Data–driven modeling of early visual system

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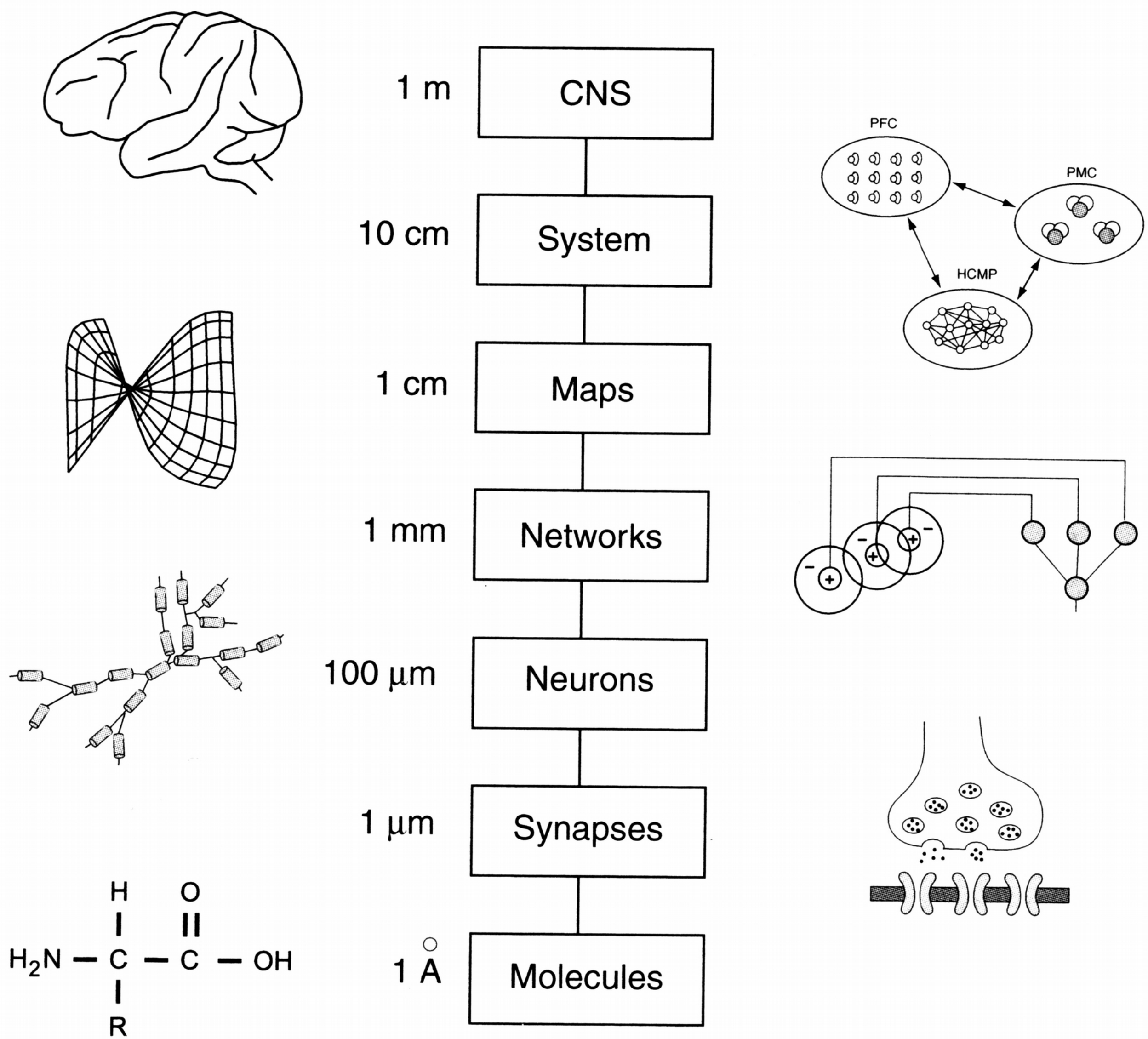
EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research, Development and Education

MINISTRY OF EDUCATION, YOUTH AND SPORTS

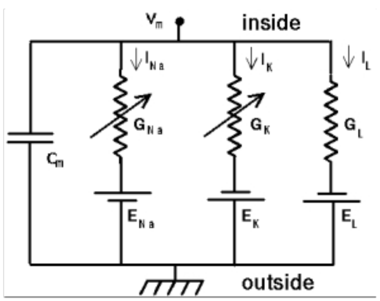
Context in the course

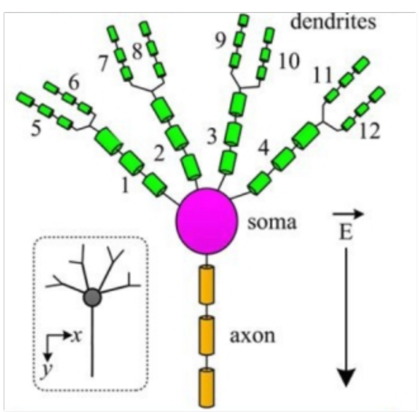


Biological fidelity of models

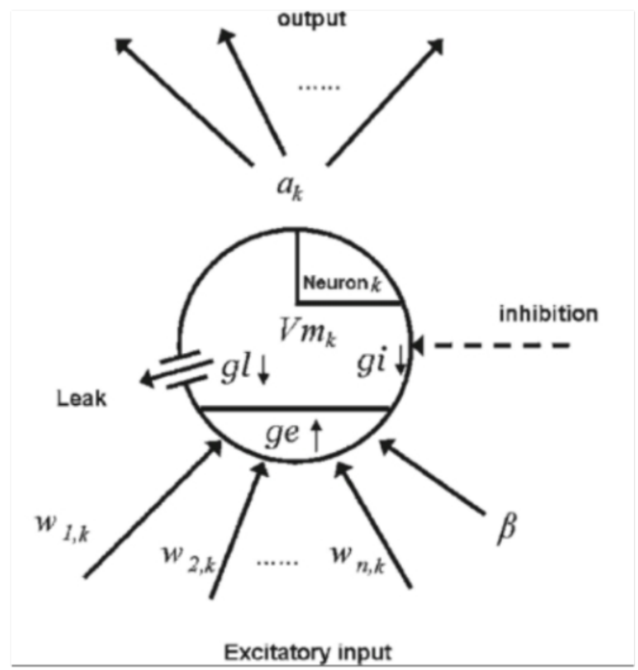
Neural model detail

hodgkin-huxley
neural model

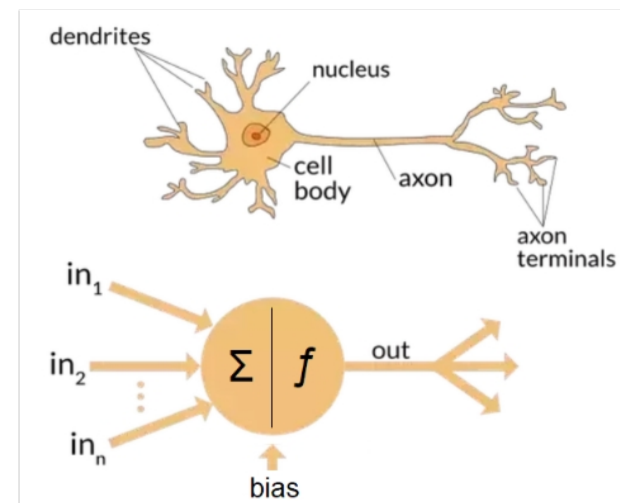




point
neuron



firing-rate
neuron

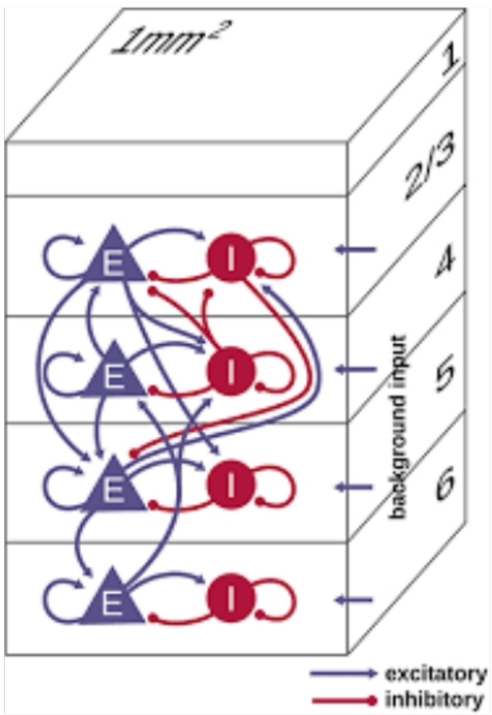


DETAILED

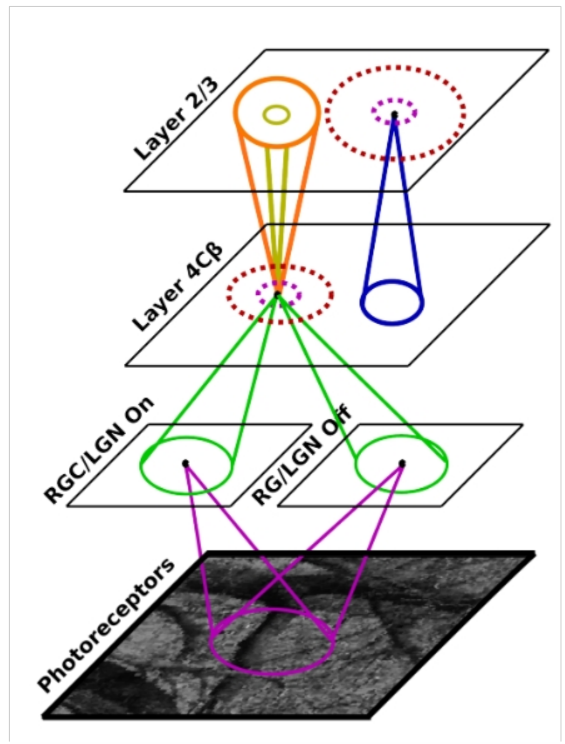
ABSTRACT

Model scope

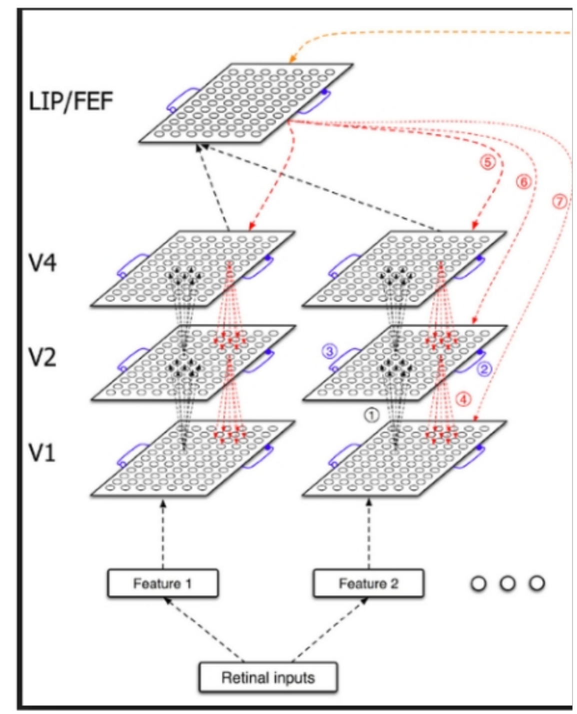
Single column



Single-area



Multi-area

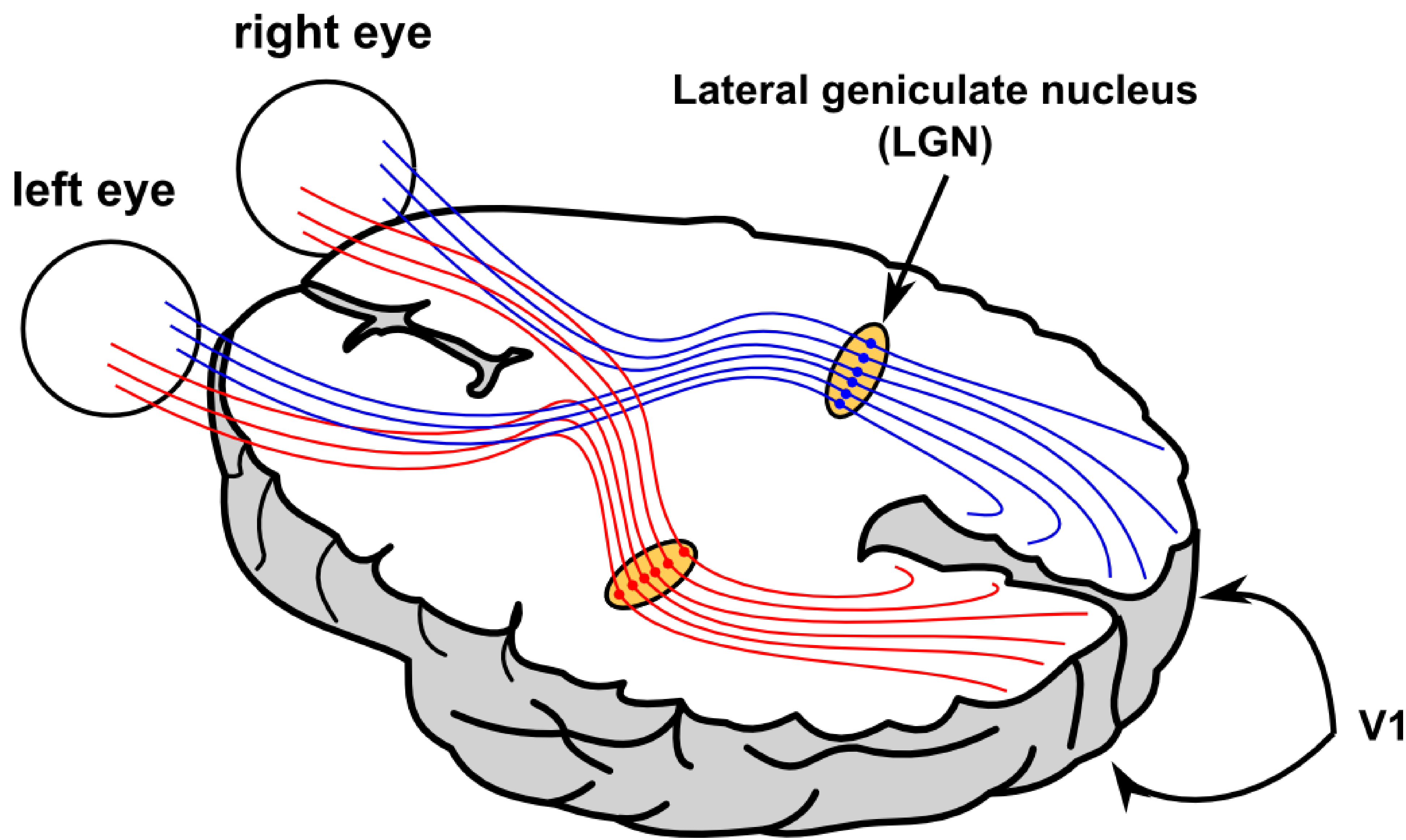


NARROW

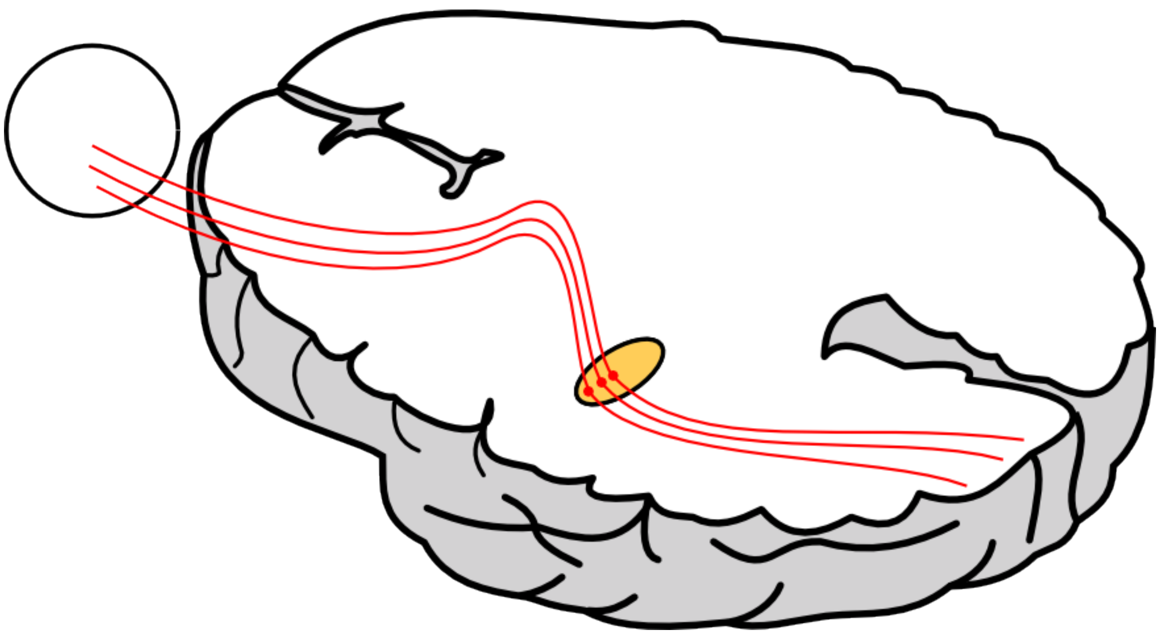
BROAD

BIOLOGICAL BACKGROUND

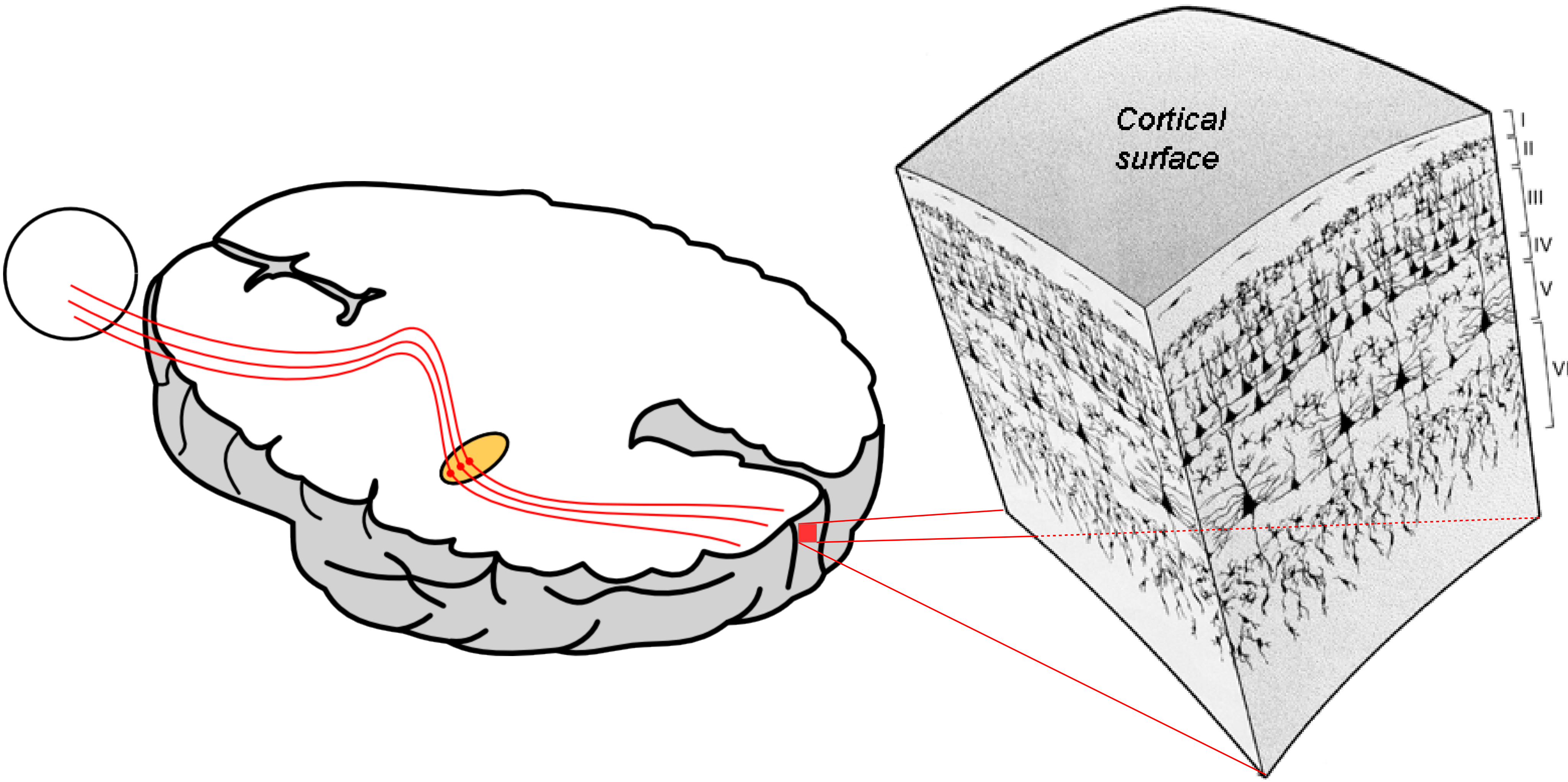
Early visual system



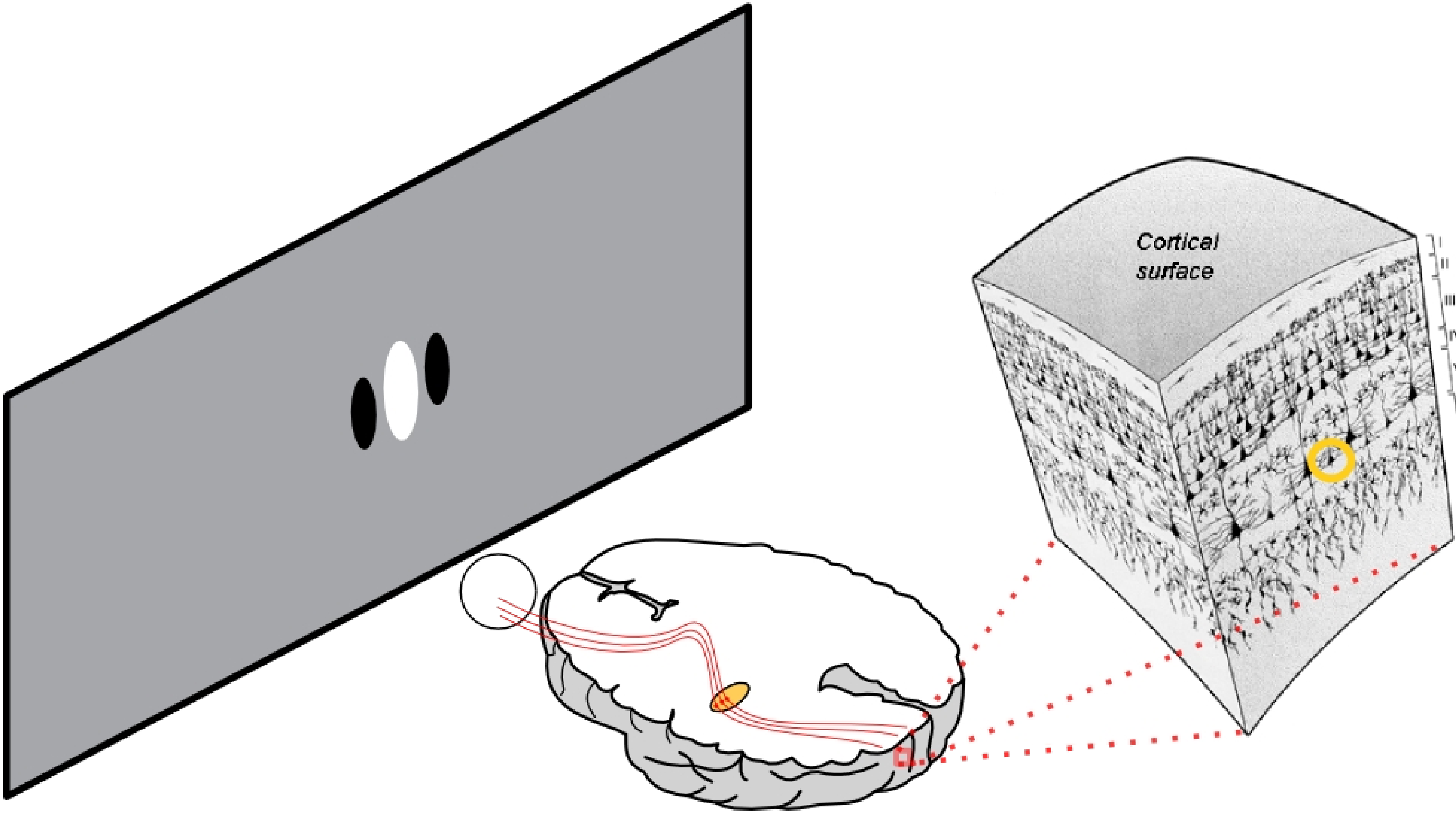
Cortical layers



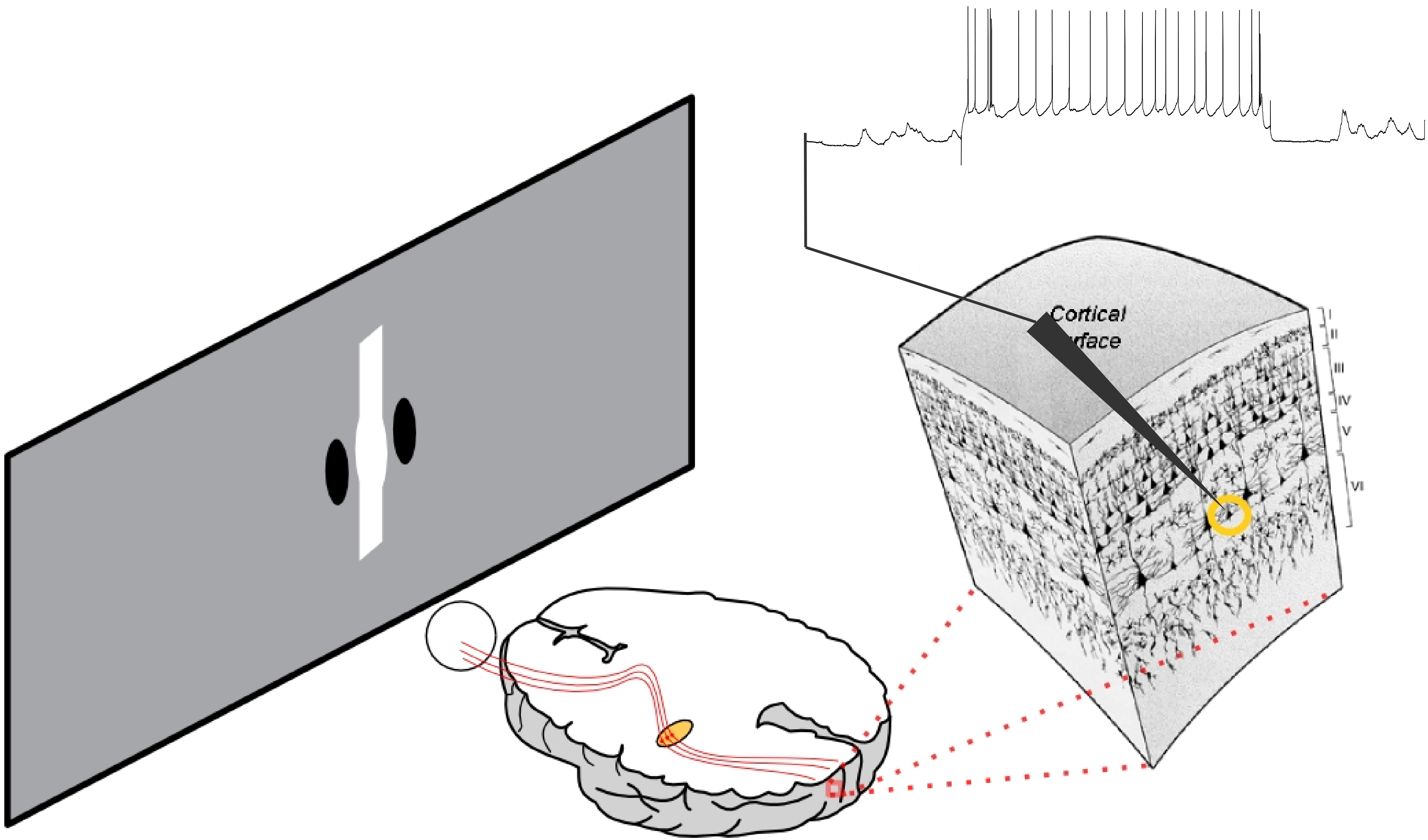
Cortical layers



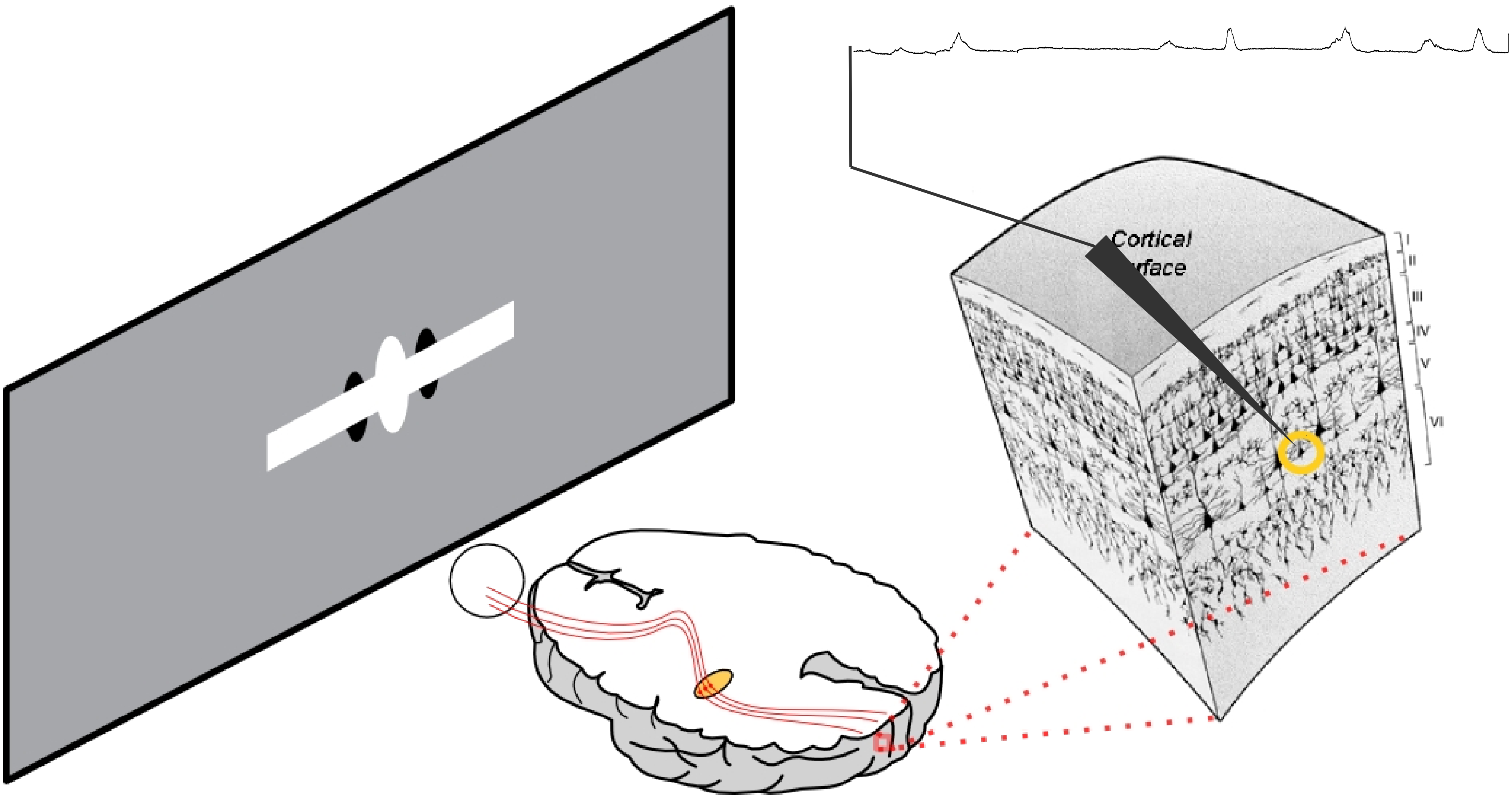
Receptive field



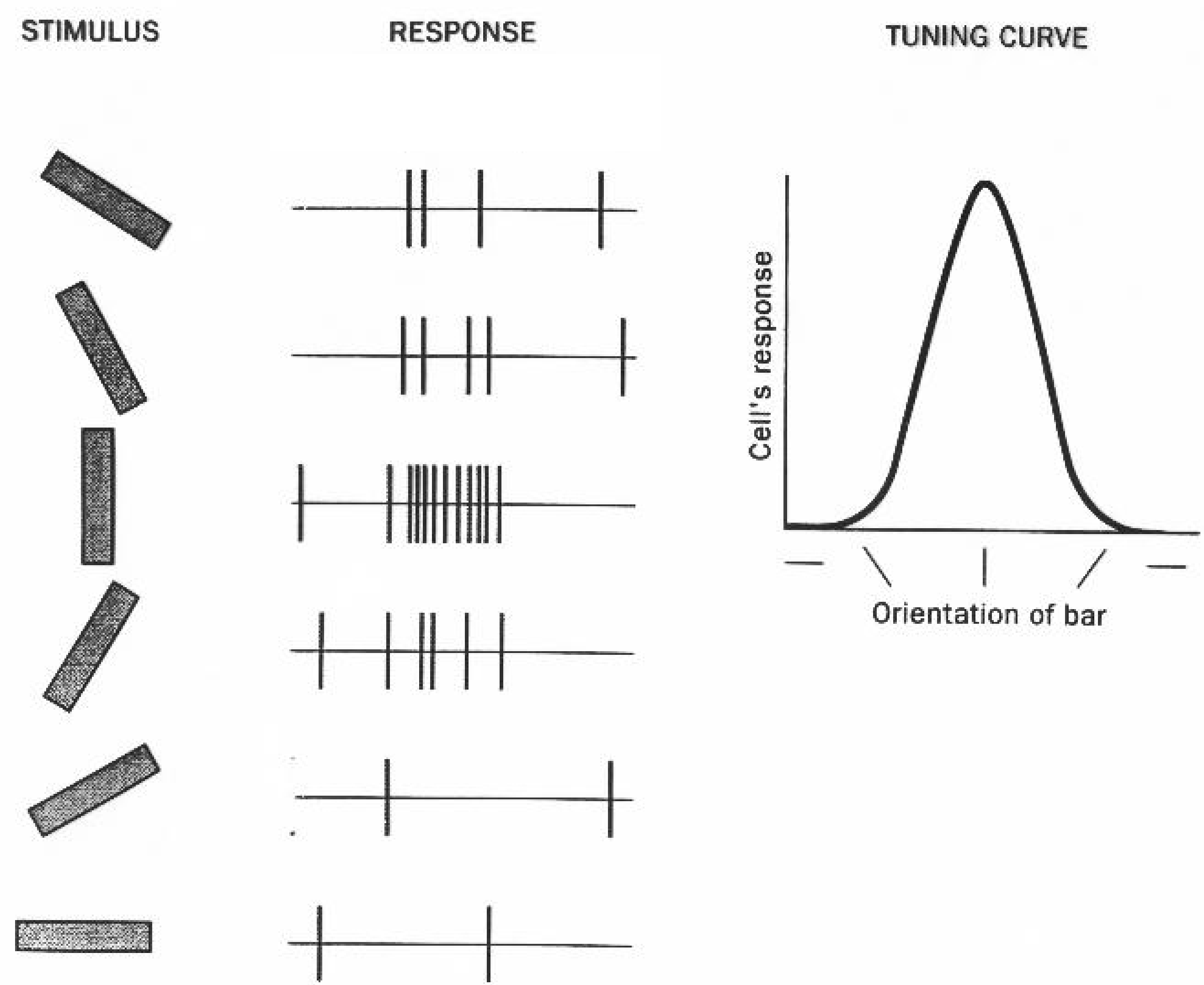
Receptive field



Receptive field



Orientation tuning curve

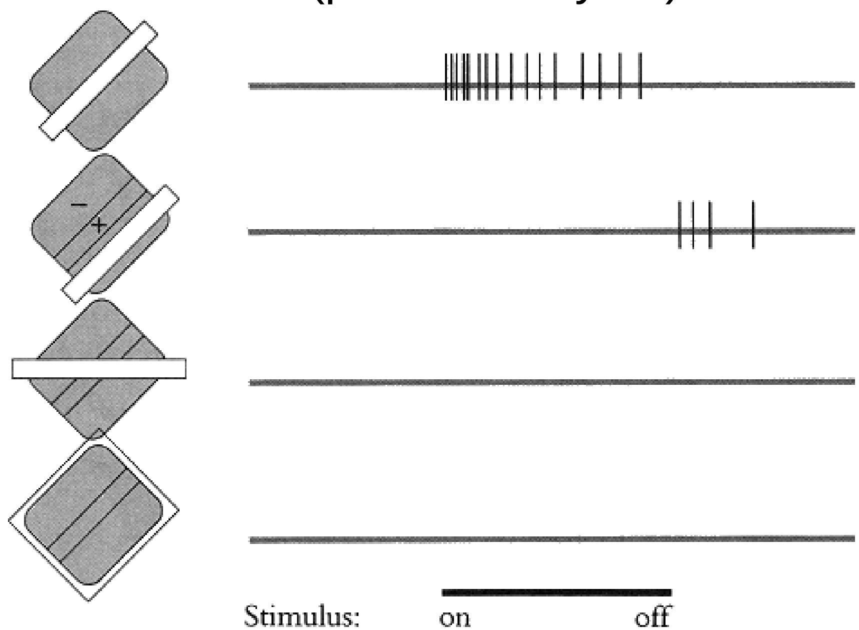


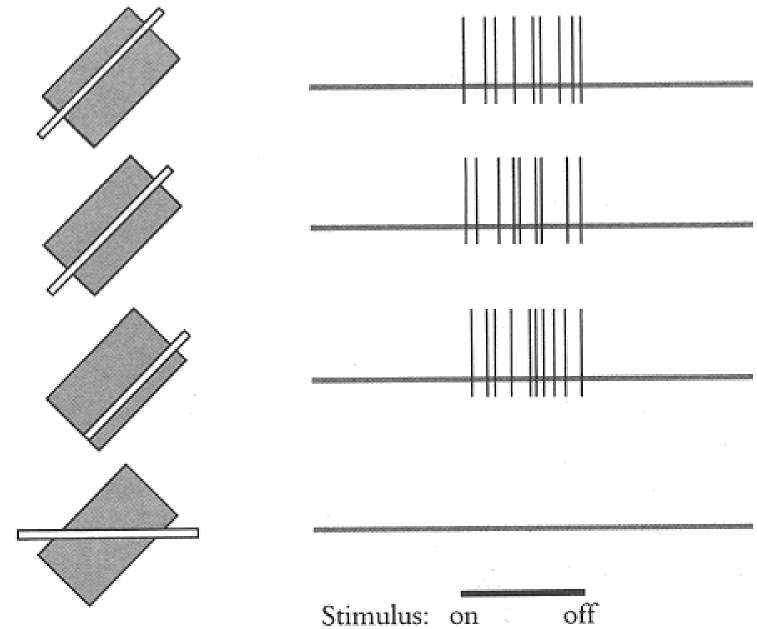
Simple/complex cells

Simple cell
(preferentially L4)

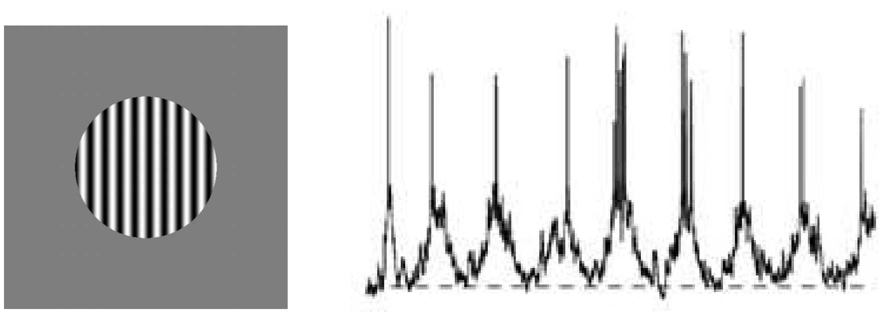
Complex cell
(preferentially L2/3)

Flashed bar

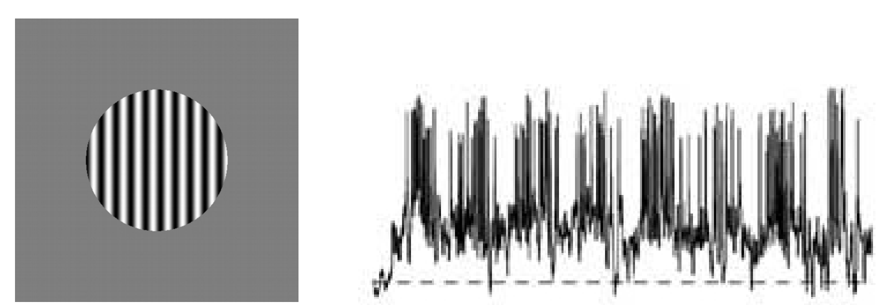




Drifting grating

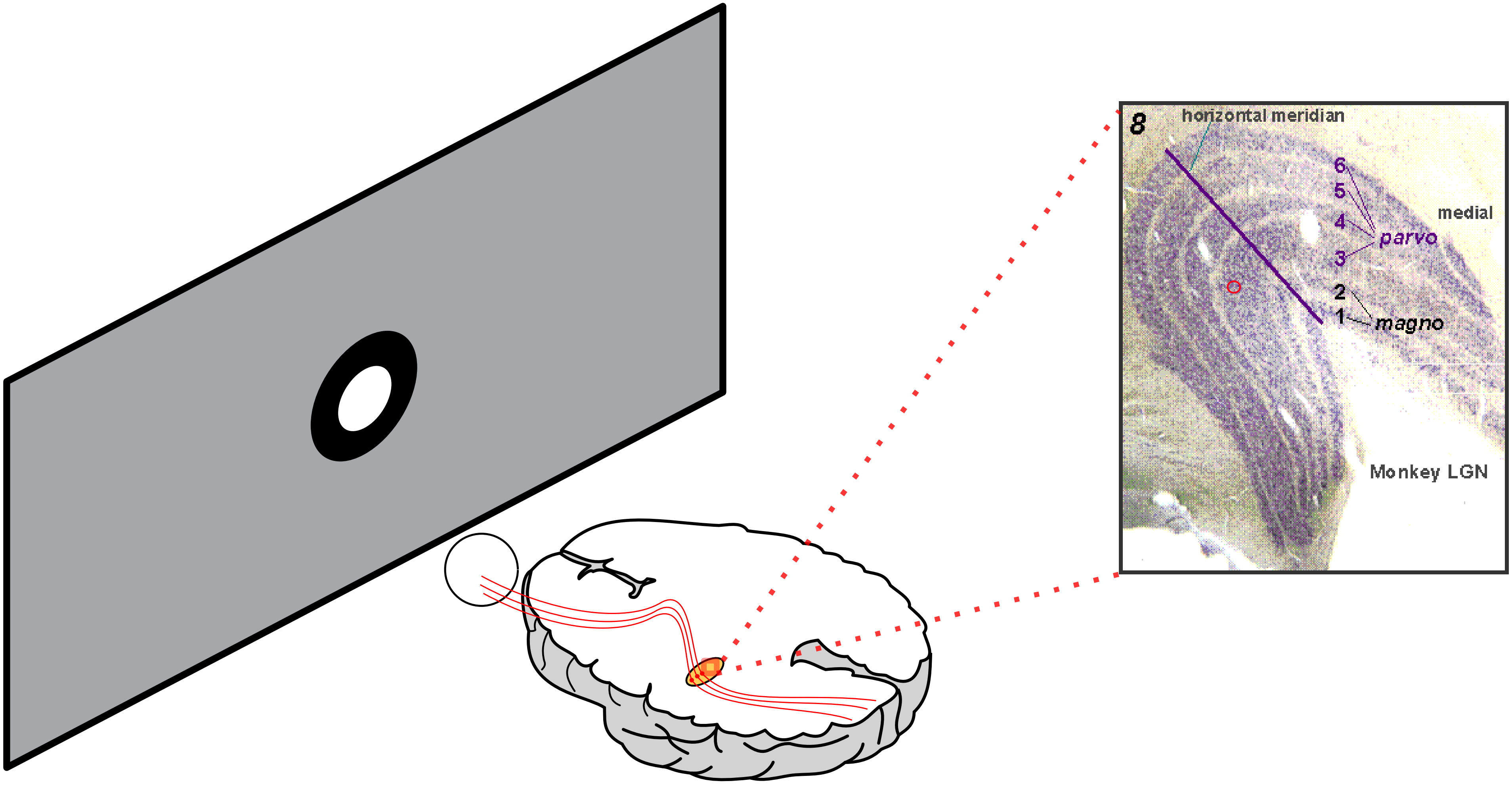


time



time

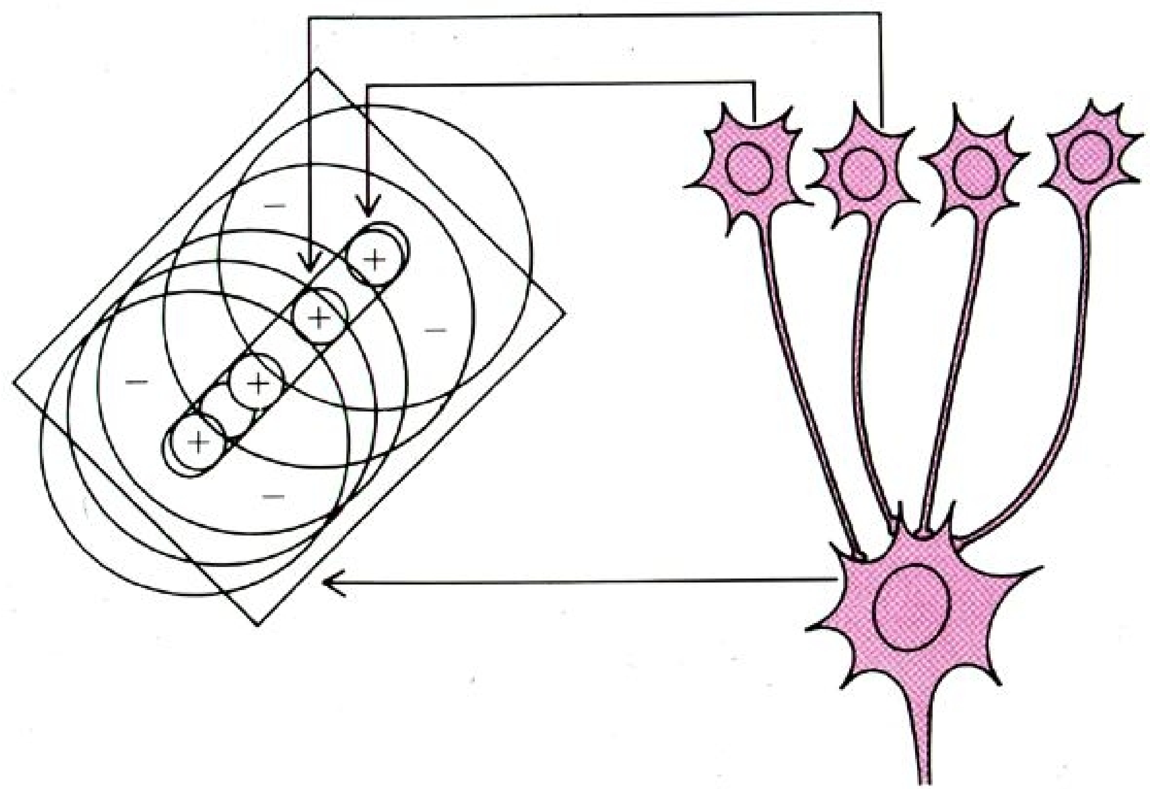
Receptive field in LGN



How is V1 simple cell formed from LGN inputs?

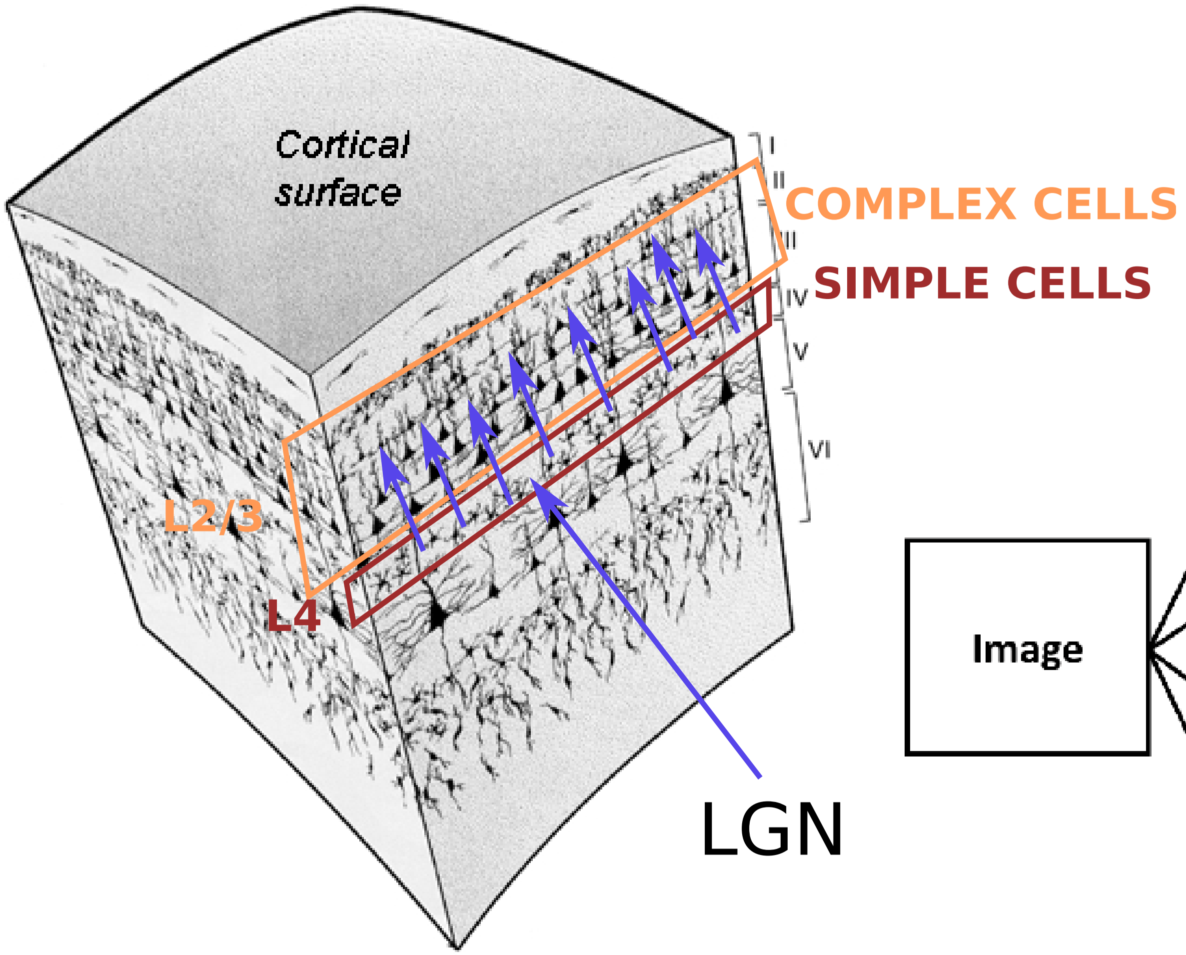
How is V1 simple cell formed from LGN inputs?

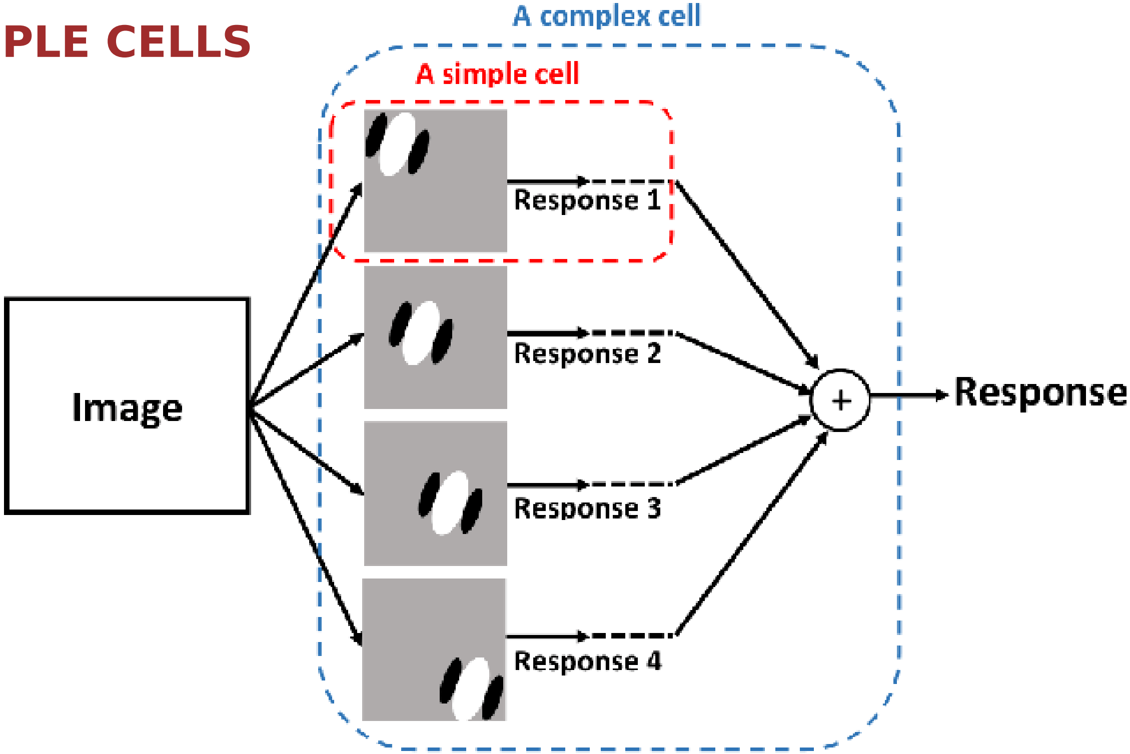
Simple cell sums LGN inputs



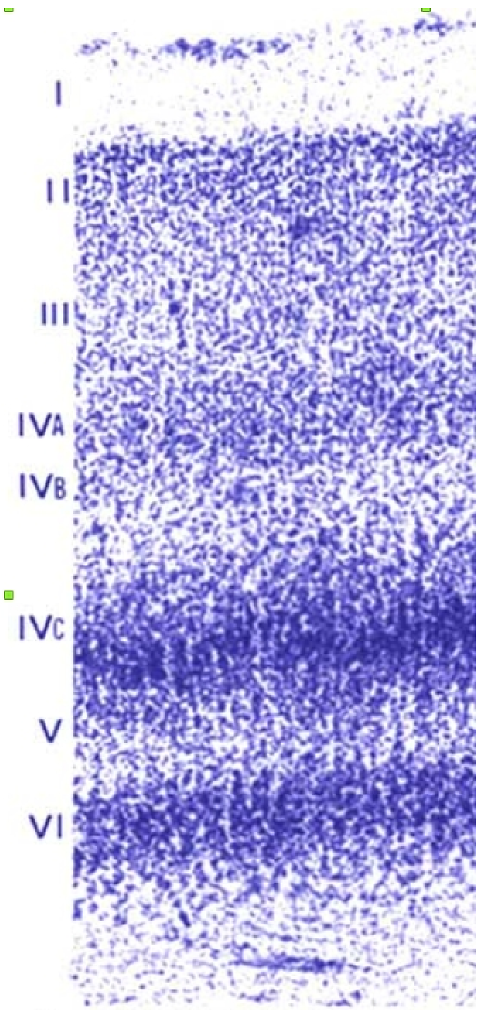
How is V1 complex cell formed from LGN inputs?

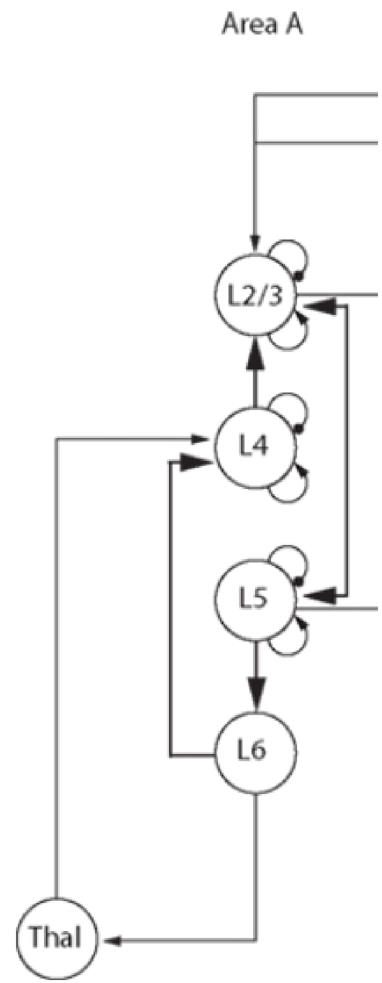
Simple to complex connectivity



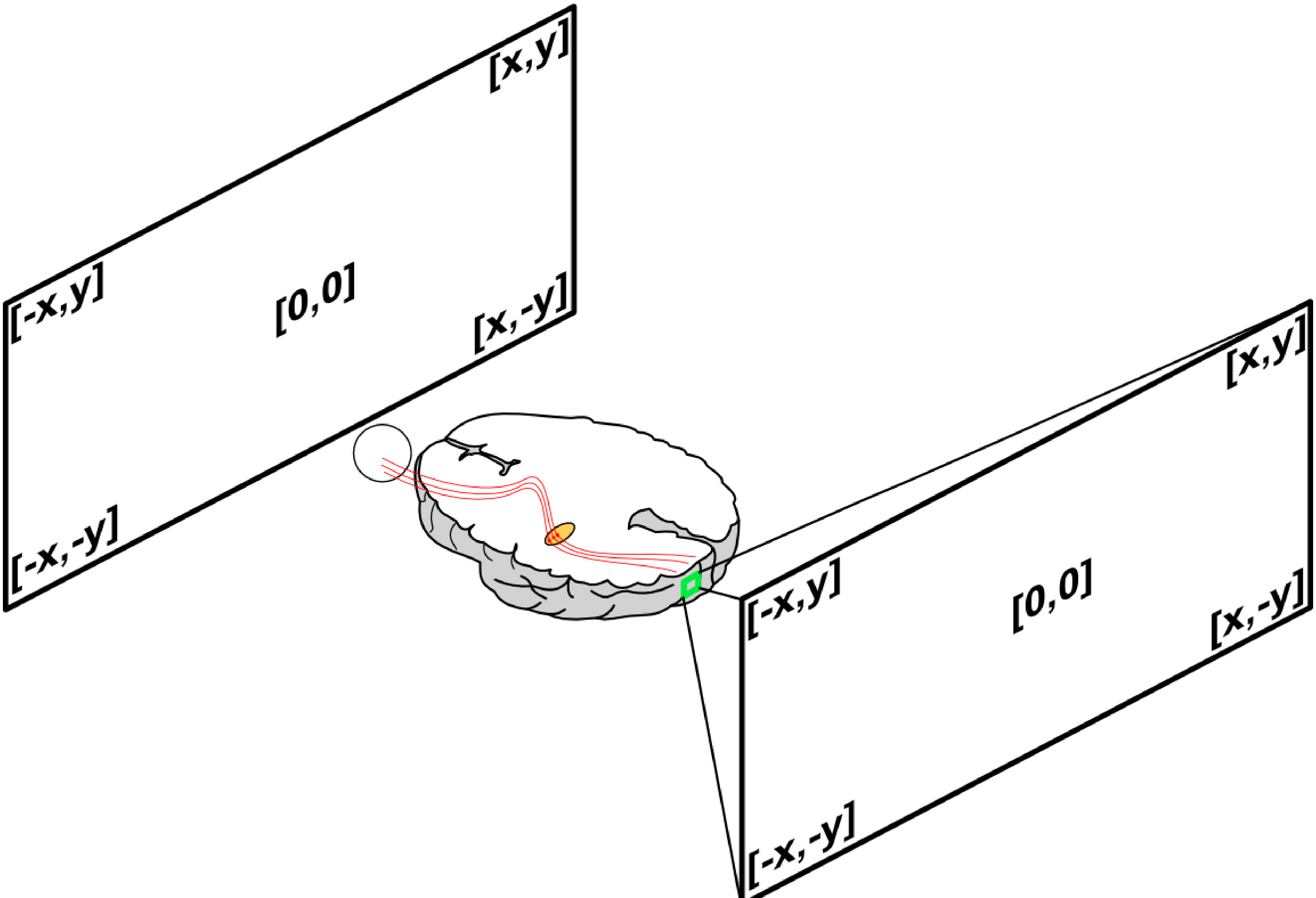


Cortical layers & Simple/Complex cells

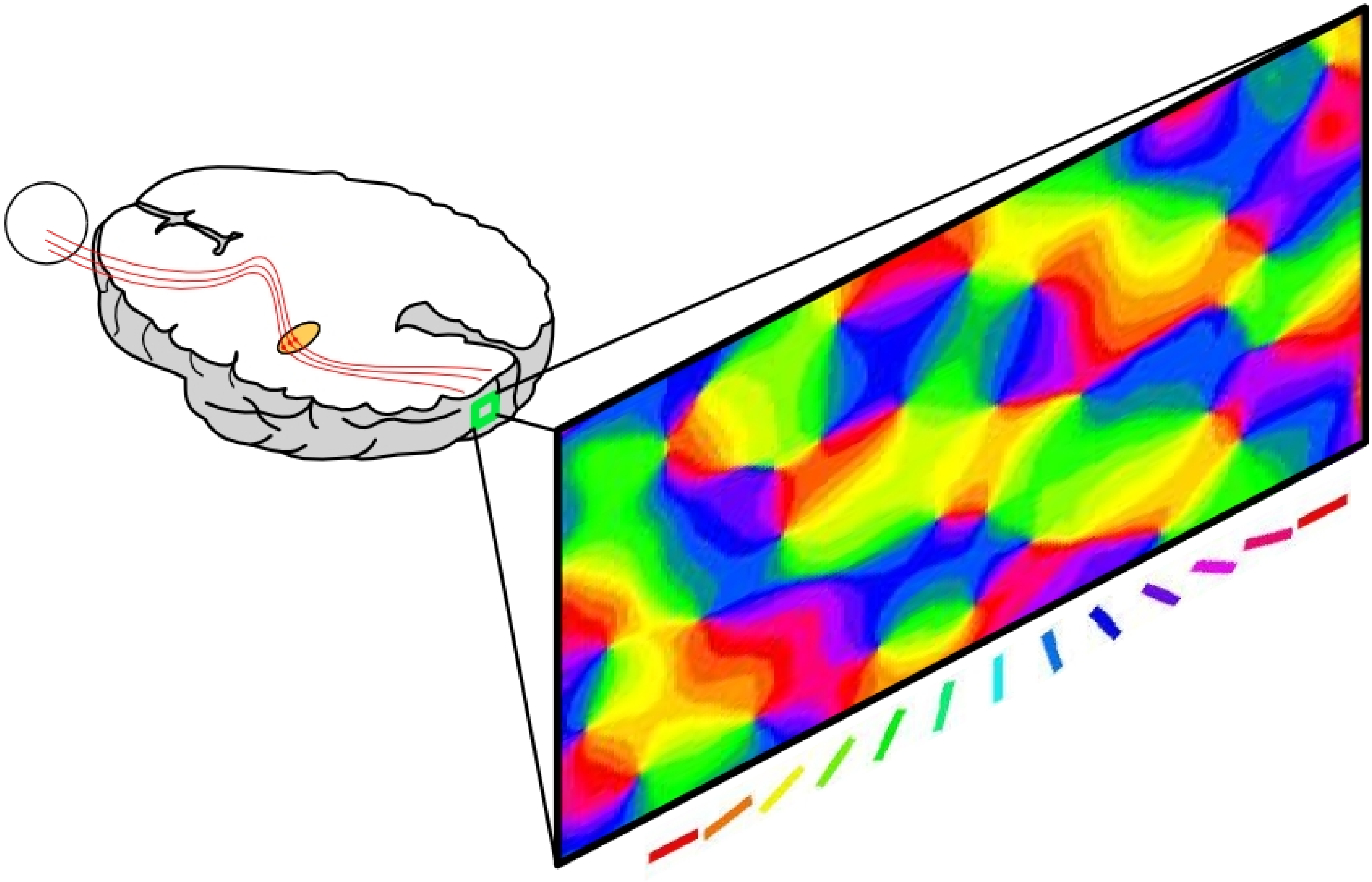




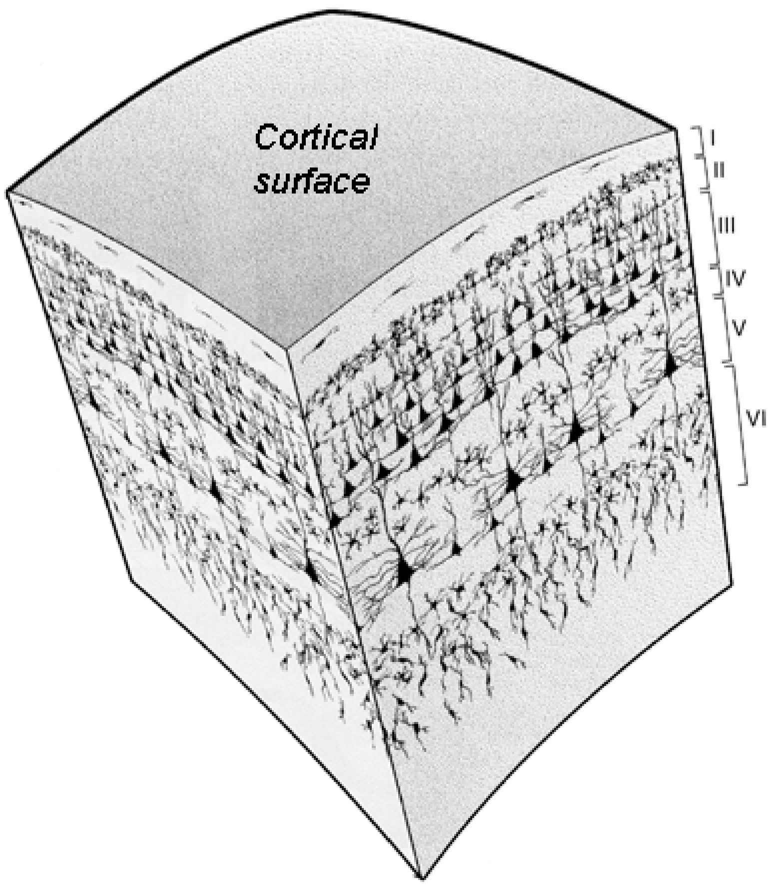
Retinotopic mapping in cortex



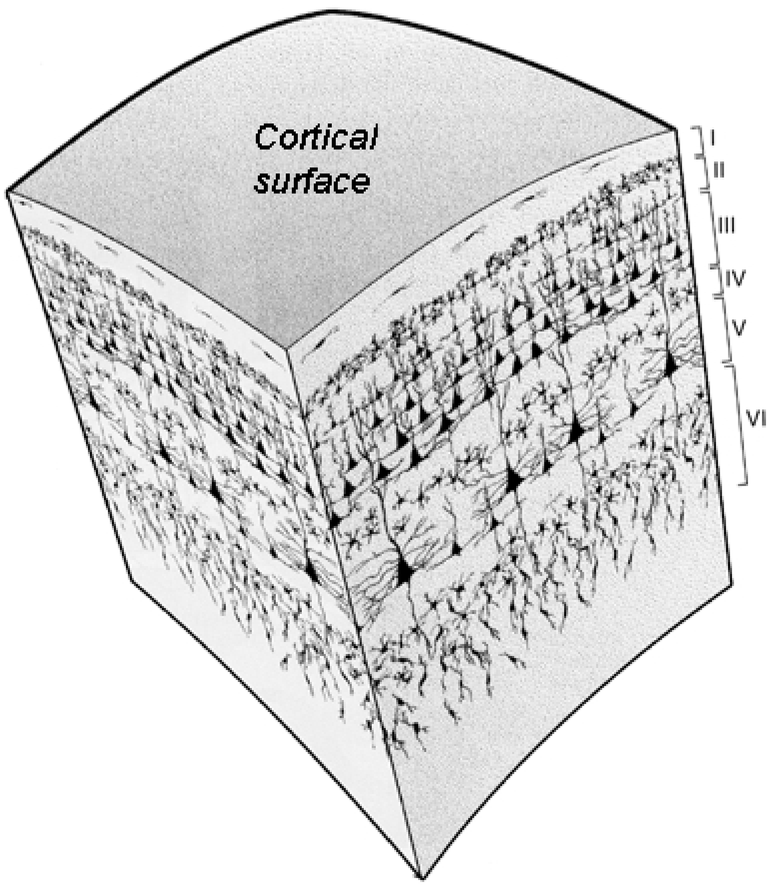
Functional topological maps in cortex

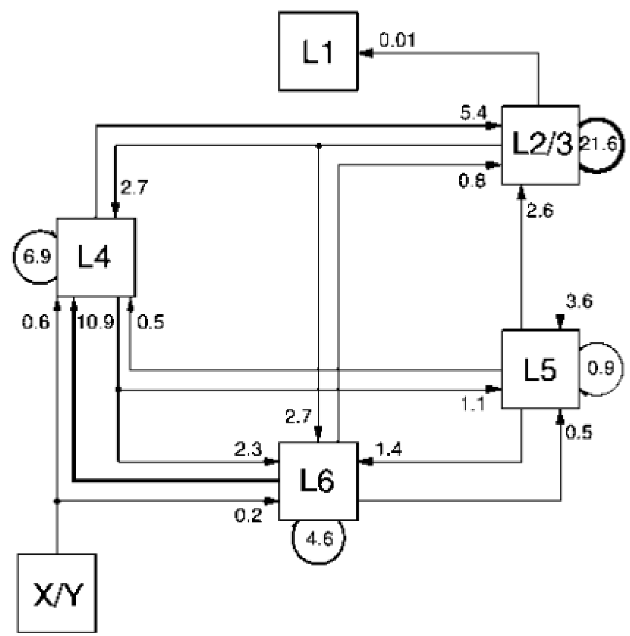


Quantifying cortical connectivity



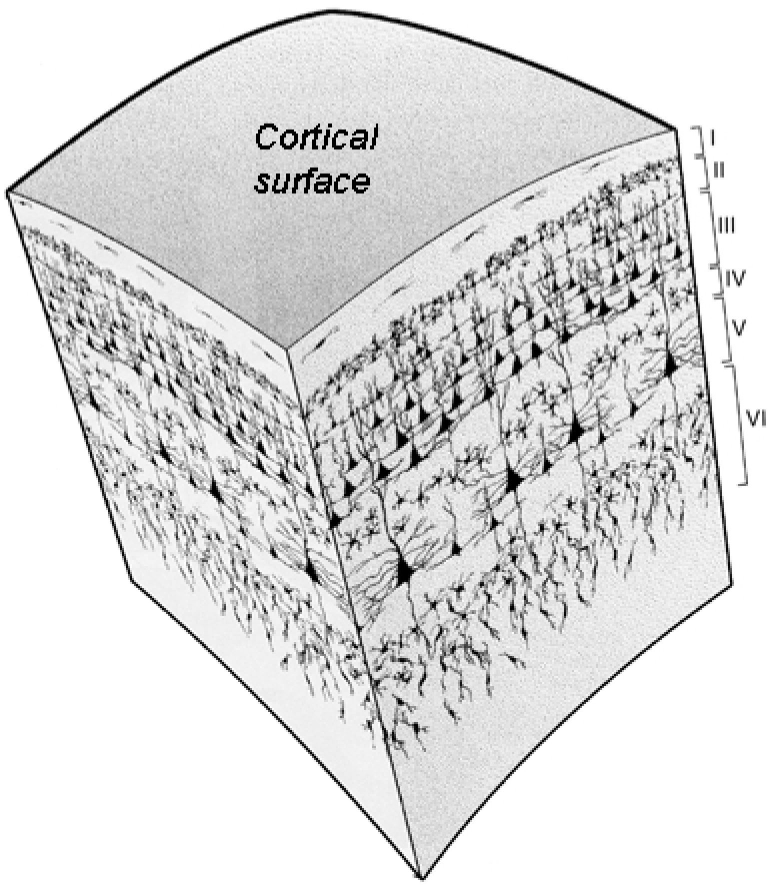
Quantifying cortical connectivity

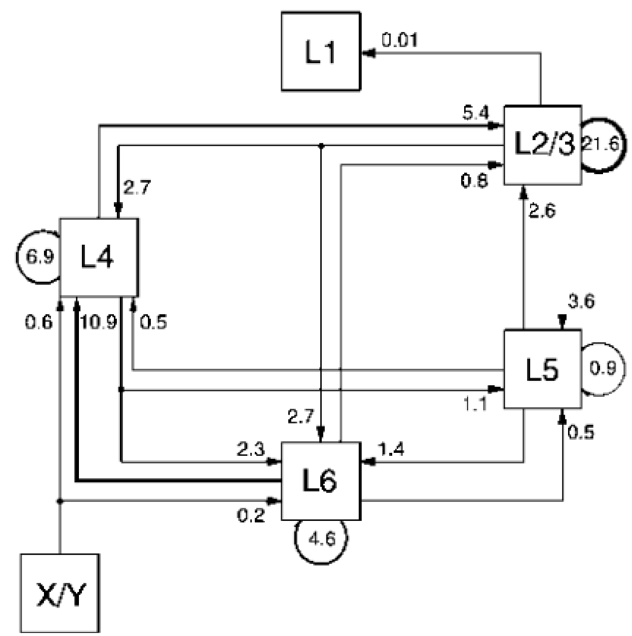




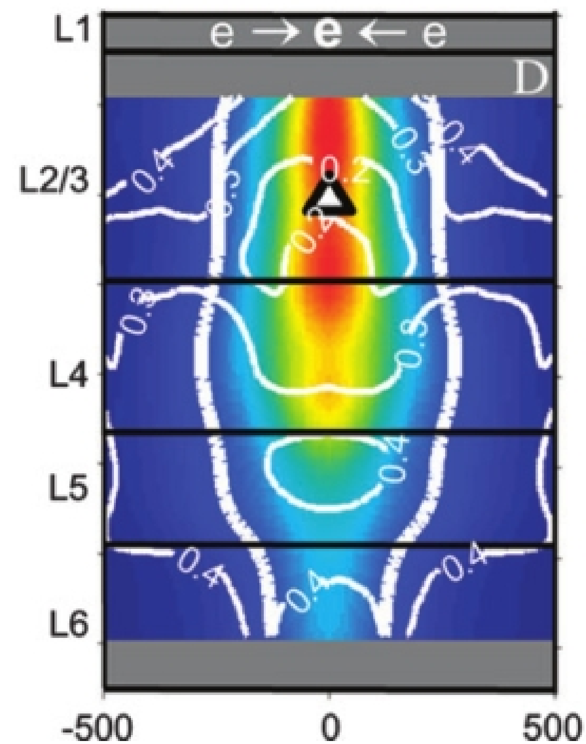
Binzegger et. al. 2004, cat

Quantifying cortical connectivity



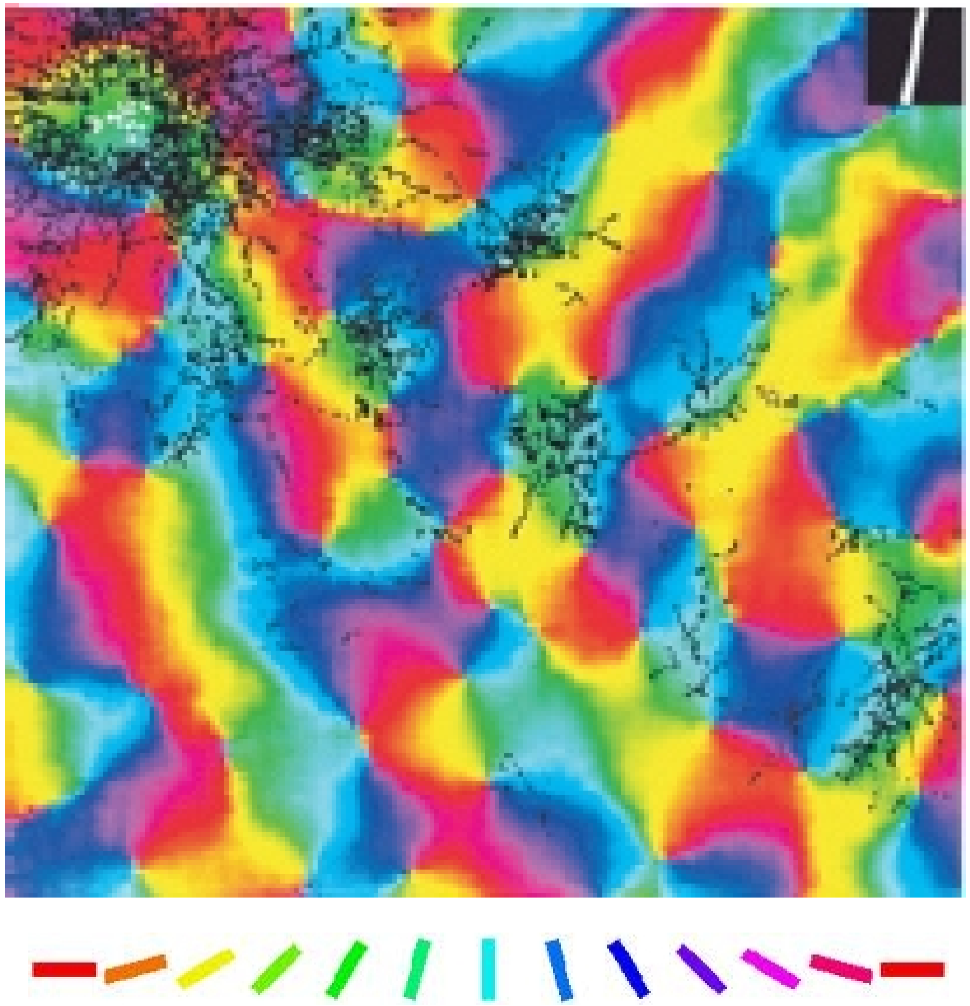


Binzegger et. al. 2004, cat



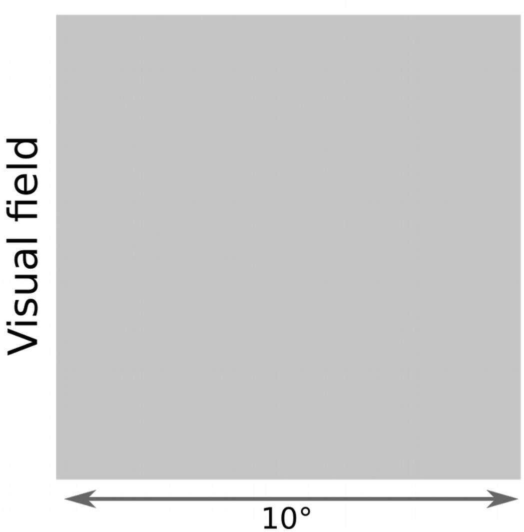
Stepanyants et al., 2008, cat

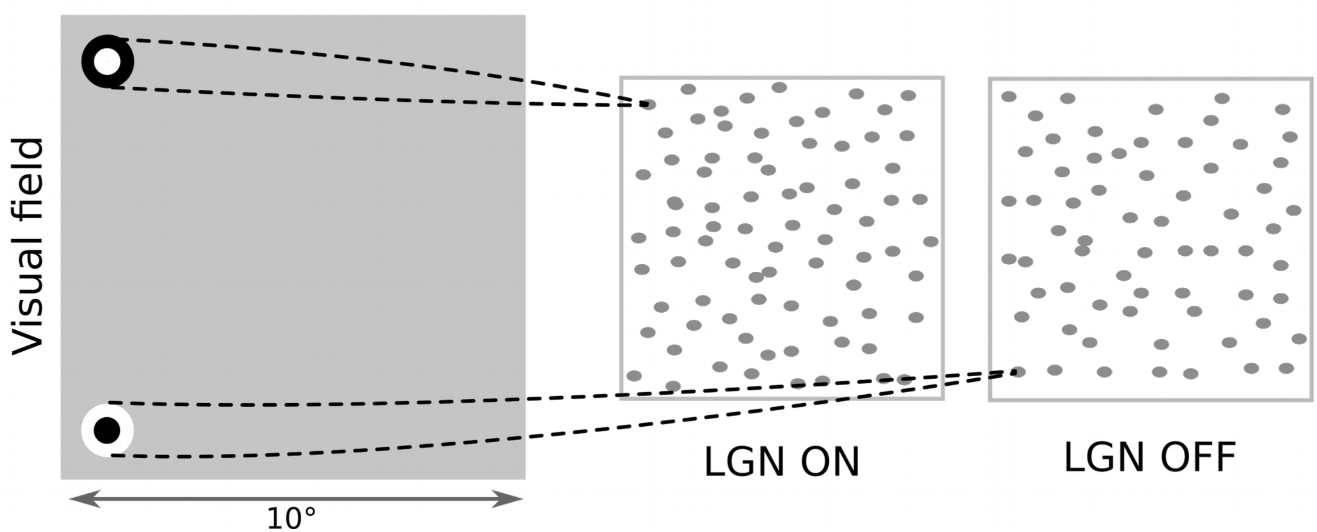
Orientation maps and functional specificity of connections

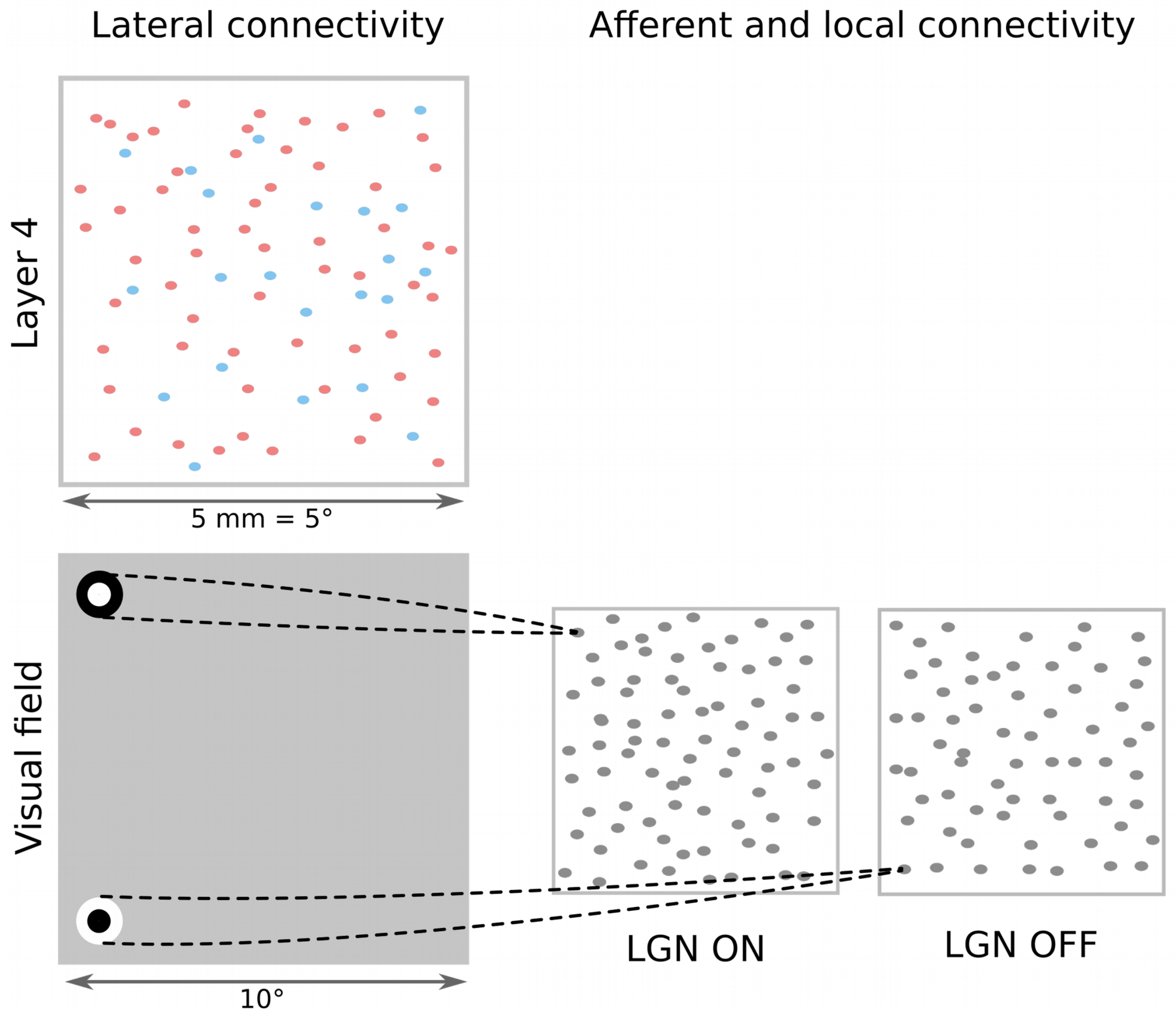


Bosking et al. 1997

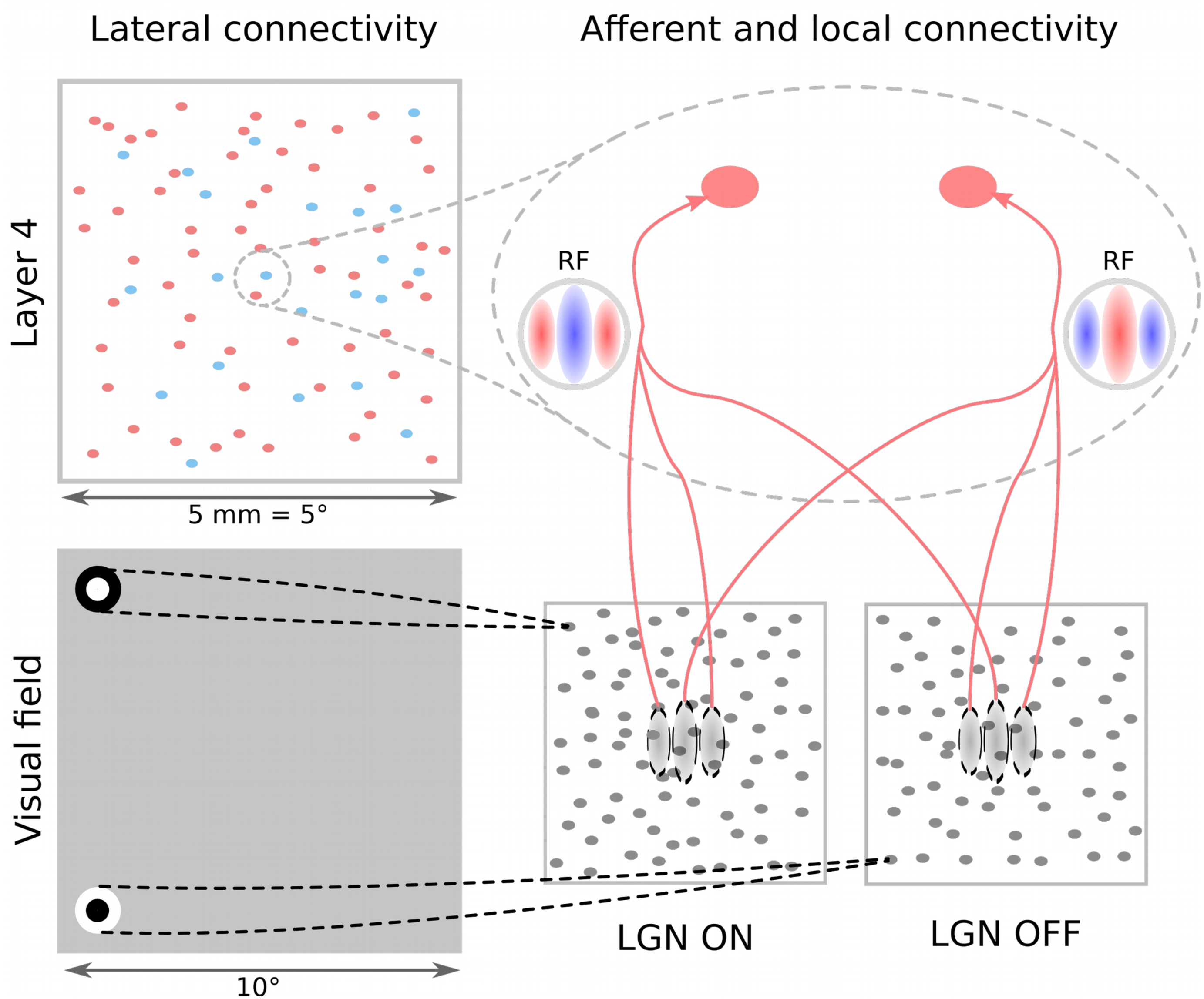
THE DATA DRIVEN MODEL

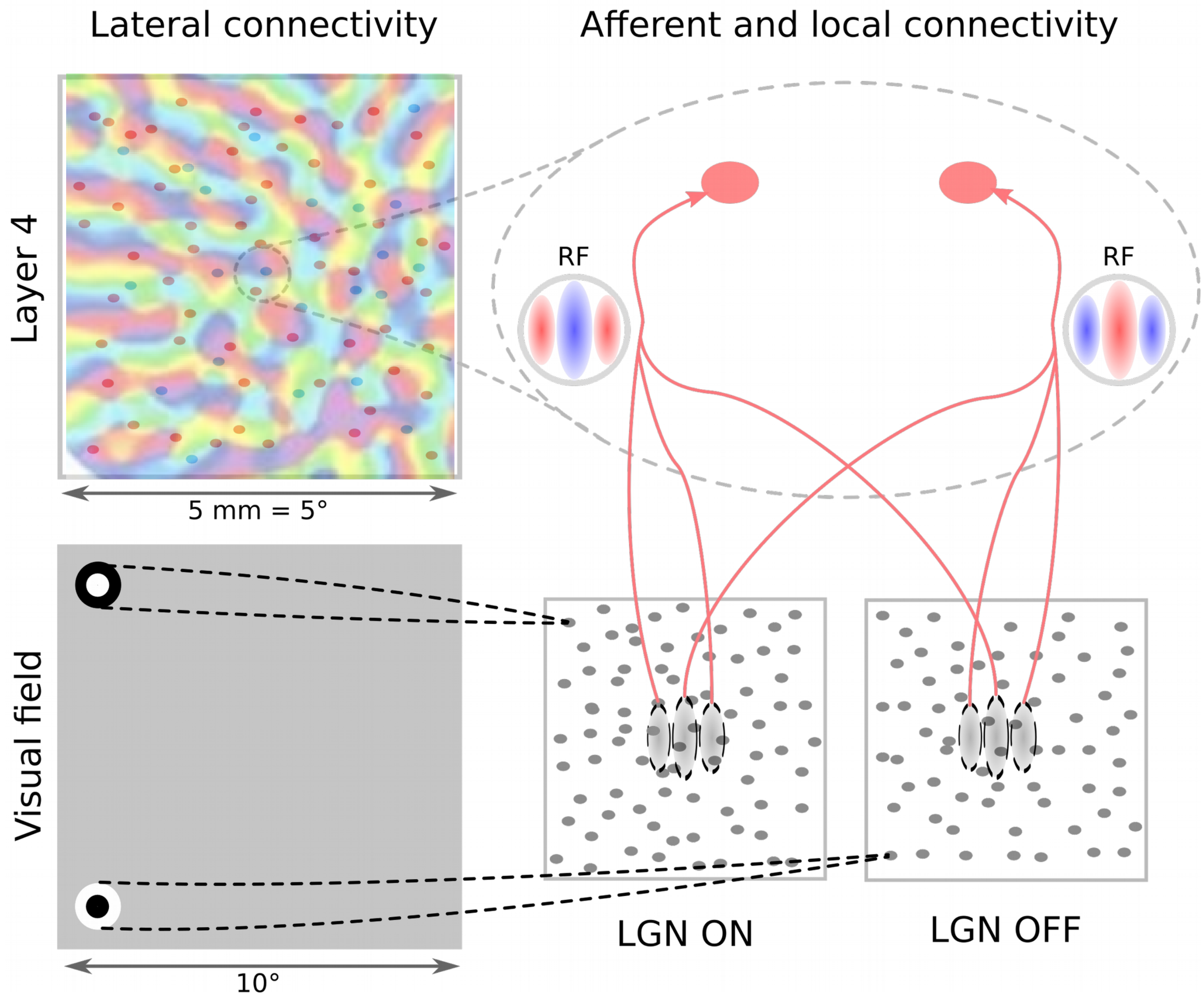

Visual field
10°


Visual field
10°
LGN ON
LGN OFF

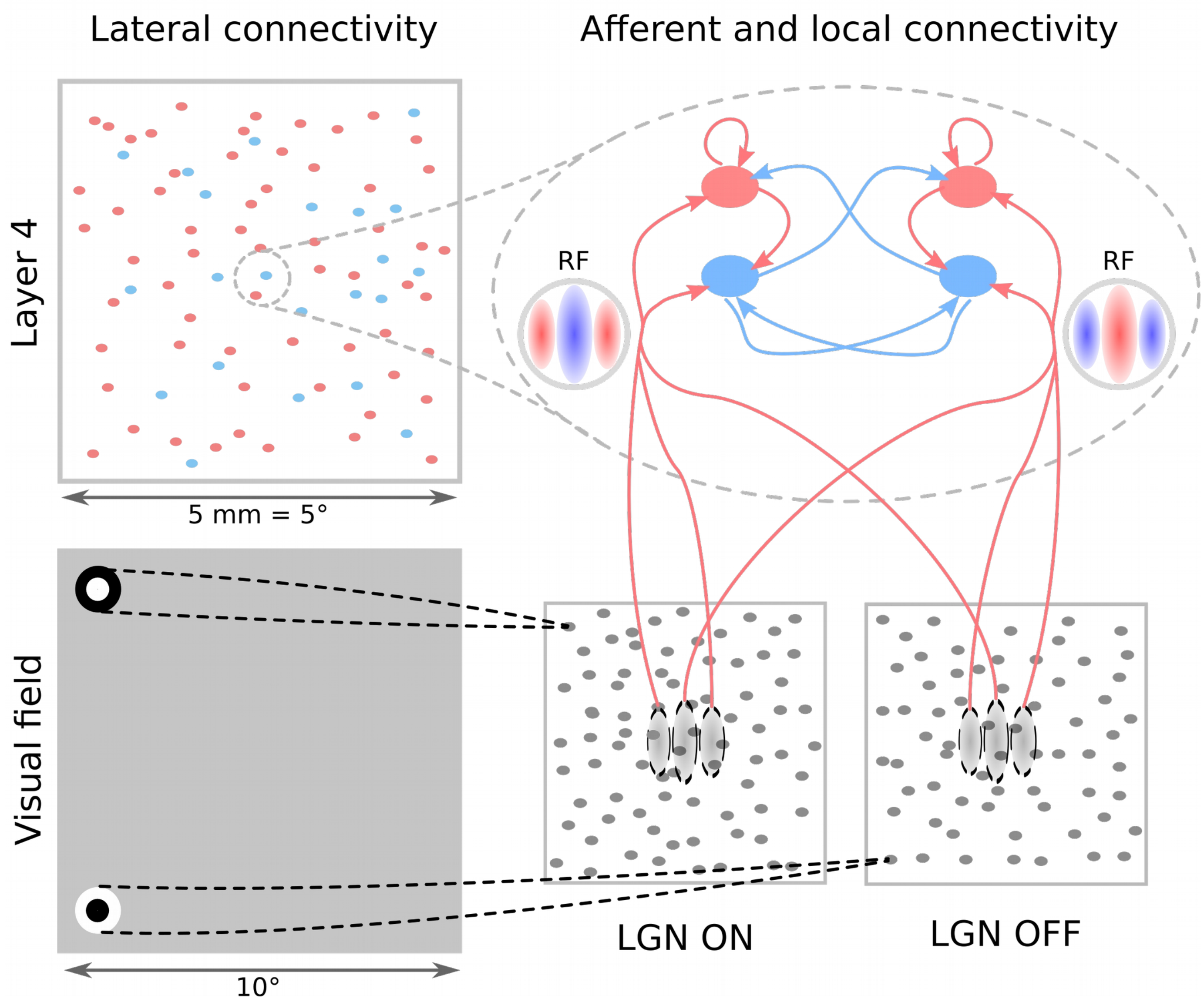


Lateral connectivity
Afferent and local connectivity
Layer 4
5 mm = 5°
Visual field
10°
LGN ON
LGN OFF

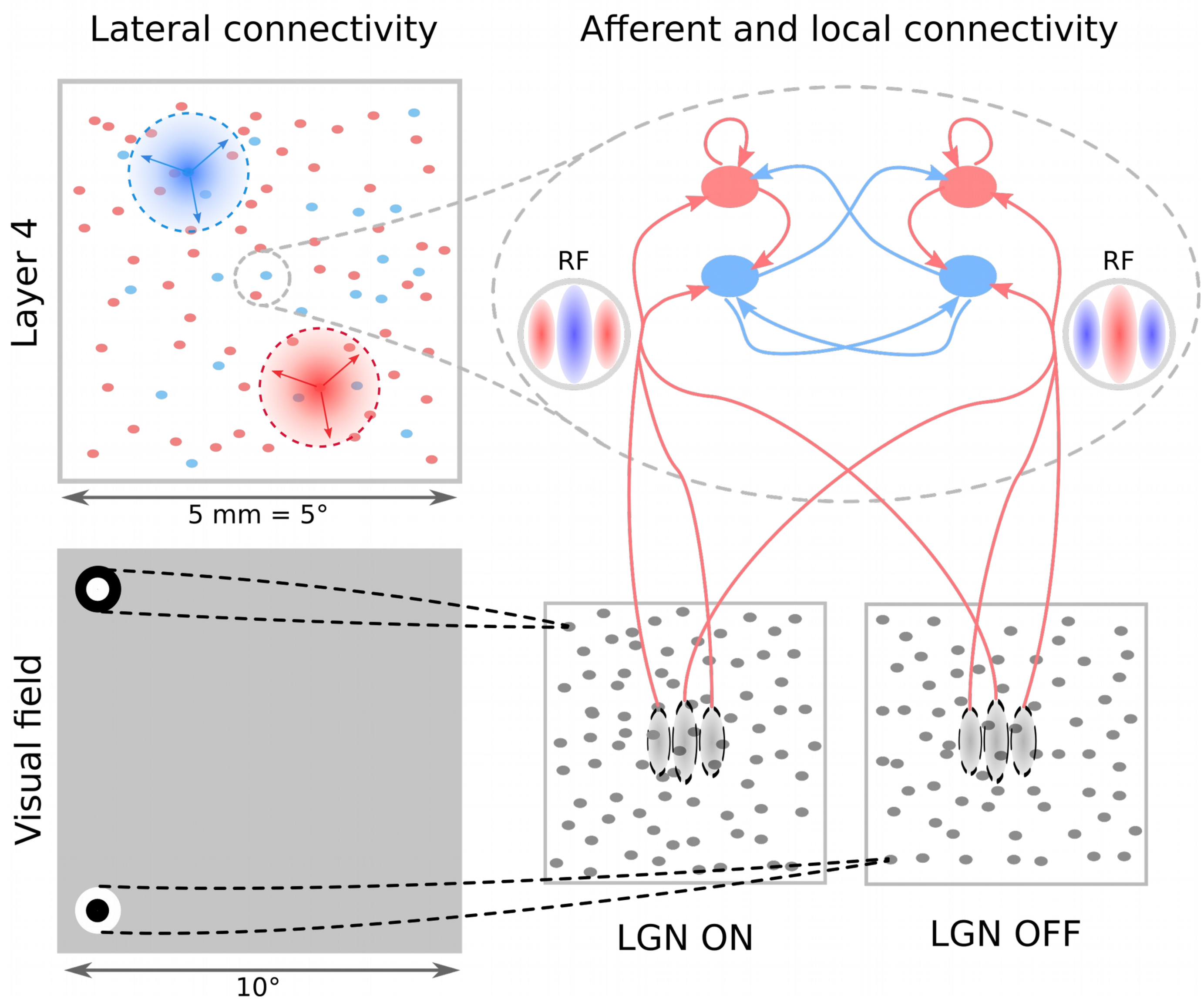

Lateral connectivity
Afferent and local connectivity
Layer 4
RF
RF
5 mm = 5°
Visual field
10°
LGN ON
LGN OFF



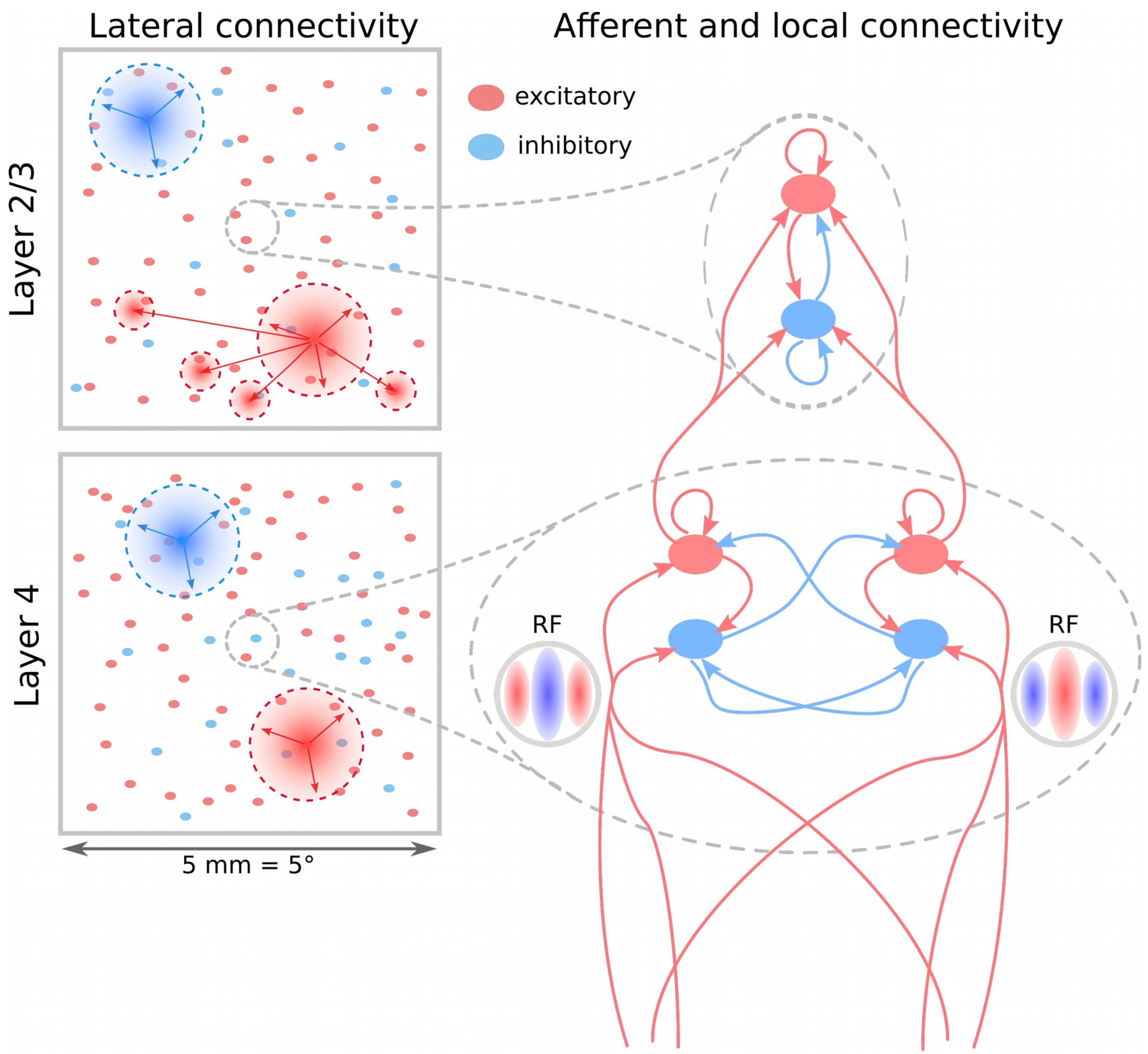
Lateral connectivity
Afferent and local connectivity
Layer 4
RF
RF
5 mm = 5°
Visual field
LGN ON
LGN OFF
10°



Lateral connectivity
Afferent and local connectivity
Layer 4
RF
RF
5 mm = 5°
Visual field
LGN ON
LGN OFF
10°



Lateral connectivity
Afferent and local connectivity
Layer 4
RF
RF
5 mm = 5°
Visual field
LGN ON
LGN OFF
10°



Lateral connectivity
Afferent and local connectivity
excitatory
inhibitory
Layer 2/3
Layer 4
5 mm = 5°
RF
RF

THE MODEL (neuron model)

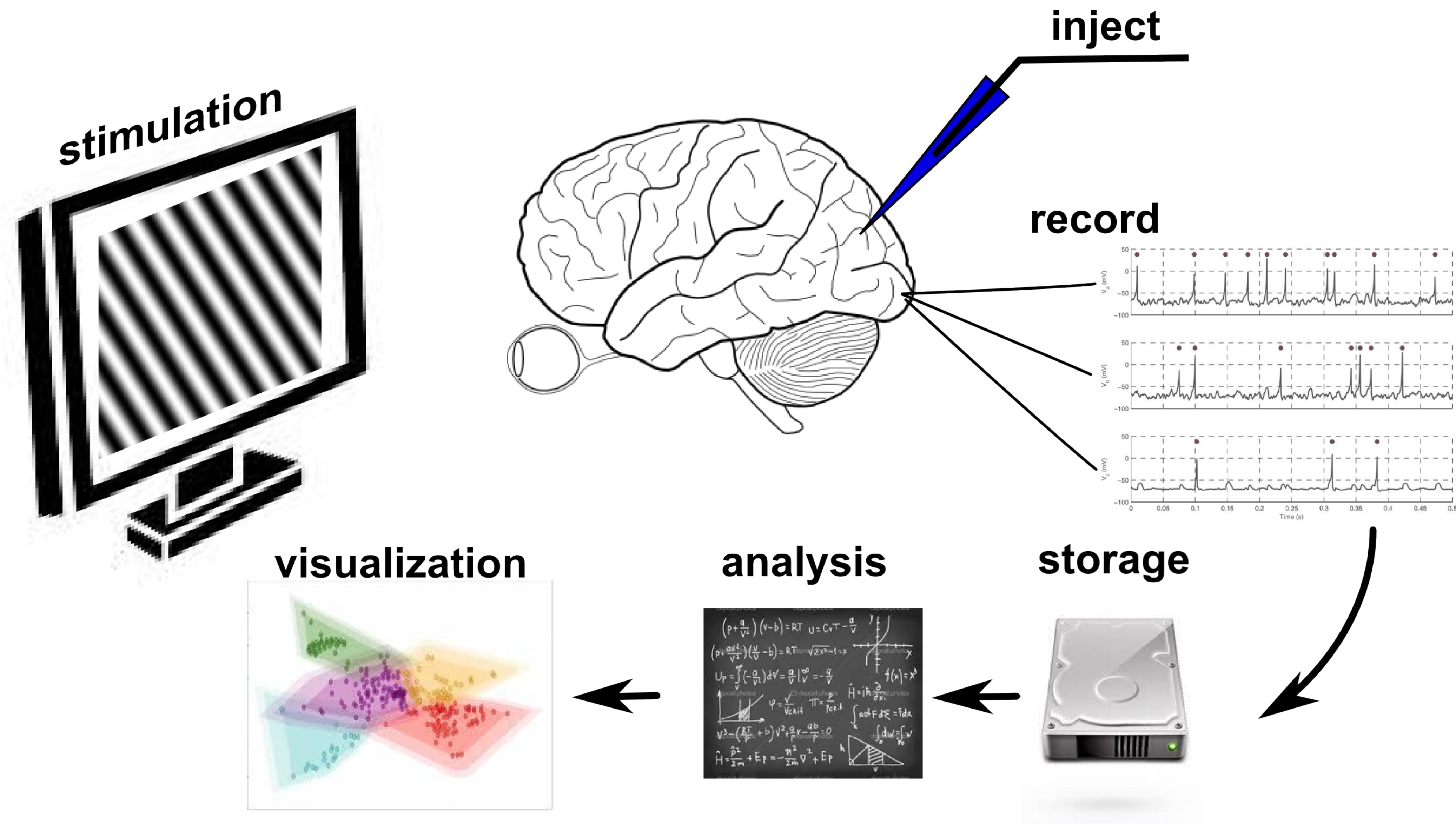
- 4:1 exc:inh ratio, $\sim 10^4$-10^5 neurons
- Adaptive exponential integrate and fire model

$$C\frac{dV}{dt} = -g_L(V - E_L) + g_L\Delta_T \exp(\frac{V - V_T}{\Delta_T}) - w + I \qquad (1)$$

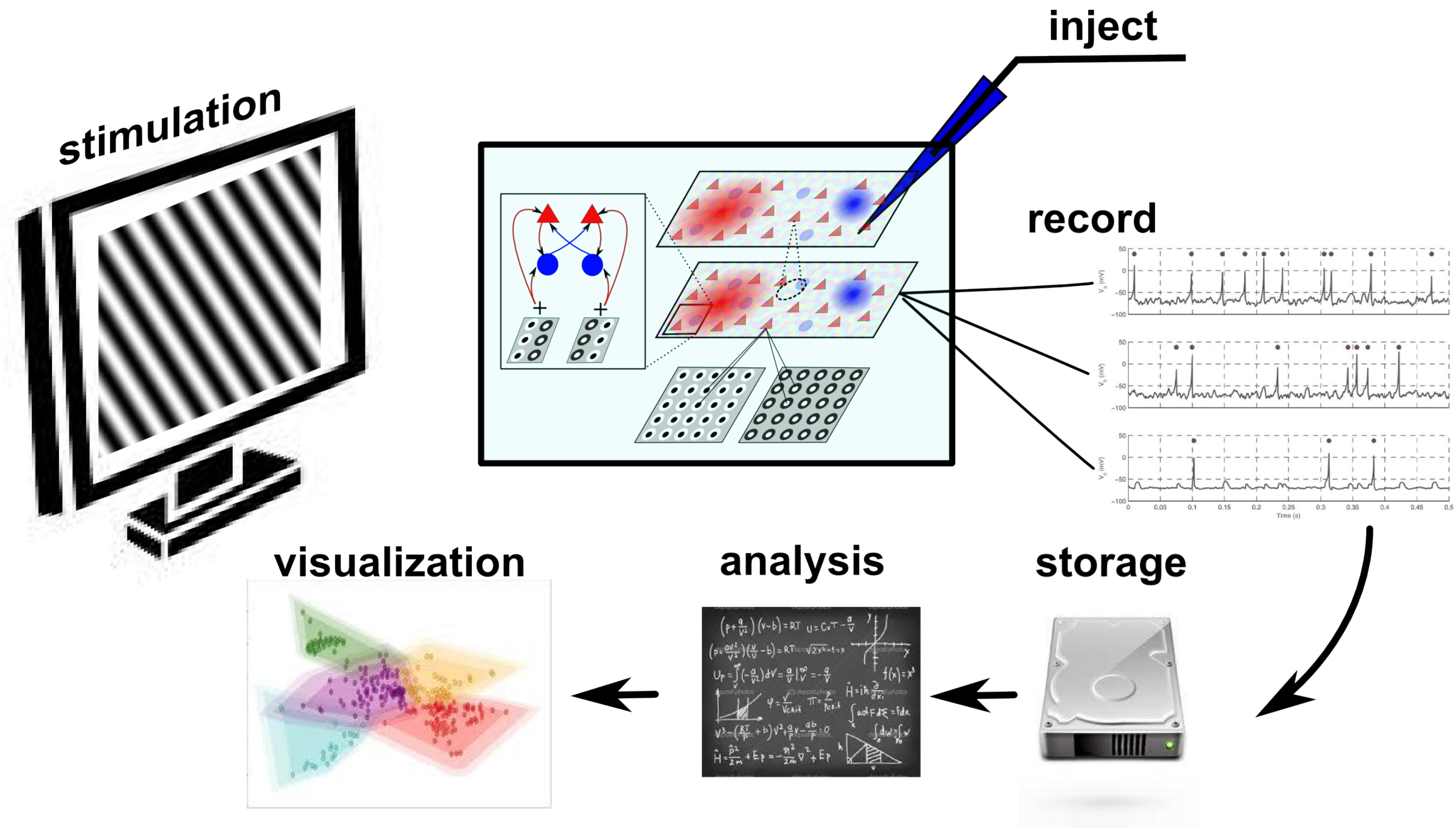
$$\tau_w \frac{dw}{dt} = a(V - E_L) - w \qquad (2)$$

- Parameters *a* and *b* were uniformly randomly distributed within physiological boundaries
- Exponential synapses
- Synaptic depression

Experimental setup



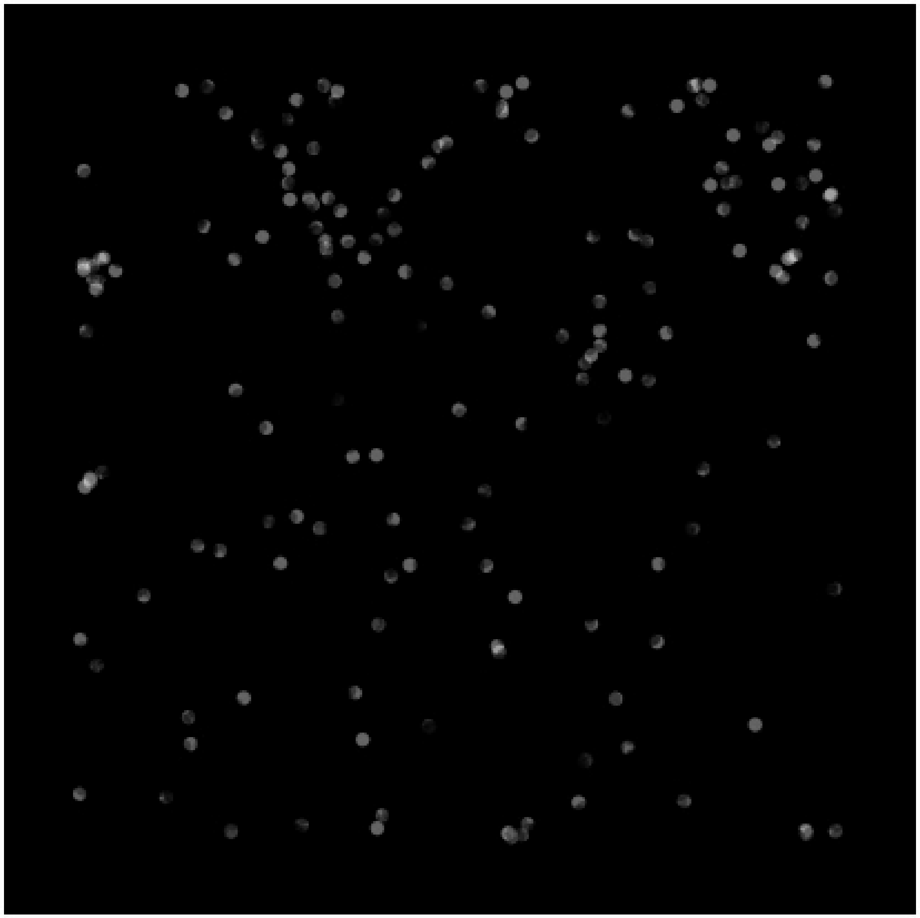
Experimental setup



RESULTS

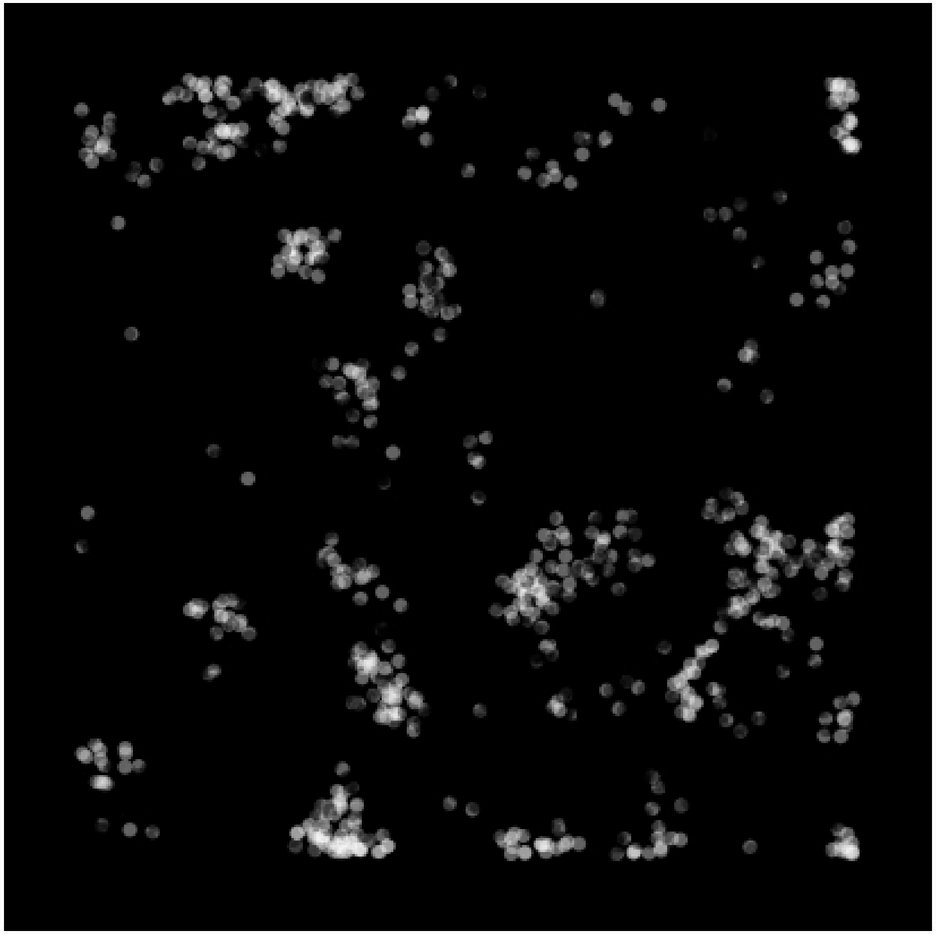
Spontaneous activity

LAYER 4

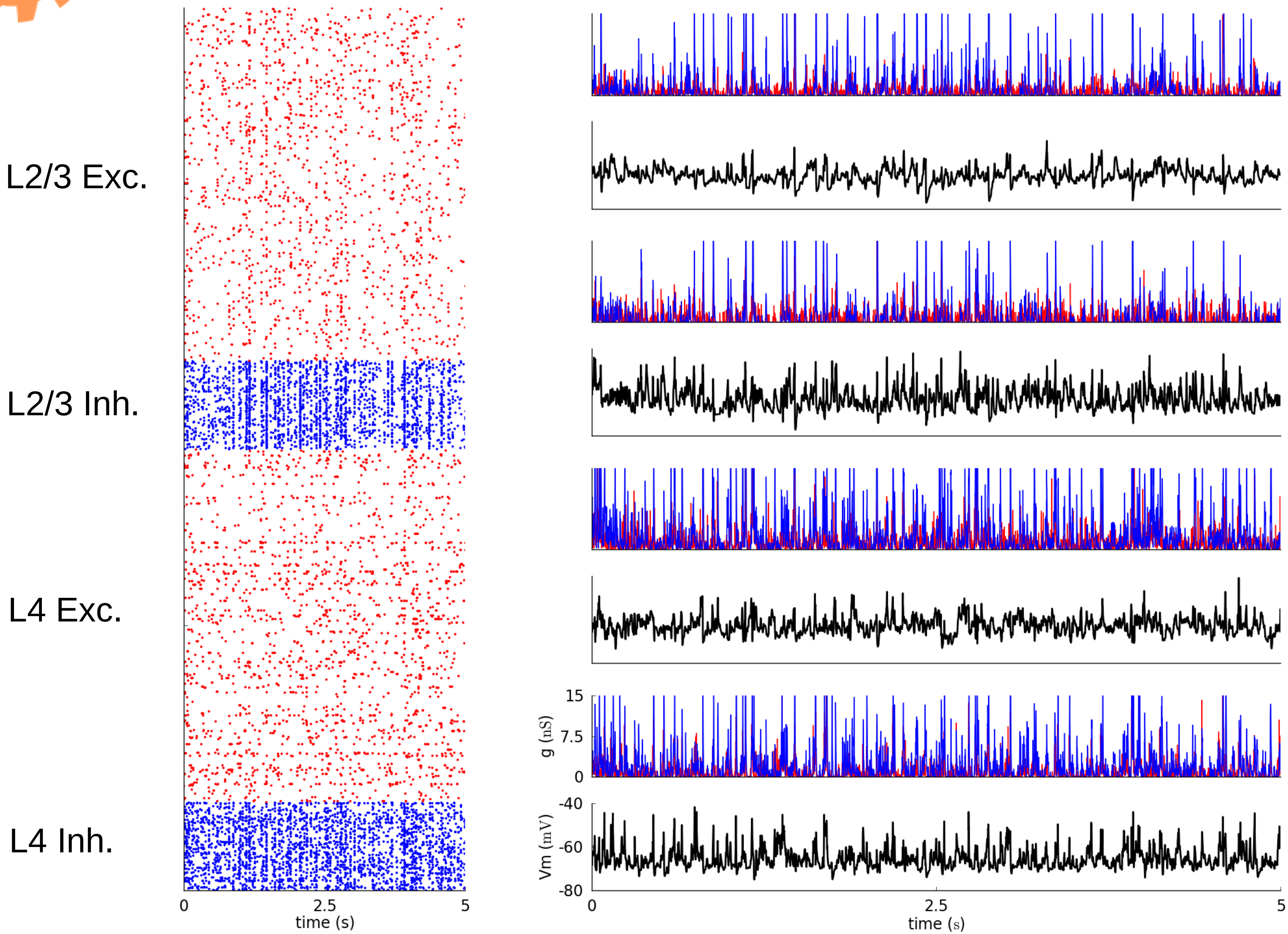


Spontaneous activity

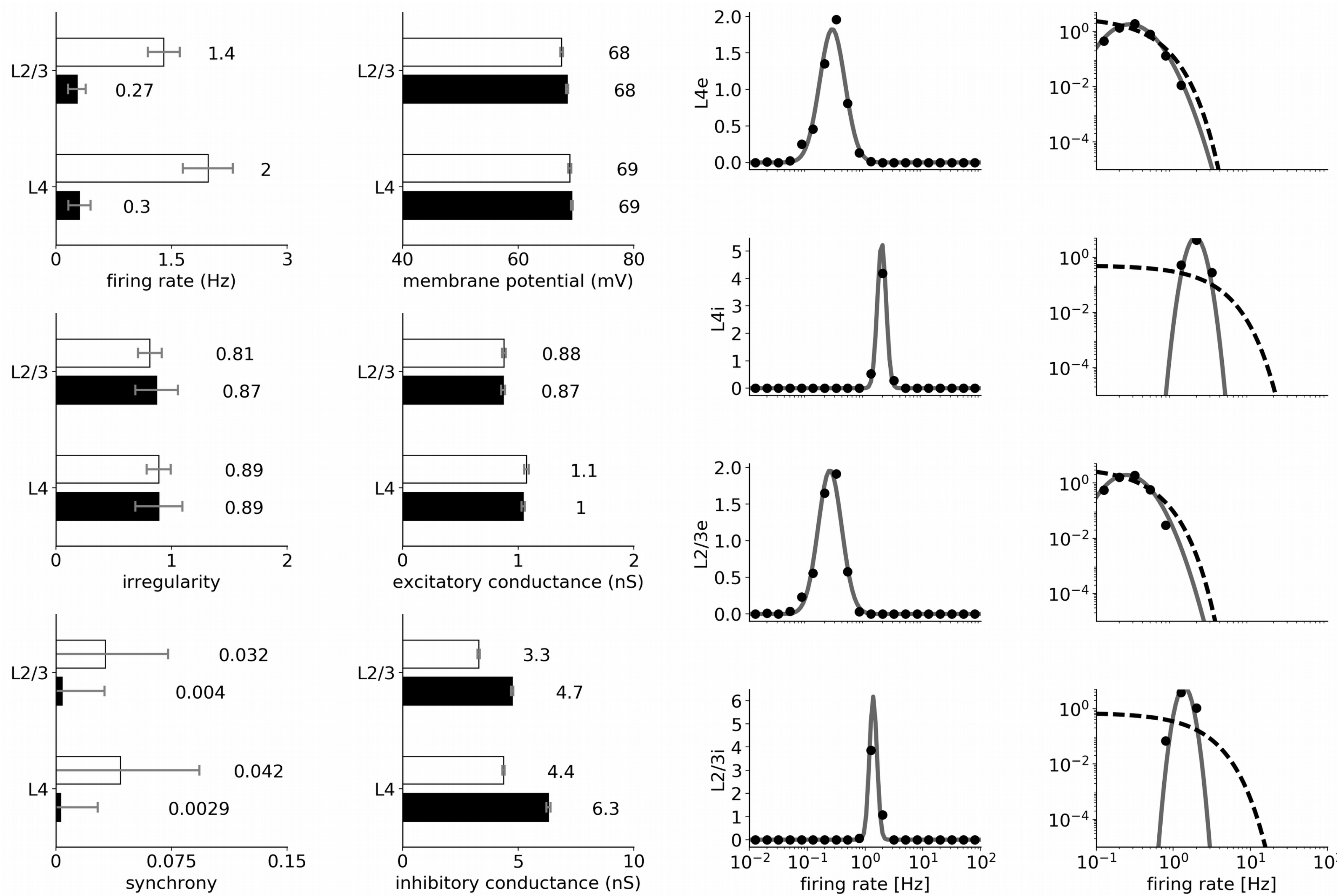
LAYER 2/3



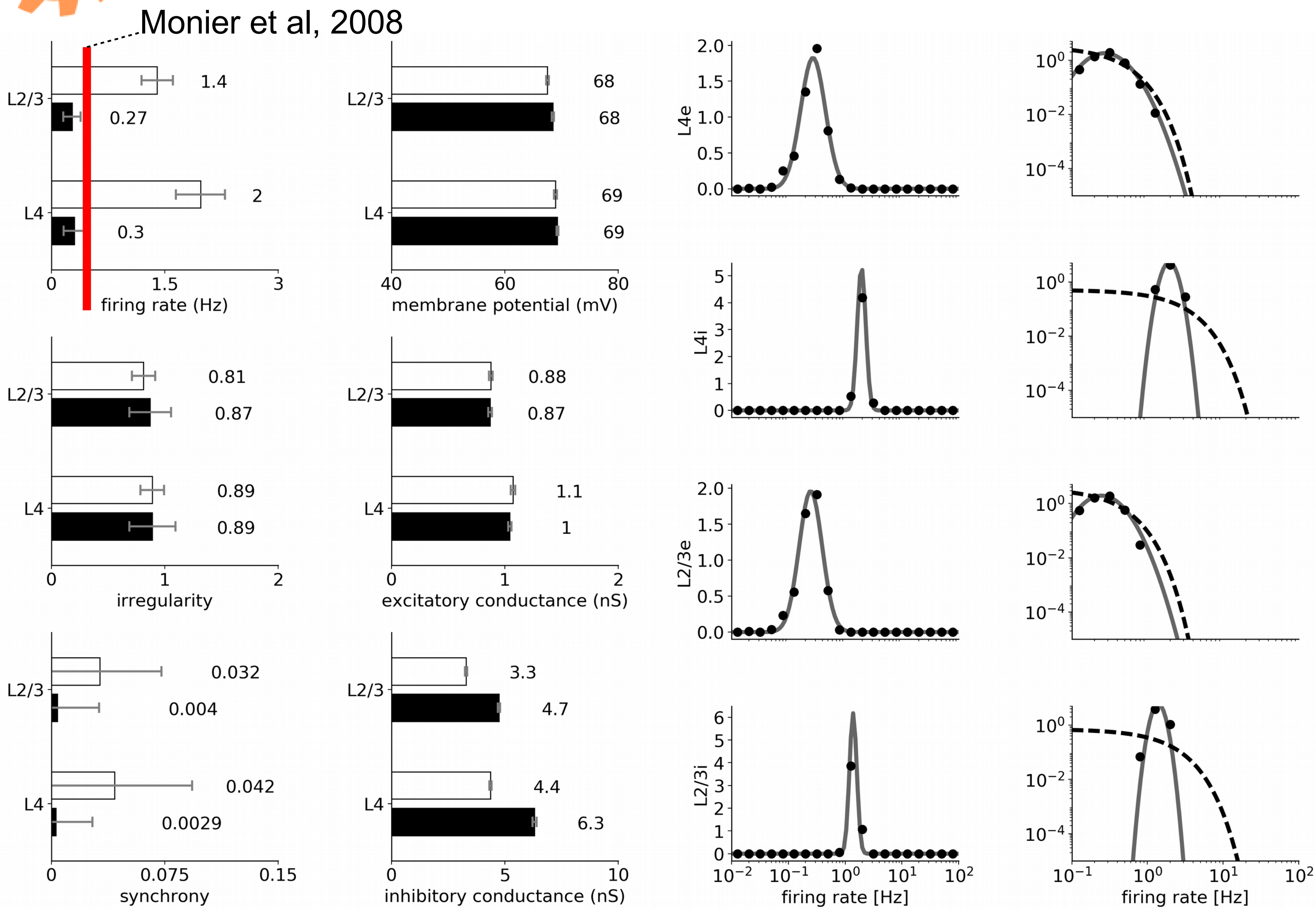
Spontaneous activity



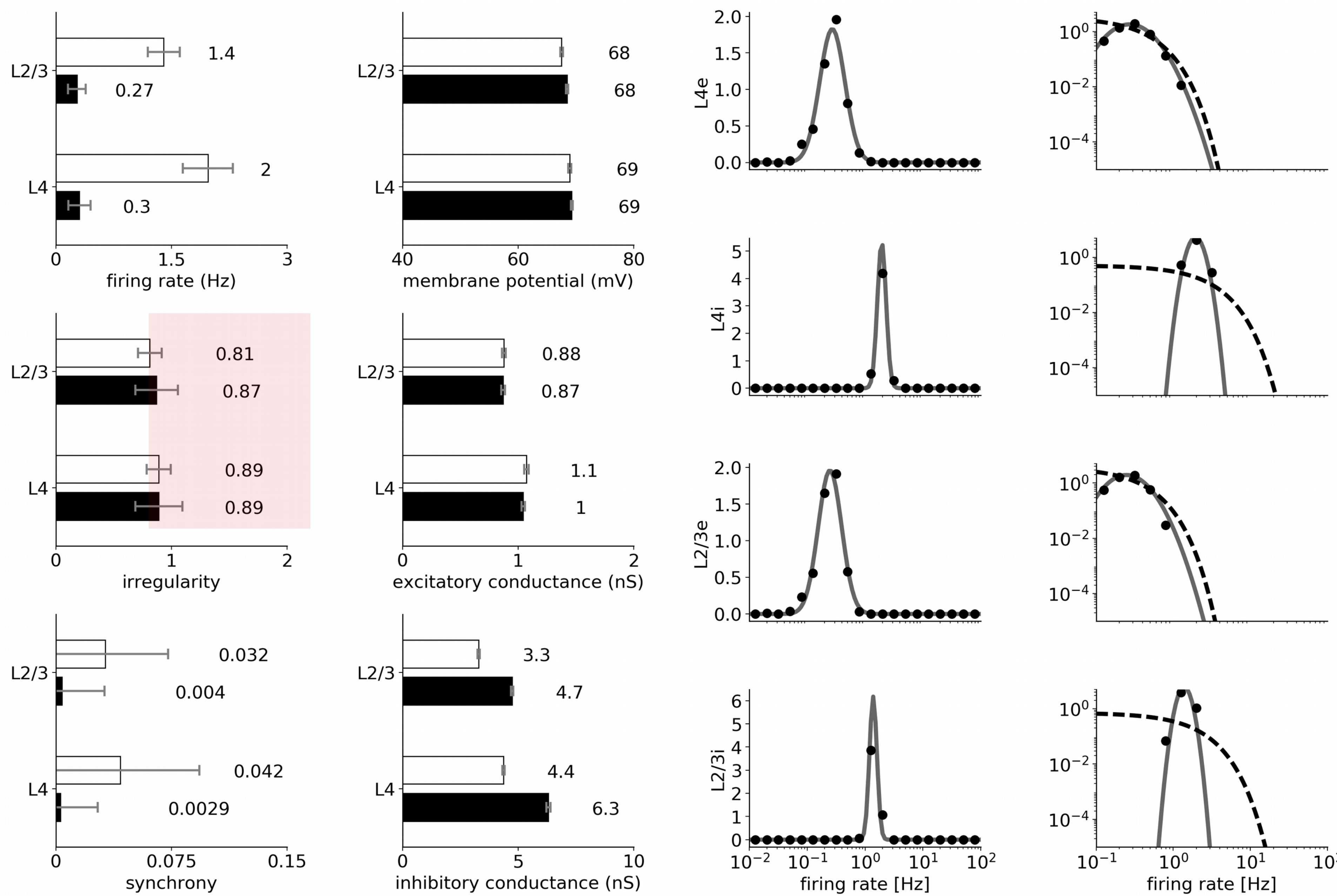
SA: statistics



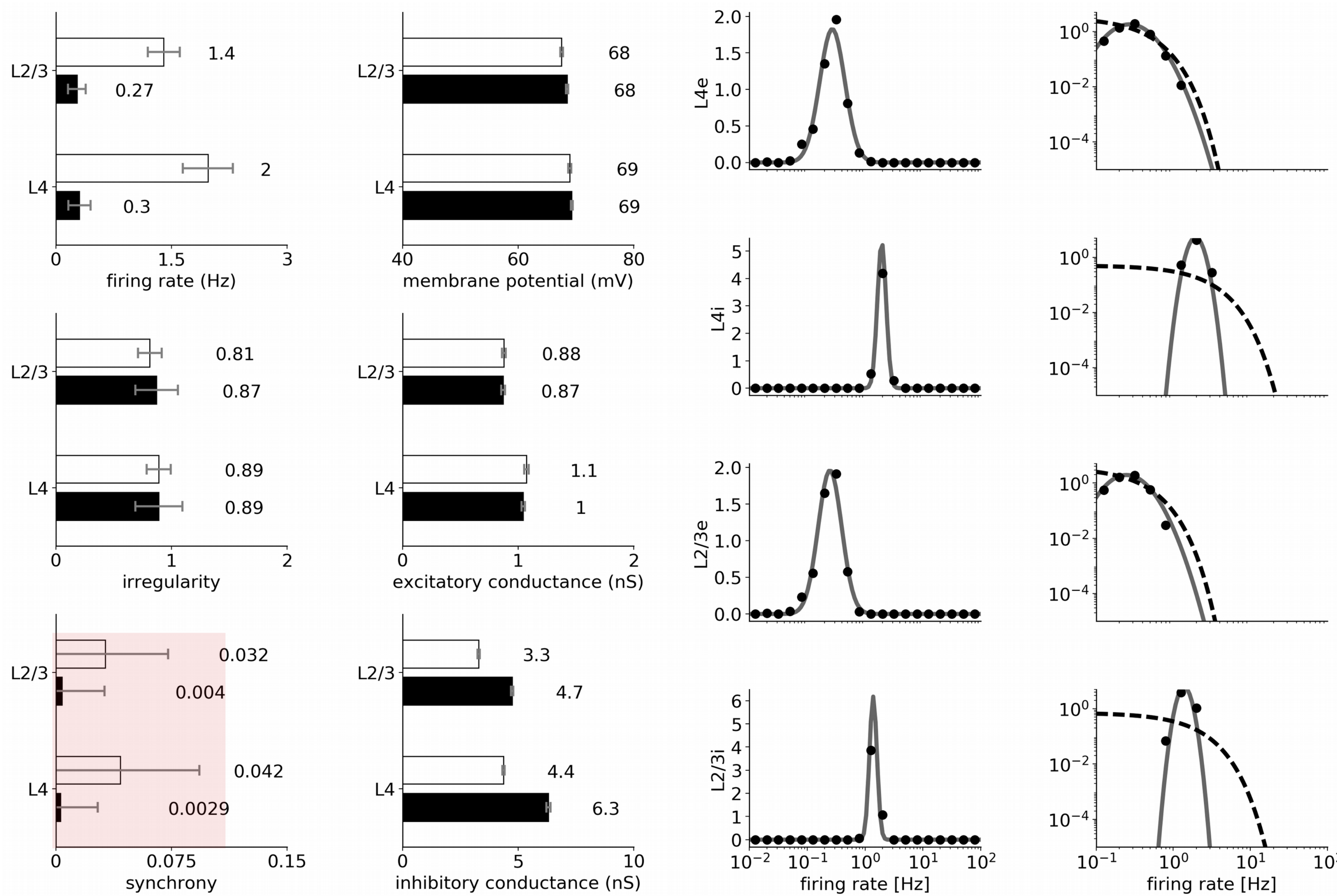
SA: mean firing rate



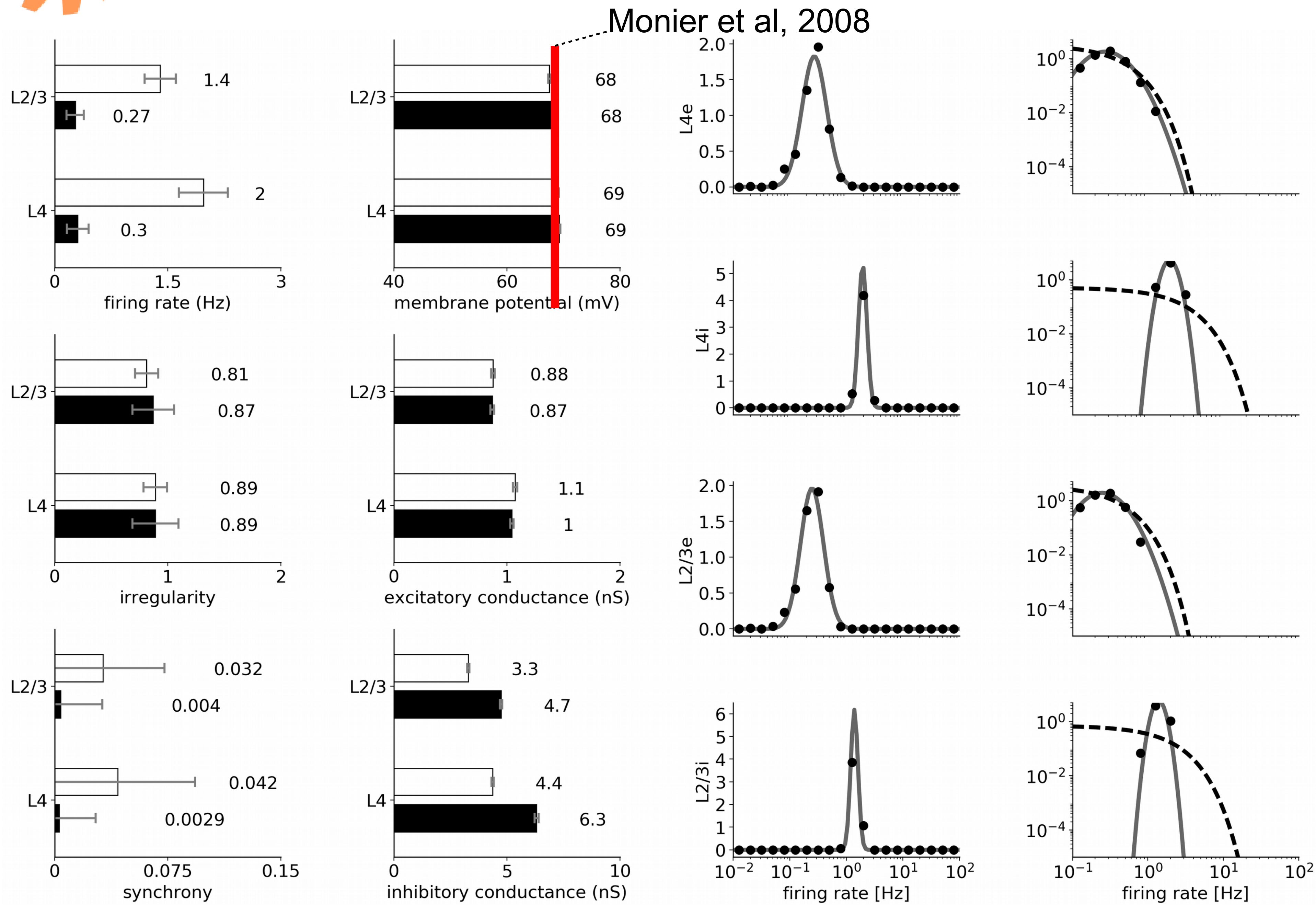
SA: irregularity



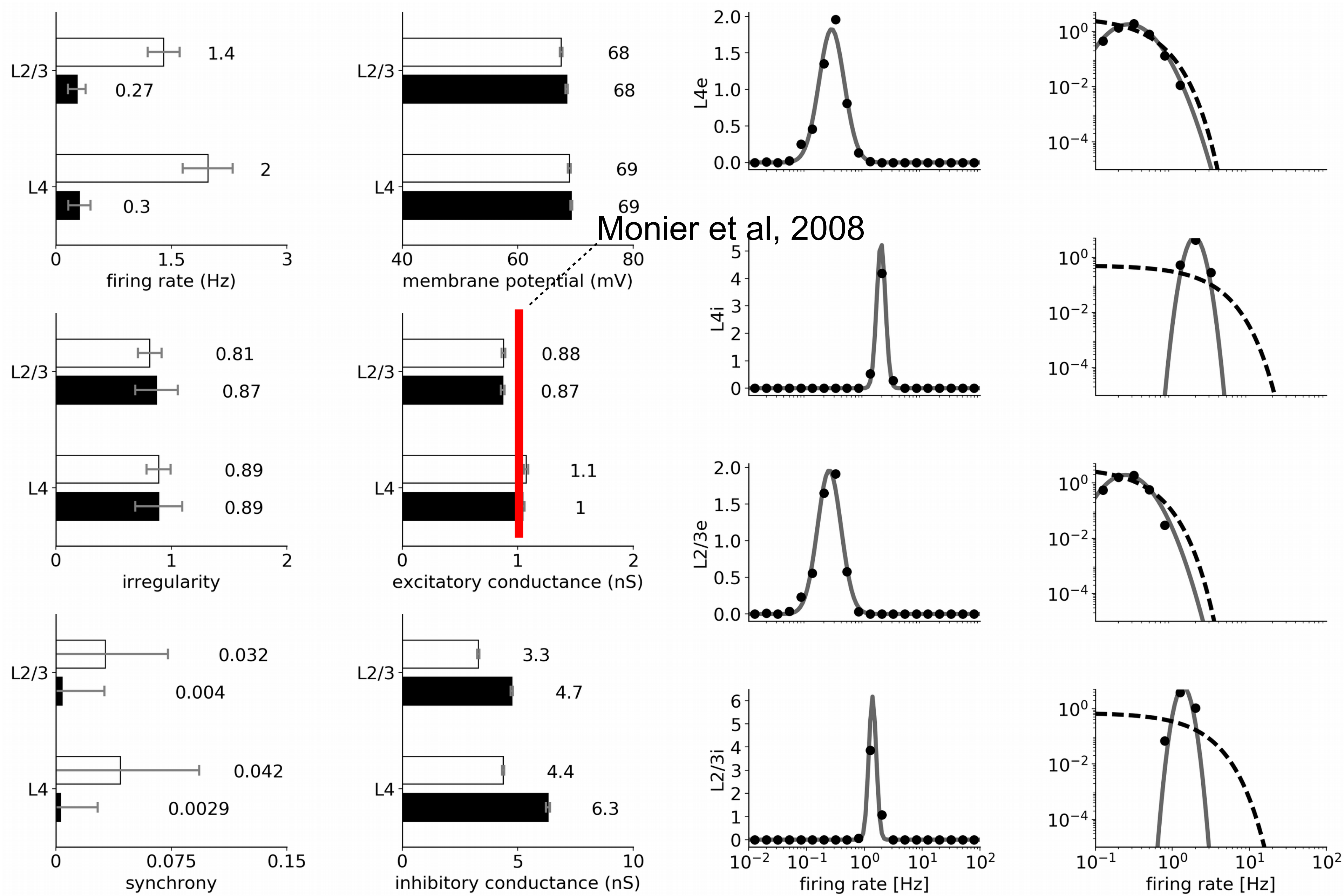
SA: synchrony



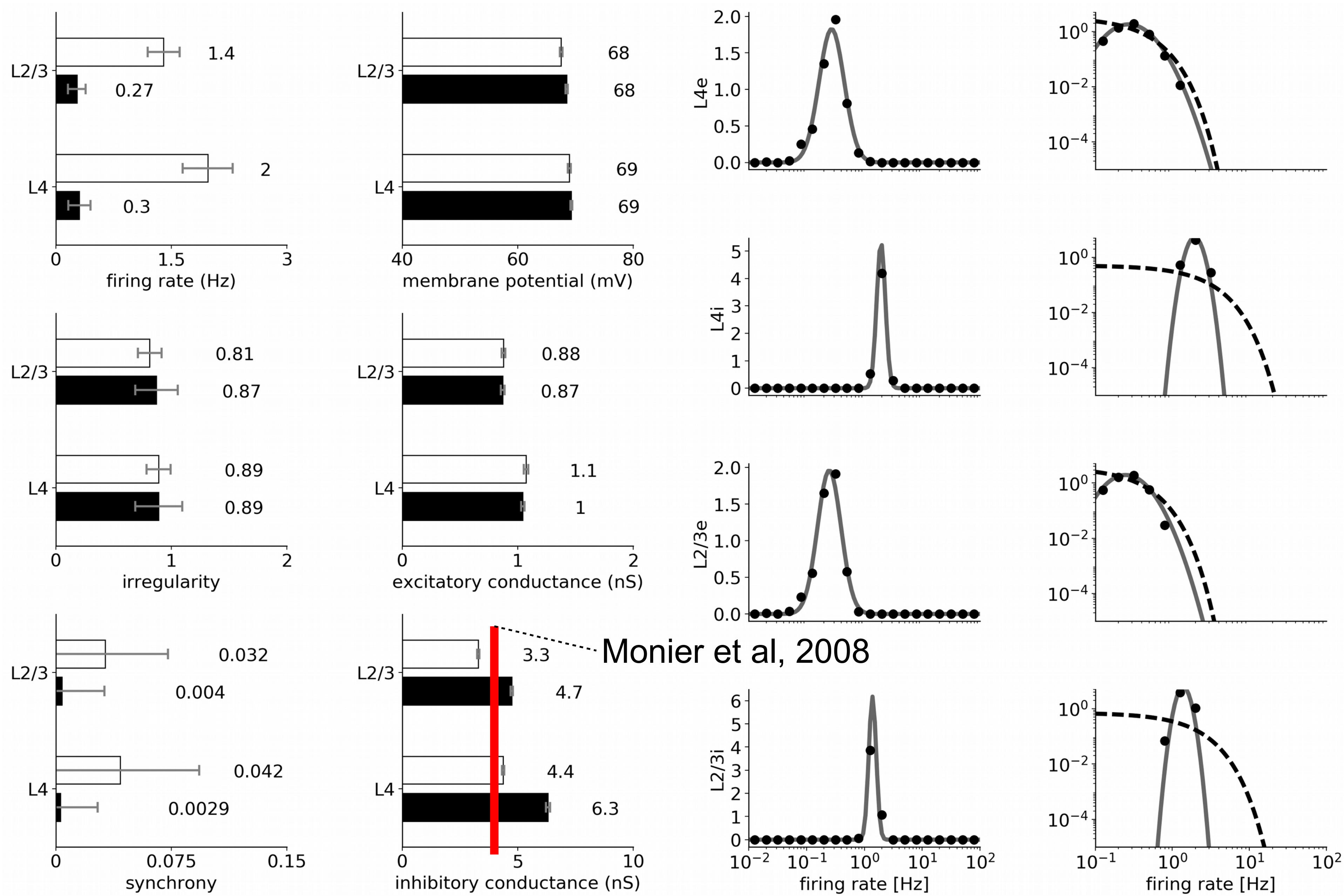
SA: mean firing rate



SA: mean firing rate

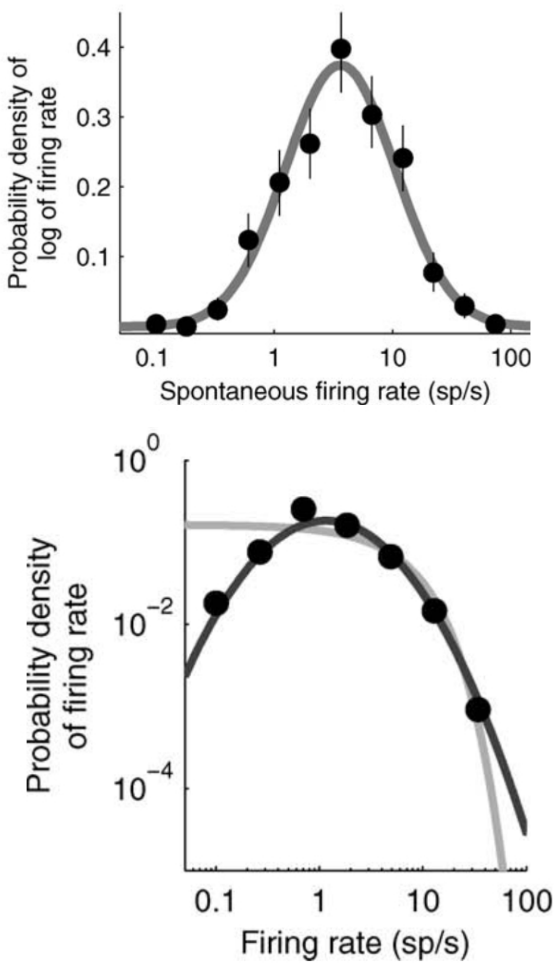


SA: mean firing rate



SA: mean firing rate

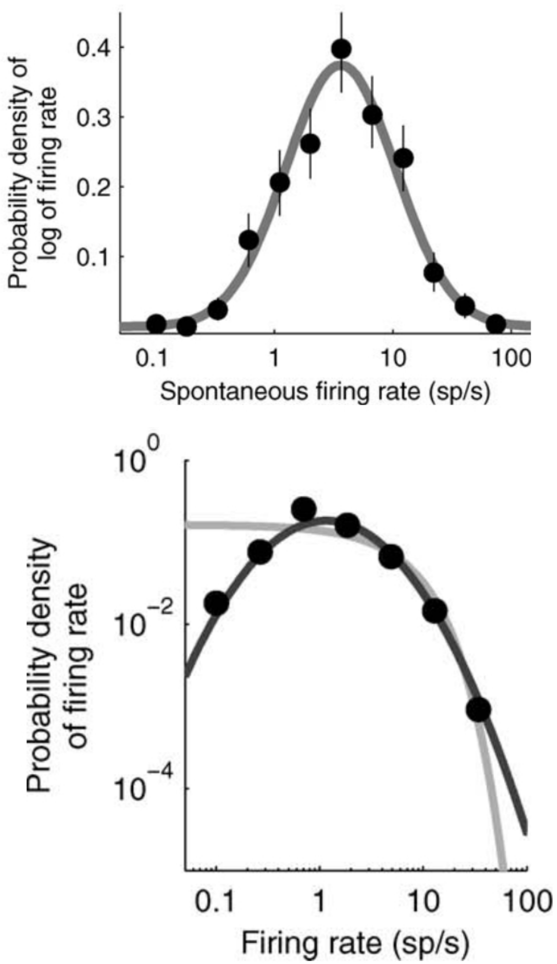
RAT AUDITORY



Hromadka et al., 2008

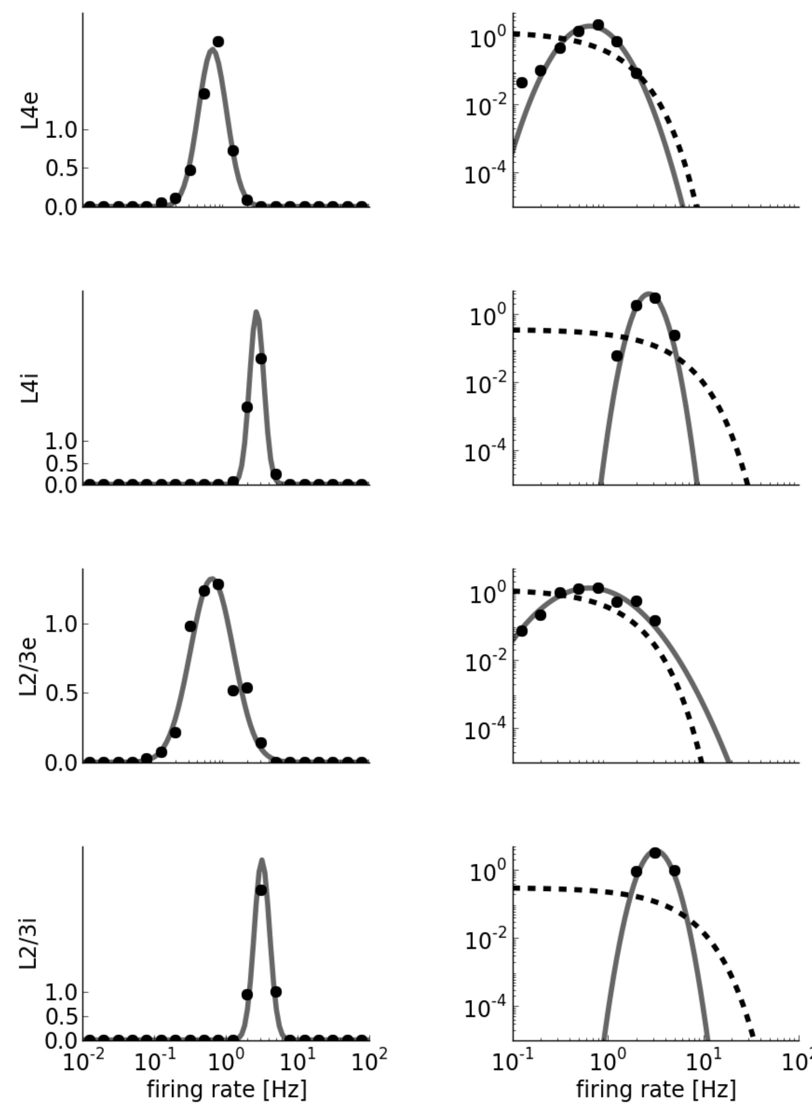
SA: mean firing rate

RAT AUDITORY

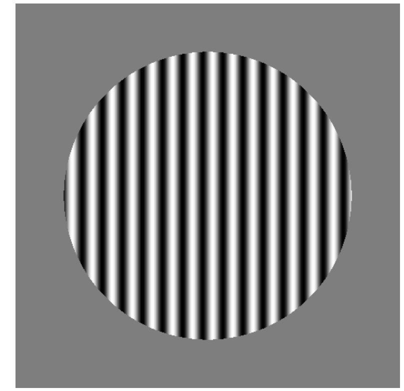


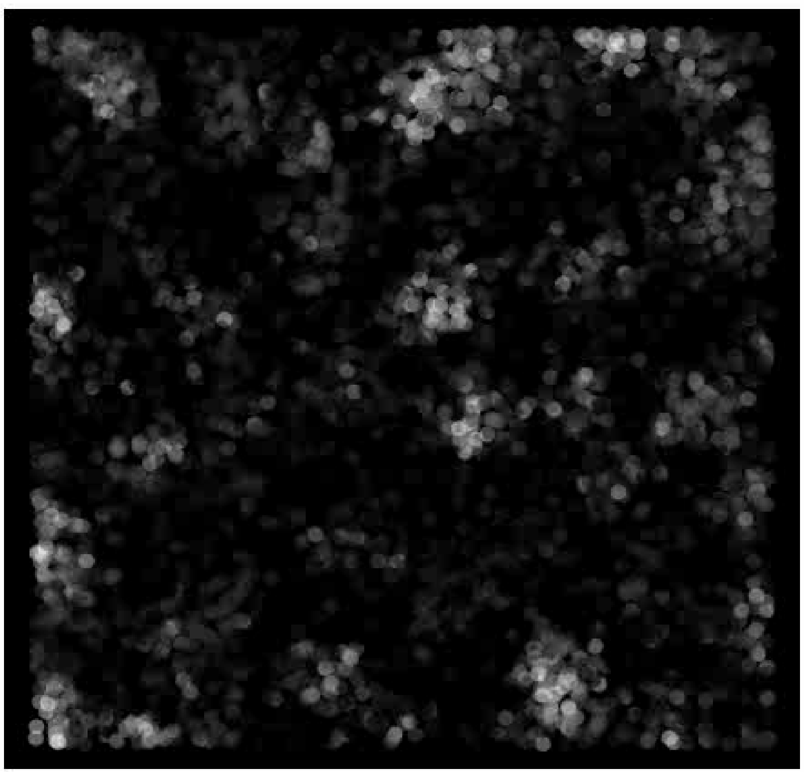
Hromadka et al., 2008

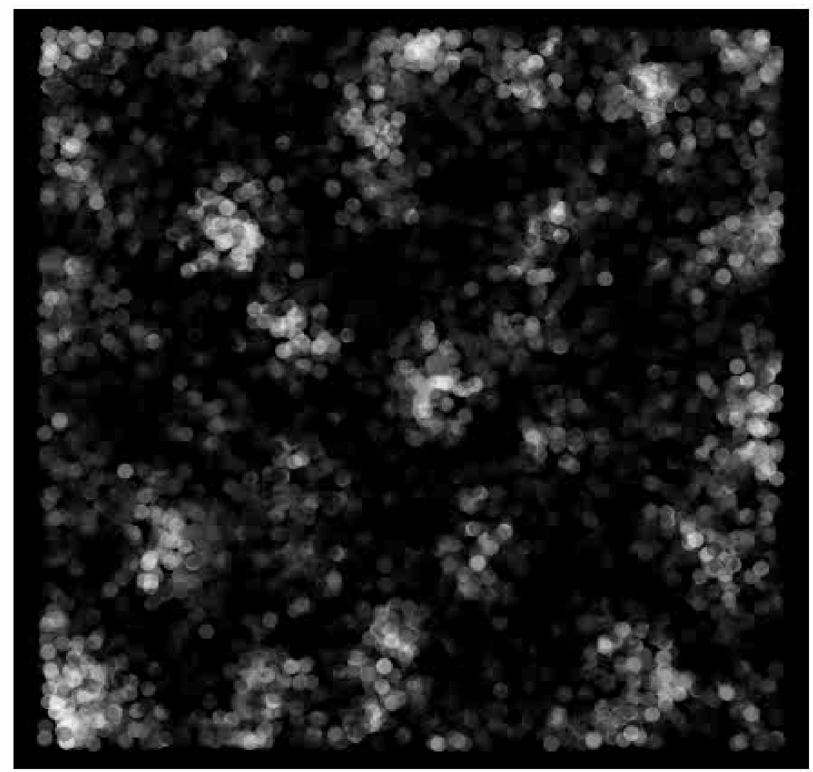
MODEL



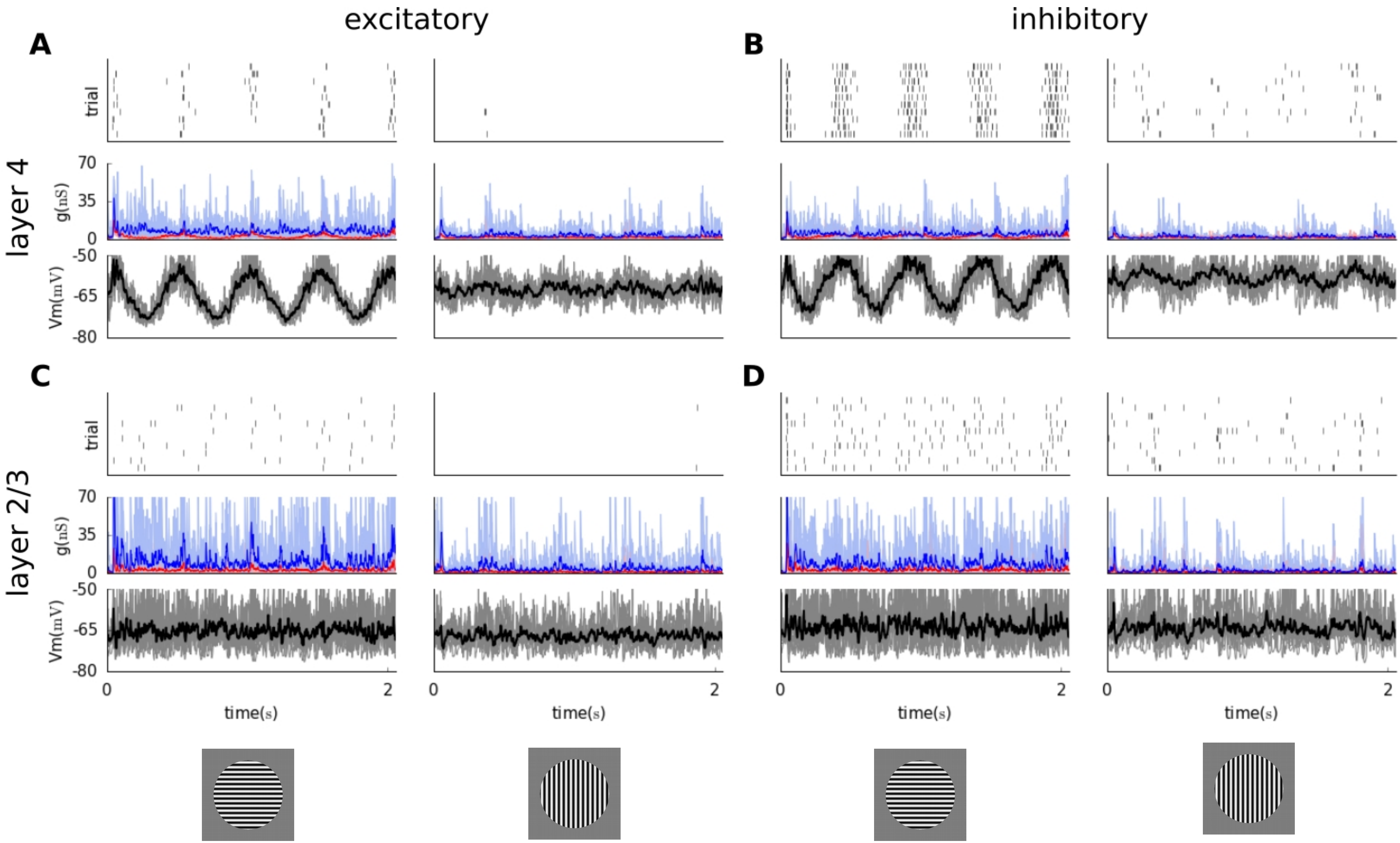
Grating response (L2/3)



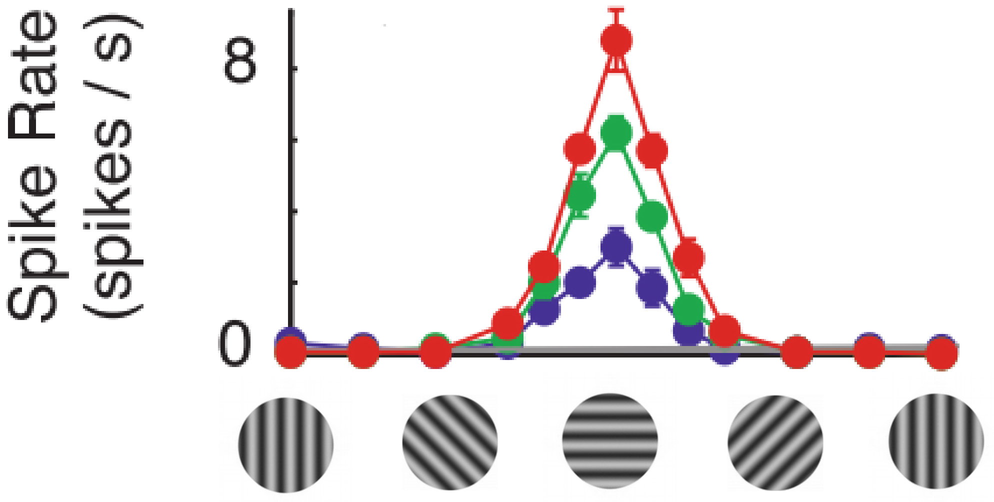




Grating response

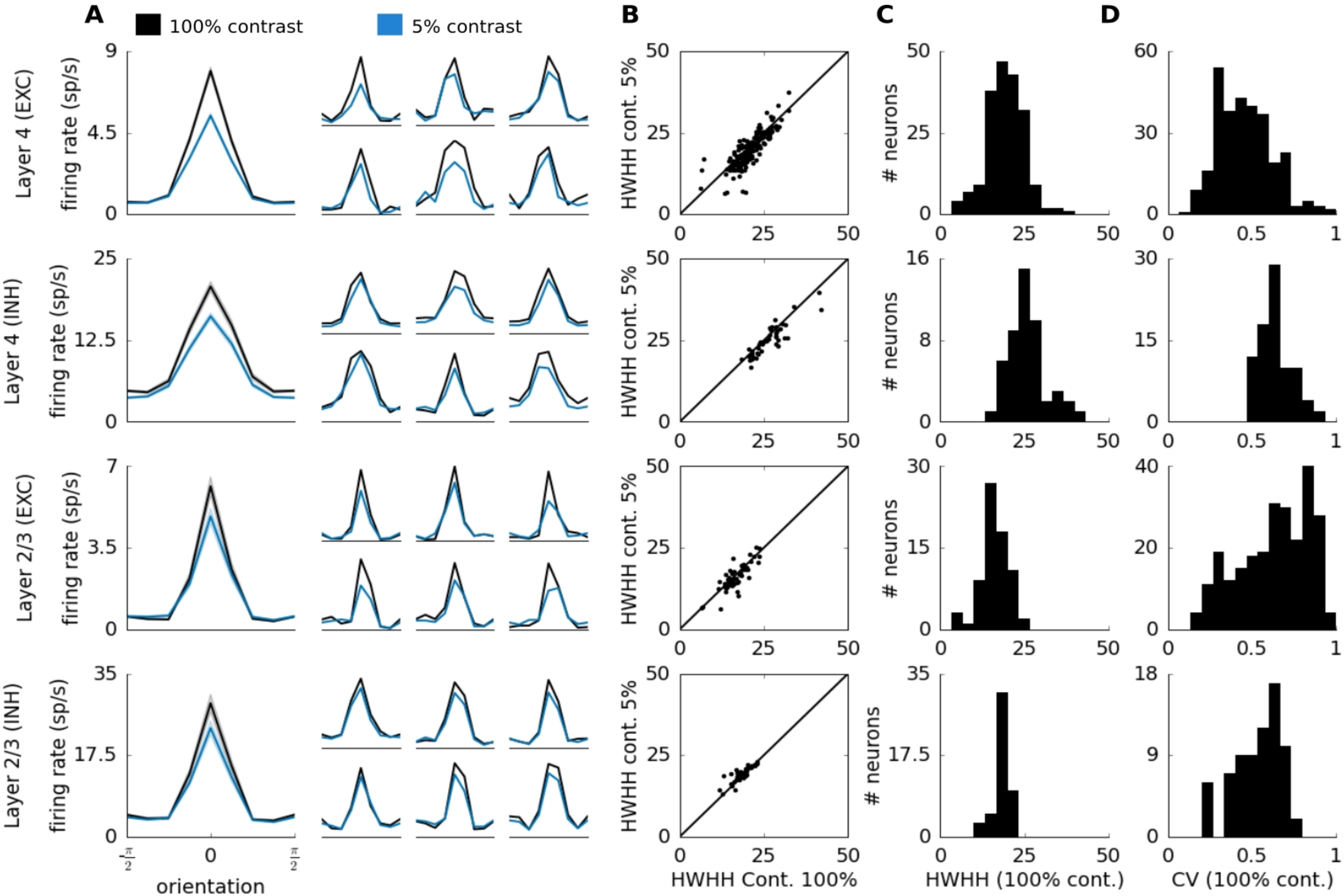


Orientation tuning (DATA)

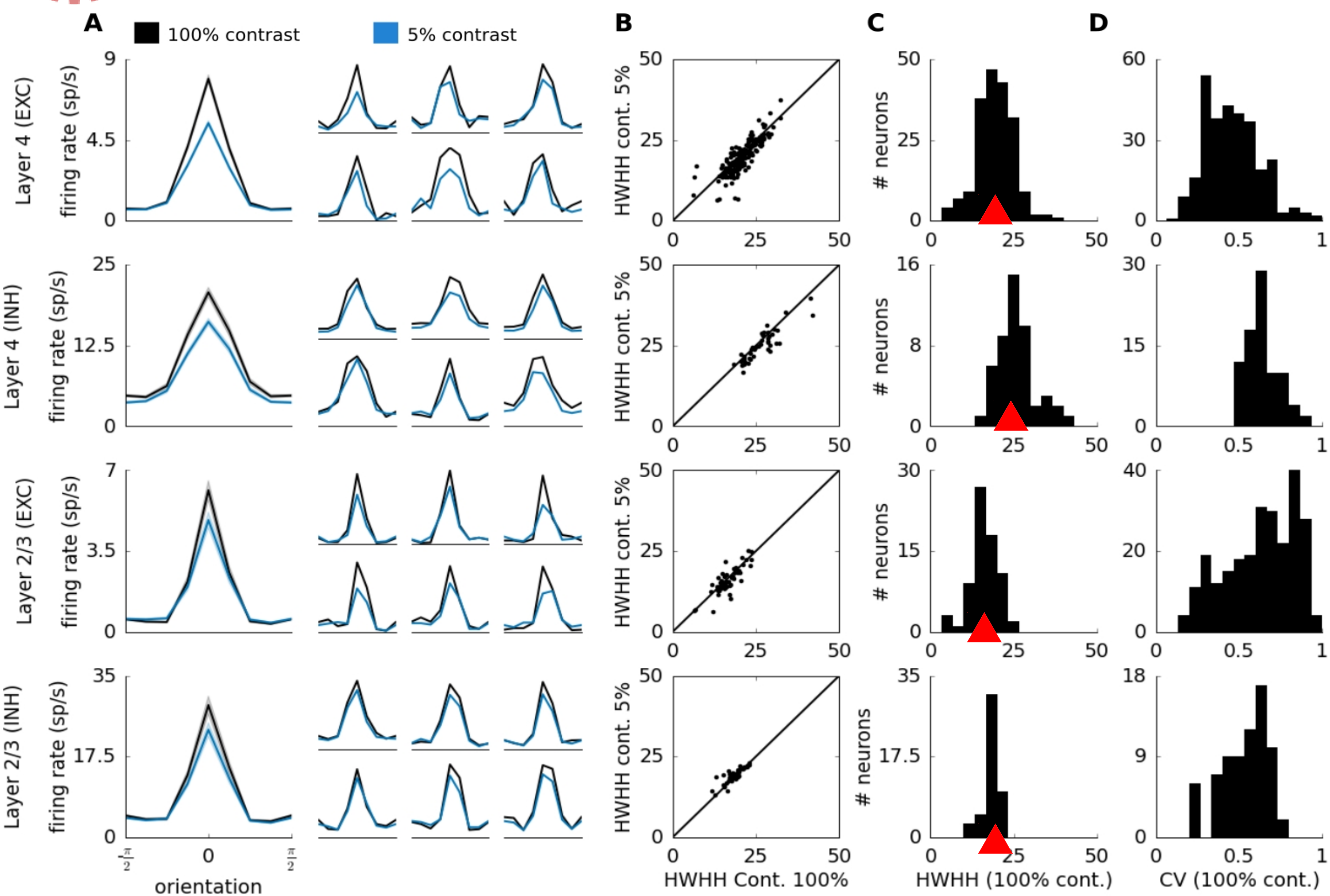


Cat, Anderson et al. (2000)

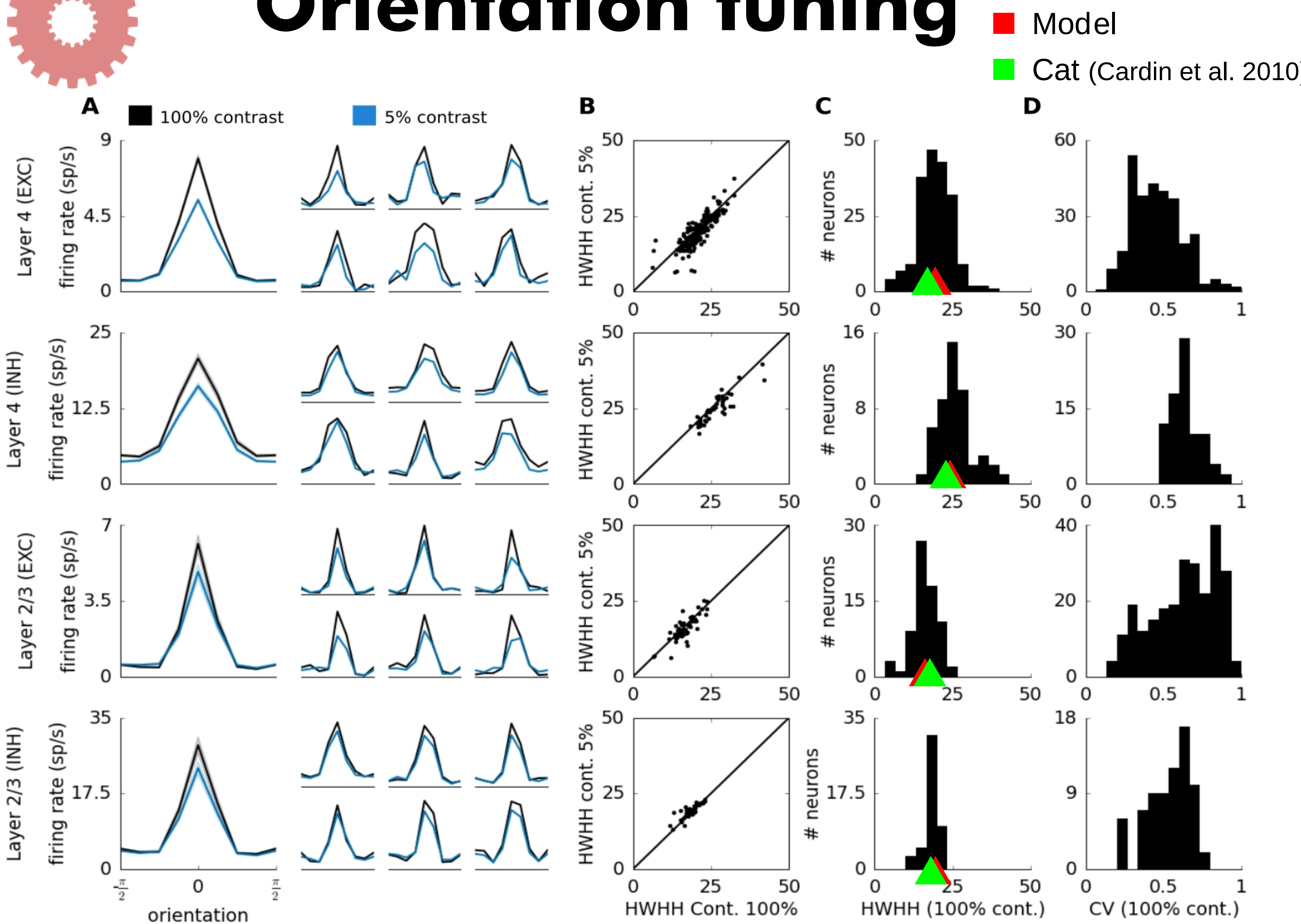
Orientation tuning



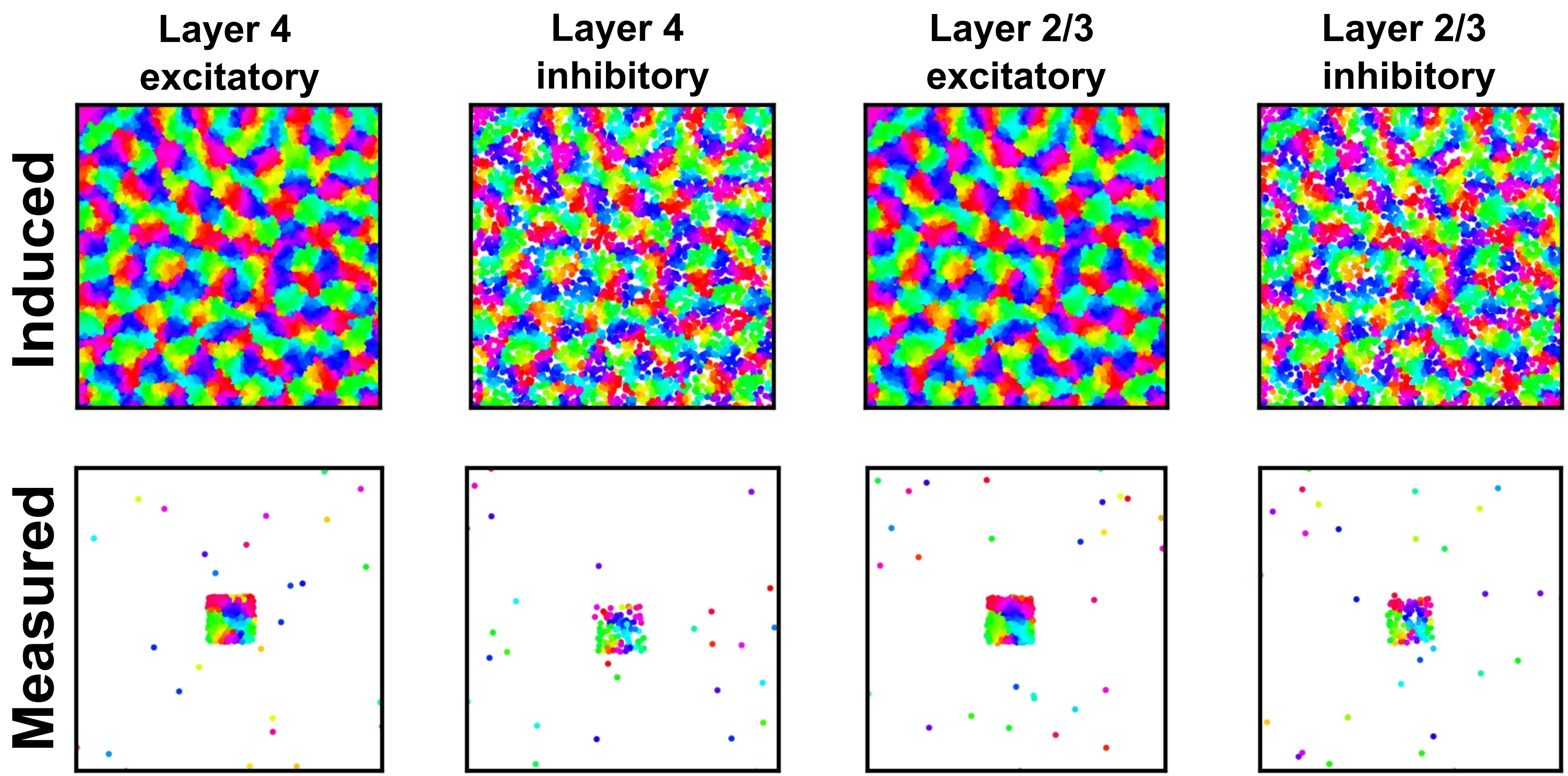
Orientation tuning



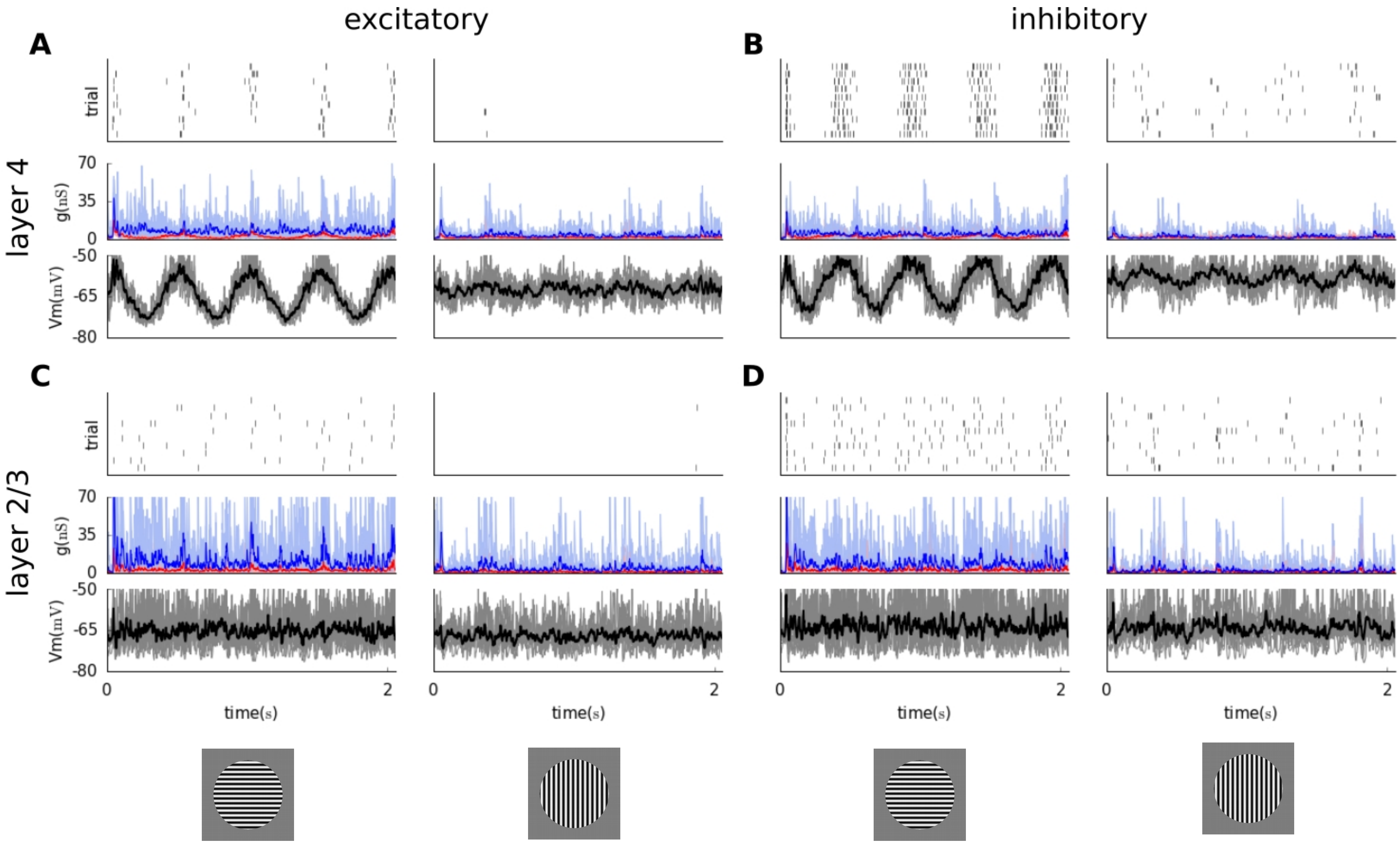
Orientation tuning



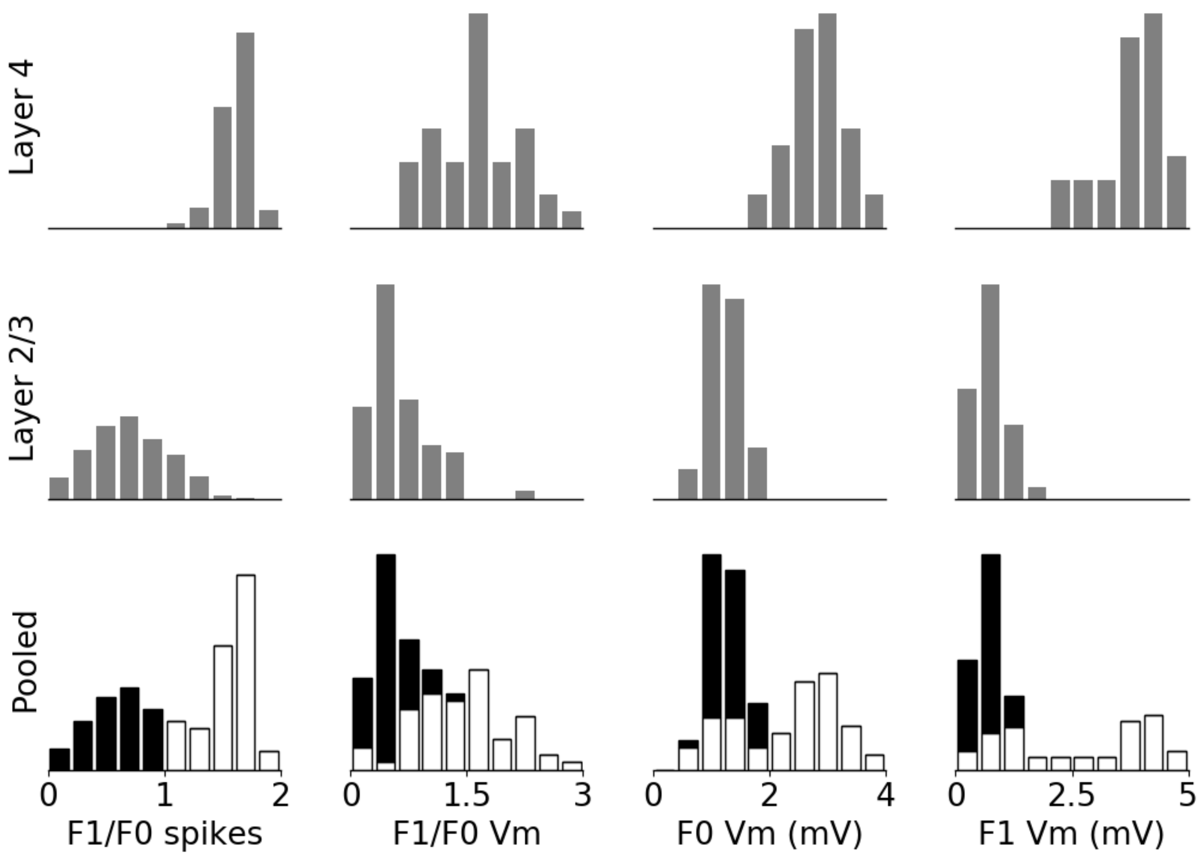
Orientation tuning — cortical view

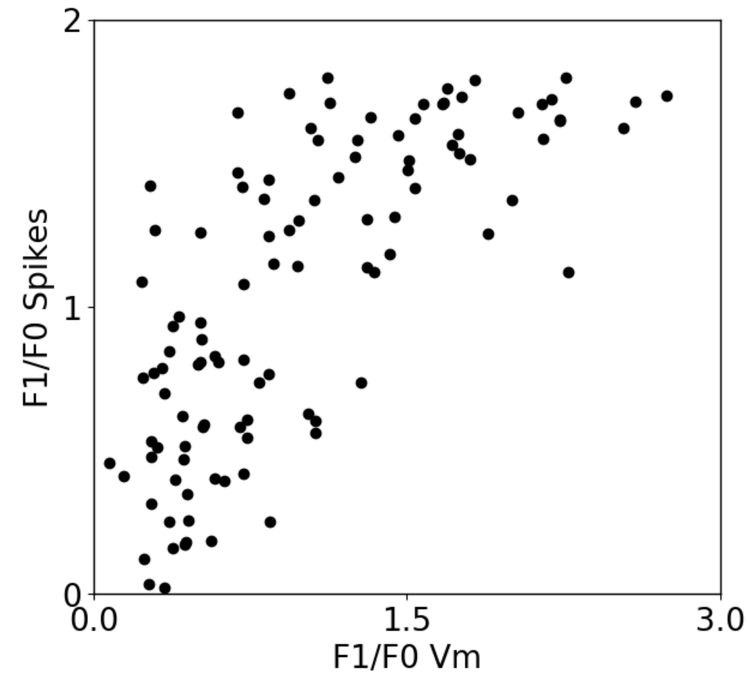


Grating response



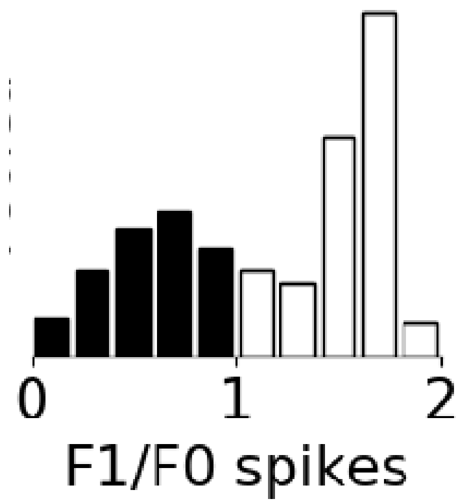
Simple vs. complex cells

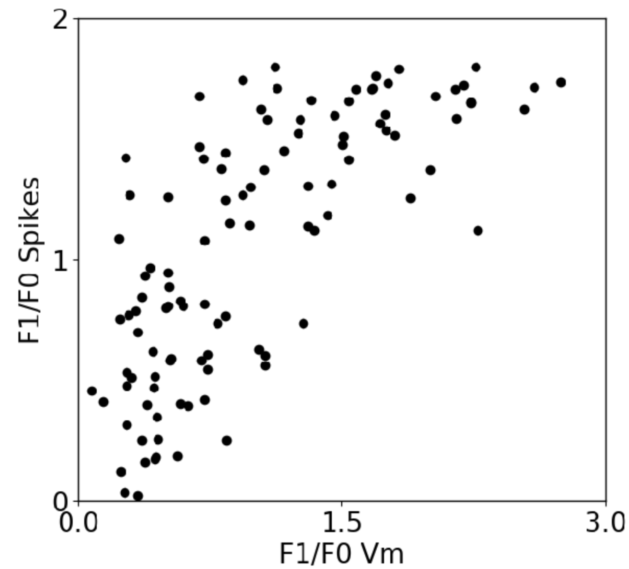




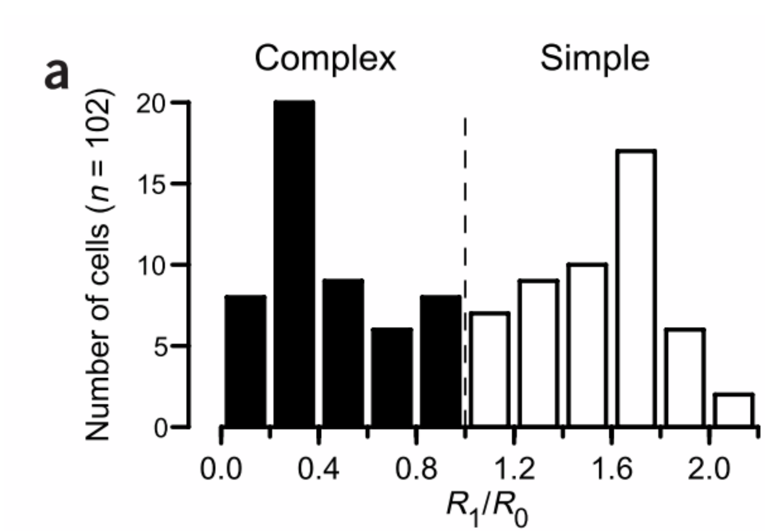
Simple vs. complex cells

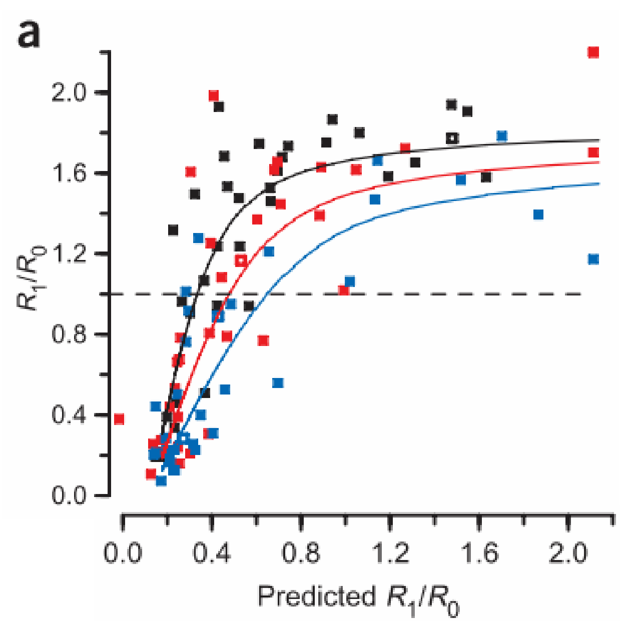
MODEL





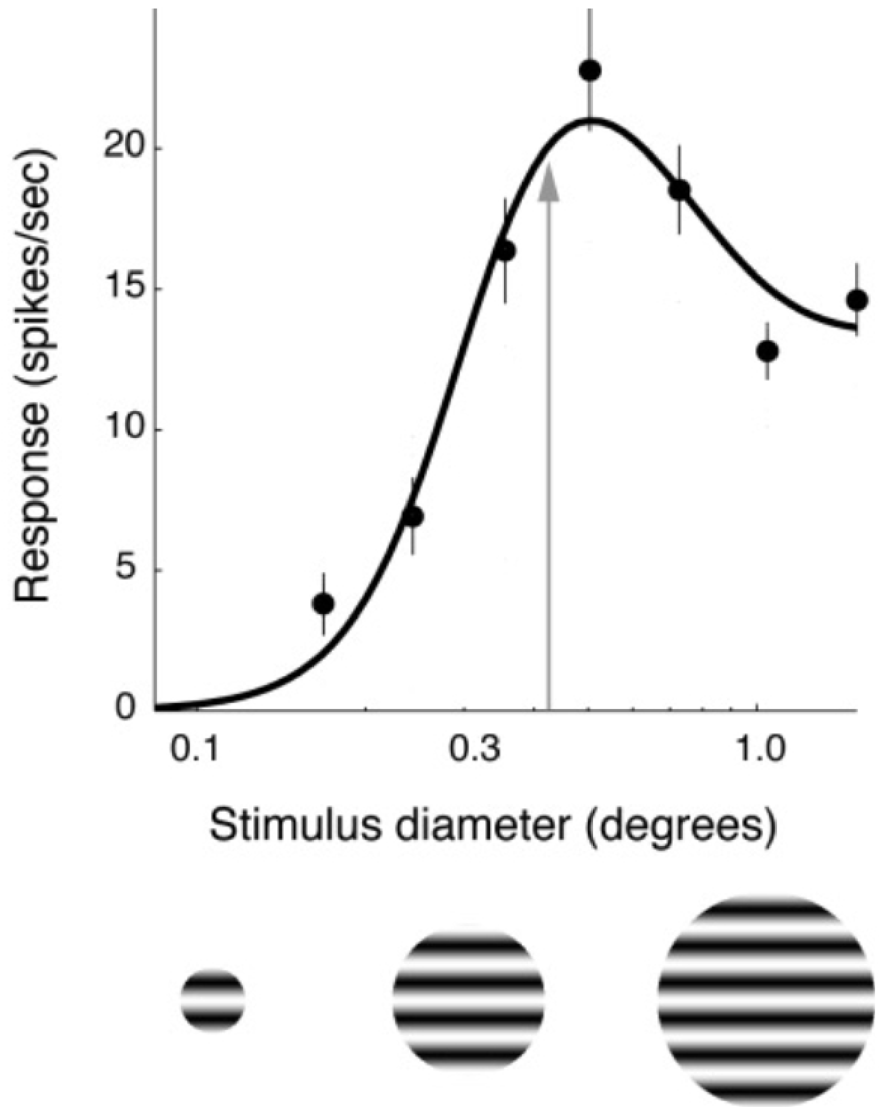
CAT





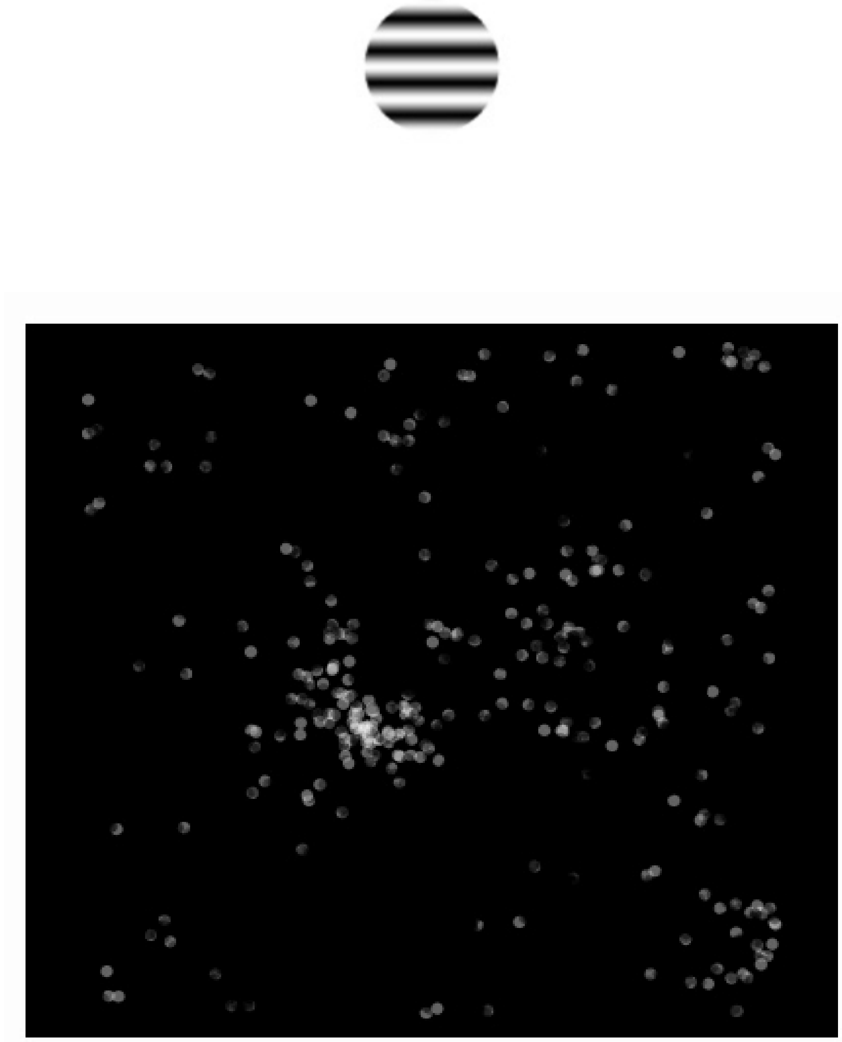
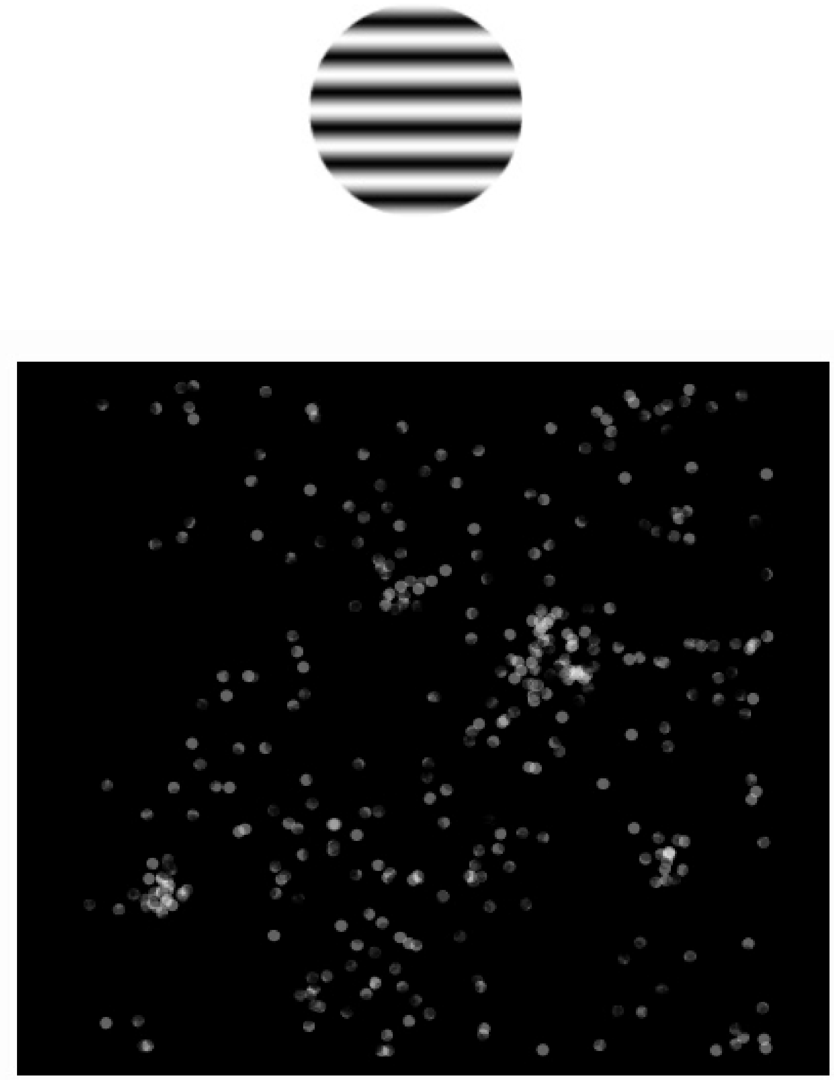
Priebe et al, 2013

Size tuning

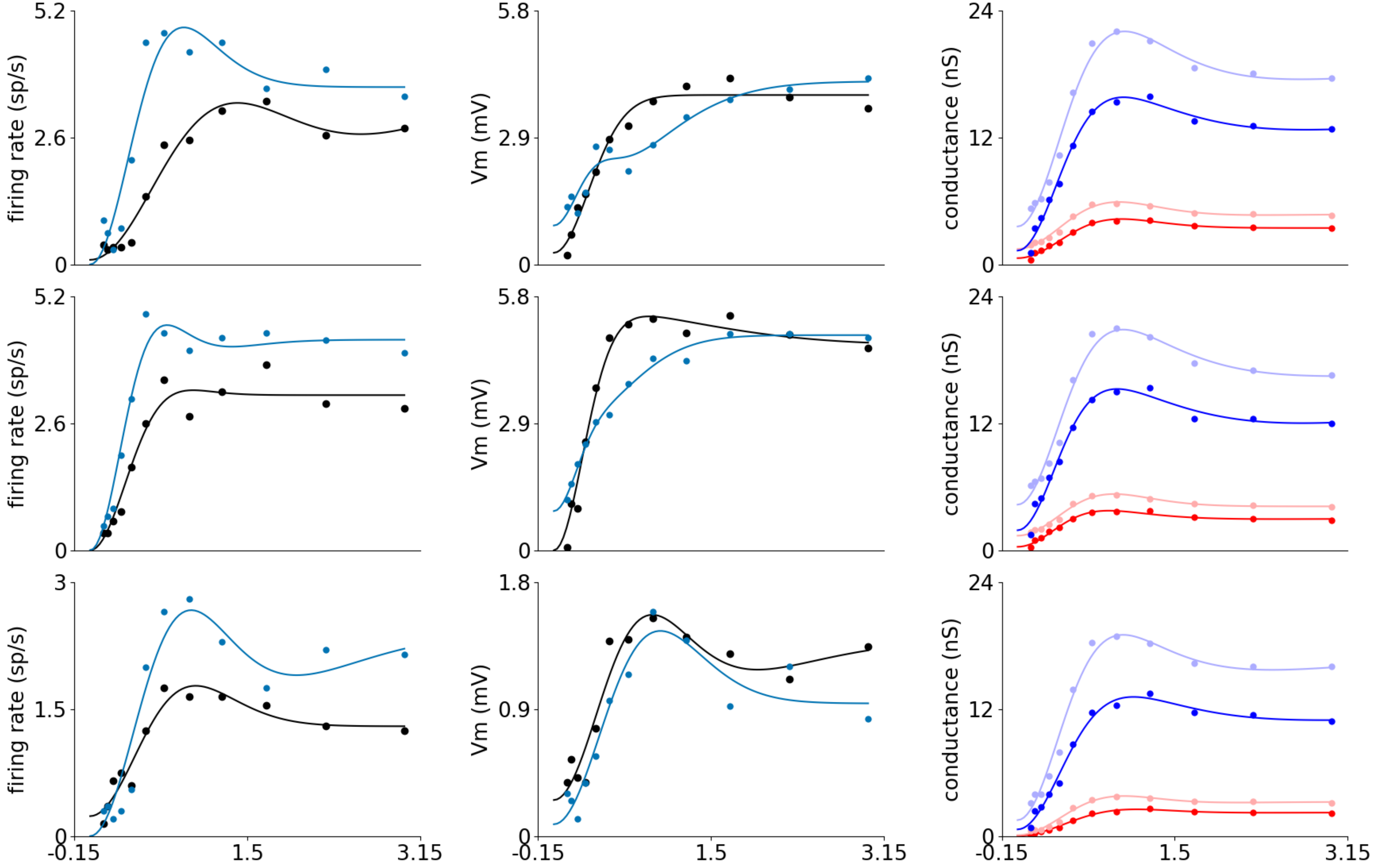


Cat, Tailby et al. 2007

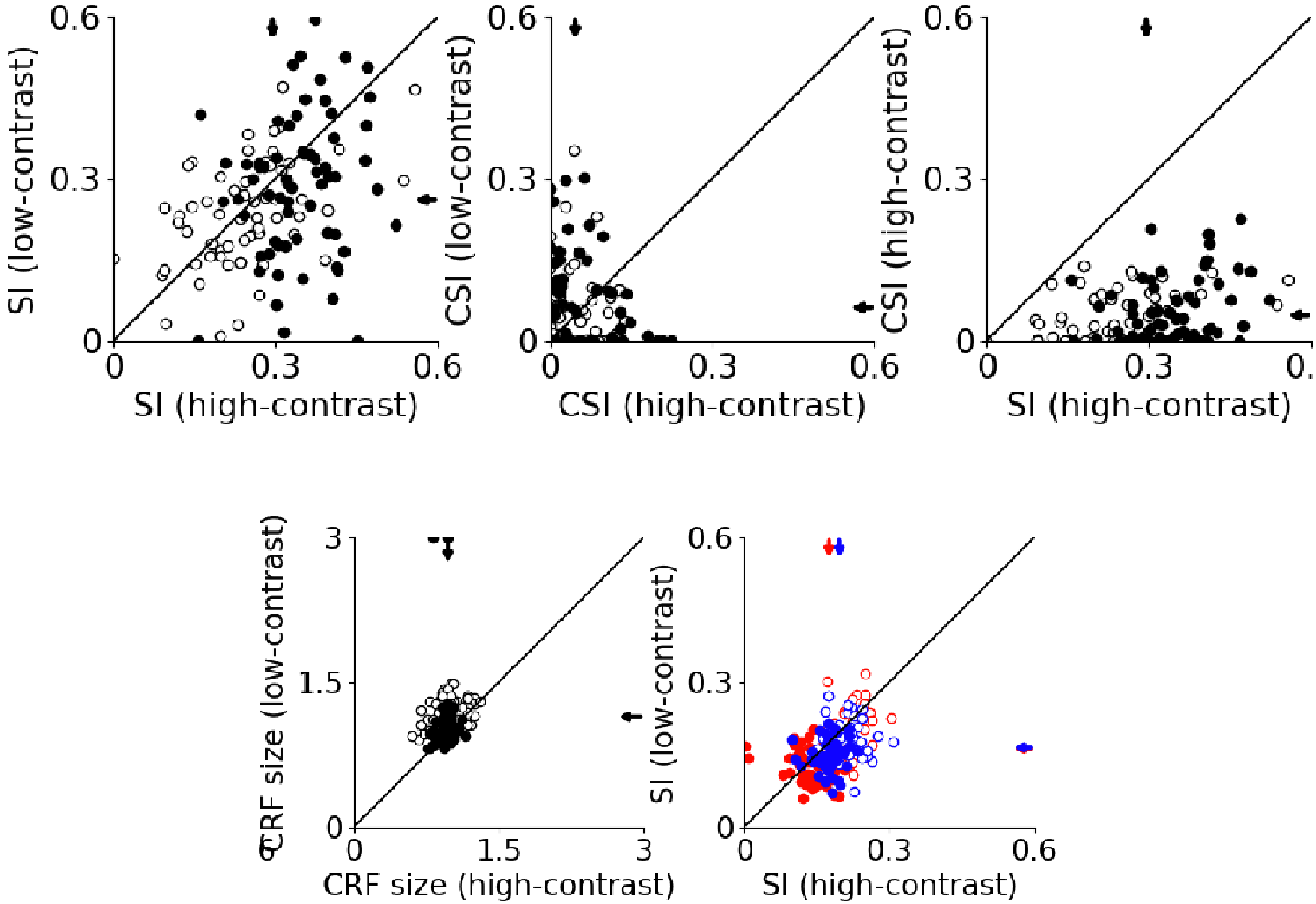
Size tuning: layer 2/3

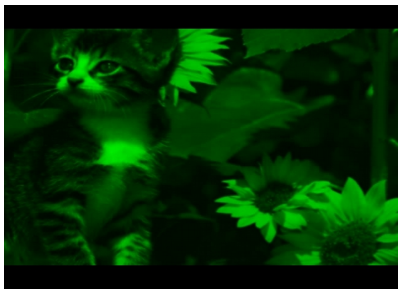
Size tuning curves

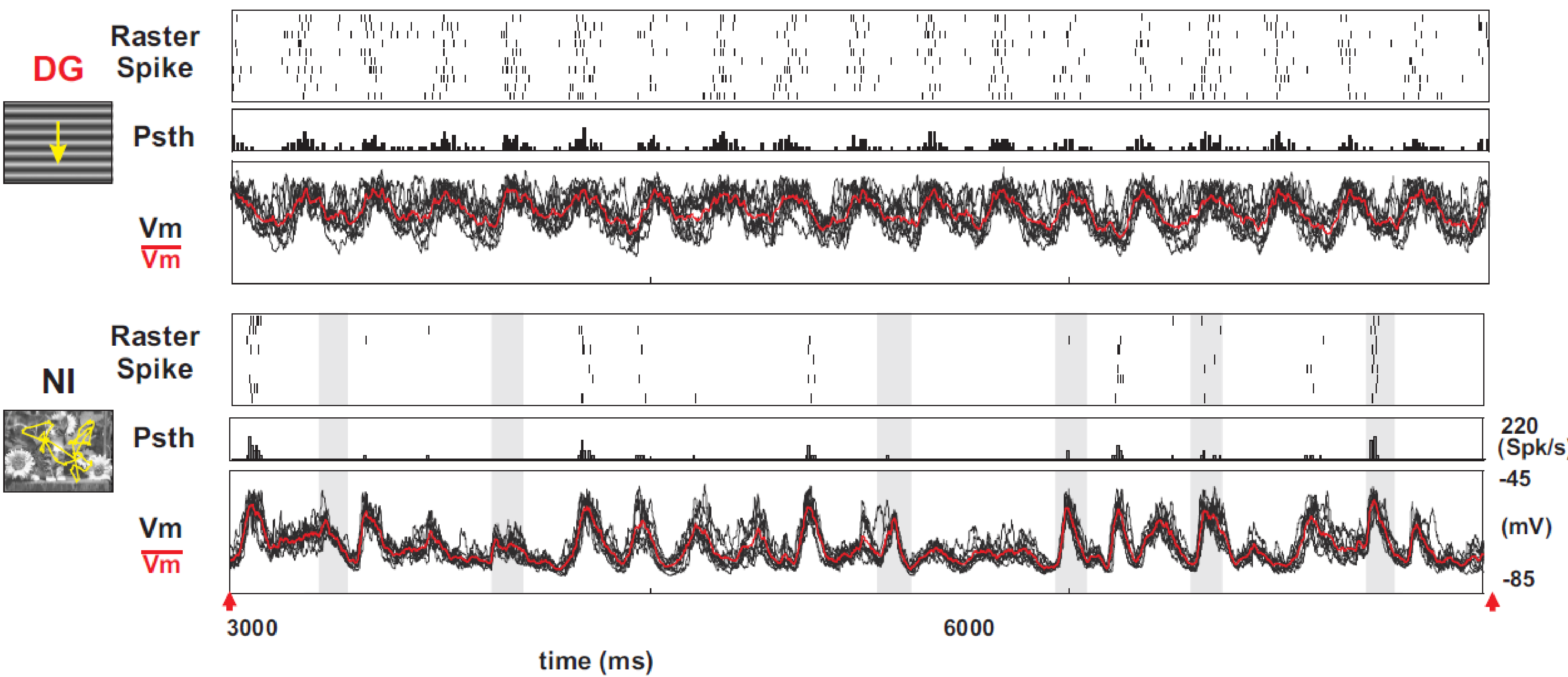


Size tuning quantified



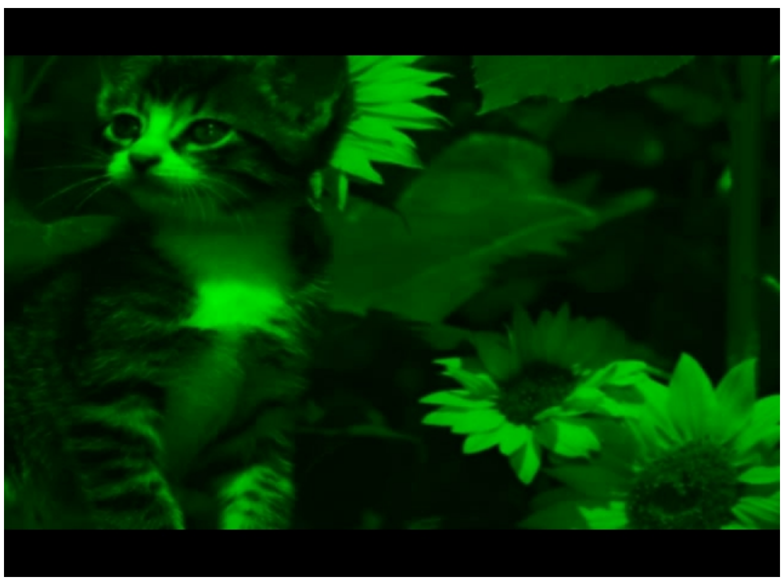
Sparse and precise neural code to natural with stimuli (DATA)

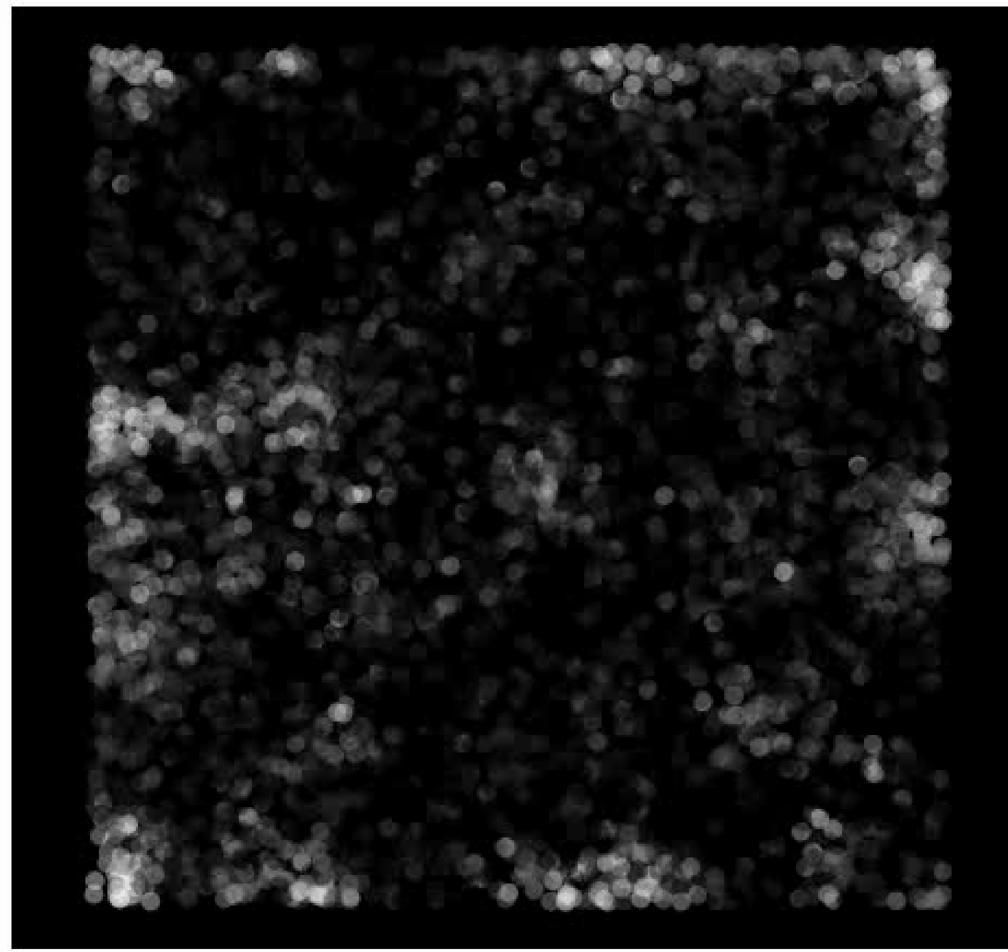




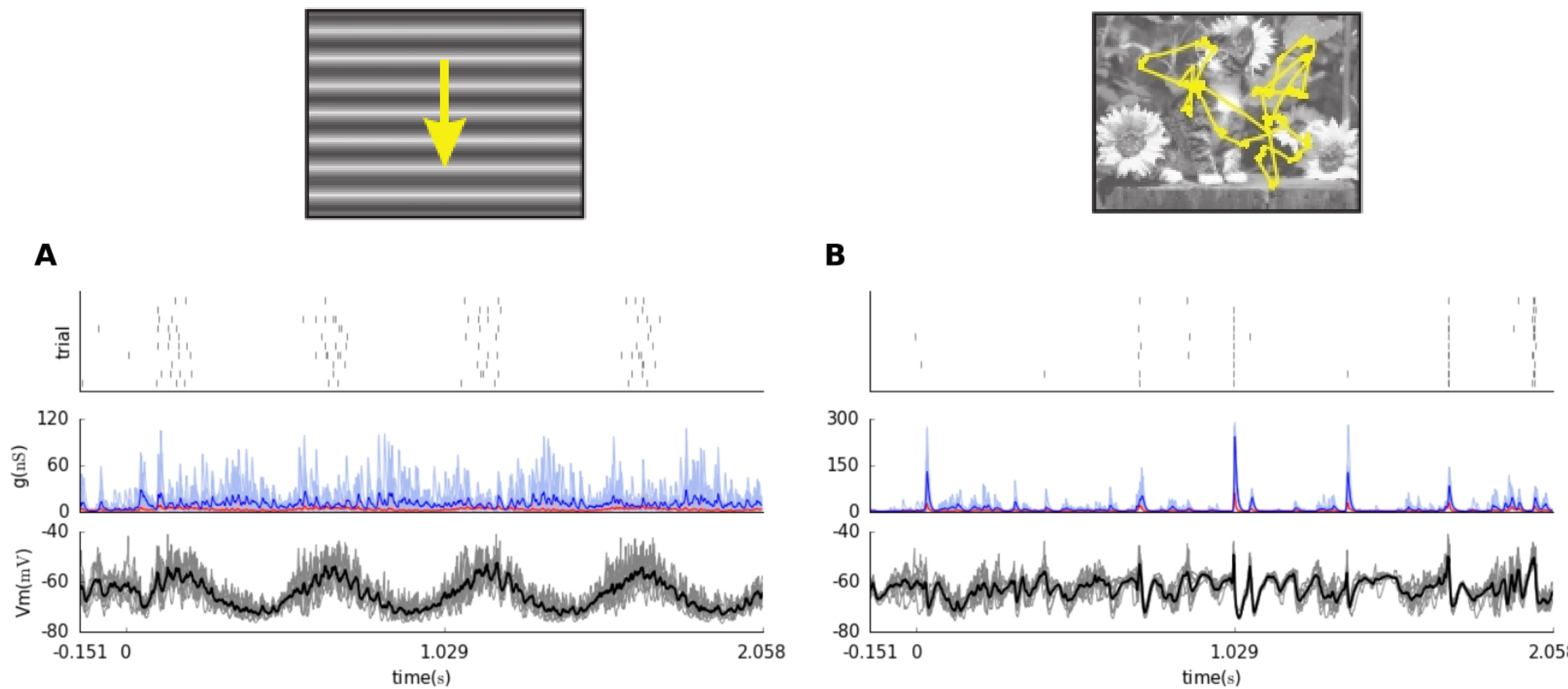
(Baudot,Levy,Marre, Monier & Yves Frégnac, 2013)

Natural image with eye-movements (L2/3)





Sparse and precise neural code to natural with stimuli (MODEL)

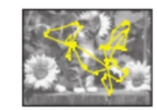


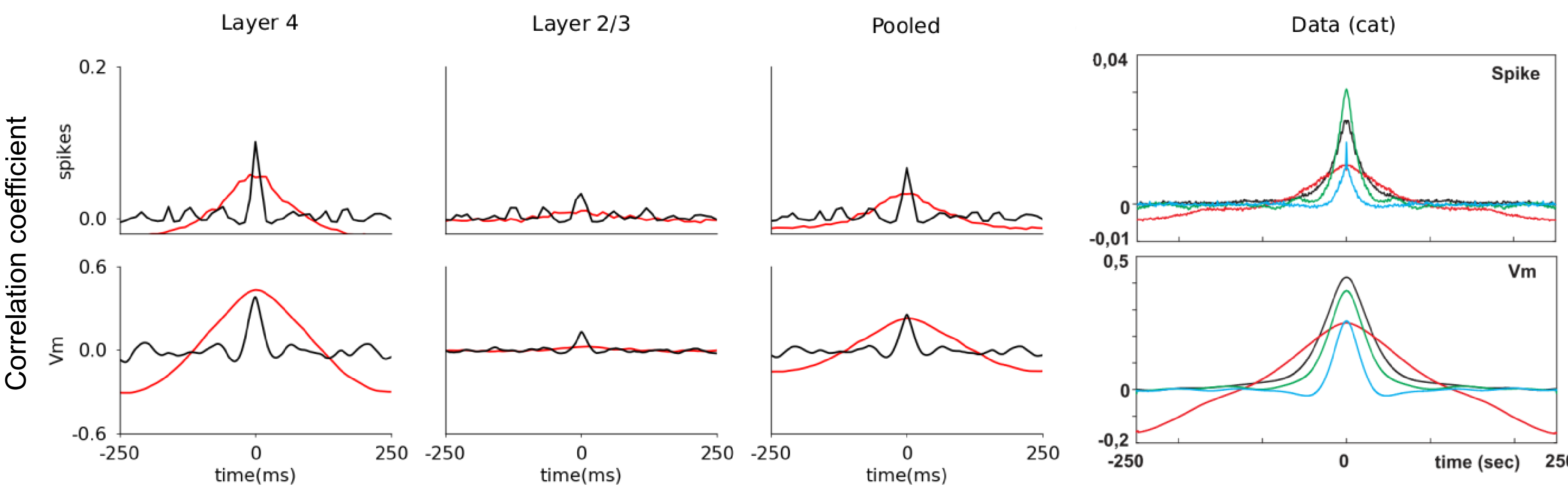
Response reliability and precision

- Trial-to-trial cross-correlation of PSTH or Vm
- Reliability can be viewed as the height of the peak
- Precision can be view as the width of the peak

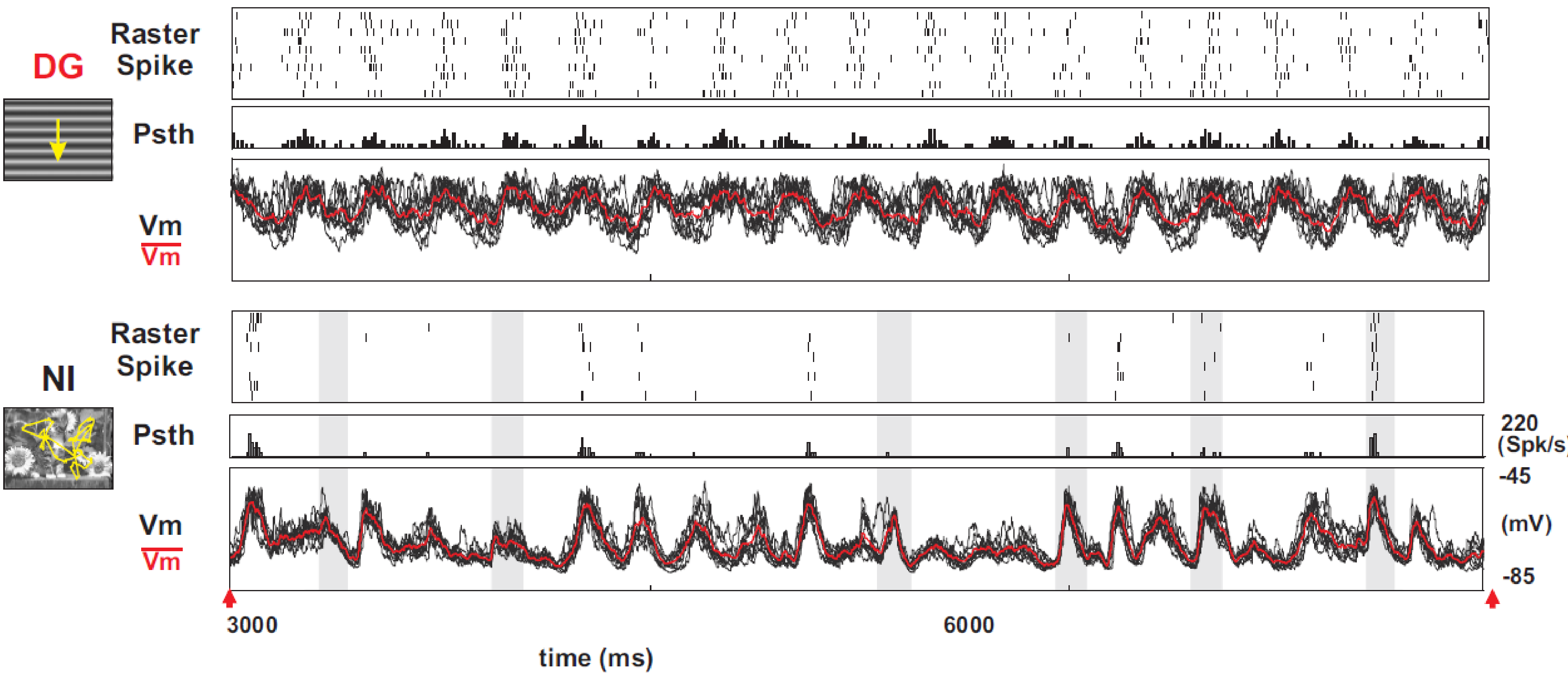
DG

NI





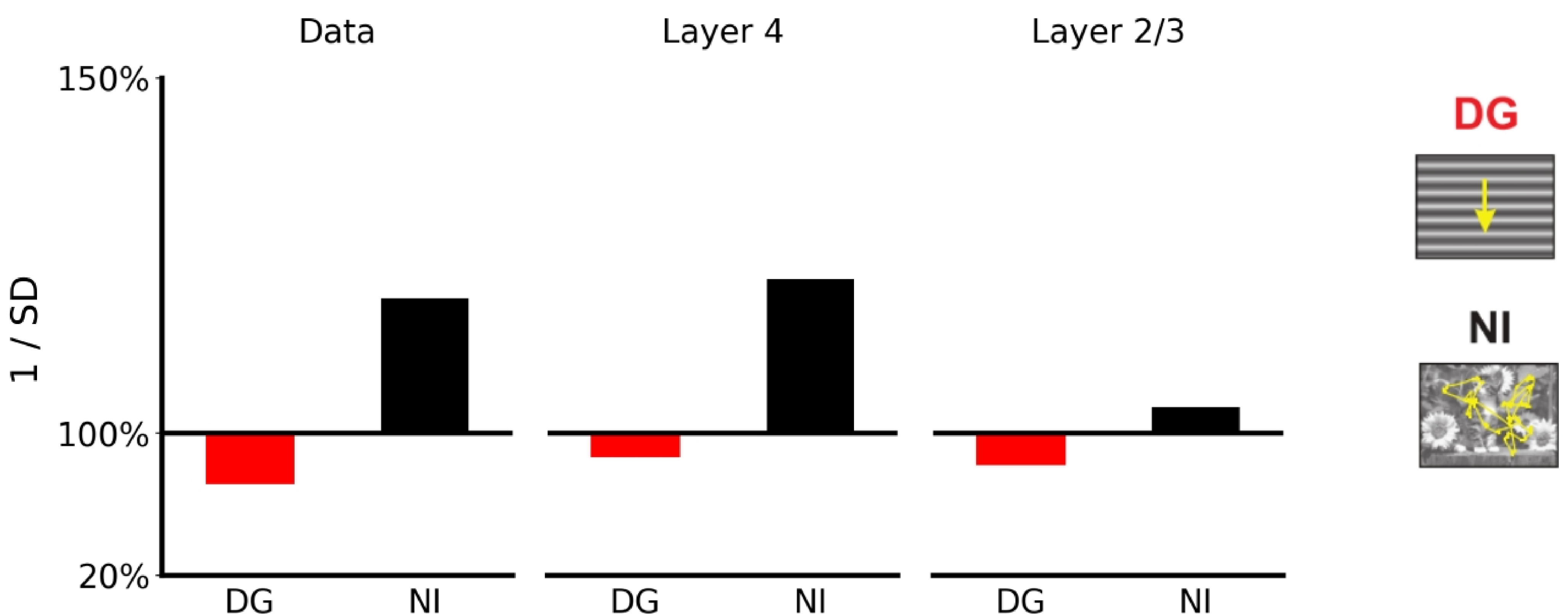
Sparse and precise neural code to natural with stimuli (DATA)



(Baudot,Levy,Marre, Monier & Yves Frégnac, 2013)

Vm variability

- Stimulus locked trial-to-trial variance of Vm
- Expressed as 1/std



CORTICAL VISUAL PROSTHESIS: SIMULATION STUDY

Motivation

39 million legally blind people around the world
(Lewis et al. 2015)

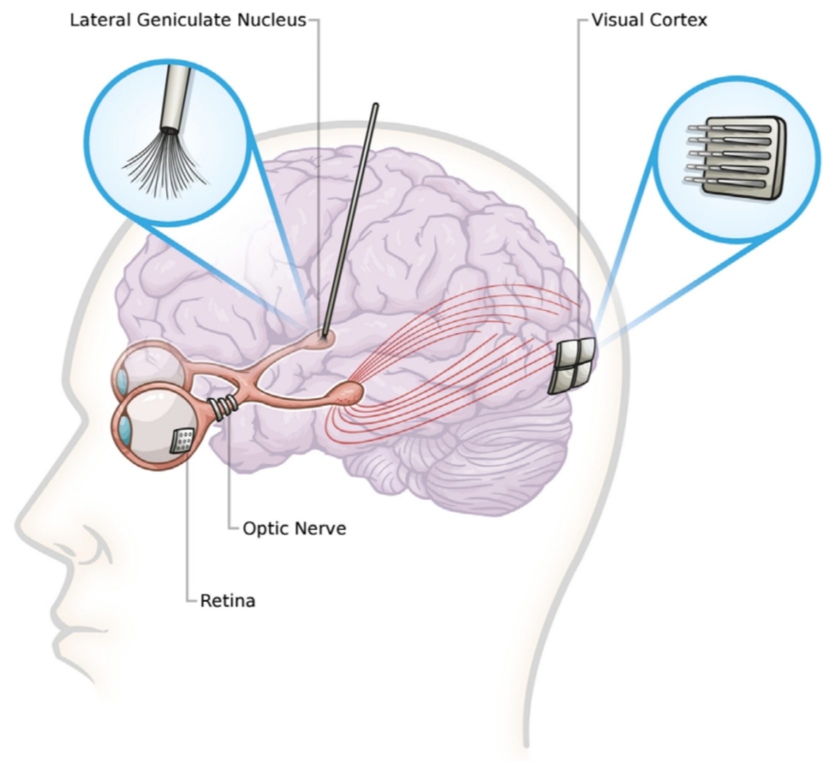
Motivation

39 million legally blind people around the world
(Lewis et al. 2015)

How can we help them?

Motivation

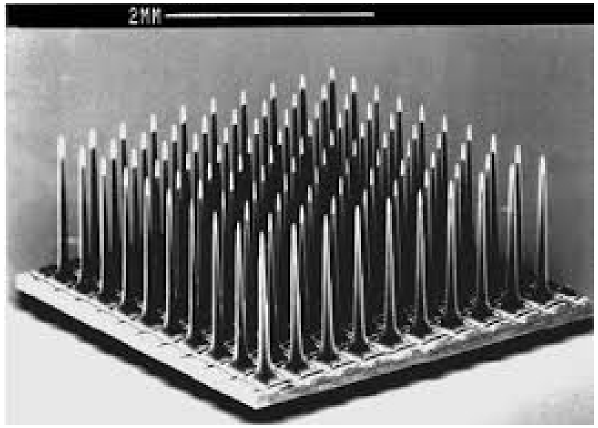
- Implantation of devices for dire stimulation along the visual stream
- Recent progress in retinal prosthesis
- However, many patients not viable for retinal intervention
- Solution: target extra-retinal visual system stages



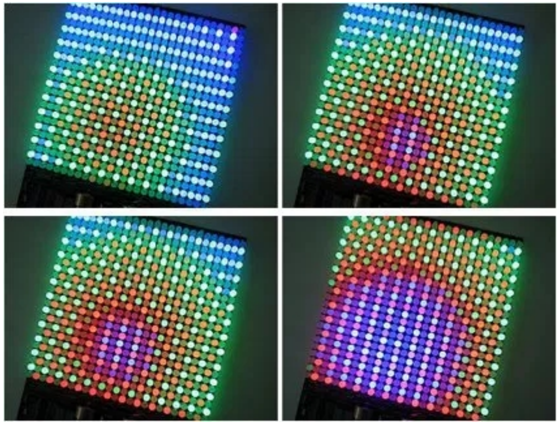
(adopted from Lewis et al. 2015)

Light vs. electrical stimulation

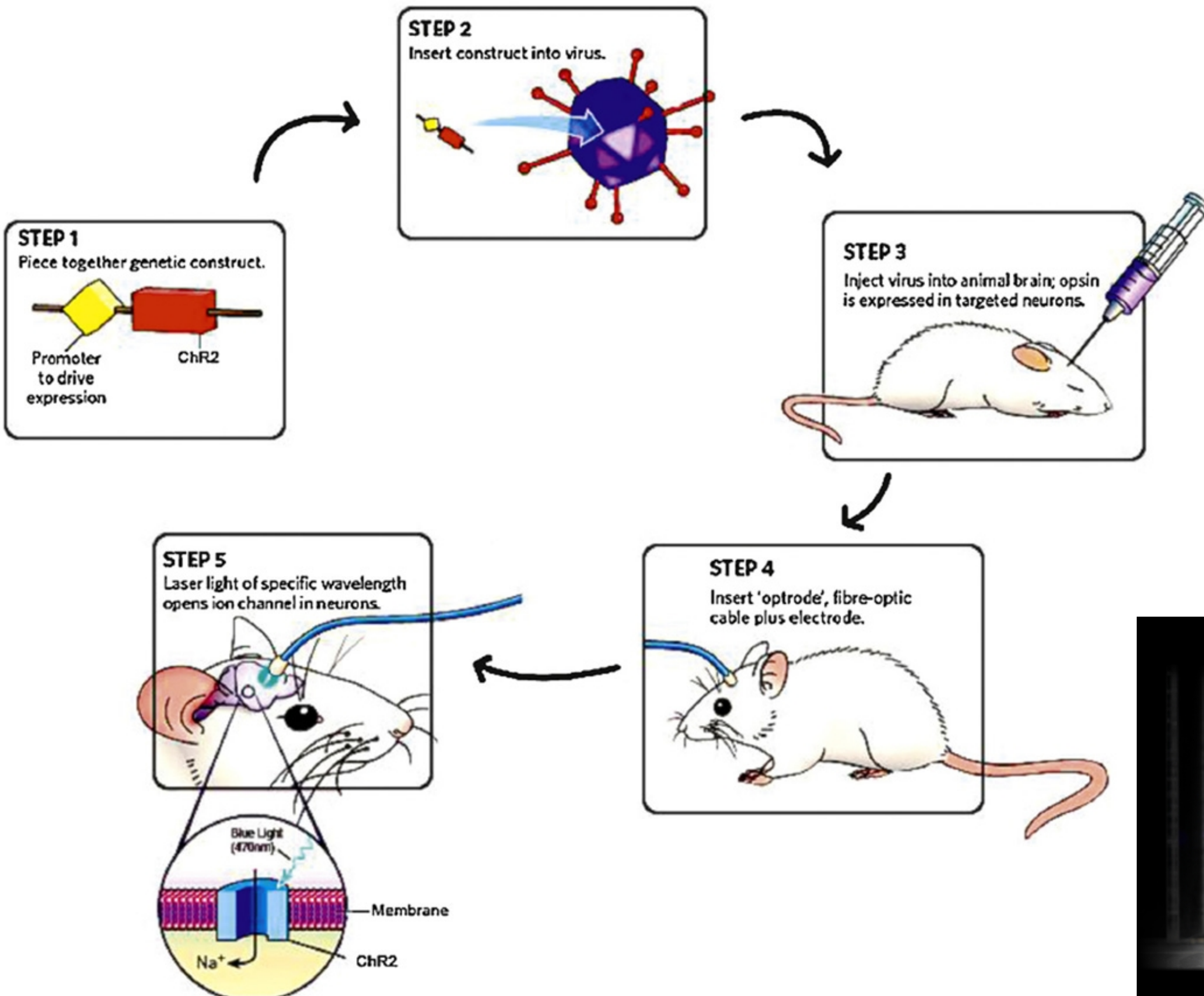
- Traditional neural prosthetics use direct electrical stimulation
- Issues with long-term viability of the implants due to:
  - direct mechanical harm during implantation
  - long-term glial encapsulation and chronic-inflamation
  - assortment of medical issues associated with long term implantation (infections etc.)
- Solution: replace electricity with stimulation with light



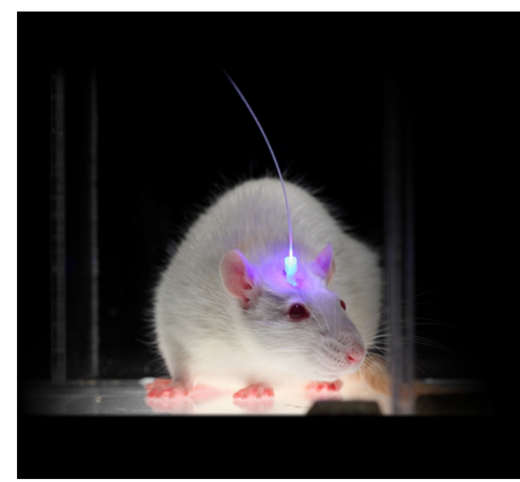
vs.



Optogenetics

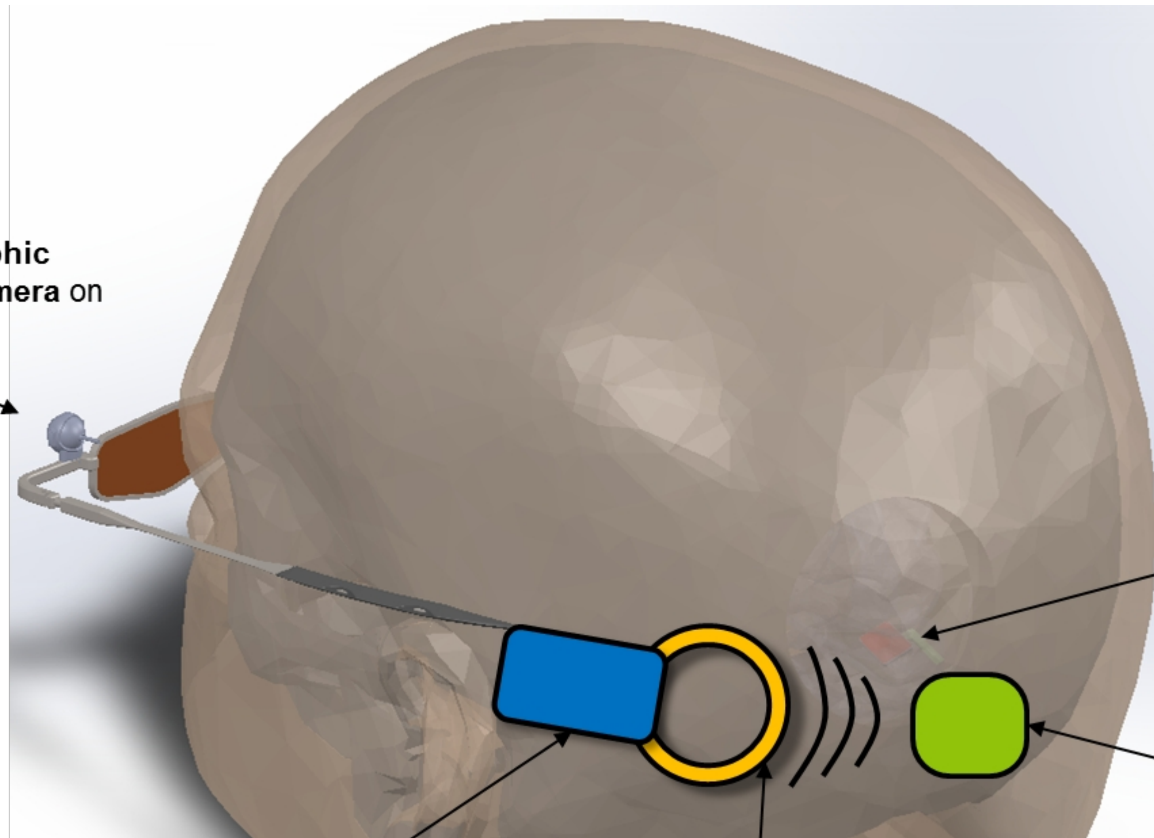


G, N et al. 2013



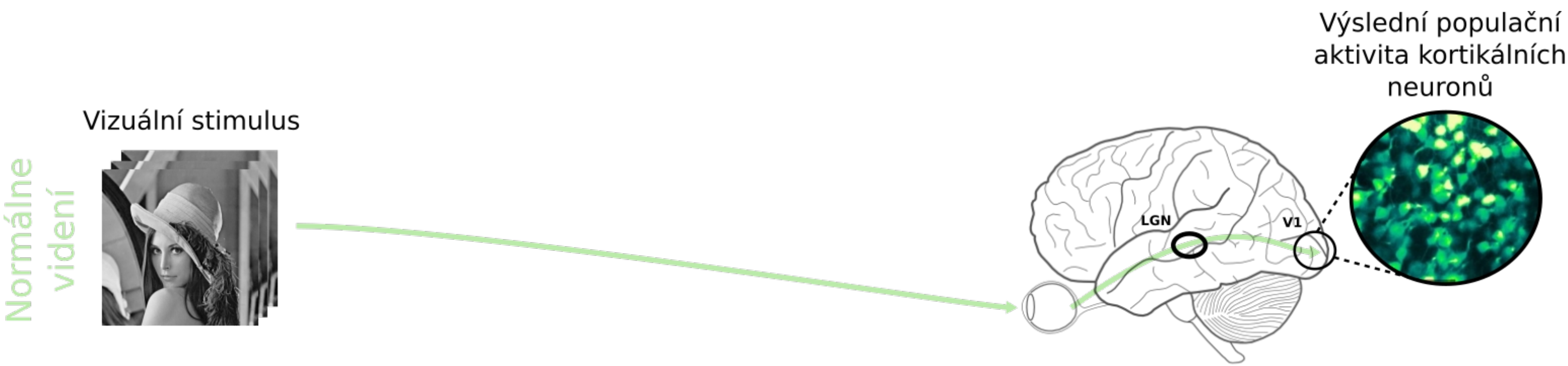
Deisseroth Lab

The Visual Prosthetic System

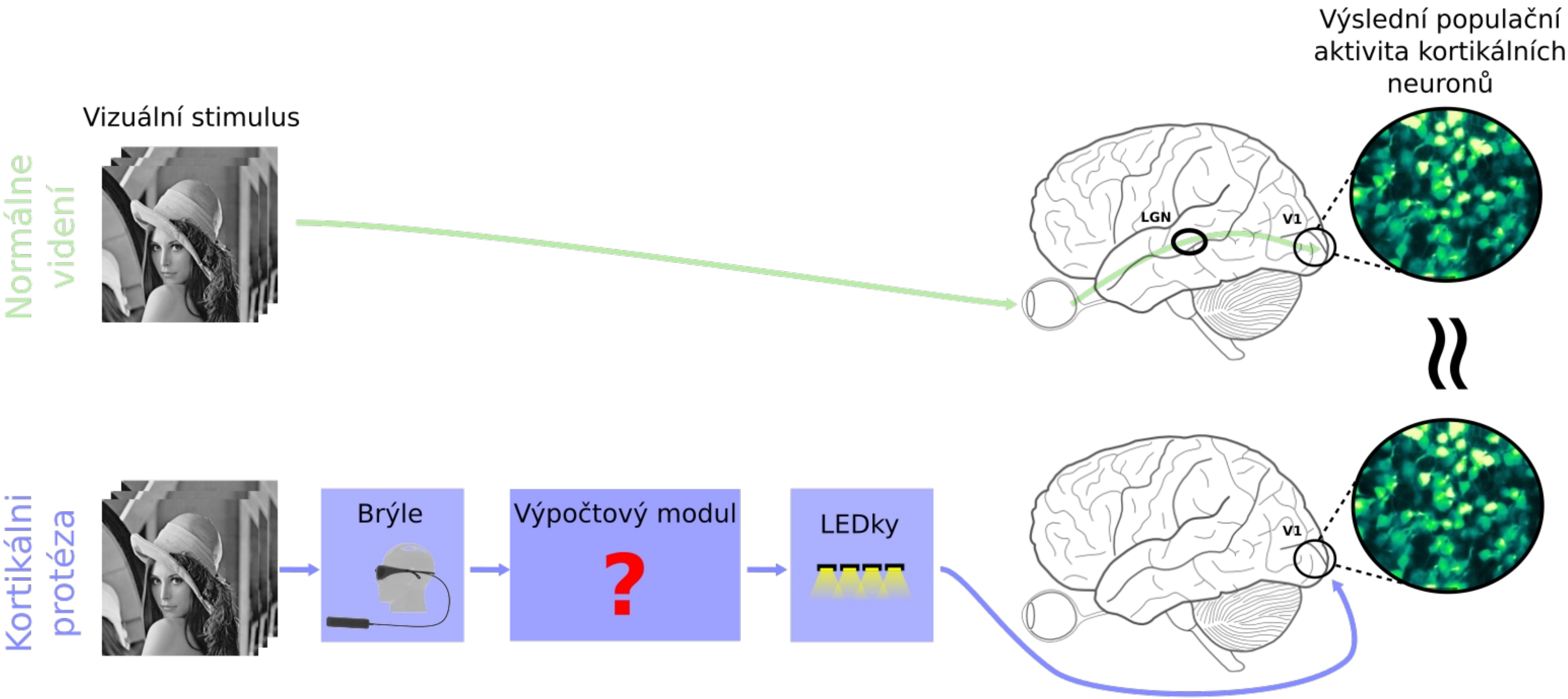


CEA LETI: http://www.leti-cea.com

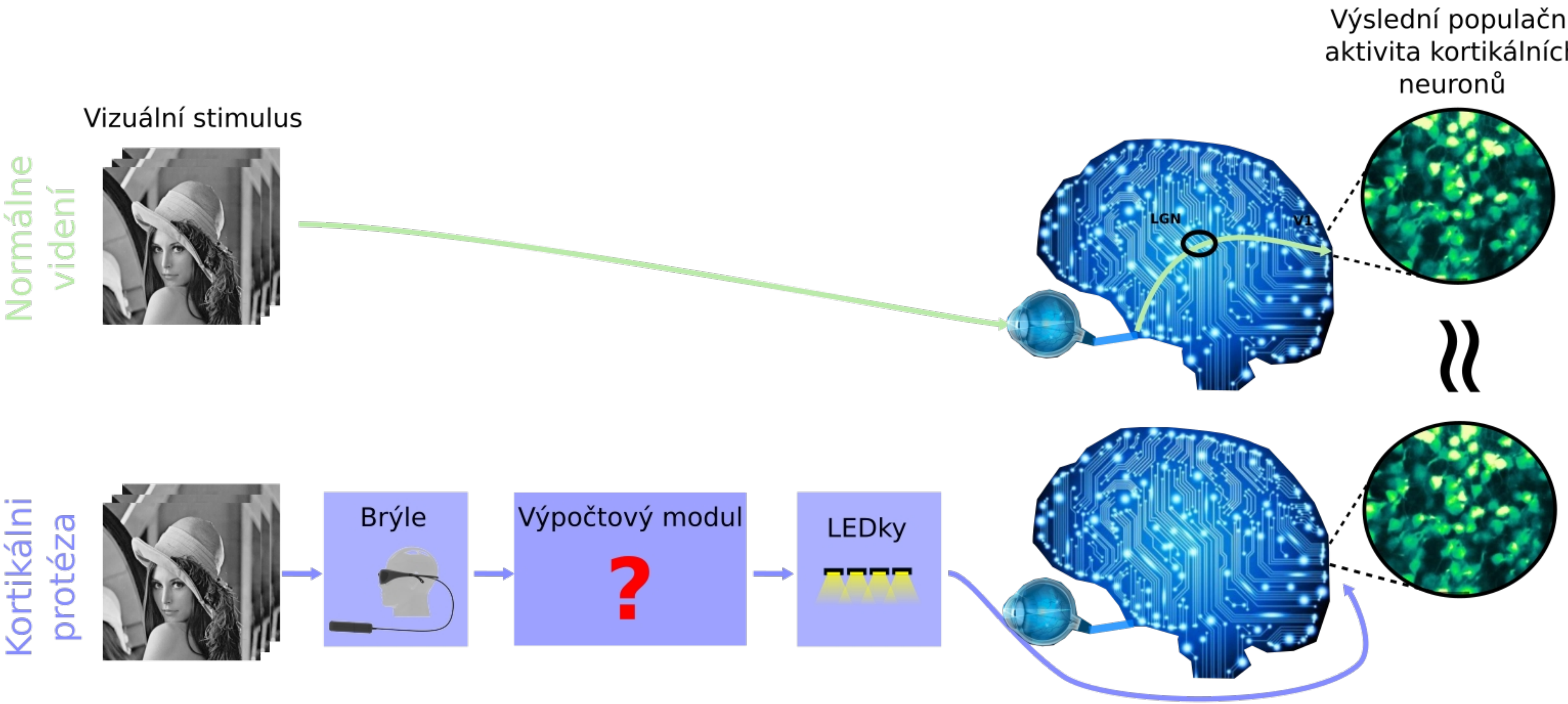
The problem


Vizuální stimulus
Normálne vidění
LGN
V1
Výslední populační aktivita kortikálních neuronů

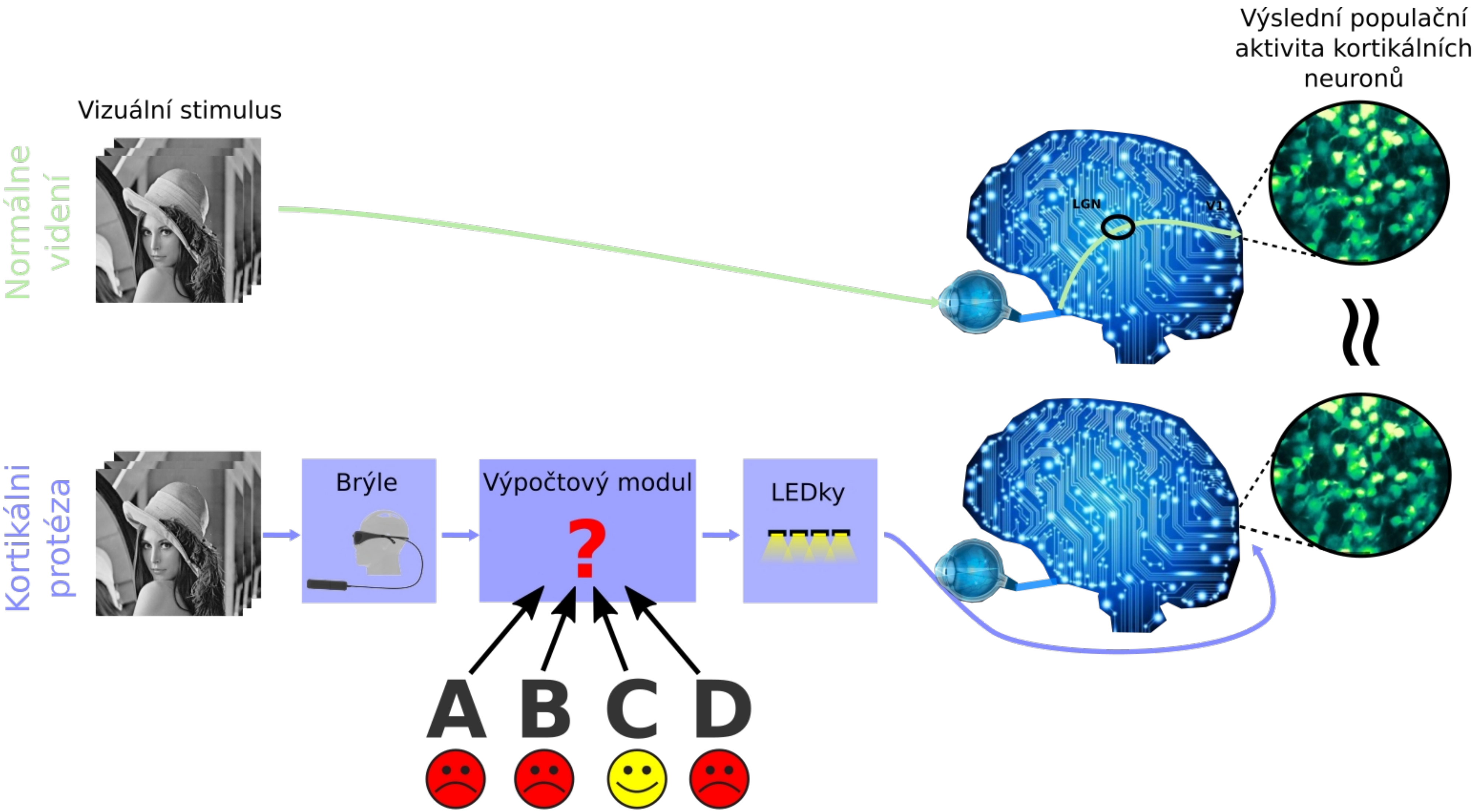
The problem


Výslední populační aktivita kortikálních neuronů
Vizuální stimulus
Normálne vidění
LGN
V1
≈
Kortikálni protéza
Brýle
Výpočtový modul
?
LEDky
V1

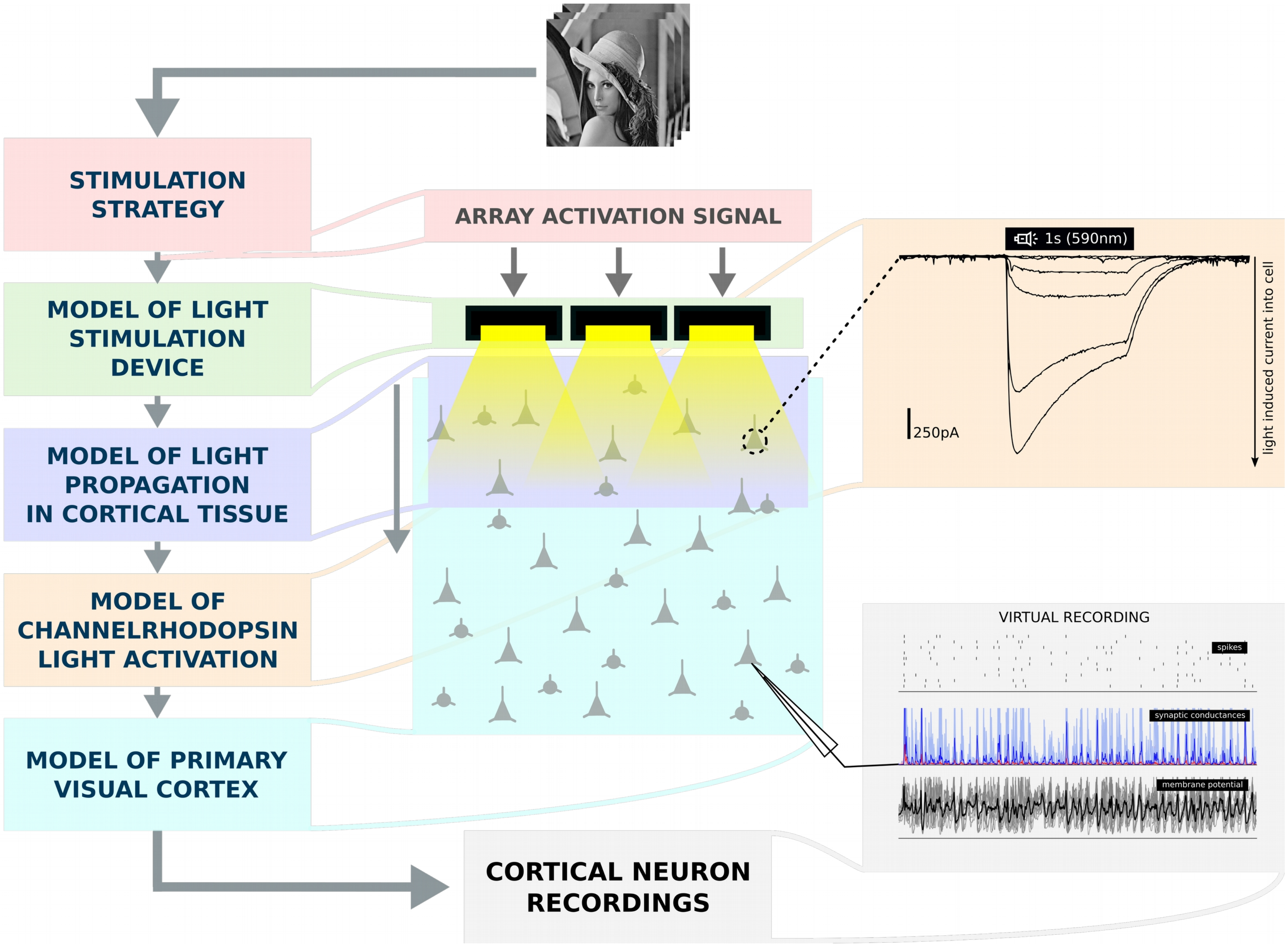
Solution: simulation of the prosthetic system



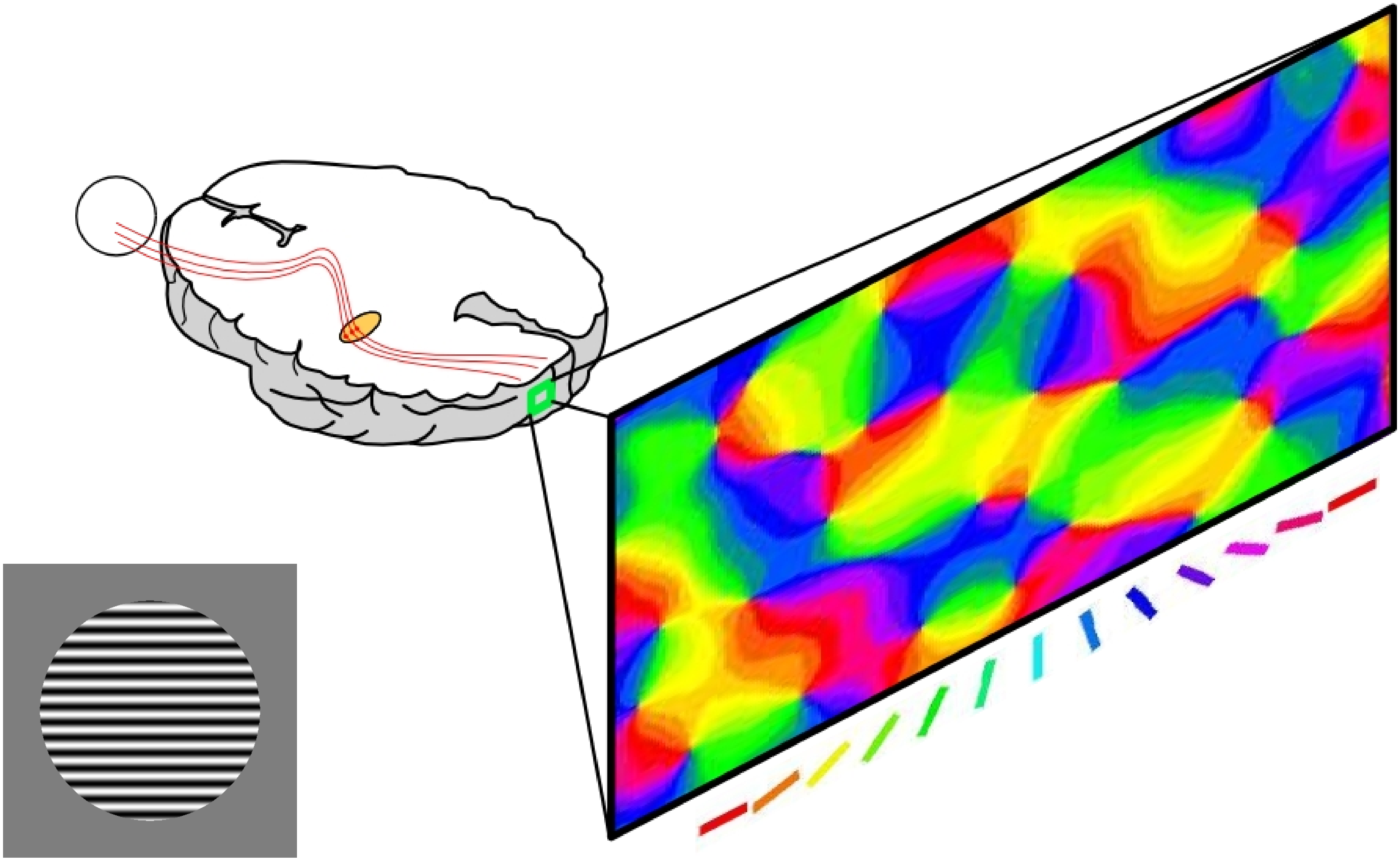
Solution: simulation of the prosthetic system



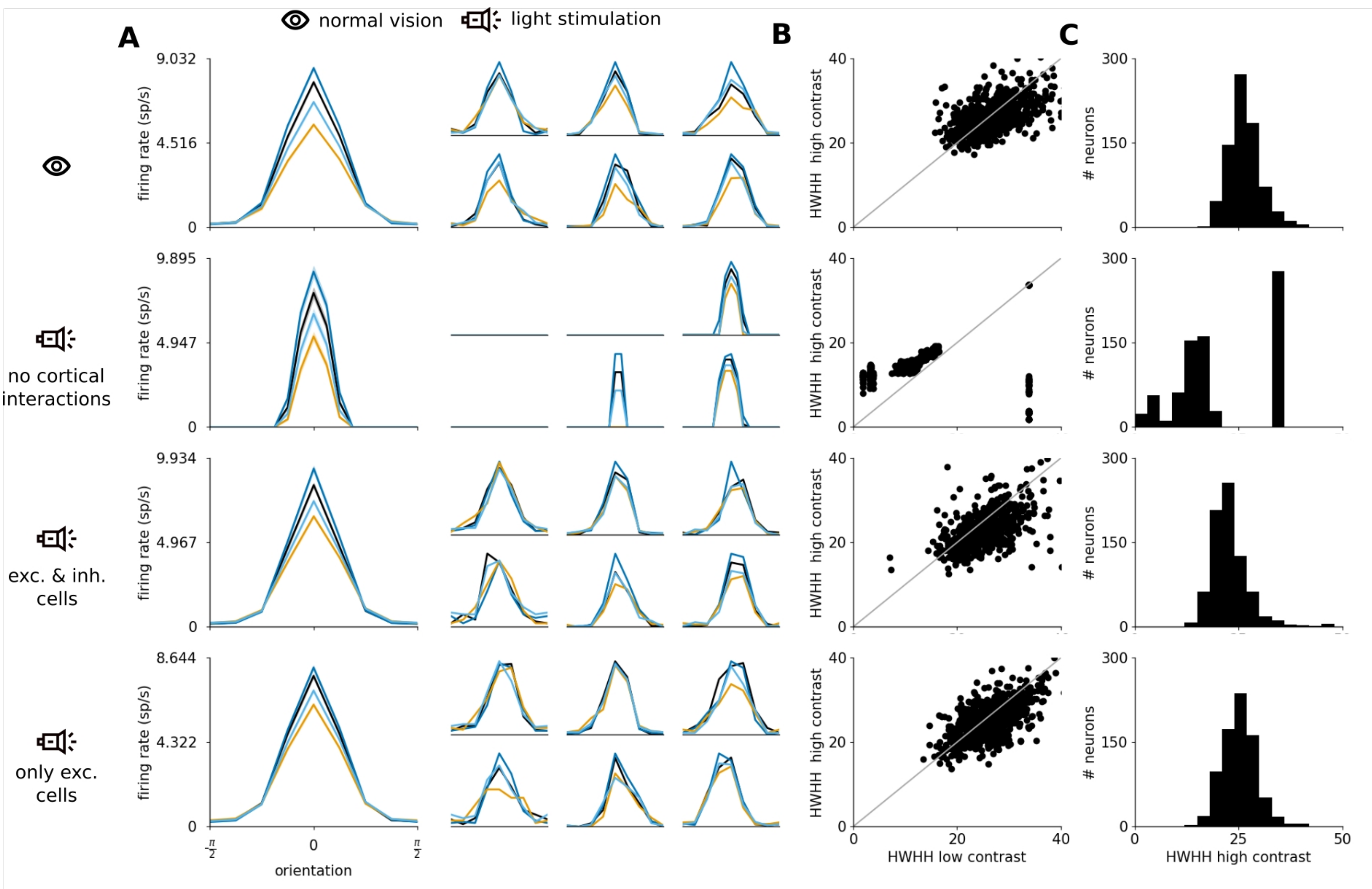
Simulation platform



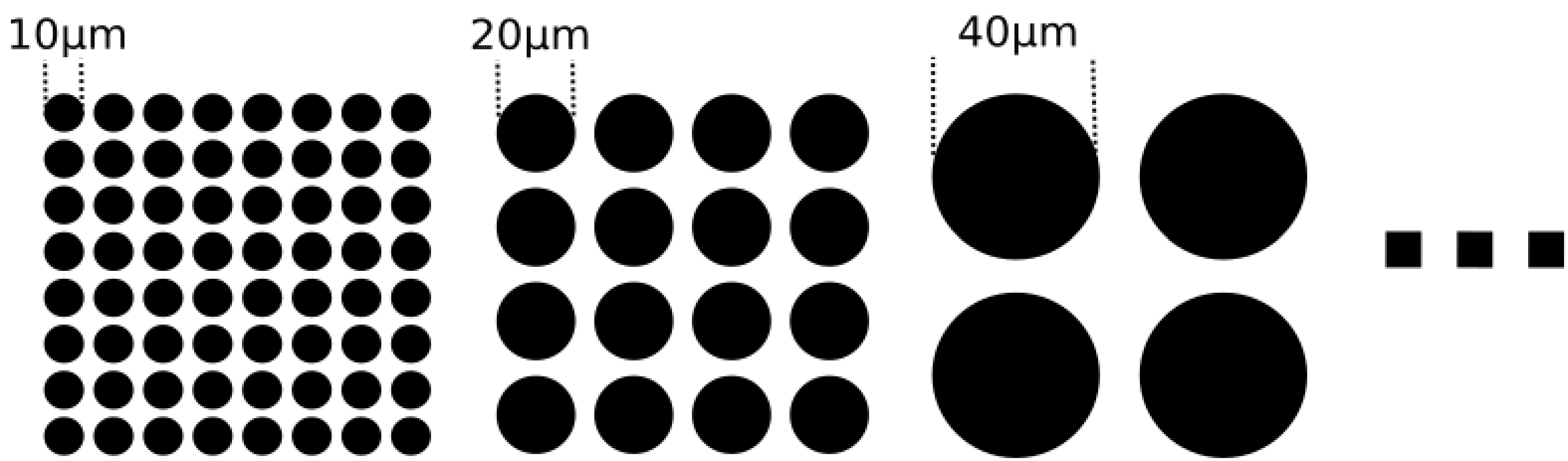
Stimulation protocol of sinusoidal gratings



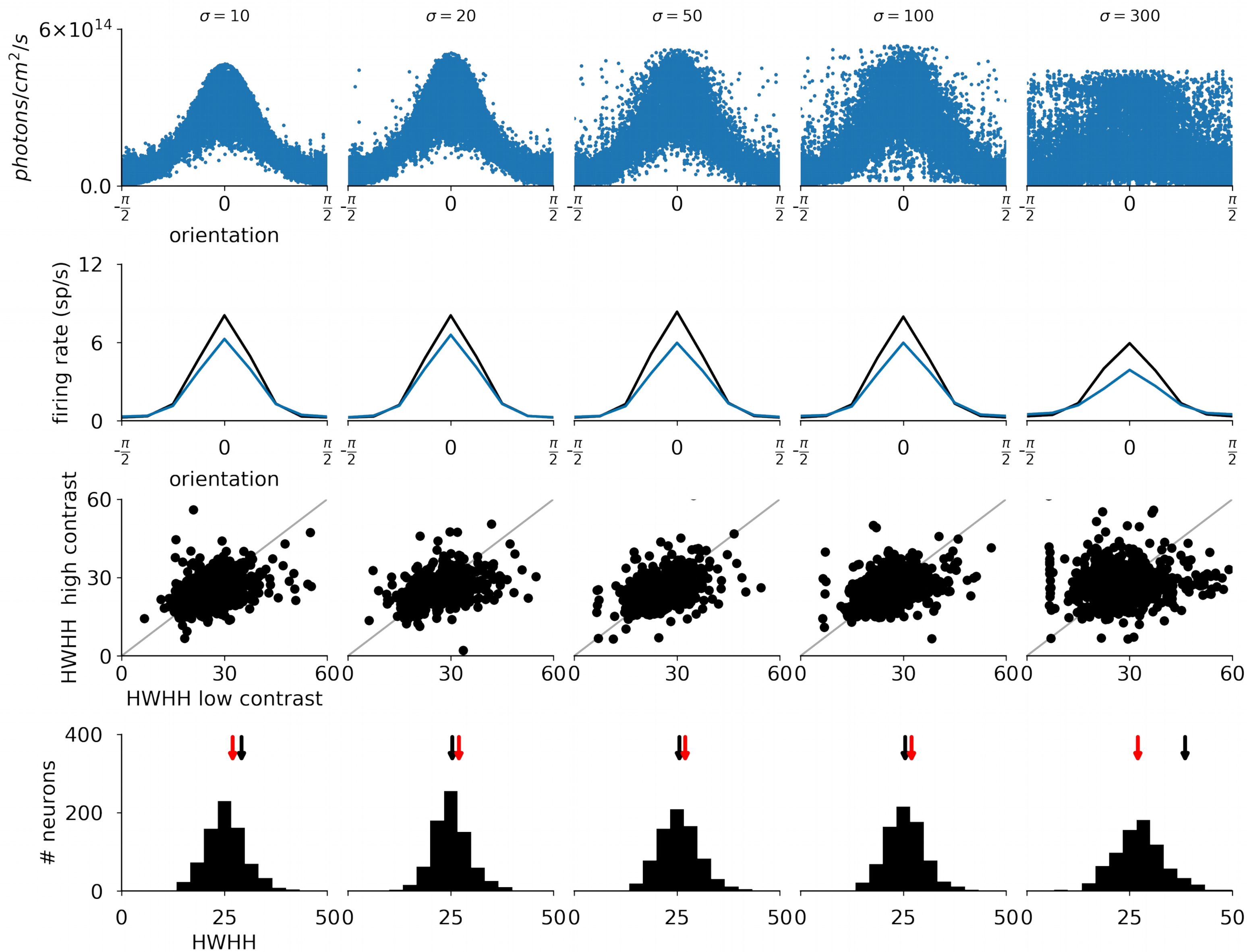
Orientation tuning in intact and opto-stimulated layer 2/3 of V1



Orientation tuning as a function of LED array density



Orientation tuning as a function of LED array density



Layer 2/3 activity under optogenetic stimulation

Visual input

Exc&Inh

Exc

Intact Vision