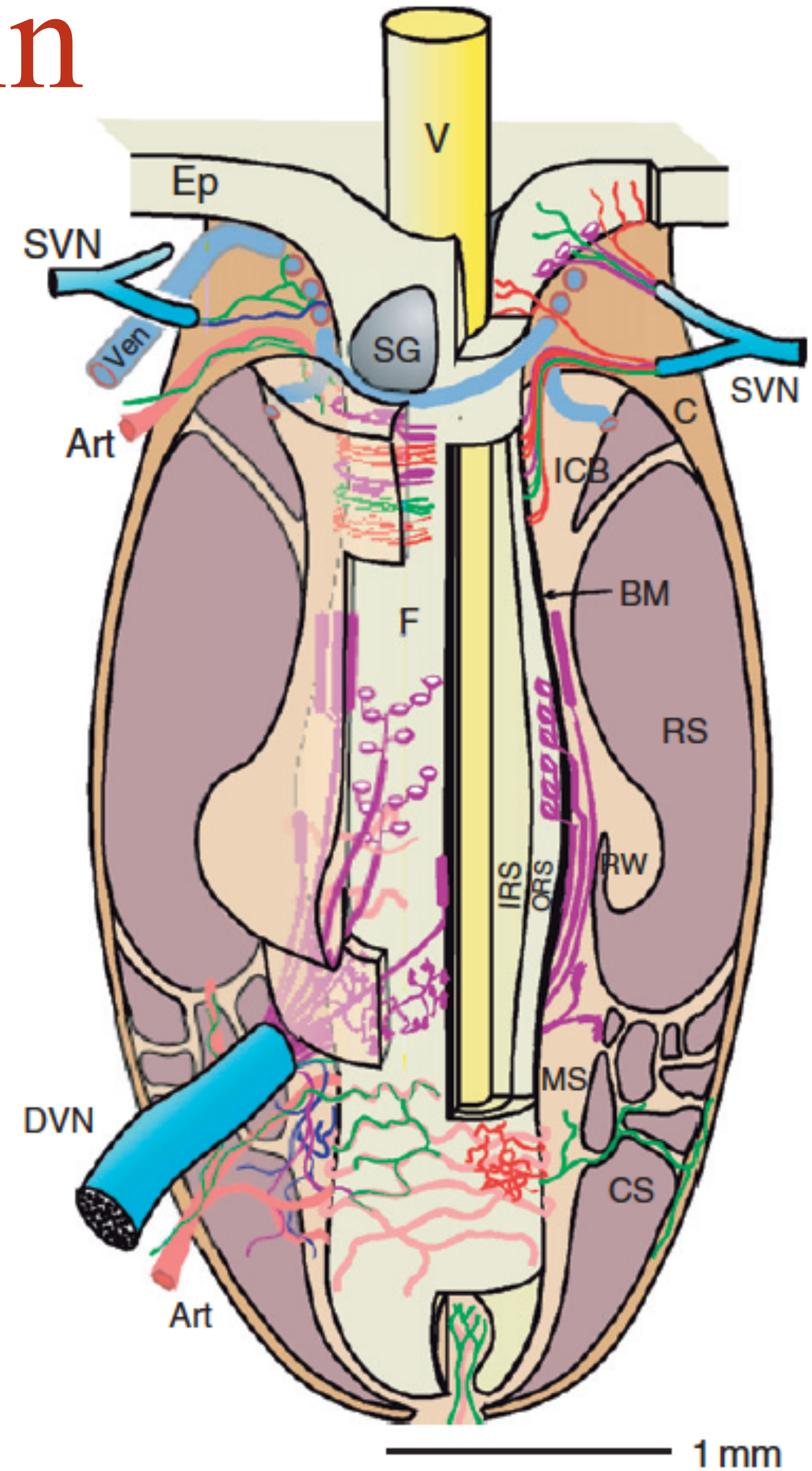
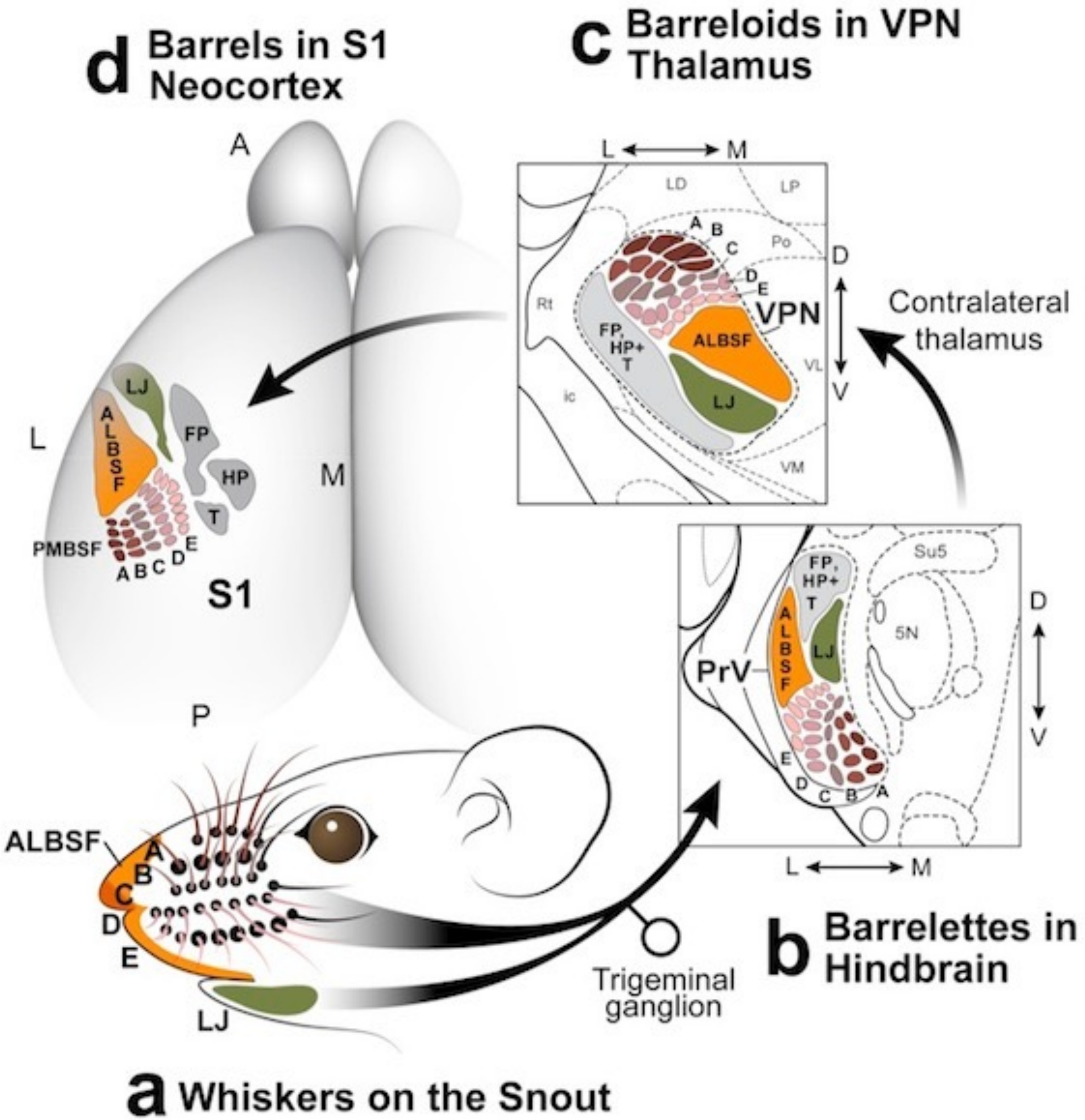


Image: Kleinfeld, 2010

Topographic processing

mechanoreceptors
↓
brain stem (**barrelettes**)
↓
thalamus (**barreloids**)
↓
cortex (**barrels**)

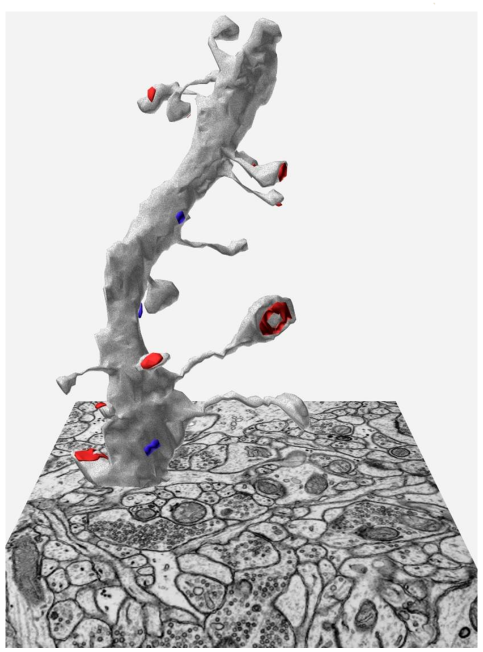


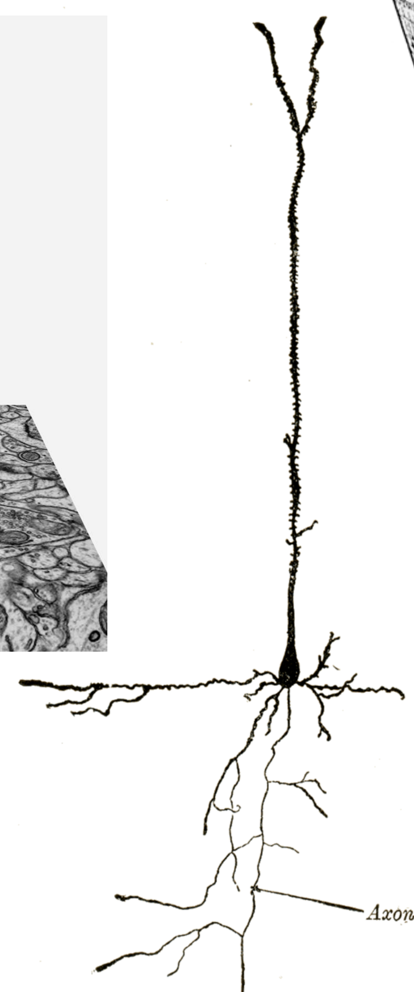
Zembrzycki et al. Nature Neuroscience, 2013

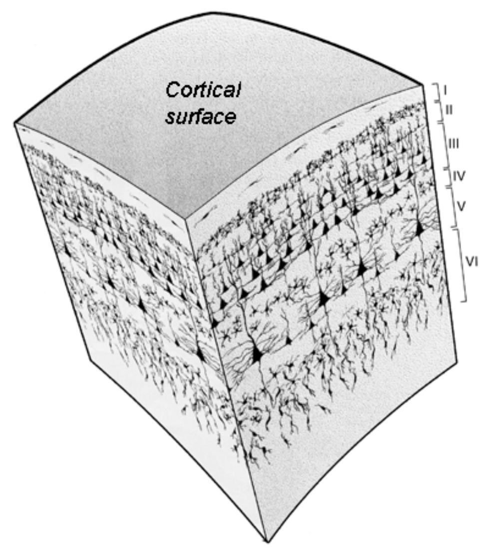
Neural mechanisms of sensorimotor control

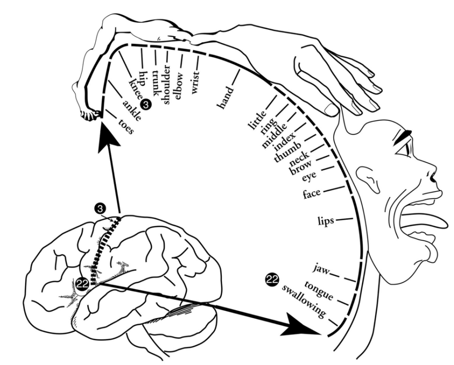
1Å → Molecules ⇄ 1μm → Synapses ⇄ 100 μm → Neurons ⇄ 1 mm → Networks ⇄ 1 cm → Maps ⇄ 10 cm → Systems ⇄ 1 m → CNS

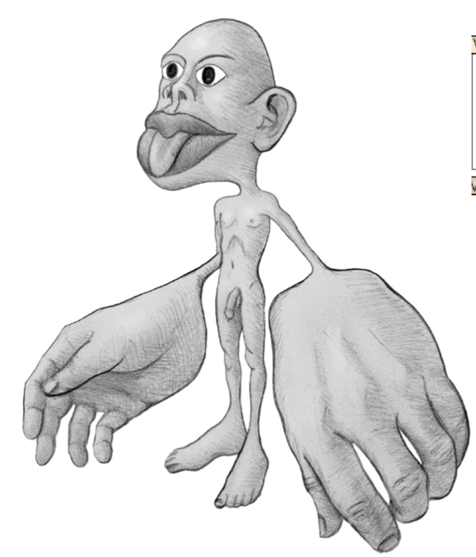
1Å	1μm	100 μm	1 mm	1 cm	10 cm	1 m
Molecules	Synapses	Neurons	Networks	Maps	Systems	CNS

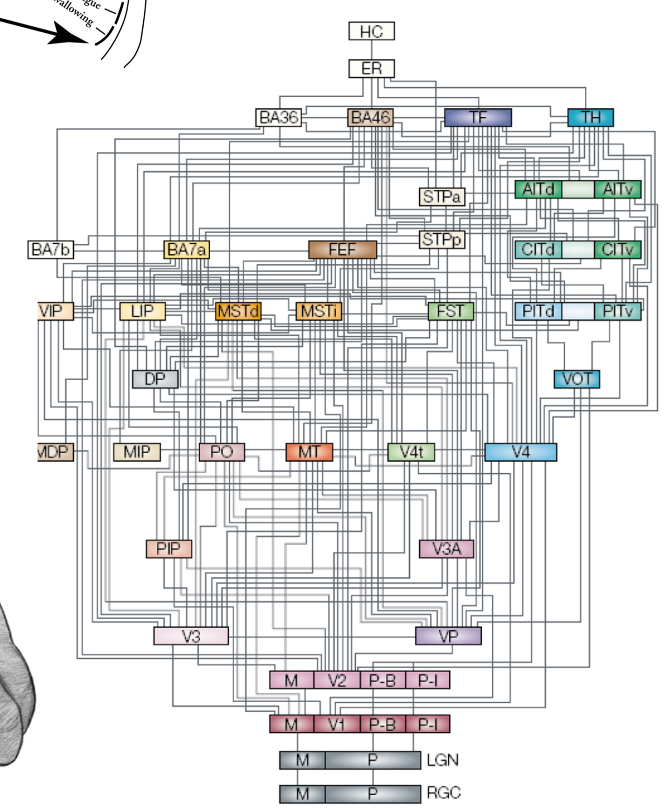


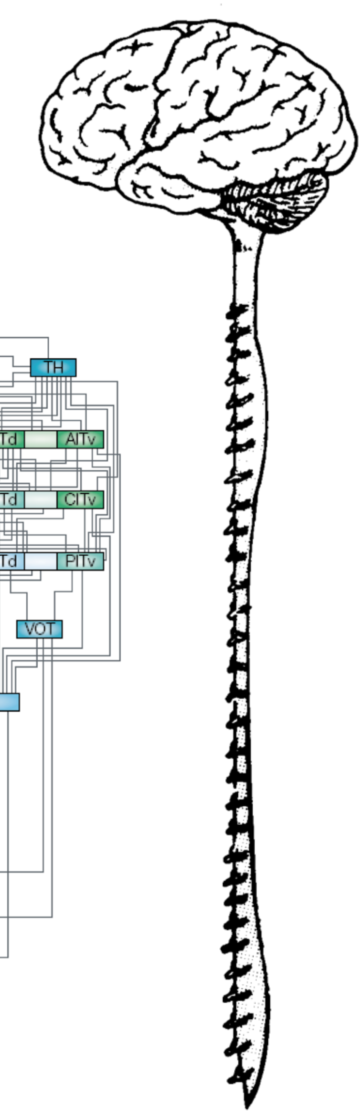










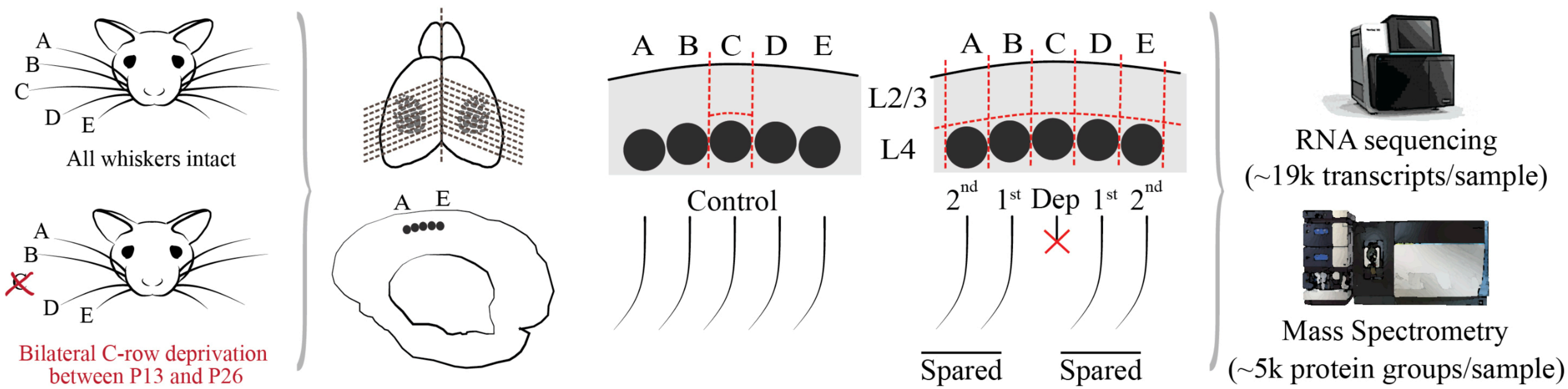


barrelomics.science.ru.nl

BARREL OMICS
molecules of somatosensory map plasticity

Home Transcriptome Proteome Isoforms Interactome Data Exploration Contact

Welcome to the -OMICS page of the Department of Neurophysiology at the Donders Institute for Brain, Cognition and Behaviour. The Cortical Plasticity focus group in the Department, led by Dr. Tansu Celikel, systematically searches for the molecular, cellular and network mechanisms of cortical plasticity as we induce neuroplasticity by controlling the sensory and perceptual experience of mice. High-throughput -OMICS based molecular screening is accompanied by targeted molecular and cellular (in)activation studies to causally link molecules and synapses to circuits and behaviour. This portal is an interactive gateway to the molecular data that we collect.

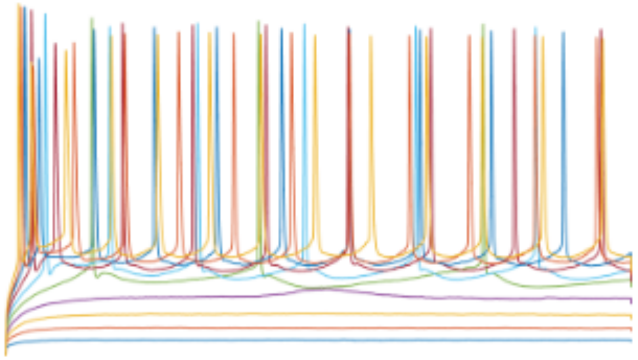


Featured dataset: The transcriptome and proteome of the mouse barrel cortex in single column and laminae resolution in control animals (with all whiskers intact) and after ~2 week long sensory deprivation. The data acquisition procedures, experimental data (raw and processed), and statistical comparisons could be accessed via the tabs on the header.

Terms of Use If you use the data or the figures provided herein in your publications, please consider citing the following paper(s) where the data originate from:

Transcriptome: *Kole et al (2017). Transcriptional mapping of the primary somatosensory cortex upon sensory deprivation.*
Proteome: *Kole et al (2017). Proteomic landscape of the primary somatosensory cortex upon sensory deprivation.*
Sample preparation: *Kole and Celikel (preprint). Neocortical microdissection at columnar and laminar resolution for molecular interrogation. bioRxiv.*

Databank of single neuron recordings



Supporting data for "A databank for intracellular electrophysiological mapping of the adult somatosensory cortex"

Dataset type: Neuroscience, Electrophysiology

Data released on November 16, 2018

Lantyer Ad; Calcini N; Bijlsma A; Kole K; Emmelkamp M; Peeters M; Scheenen WJJ; Zeldenrust F; Celikel T (2018): Supporting data for "A databank for intracellular electrophysiological mapping of the adult somatosensory cortex" GigaScience Database. http://dx.doi.org/10.5524/100535

DOI 10.5524/100535

Neurons in the supragranular layers of the somatosensory cortex integrate sensory (bottom-up) and cognitive/perceptual (top-down) information as they orchestrate communication across cortical columns. It has been inferred, based on intracellular recordings from juvenile animals, that supragranular neurons are electrically mature by the fourth postnatal week. However, the dynamics of the neuronal integration in the adulthood is largely unknown. Electrophysiological characterization of the active properties of these neurons throughout adulthood will help to address the biophysical and computational principles of the neuronal integration. Here we provide a database of whole-cell intracellular recordings from 294 neurons located in the supragranular layers (L2/3) of the primary somatosensory cortex in adult mice (9-45 weeks old) from both sexes (females, N=184; males, N=110). Data include 336 somatic current-clamp (CC) and 515 voltage-clamp (VC) experiments, recorded using a step-and-hold protocol (CC, N=236; VC, N=54), frozen noise injections (CC, N=100) and triangular voltage sweeps (VC, 10 (N=142), 50 (N=157) and 100 ms (N=162)), from regularly spiking (N=161) and fast-spiking neurons (N=78). The data could be used to systematically study the properties of somatic integration, and the principles of action potential generation across sexes and across electrically characterized neuronal classes in adulthood. Understanding the principles of the somatic transformation of postsynaptic potentials into action potentials will shed light onto the computational principles of intracellular information transfer in single neurons and information processing in neuronal networks, helping to recreate neuronal functions in artificial systems.

Keywords:
whole-cell intracellular recordings somatic patch-clamp current-clamp voltage-clamp acute brain slices adult brain barrel cortex frozen noise big data

Intermezzo: measuring information transfer in vitro

Zeldenrust et al., Frontiers in Computational Neuroscience, 2017

github.com/fleurzeldenrust/In-vitro-method-for-information-calculation

In-vitro experiments

How do biophysical properties (i.e. conductances) influence information processing?

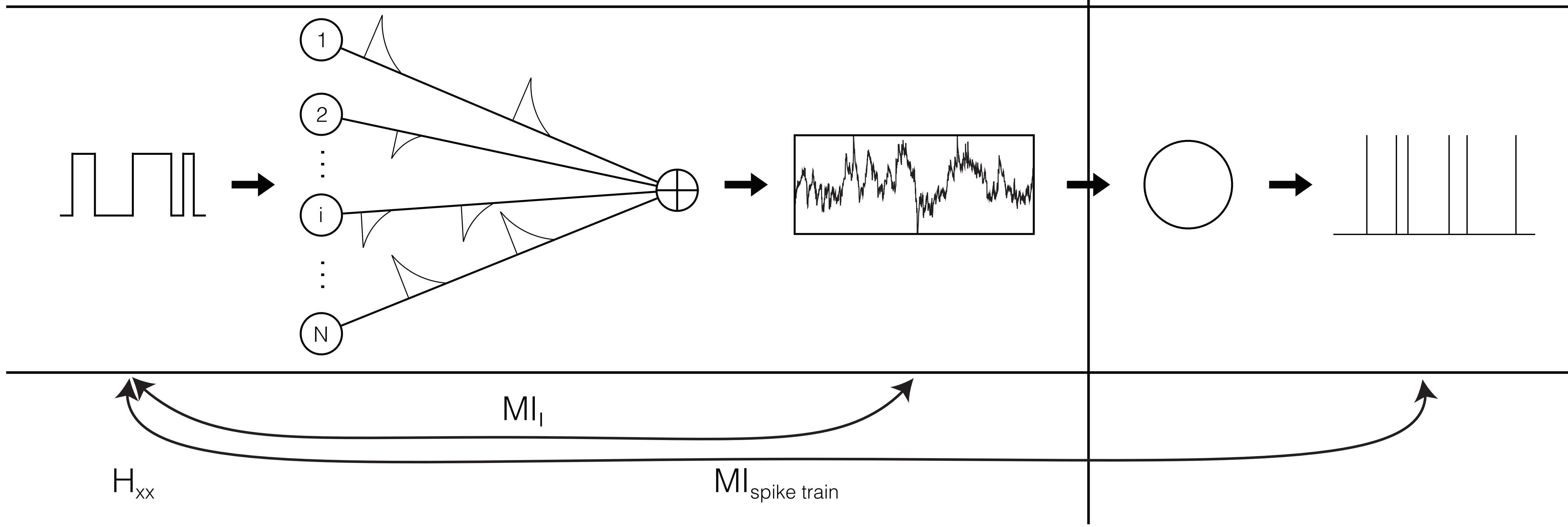
What is the information loss of the spike-generating process?

- cells stay alive for ~ 1 hour (shorter for strong stimuli)
- often multiple ‘settings’ need to be tested (drug applications, step protocols for cell determination)
- ‘natural' stimulus

Develop a method for in-vitro estimation of information transfer

Input from neural network

ARTIFICIAL NETWORK				IN VITRO EXPERIMENT	
stimulus (hidden state)	artificial neurons (input spike trains)	weights	input	current clamp	output spike train
$\left.\begin{matrix} r_{\text{on}} \\ r_{\text{off}} \end{matrix}\right\} \begin{matrix} \tau \\ p_1 \end{matrix}$	$\left.\begin{matrix} q^i_{\text{on}} \\ q^i_{\text{off}} \end{matrix}\right\} \mu_q$	$w_i = \log \frac{q^i_{\text{on}}}{q^i_{\text{off}}}$			
$x(t) = \begin{cases} 0 \\ 1 \end{cases}$	$s_i(t)$		$I(t)$		



Conclusions ‘*frozen noise*’ method

Reasoning: neurons extract information from noisy input

Information in the input can be controlled, determined by
- number of spikes ANN (neurons and firing rates)
- integration time (switching speed hidden state)

So this gives an estimate of information loss of the spike generation process

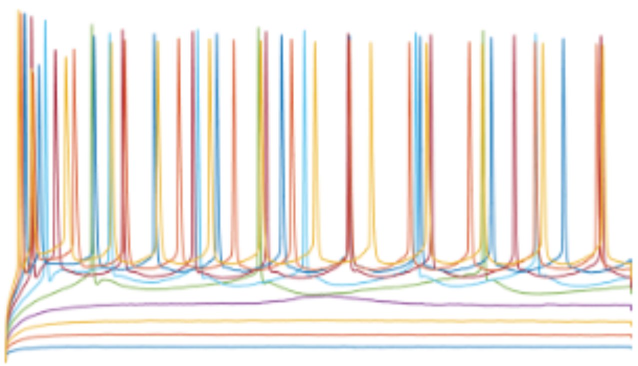
All data can be used for information estimate
- No trial repetition needed
- No decoding model needs to be fitted

Optimal response model (‘Bayesian neuron’) for comparison

Zeldenrust et al., Frontiers in Computational Neuroscience, 2017

github.com/fleurzeldenrust/In-vitro-method-for-information-calculation

Mutual information: Lantyer et al. data



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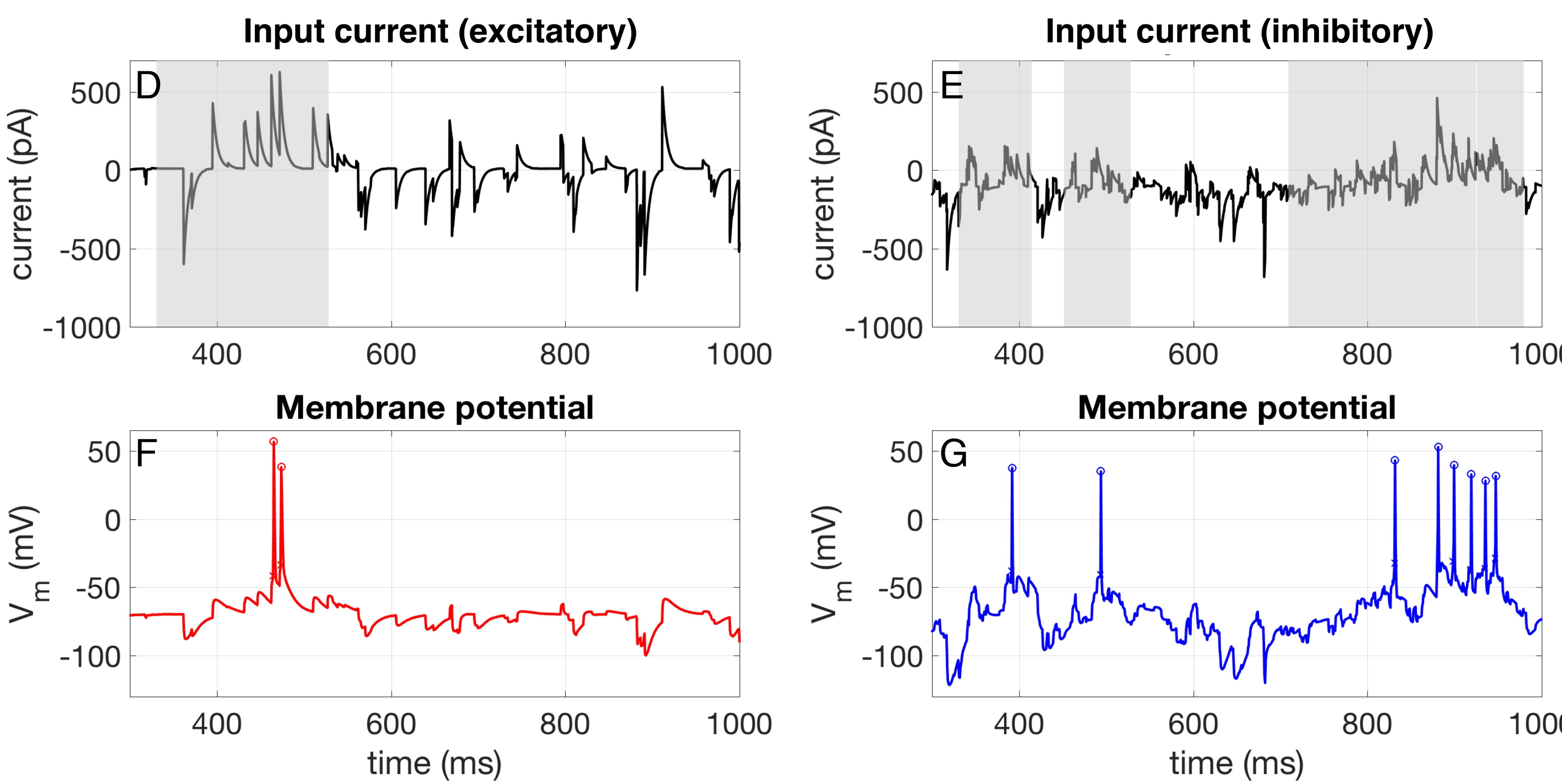
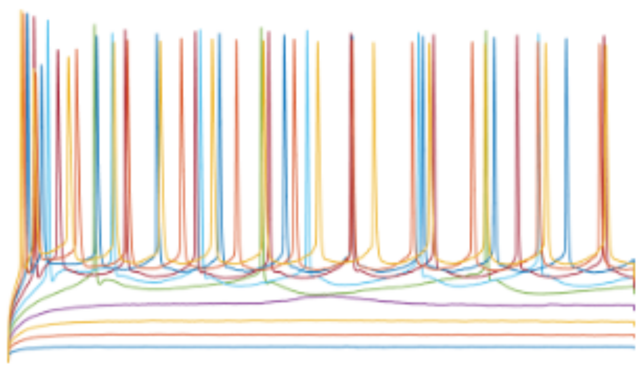
Niccolò Calcini



Mutual information: Lantyer et al. data



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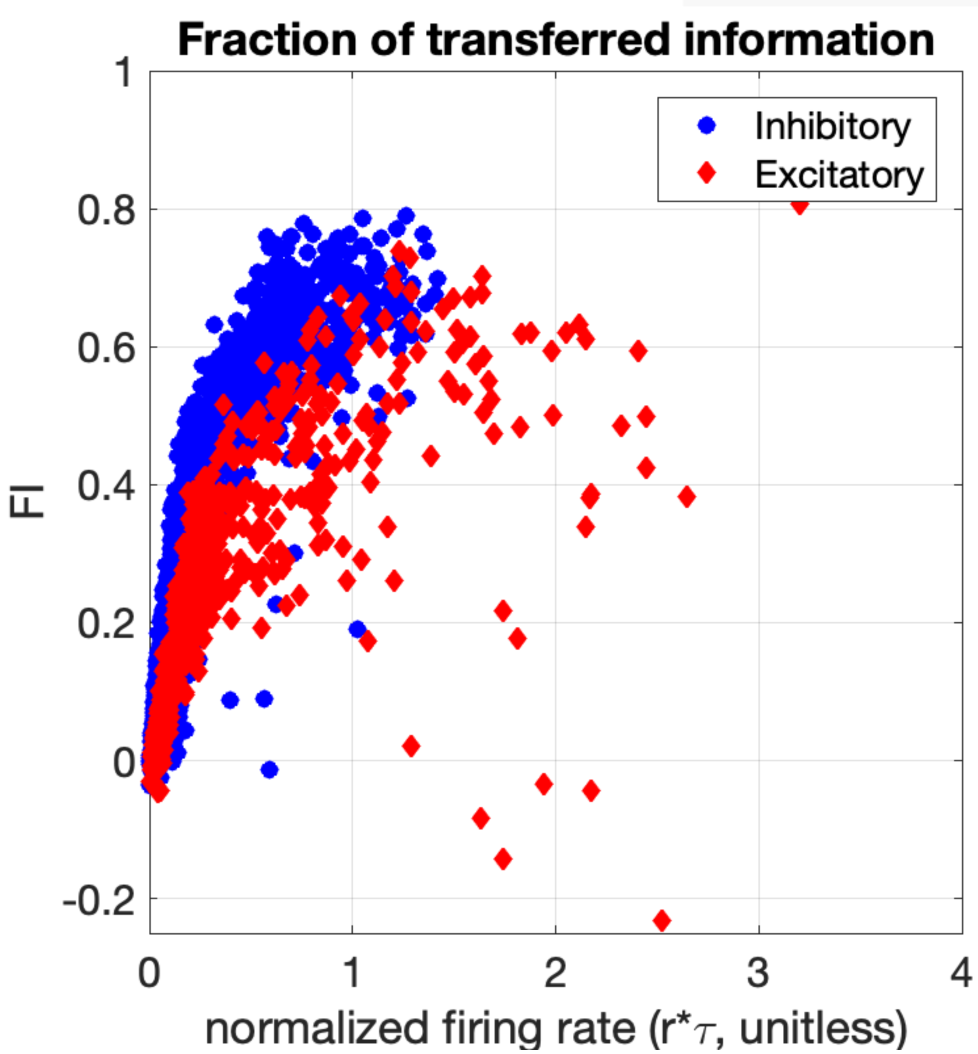
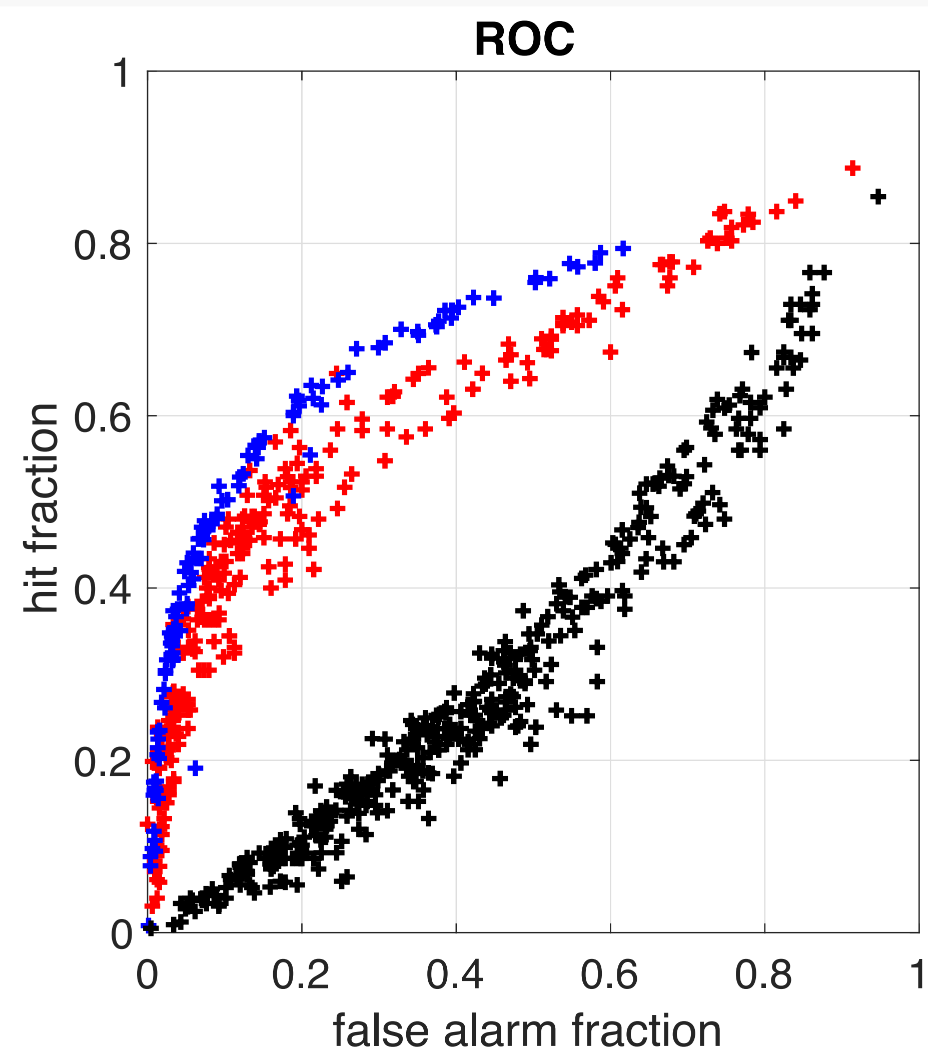
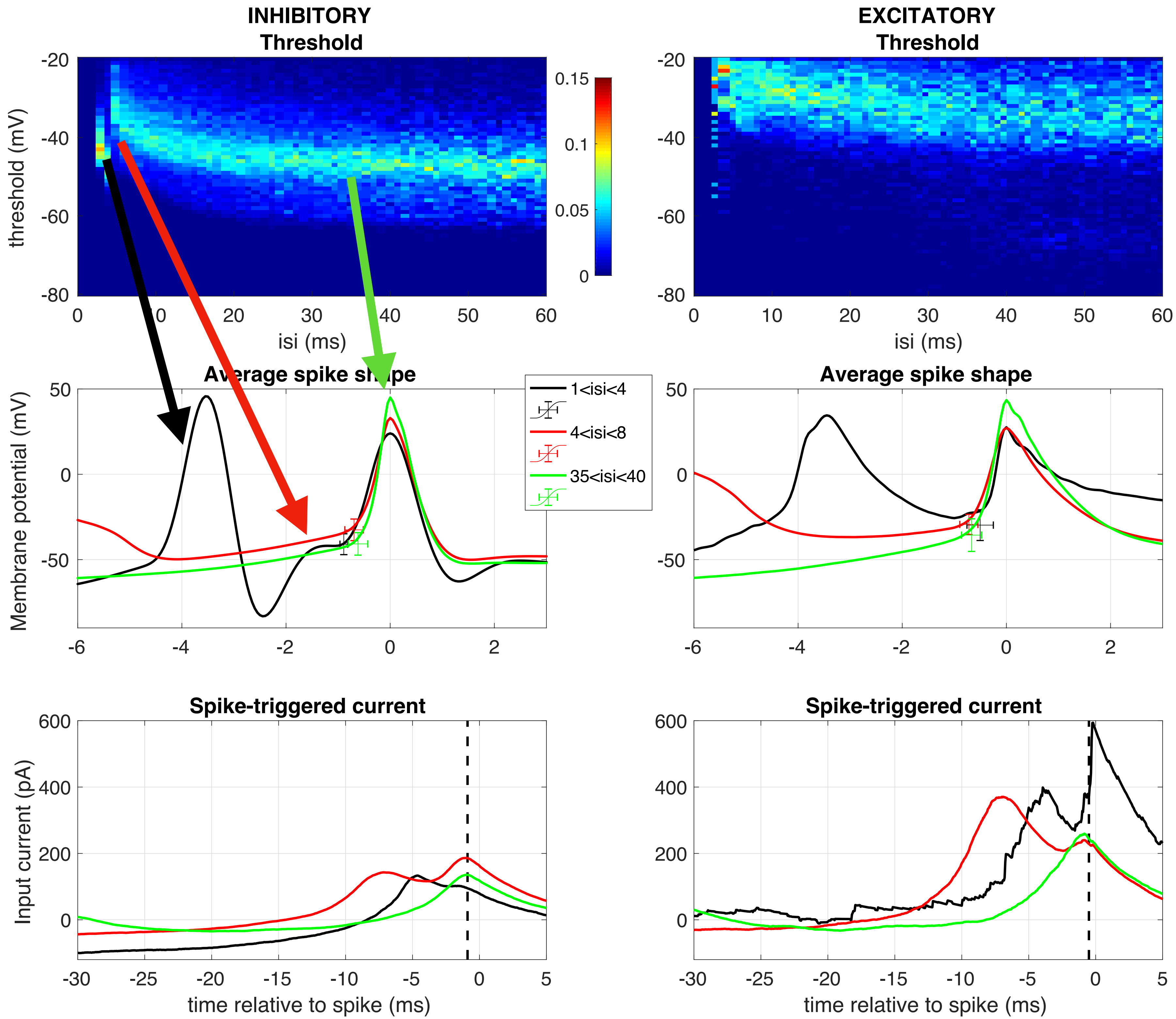




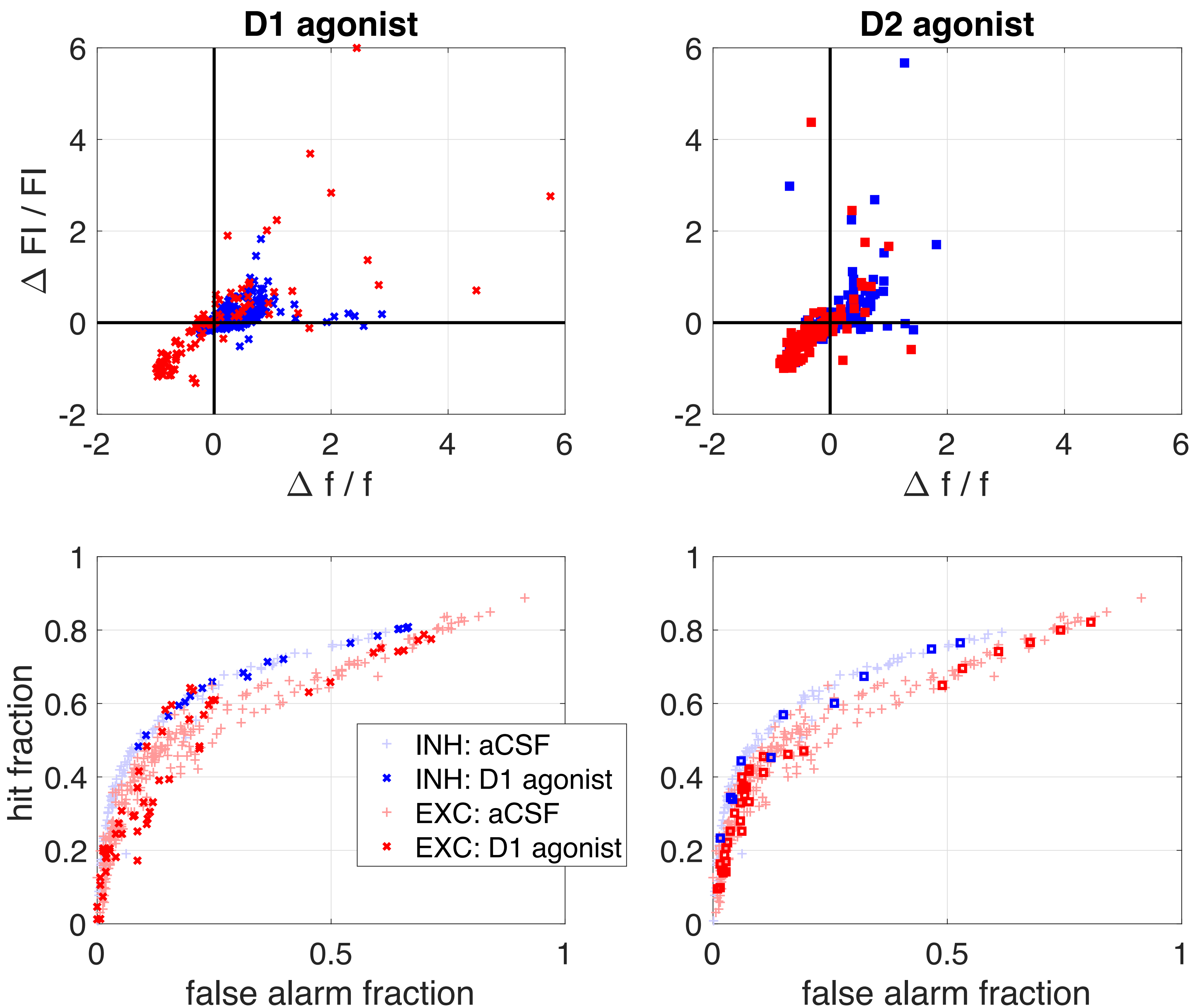
$$FI = \frac{MI_{\text{spike train}}}{MI_{\text{input current}}}$$

Other properties: Lantyer et al. data



Niccolò Calcini

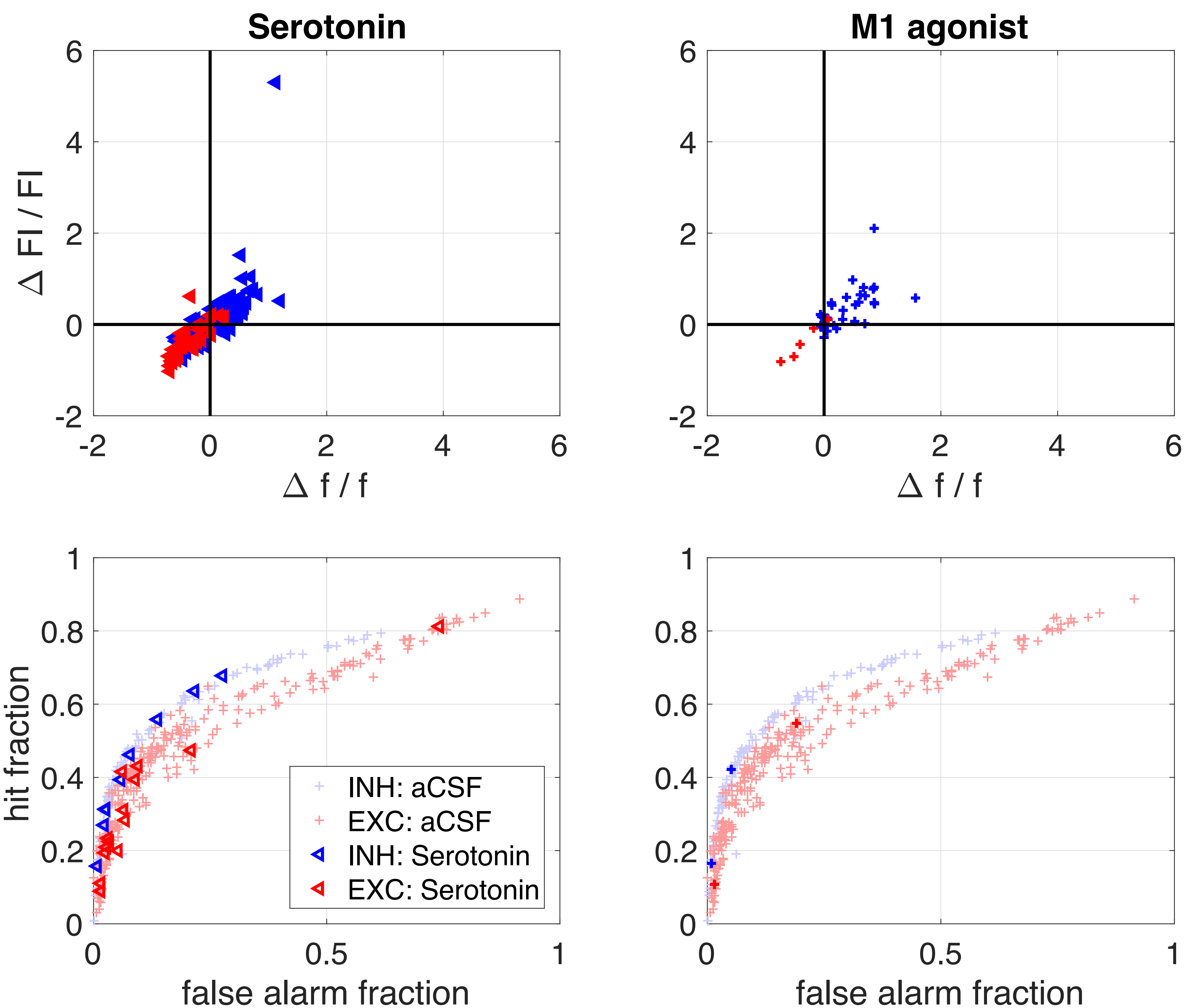
Mutual information: effect of modulators



Niccolò Calcini

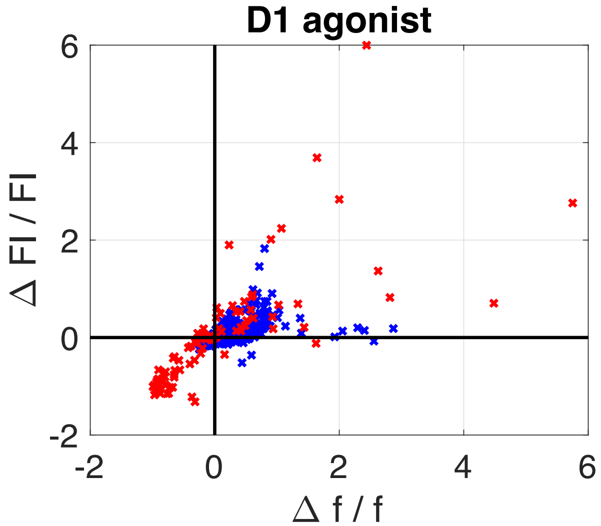
Xuan Yan

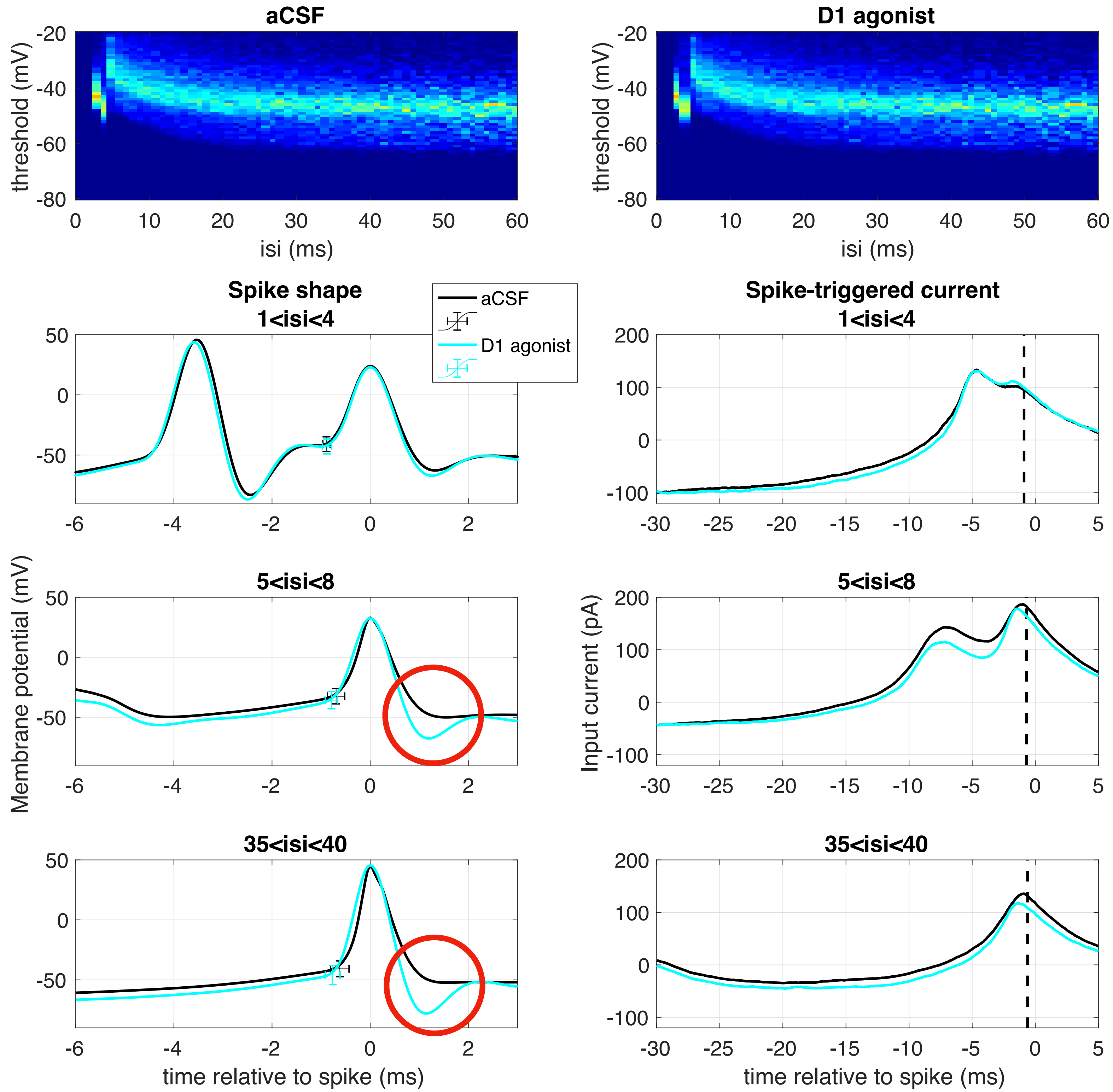
Mutual information: effect of modulators




Xuan Yan

Other properties: effect of D1 agonist

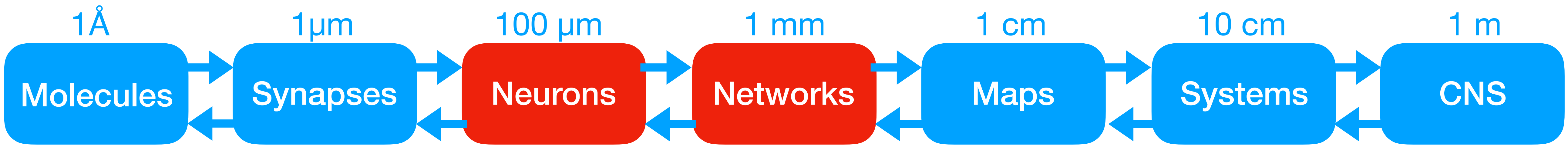


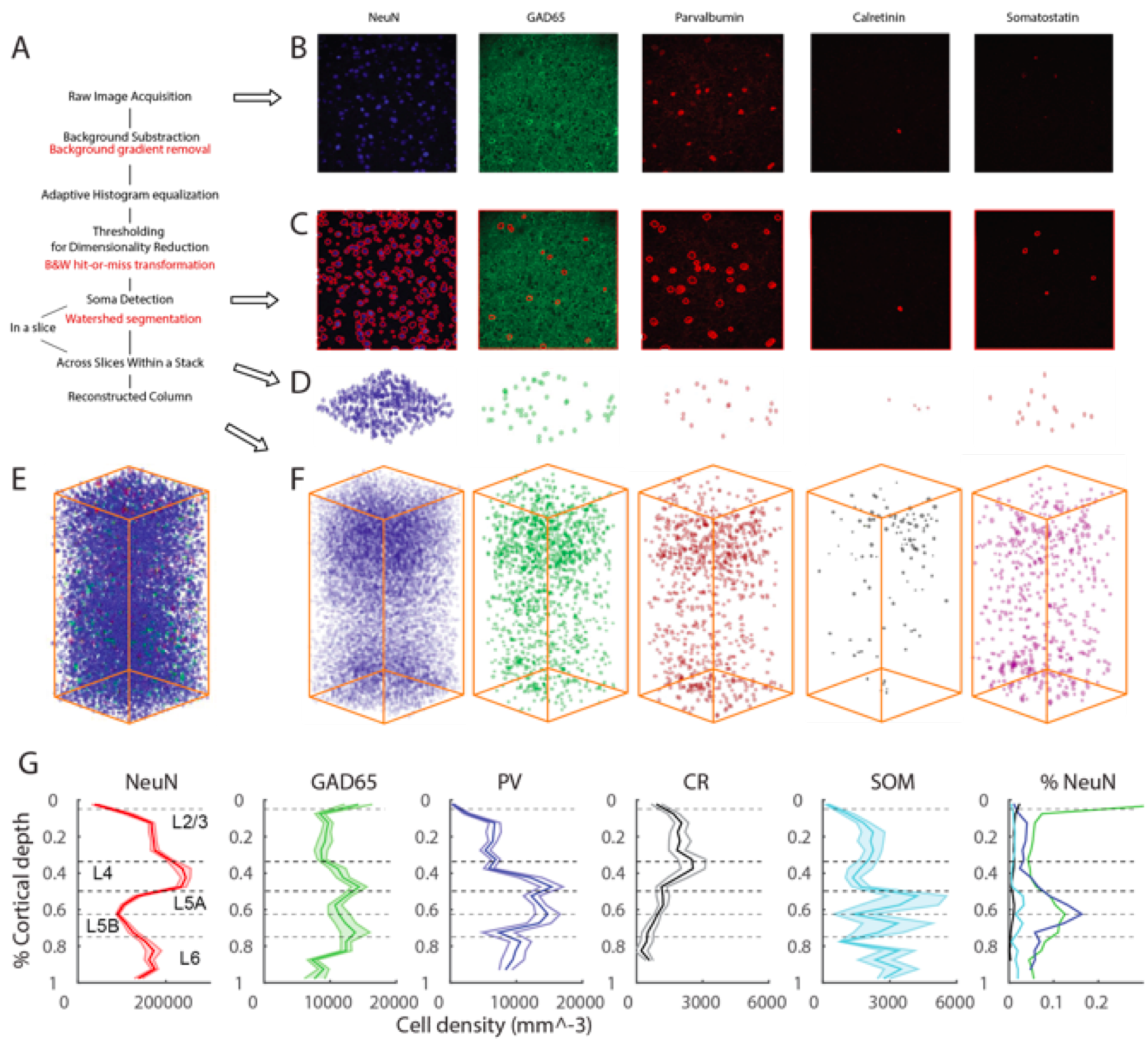


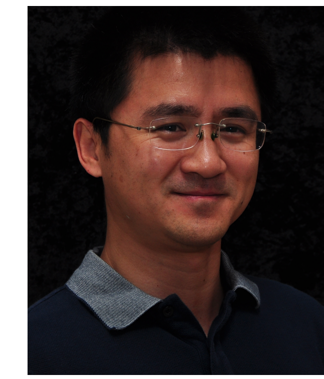
Niccolò Calcini

Xuan Yan

Large-scale model



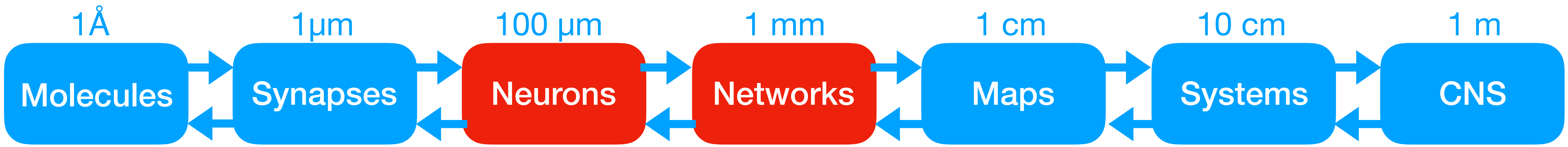




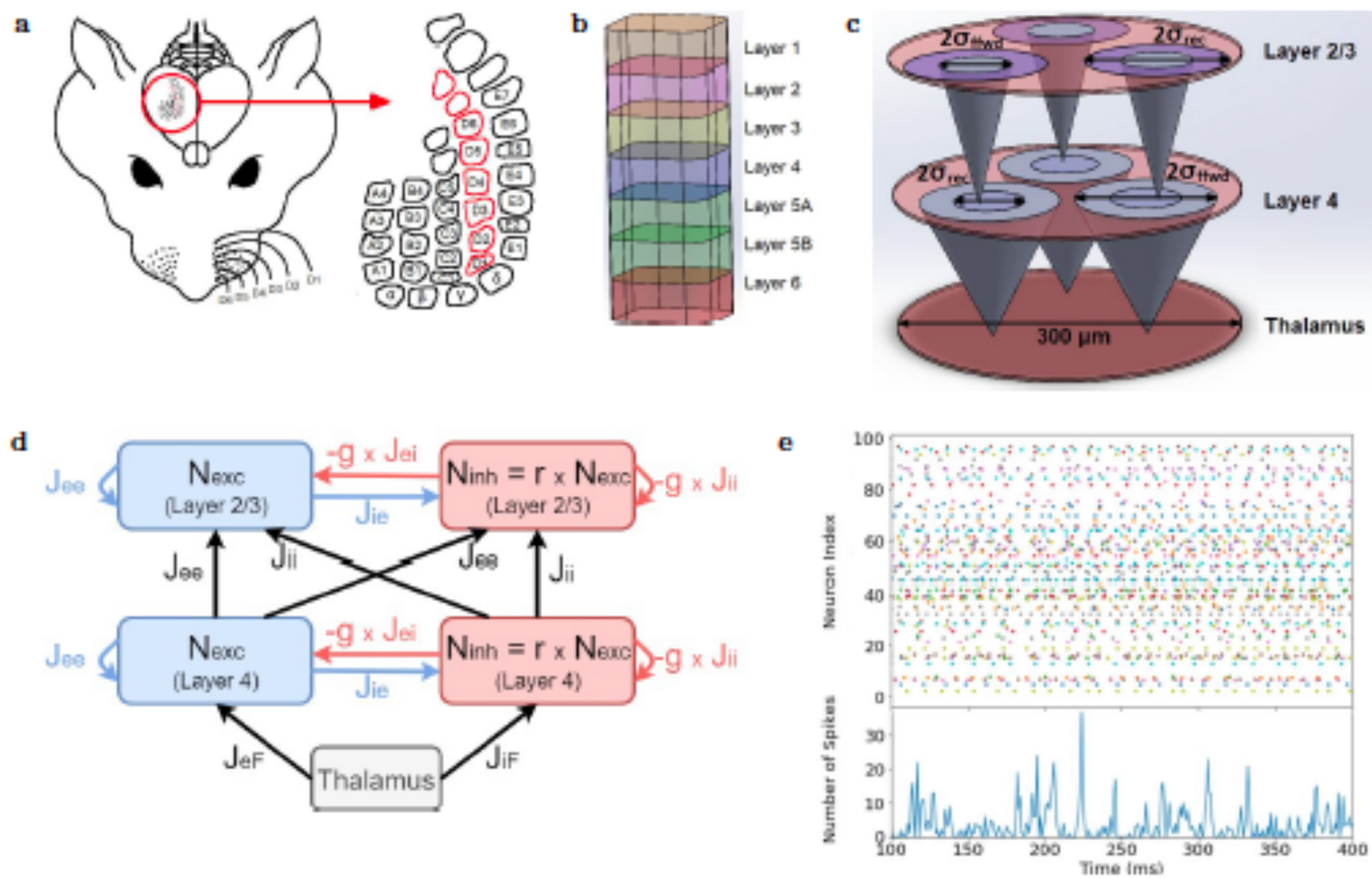
Chao Huang

github.com/DepartmentofNeurophysiology/Cortical-representation-of-touch-in-silico

Large-scale model



How do realistic deviations from random connectivity influence the activity of ‘balanced networks’?



Prescilla Uijtewaal

Behaviour

1Å Molecules ⇄ 1µm Synapses ⇄ 100 µm Neurons ⇄ 1 mm Networks ⇄ 1 cm Maps ⇄ 10 cm Systems ⇄ 1 m CNS

Supporting data for "An open-source high-speed infrared videography database to study the principles of active sensing in freely navigating rodents"

Dataset type: Imaging, Neuroscience

Data released on October 18, 2018

Azarfar A; **Zhang Y**; **Alishbayli A**; **Miceli S**; **Kepser L**; **der Wielen Dv**; **de Moosdijk Mv**; **Homberg J**; **Schubert D**; **Proville R**; **Celikel T** (2018): Supporting data for "An open-source high-speed infrared videography database to study the principles of active sensing in freely navigating rodents" GigaScience Database. http://dx.doi.org/10.5524/100512

DOI 10.5524/100512

Active sensing is crucial for navigation. It is characterized by self-generated motor action controlling the accessibility and processing of sensory information. In rodents, active sensing is commonly studied in the whisker system. As rats and mice modulate their whisking contextually, they employ frequency and amplitude modulation. Understanding the development, mechanisms and plasticity of adaptive motor control will require precise behavioral measurements of whisker position. Advances in high-speed videography and analytical methods now permit collection and systematic analysis of large datasets. Here we provide 6642 videos as freely moving juvenile (3rd-4th postnatal week) and adult rodents explore a stationary object on the gap-crossing task. The dataset includes sensory exploration with single- or multi-whiskers in wild-type animals, serotonin transporter knock-out rats, rats received pharmacological intervention targeting serotonergic signaling. The dataset includes varying background illumination conditions and signal-to-noise ratios (SNRs), ranging from homogenous/high contrast to non-homogenous/low-contrast. A subset of videos has been whisker and nose tracked, and are provided as reference for image processing algorithms. The recorded behavioral data can be directly used to study (1) development of sensorimotor computation, (2) top-down mechanisms that control sensory navigation and whisker position, (3) cross-species comparison of active sensing. It could also help to address contextual modulation of active sensing during touch induced whisking in head-fixed versus freely behaving animals. And finally, it provides the necessary data for machine learning approaches for automated analysis of sensory and motion parameters across a wide variety of SNRs with accompanying human observer determined ground-truth.

Keywords:
mystacial vibrissae object localization goal-directed behavior mouse rat sensorimotor computation whisking

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- Russian Academic Excellence Project “5–100”
- Margaret Olivia Knip Foundation

Lantyer et al. dataset
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- Yiping Zhang
- Alireeza Azarfar
- Xuan Yan
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- Wytse Wadman
- Sicco de Knecht

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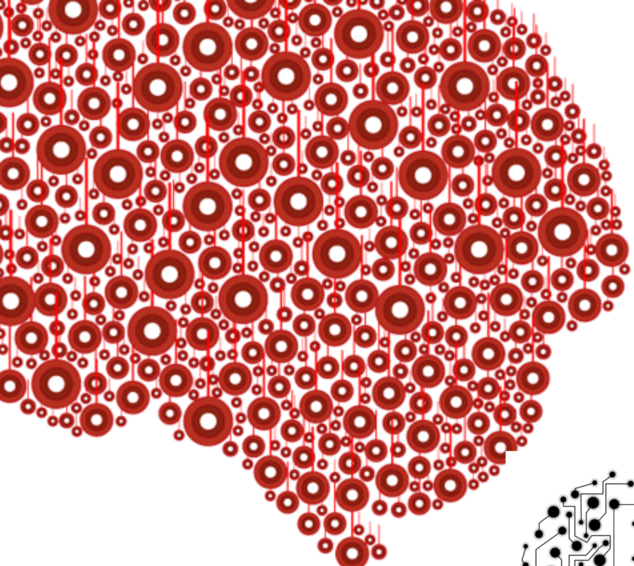
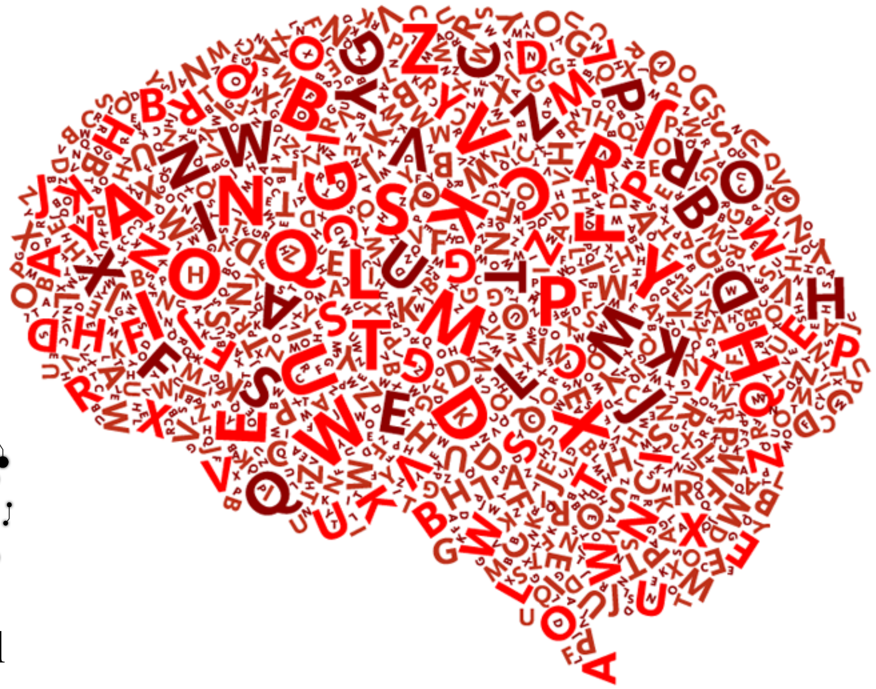
- Boris Gutkin
- Sophie Denève





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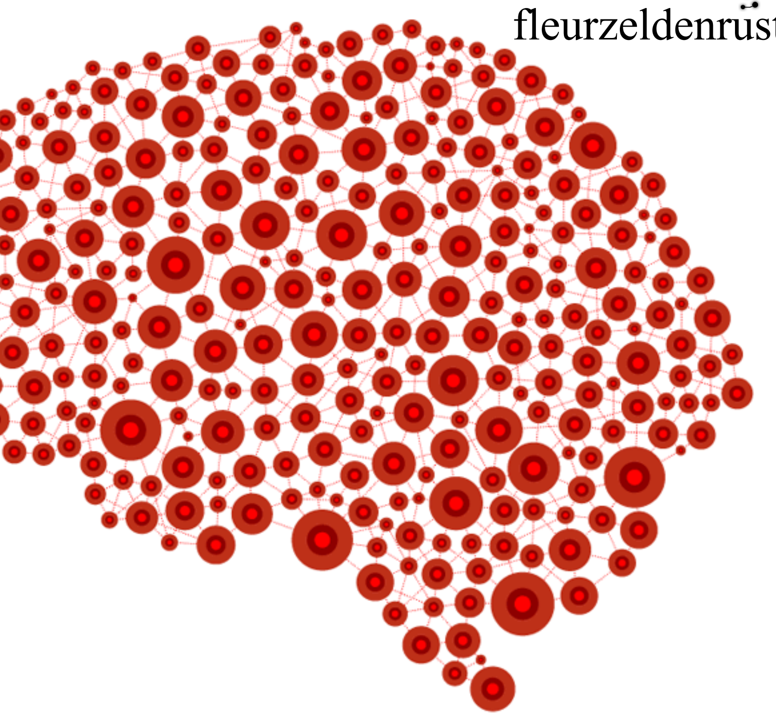
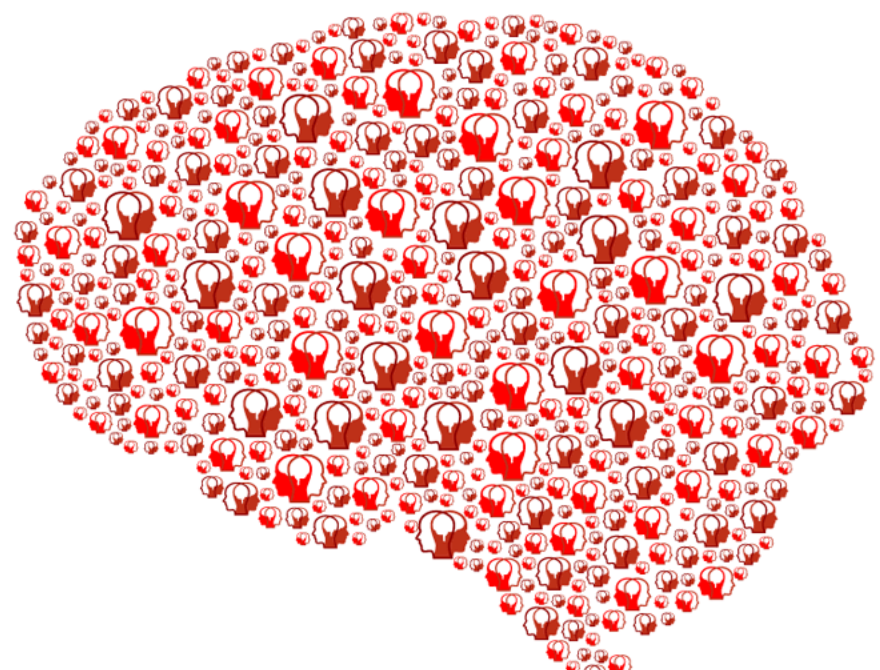
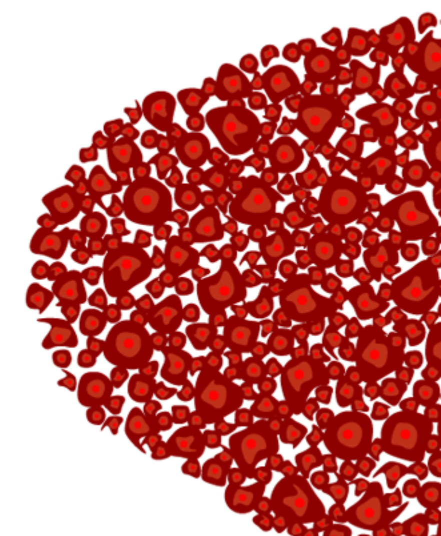


Questions?





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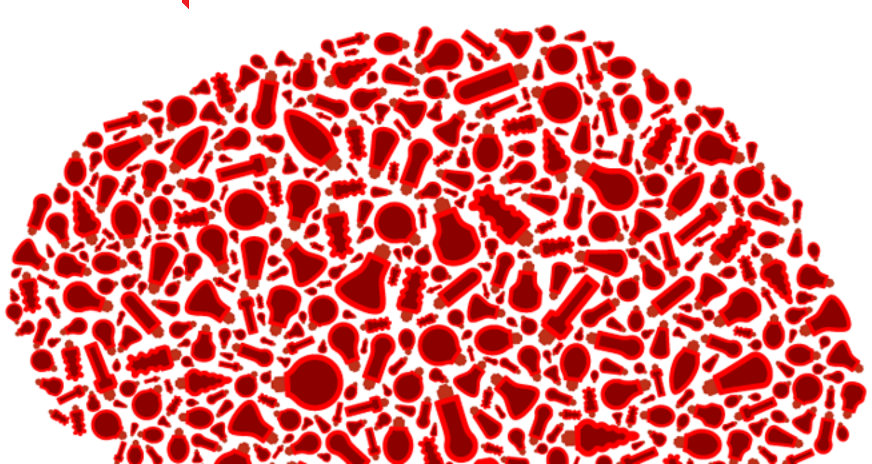

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