Pairwise Correlation

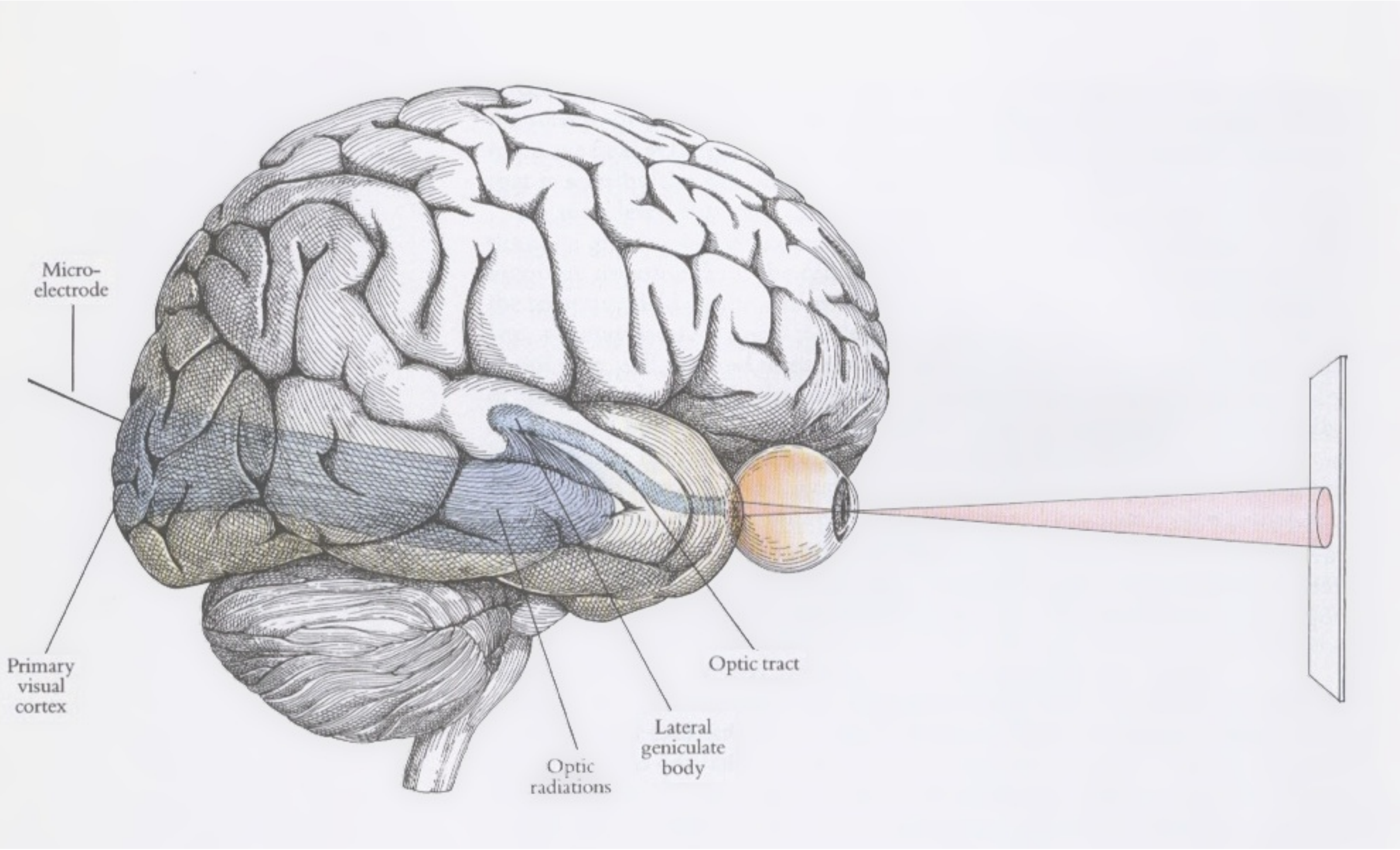
Cold Spring Harbor
Neural Data Science 2019

Matthew A Smith

Departments of Biomedical Engineering
and Neuroscience Institute
(as of September 1)

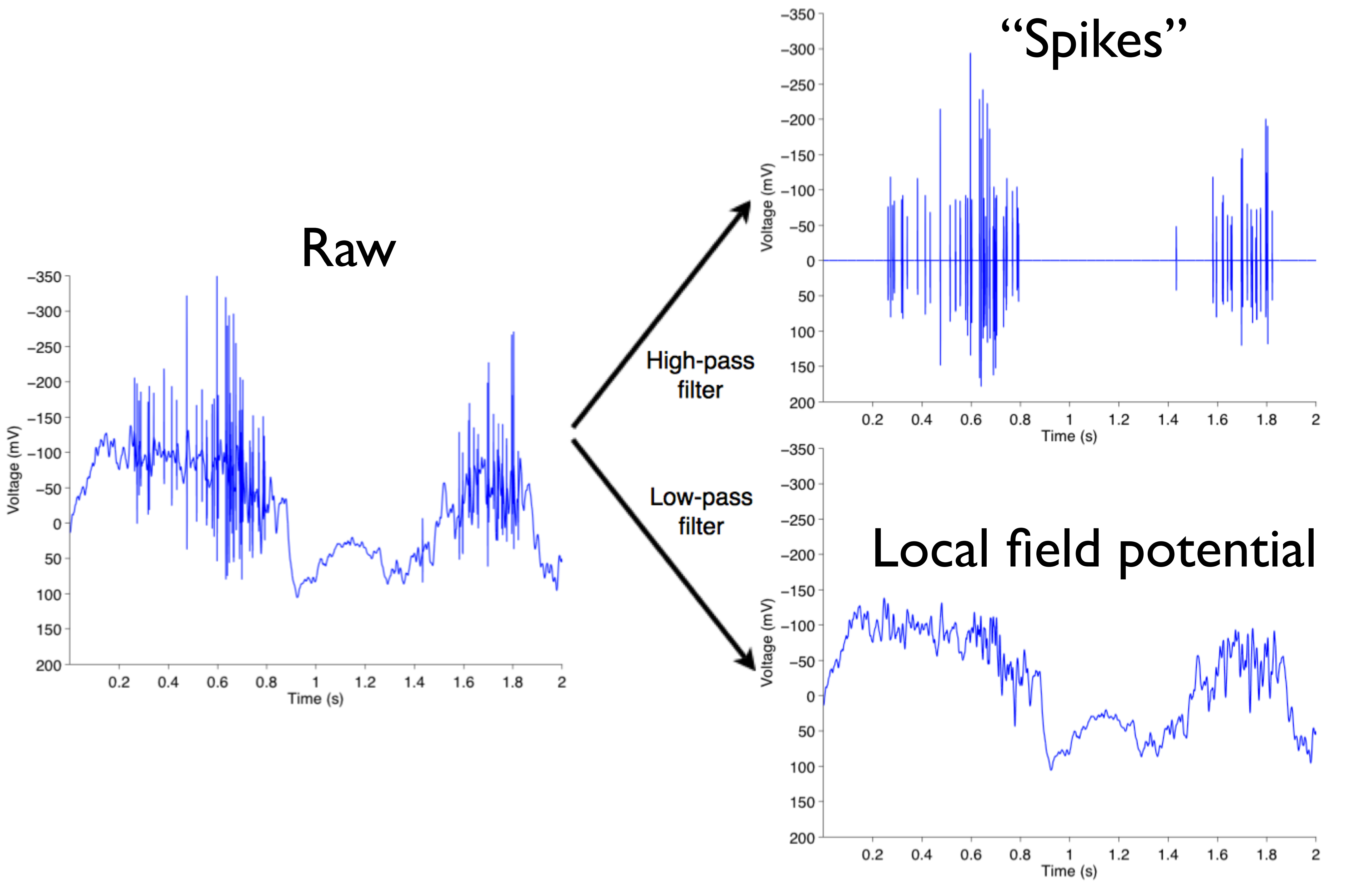
CNBC
CENTER FOR THE NEURAL BASIS OF COGNITION

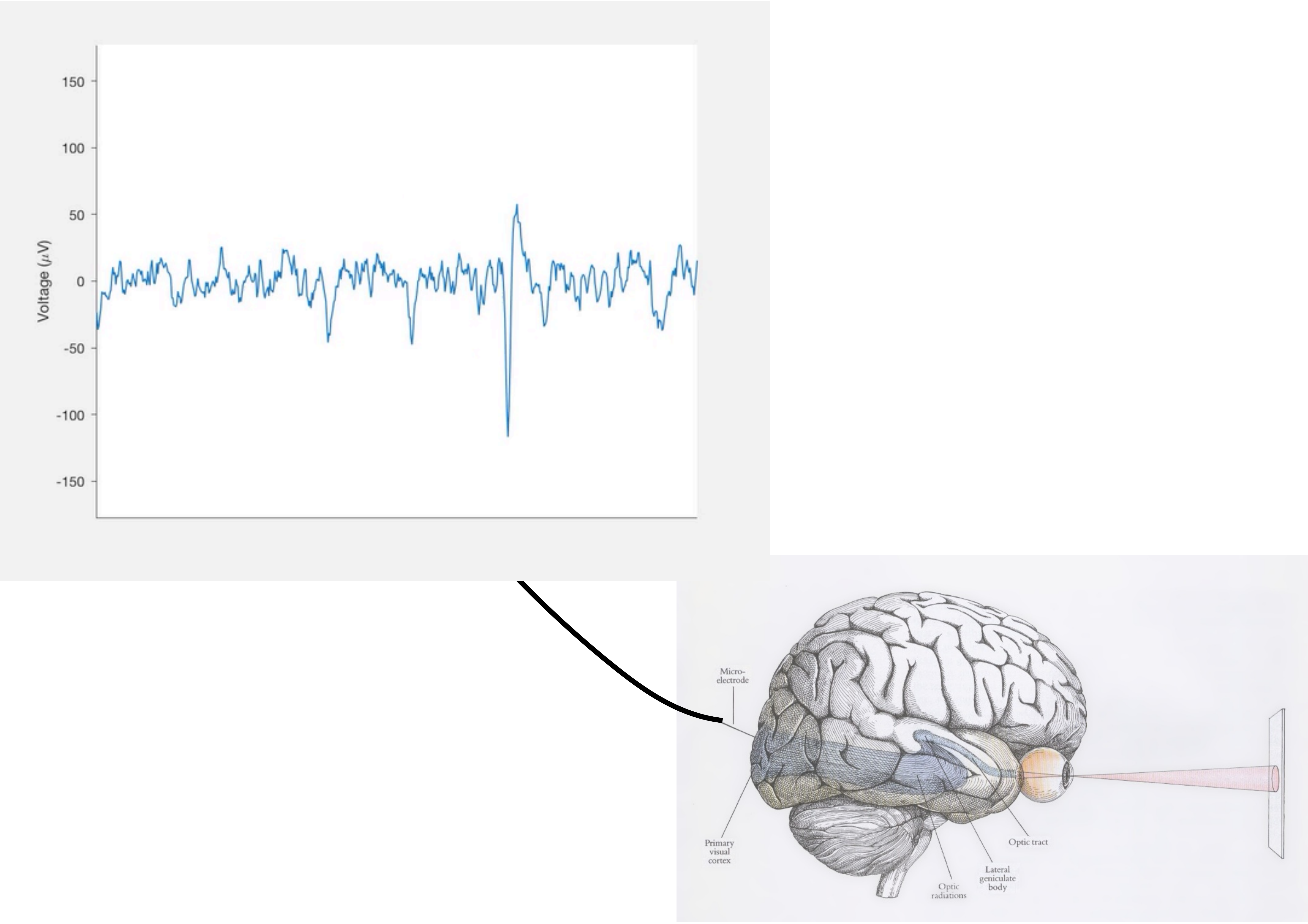
Carnegie Mellon University


Micro-
electrode
Primary
visual
cortex
Optic
radiations
Lateral
geniculate
body
Optic tract

Hubel, 1988

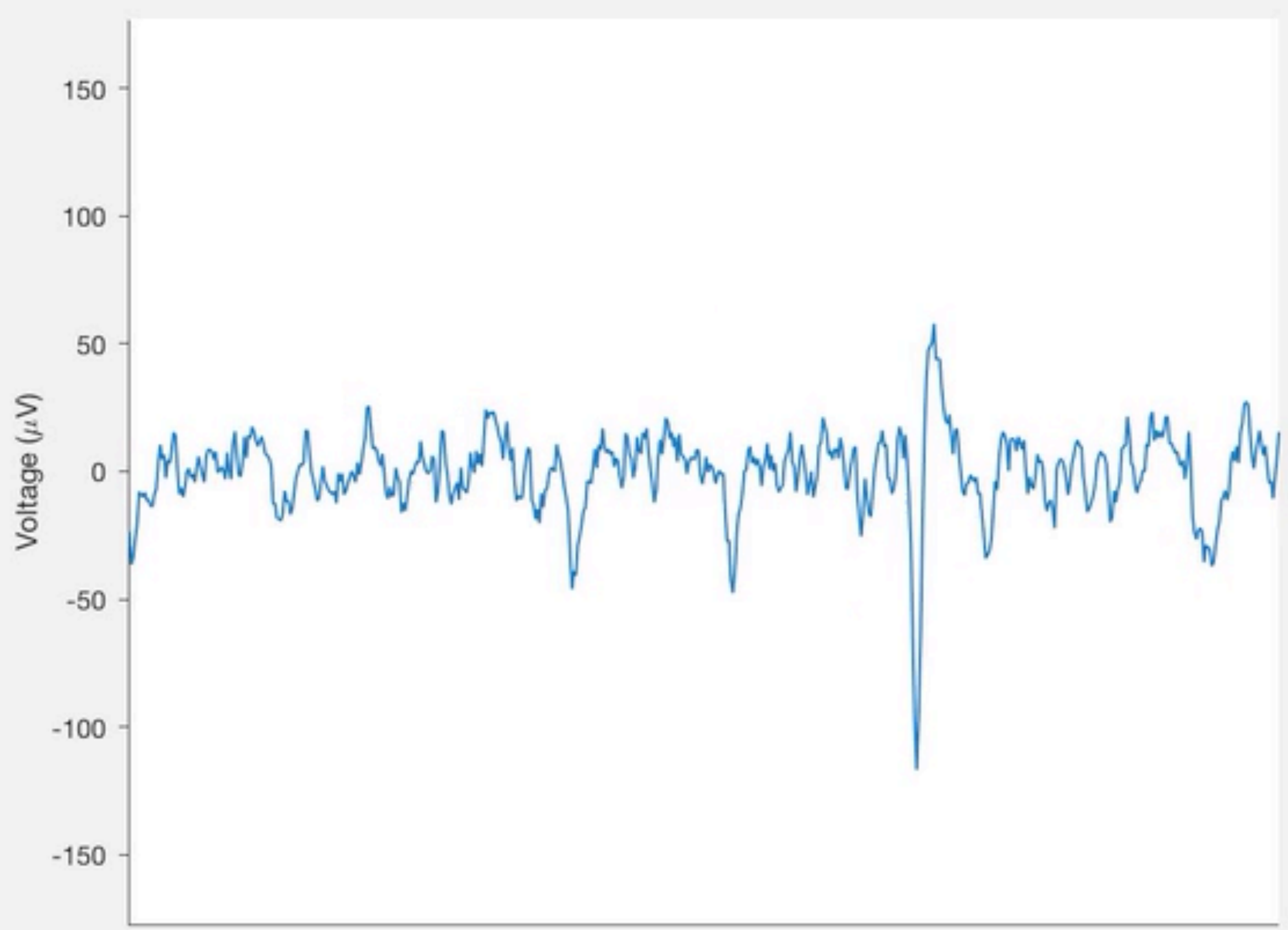
Signals from microelectrodes

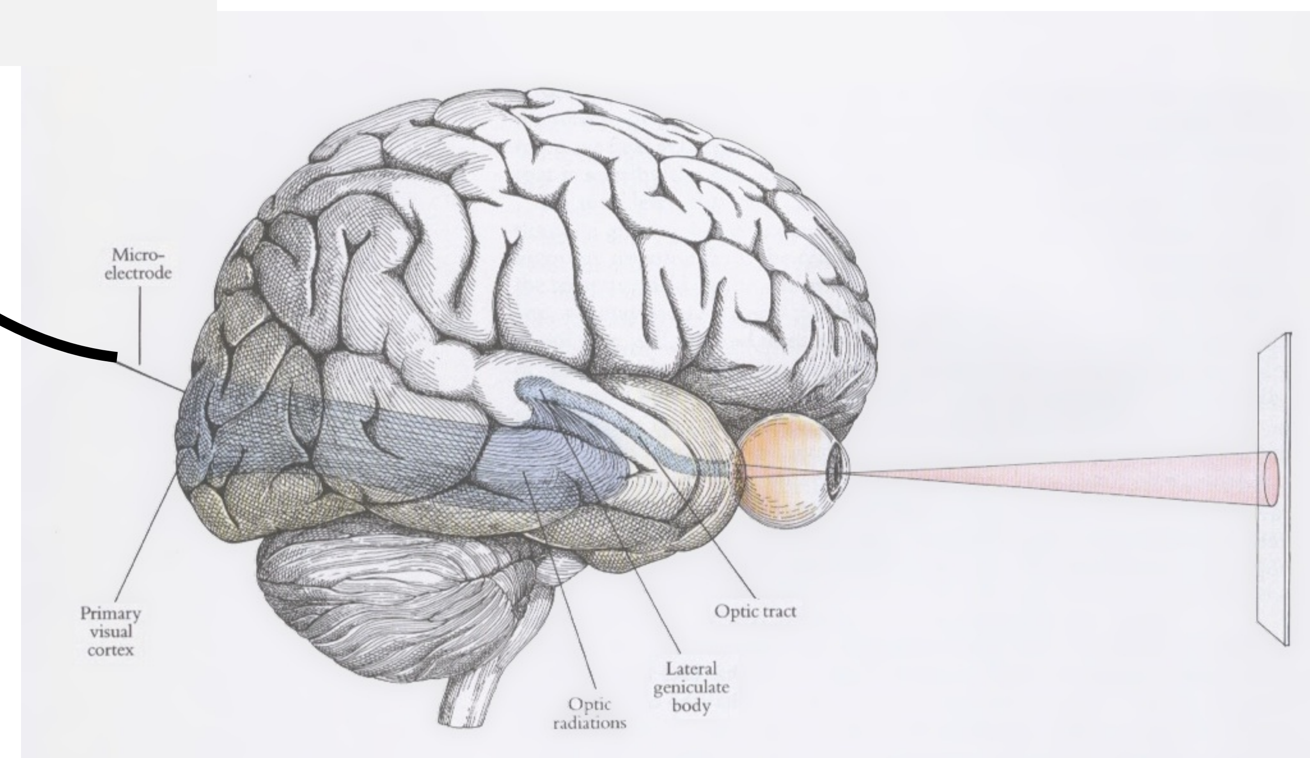




150
100
50
0
-50
-100
-150
Voltage (μV)
Micro-
electrode
Primary
visual
cortex
Optic
radiations
Lateral
geniculate
body
Optic tract

Hubel, 1988


150
100
50
0
-50
-100
-150
Voltage (μV)


Micro-
electrode
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visual
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Optic tract
Lateral
geniculate
body
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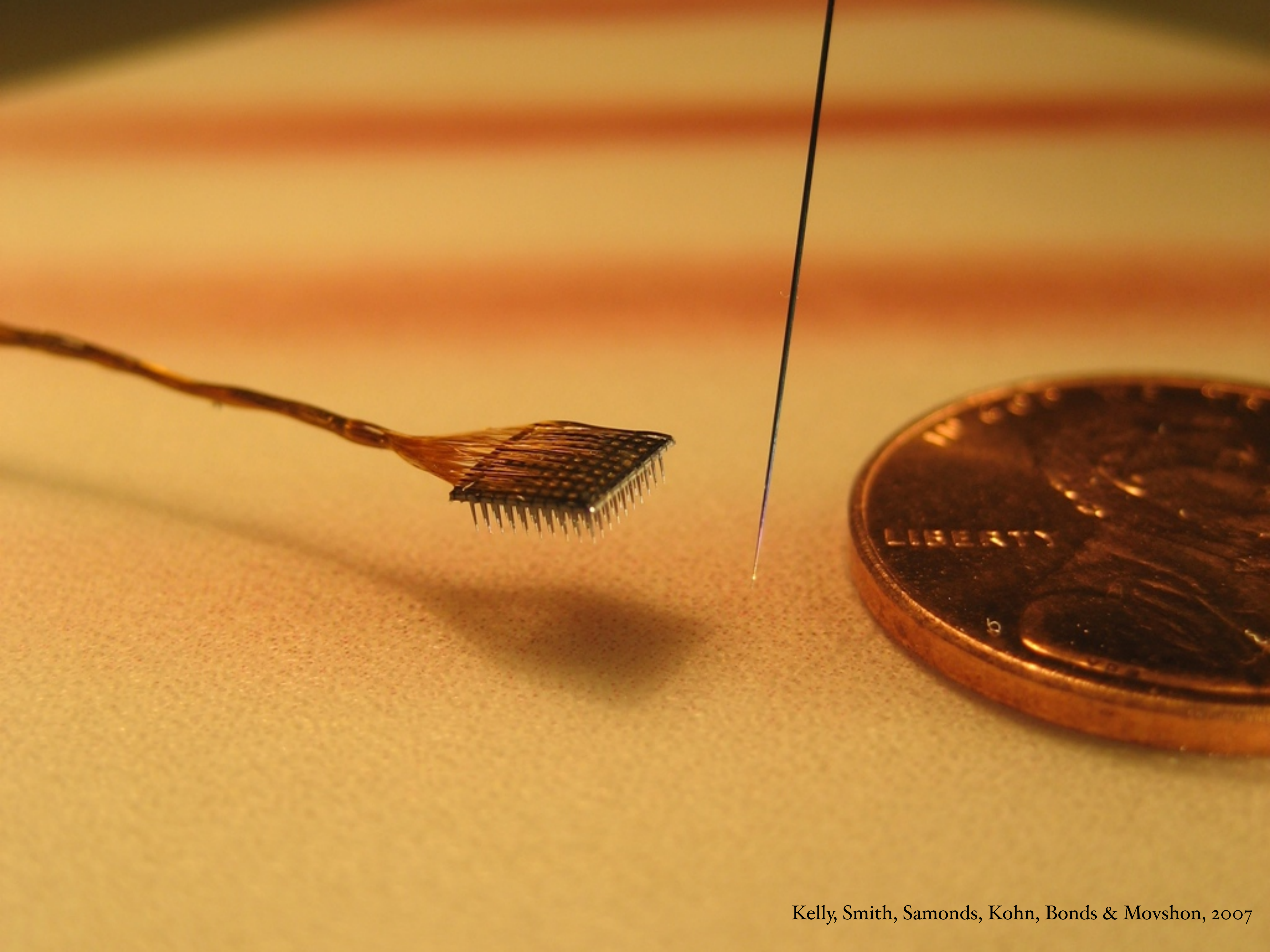
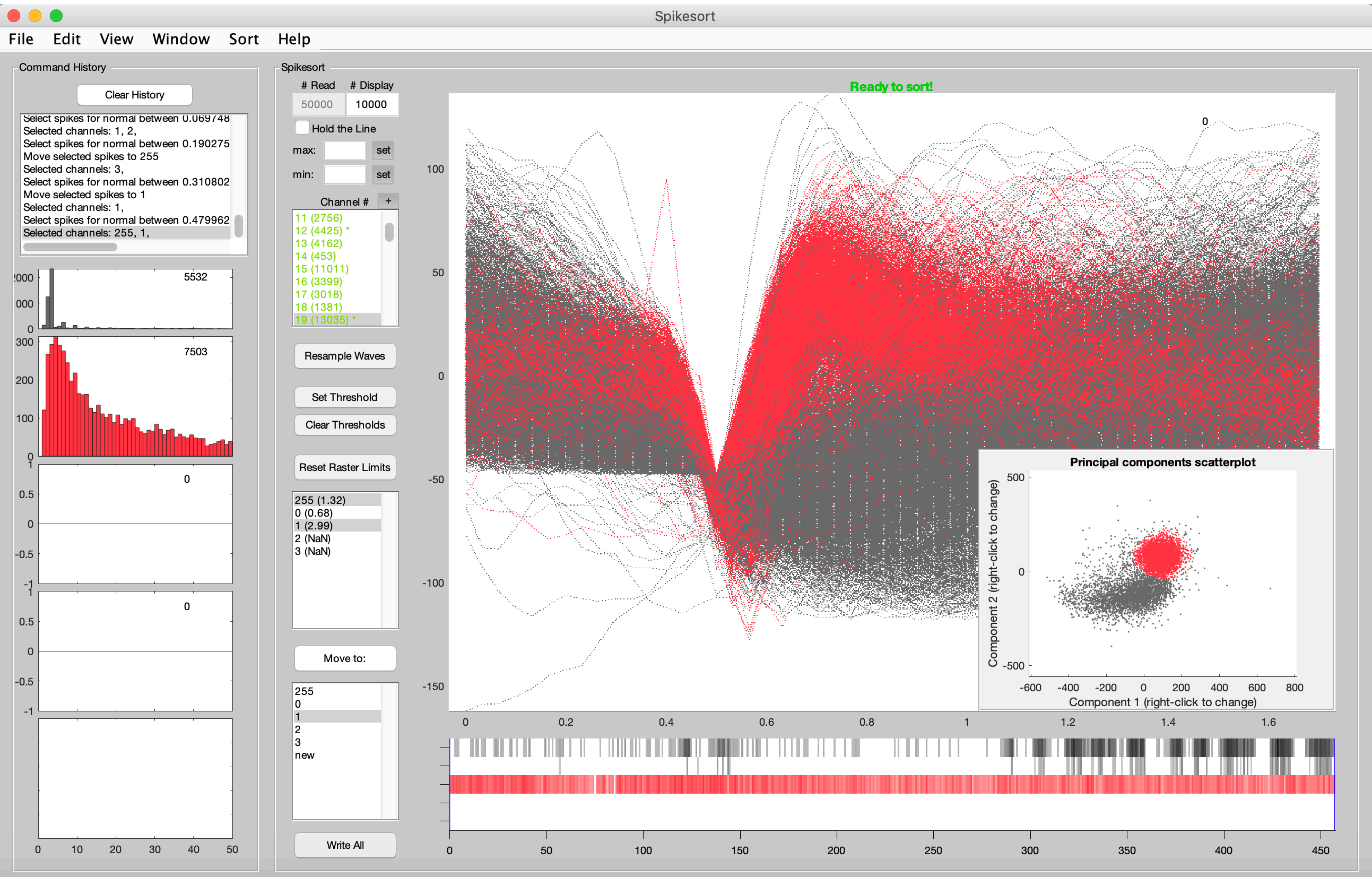
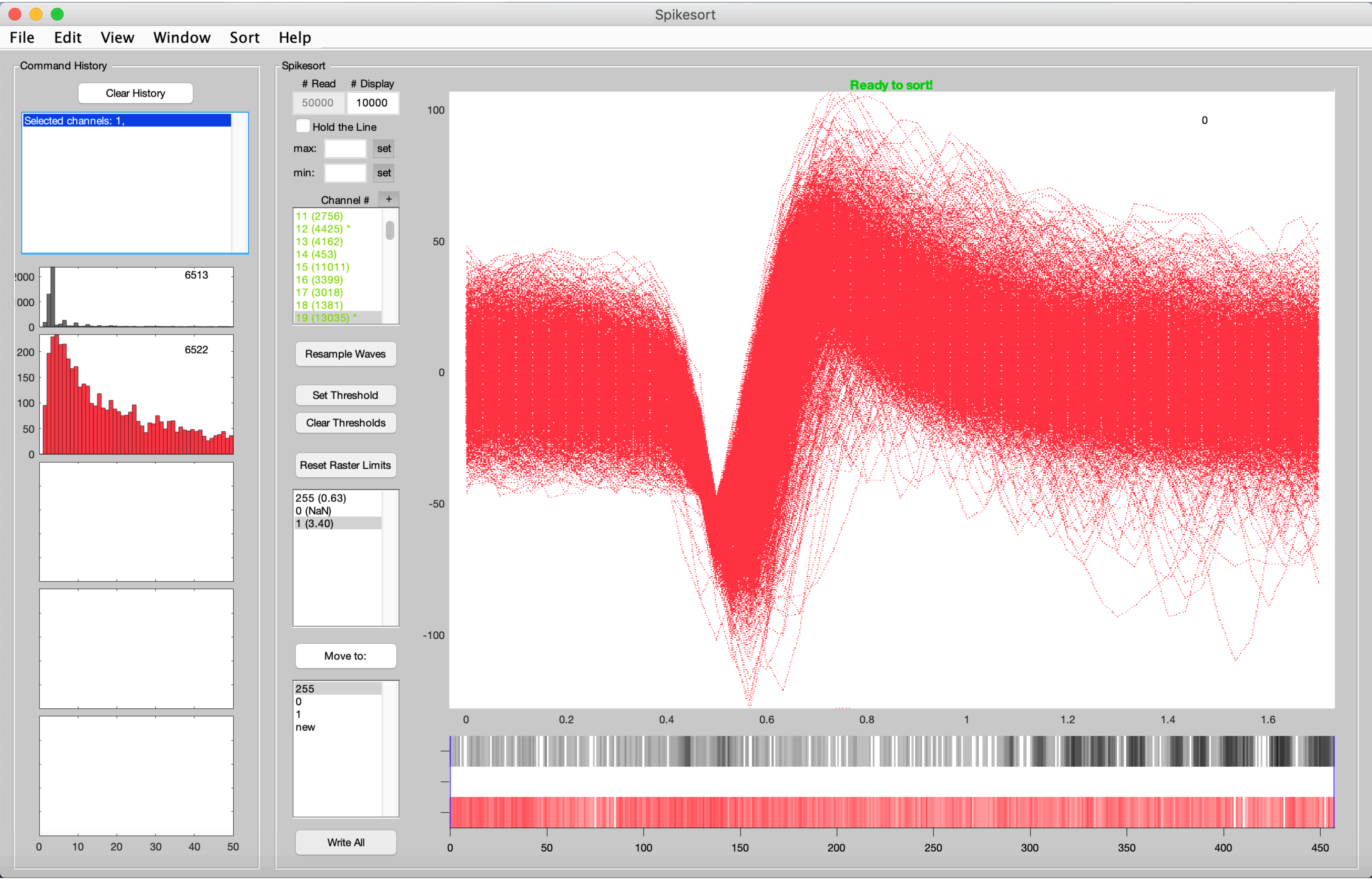
Hubel, 1988



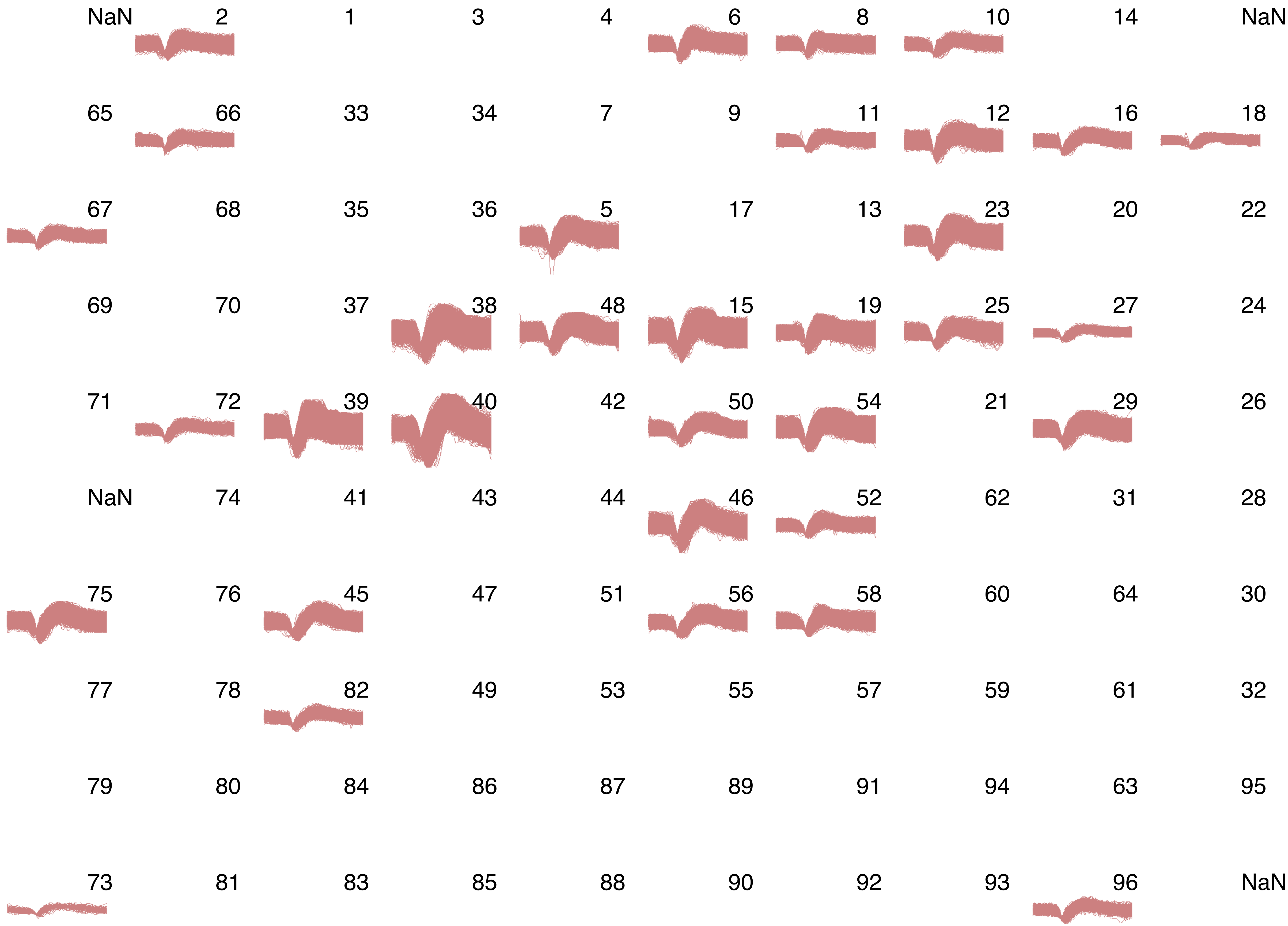
Kelly, Smith, Samonds, Kohn, Bonds & Movshon, 2007



https://github.com/smithlabvision/spikesort



https://github.com/smithlabvision/spikesort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67 68 35 36 5 17 13 23 20 22
69 70 37 38 48 15 19 25 27 24
71 72 39 40 42 50 54 21 29 26
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75 76 45 47 51 56 58 60 64 30
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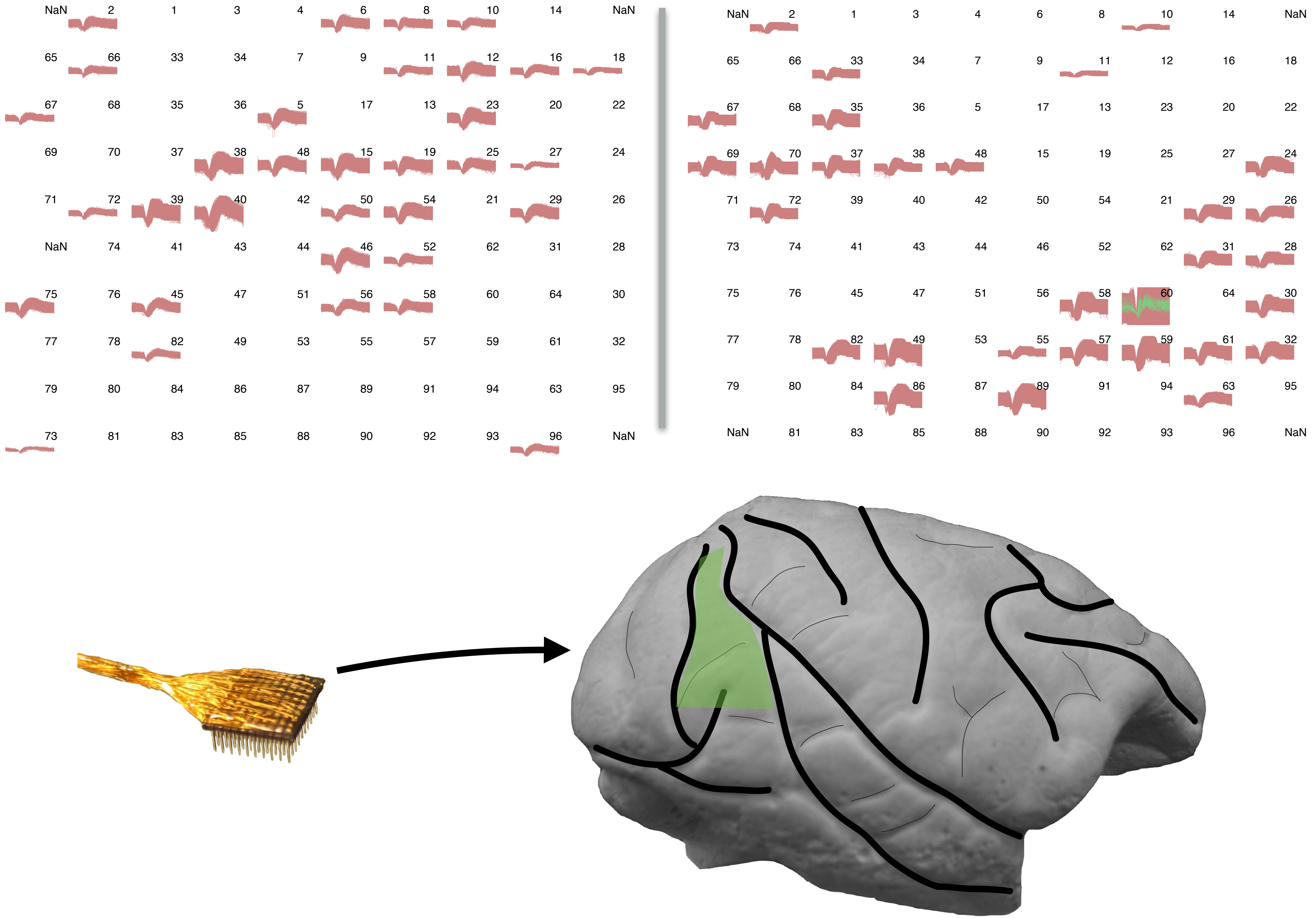
79 80 84 86 87 89 91 94 63 95
73 81 83 85 88 90 92 93 96 NaN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77 78 82 49 53 55 57 59 61 32
79 80 84 86 87 89 91 94 63 95
73 81 83 85 88 90 92 93 96 NaN
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65 66 33 34 7 9 11 12 16 18
67 68 35 36 5 17 13 23 20 22
69 70 37 38 48 15 19 25 27 24
71 72 39 40 42 50 54 21 29 26
73 74 41 43 44 46 52 62 31 28
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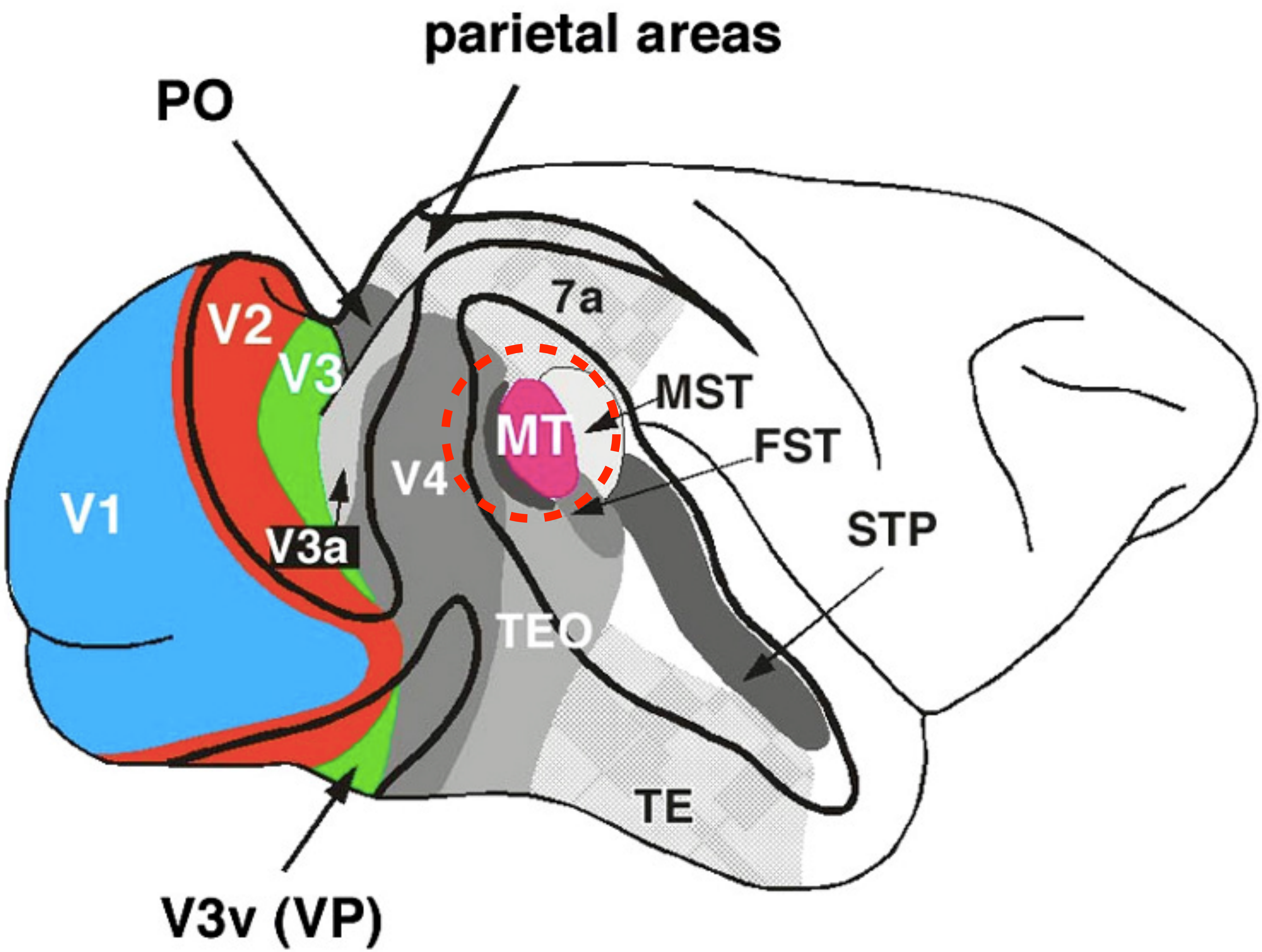
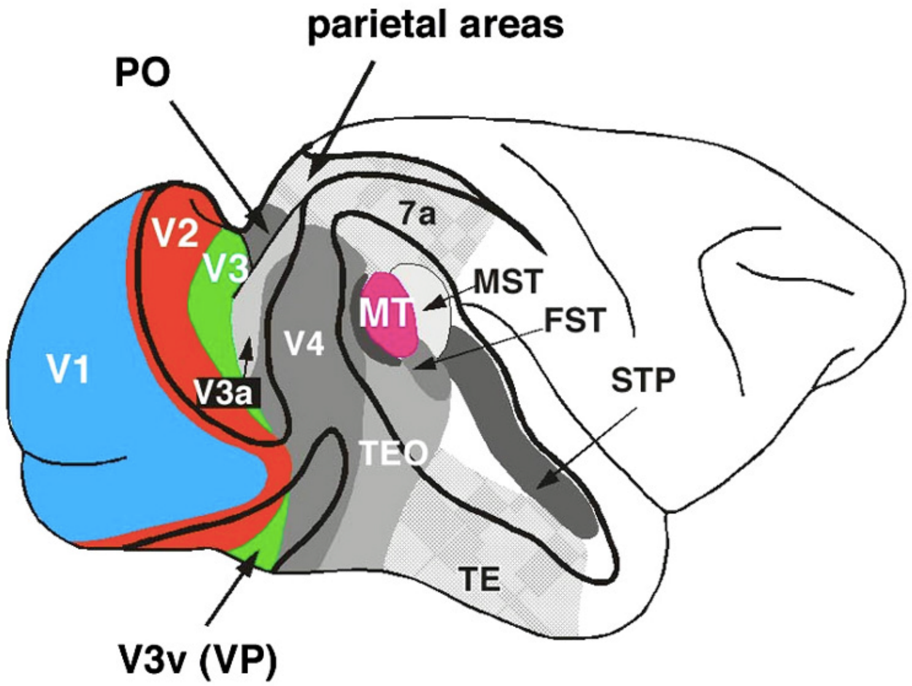
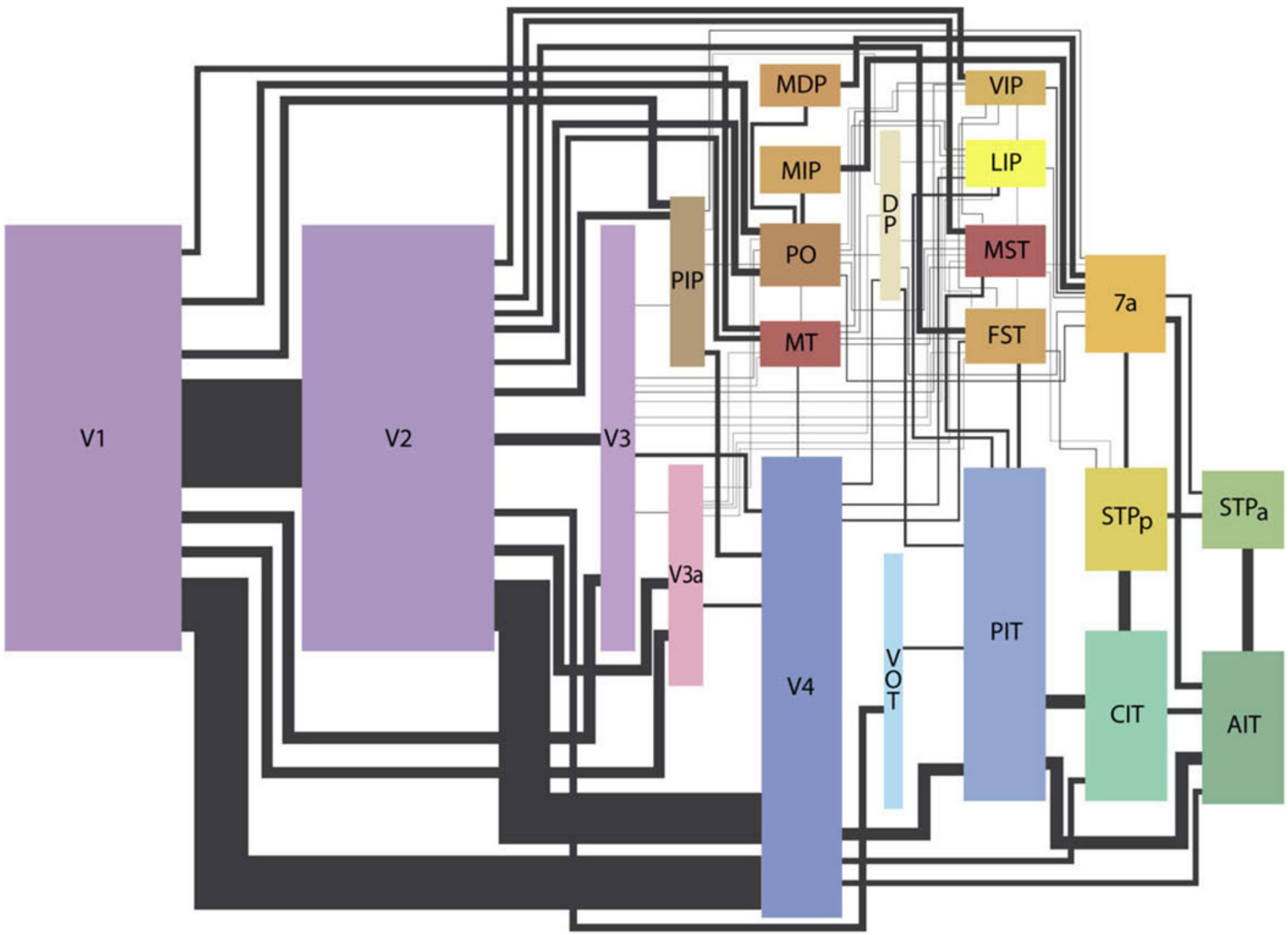
77 78 82 49 53 55 57 59 61 32
79 80 84 86 87 89 91 94 63 95
NaN 81 83 85 88 90 92 93 96 NaN

Macaque Cortex



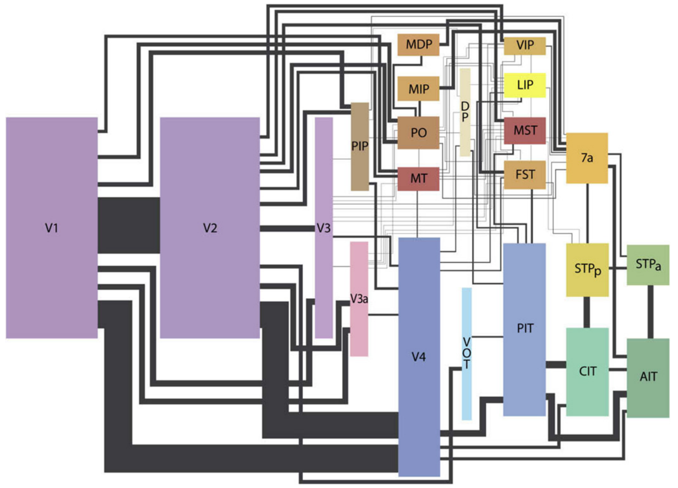
Macaque Cortex

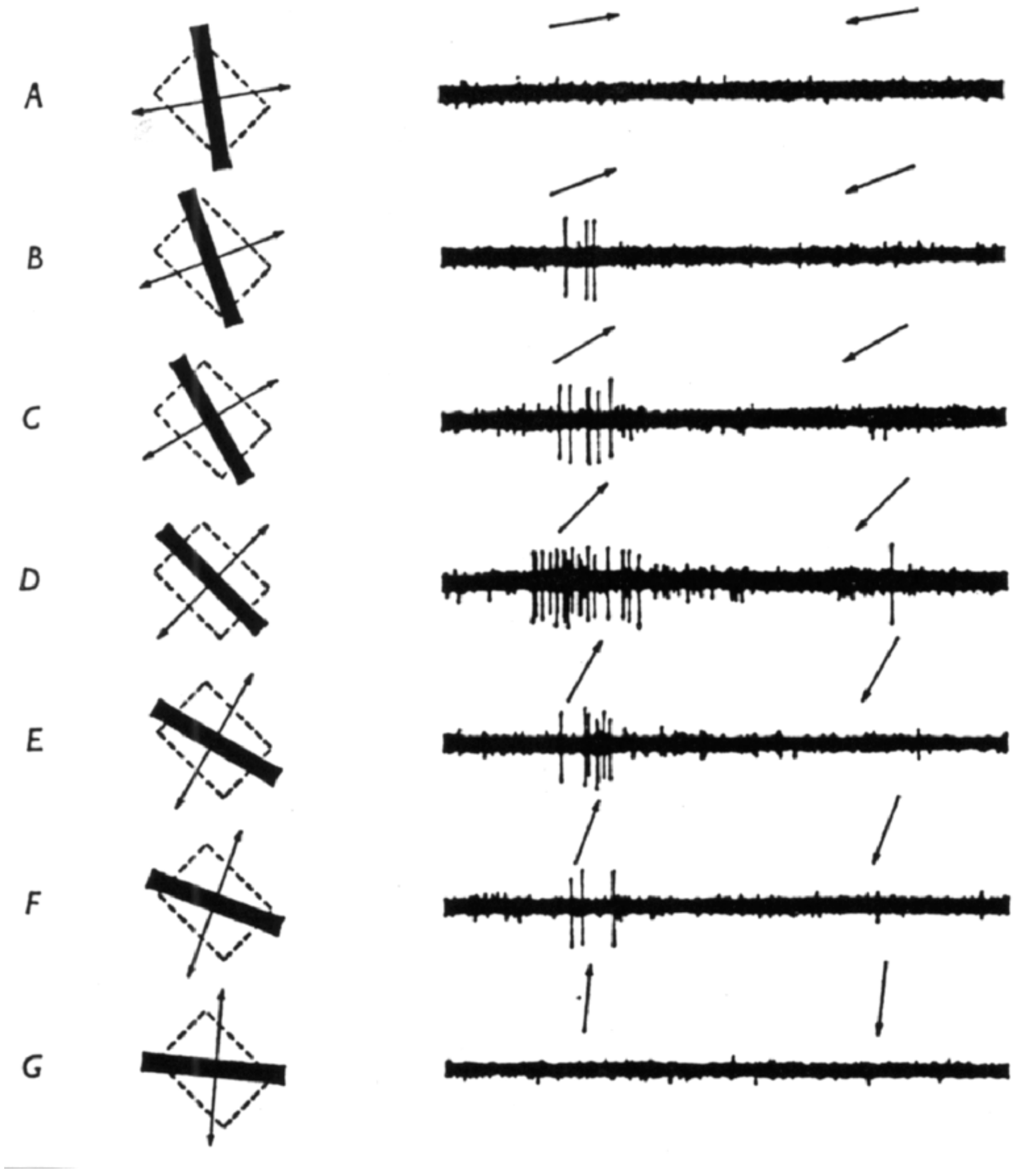




Wallisch & Movshon, 2008

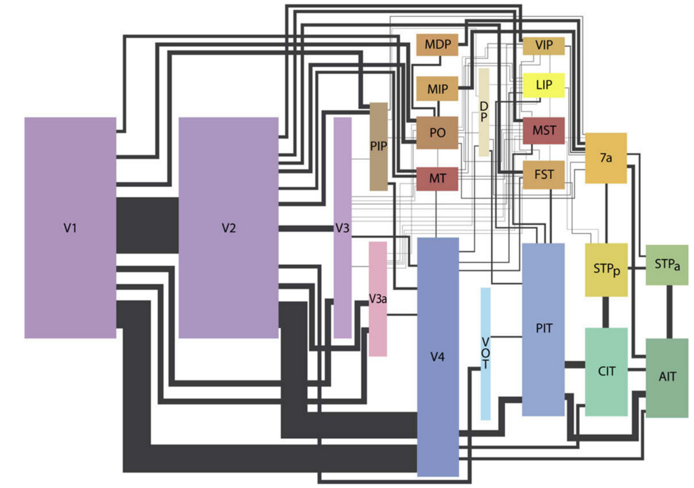
Visual Cortex (V1)

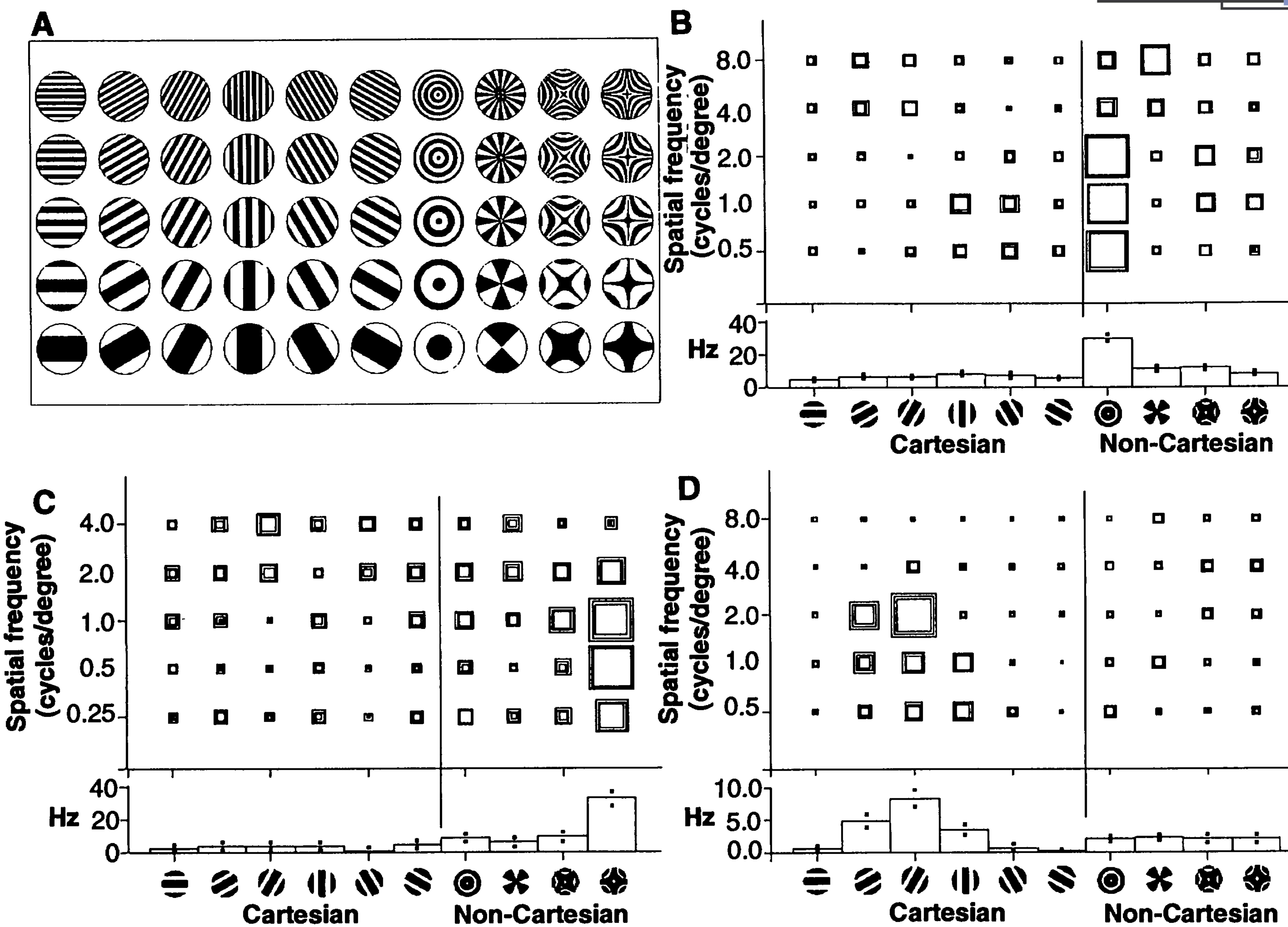




Hubel & Wiesel, 1968

Visual Cortex (V4)





Experimental Task

look at fixation dot

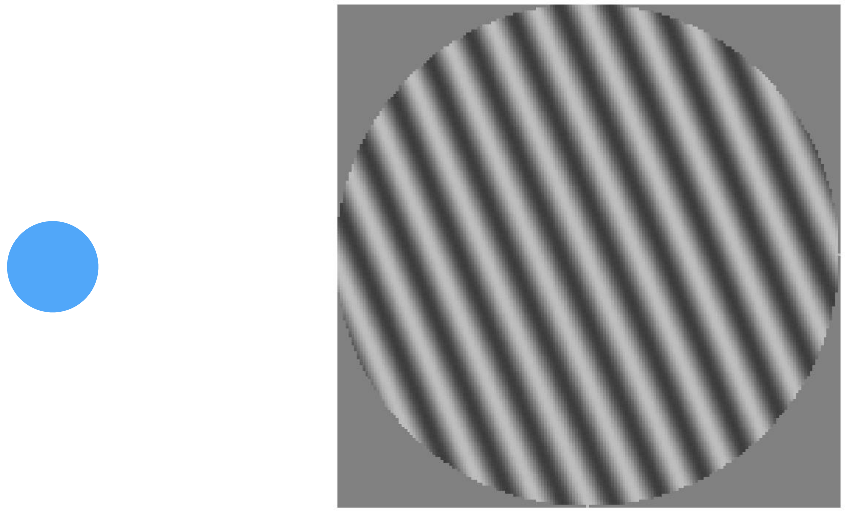
Experimental Task

Experimental Task

maintain fixation (0.5 or 1.0 s)

Experimental Task

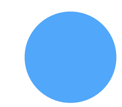
Experimental Task



maintain fixation (1.0 s stimulus duration)

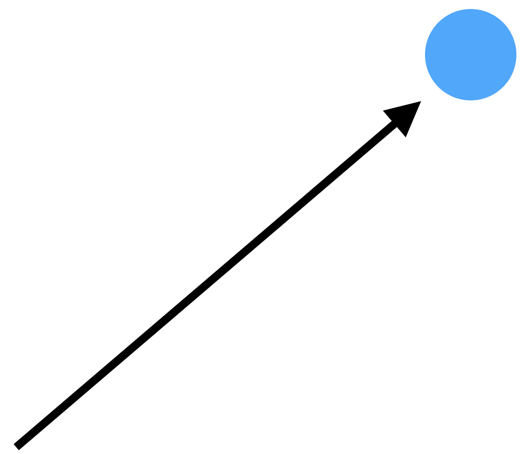
Experimental Task

Experimental Task



fixation dot jumps to random location

Experimental Task



saccade to dot to receive reward

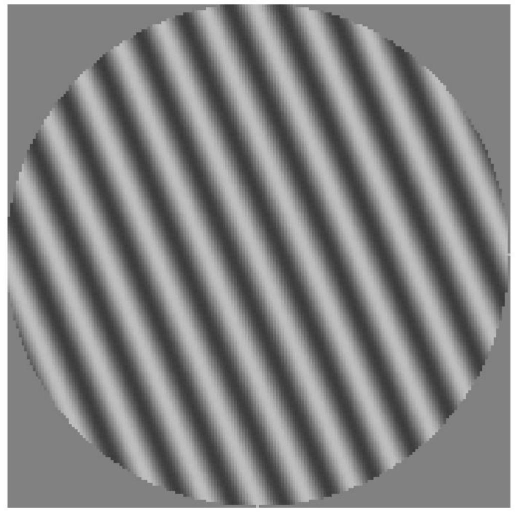
Experimental Task

saccade to dot to receive reward

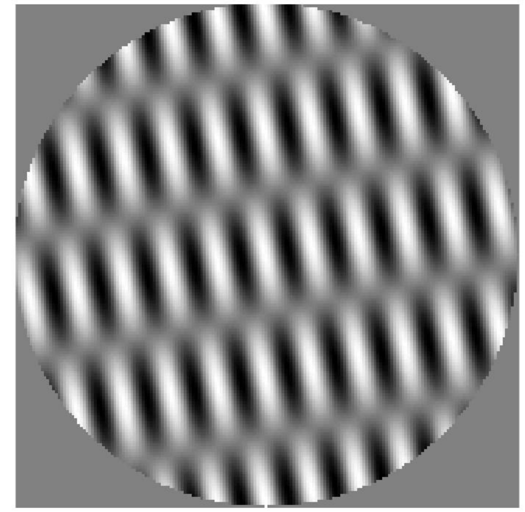
Visual stimuli

8 orientations spaced by 22.5° (or a blank)

Grating



Plaid

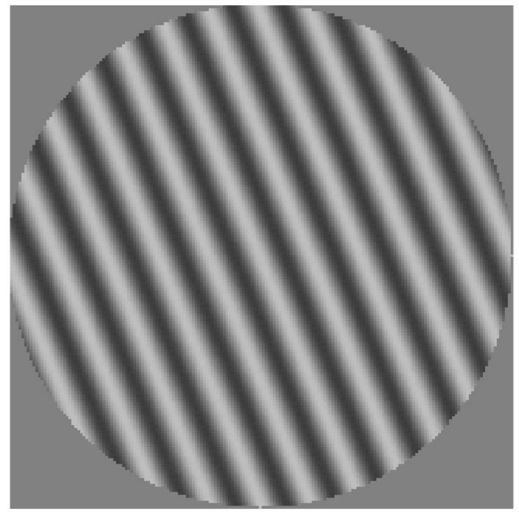


81 possible stimuli

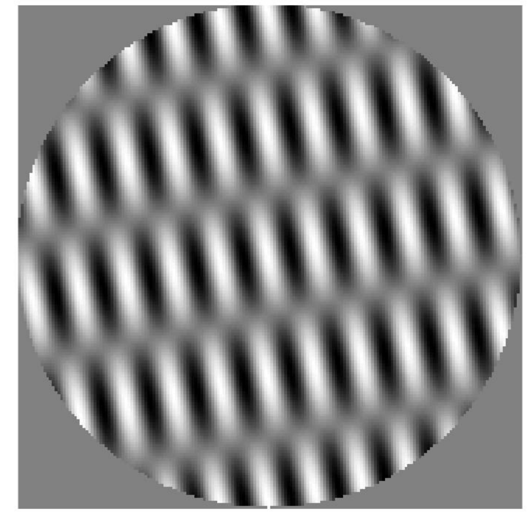
Visual stimuli

8 orientations spaced by 22.5° (or a blank)

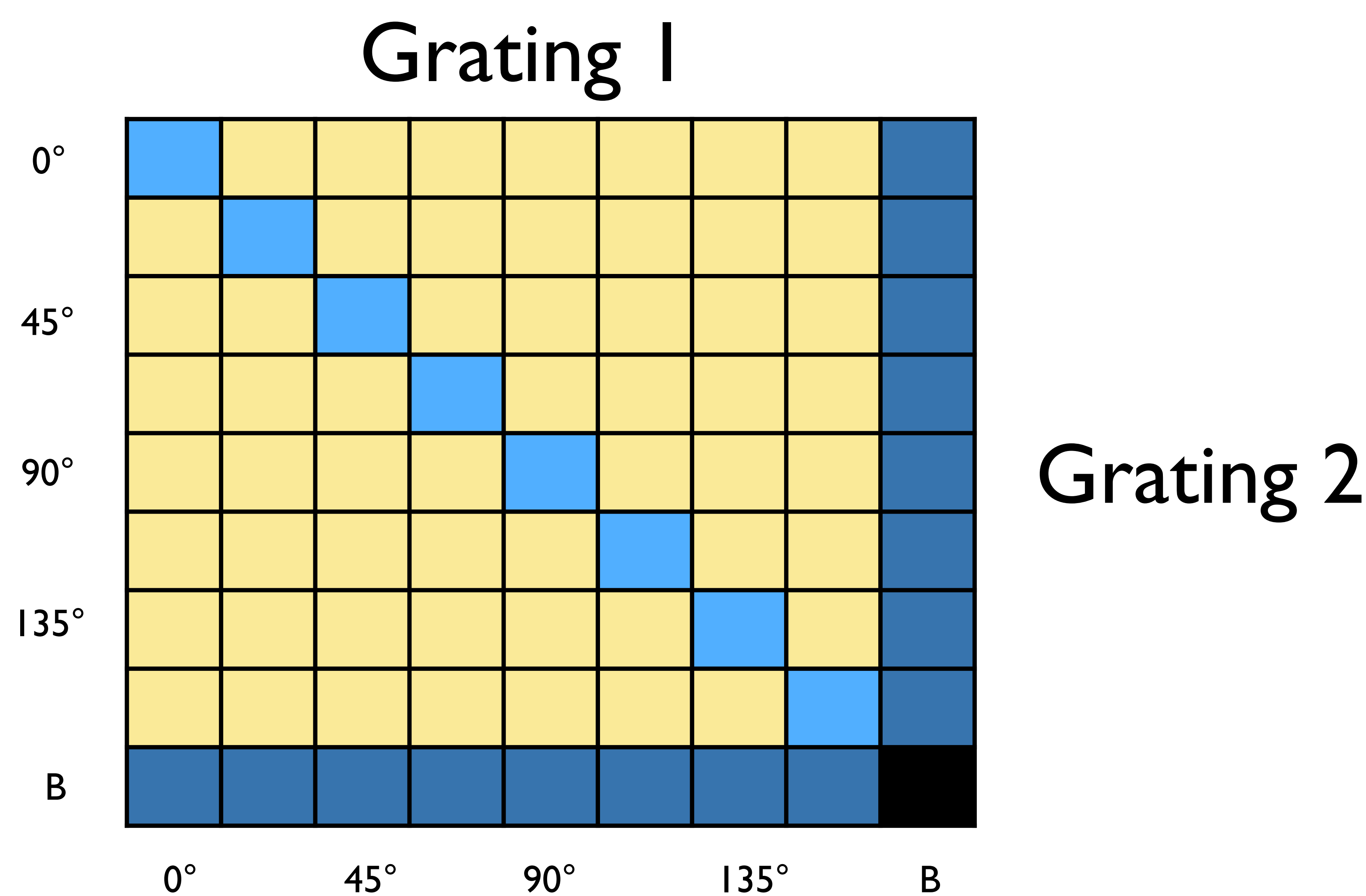
Grating



Plaid

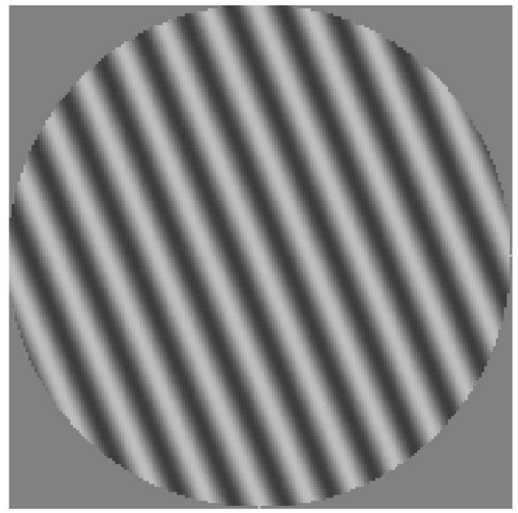


81 possible stimuli

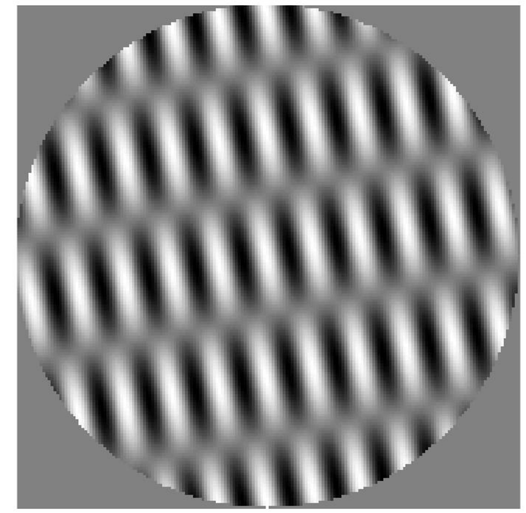


Visual stimuli

Grating

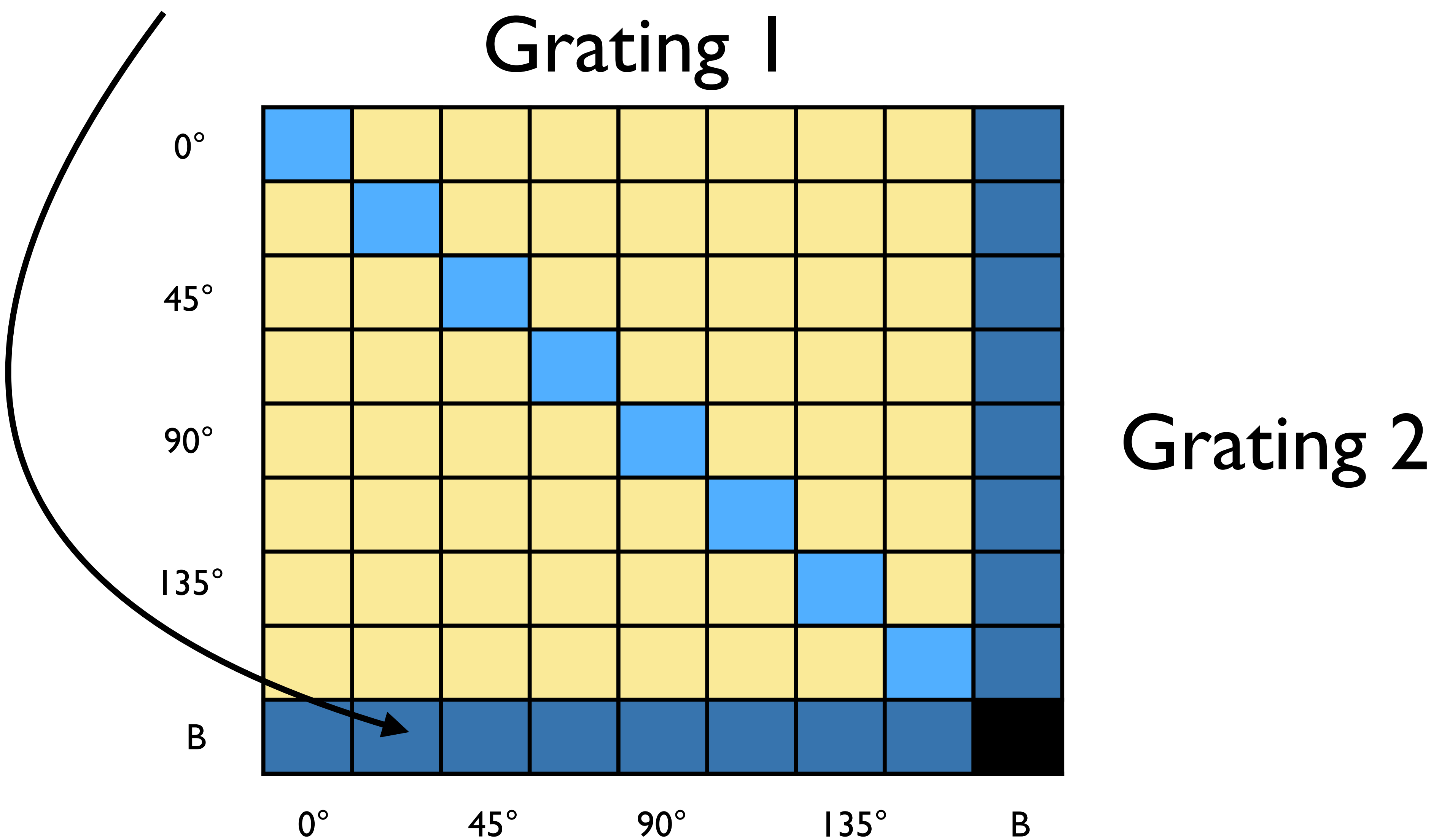


Plaid



8 orientations spaced by 22.5° (or a blank)

81 possible stimuli

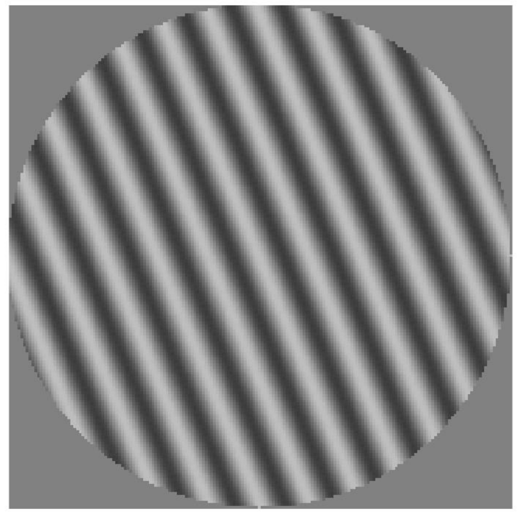


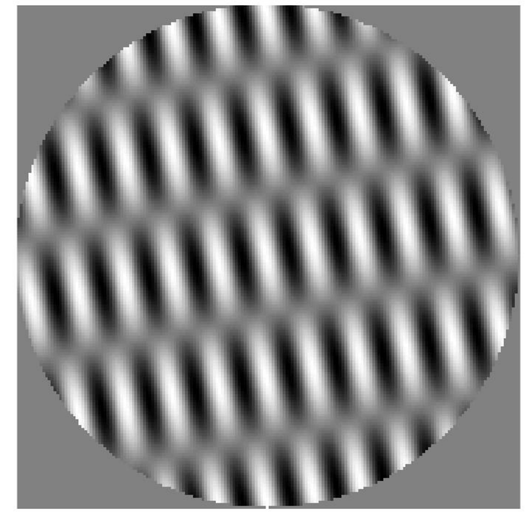
Visual stimuli

Grating

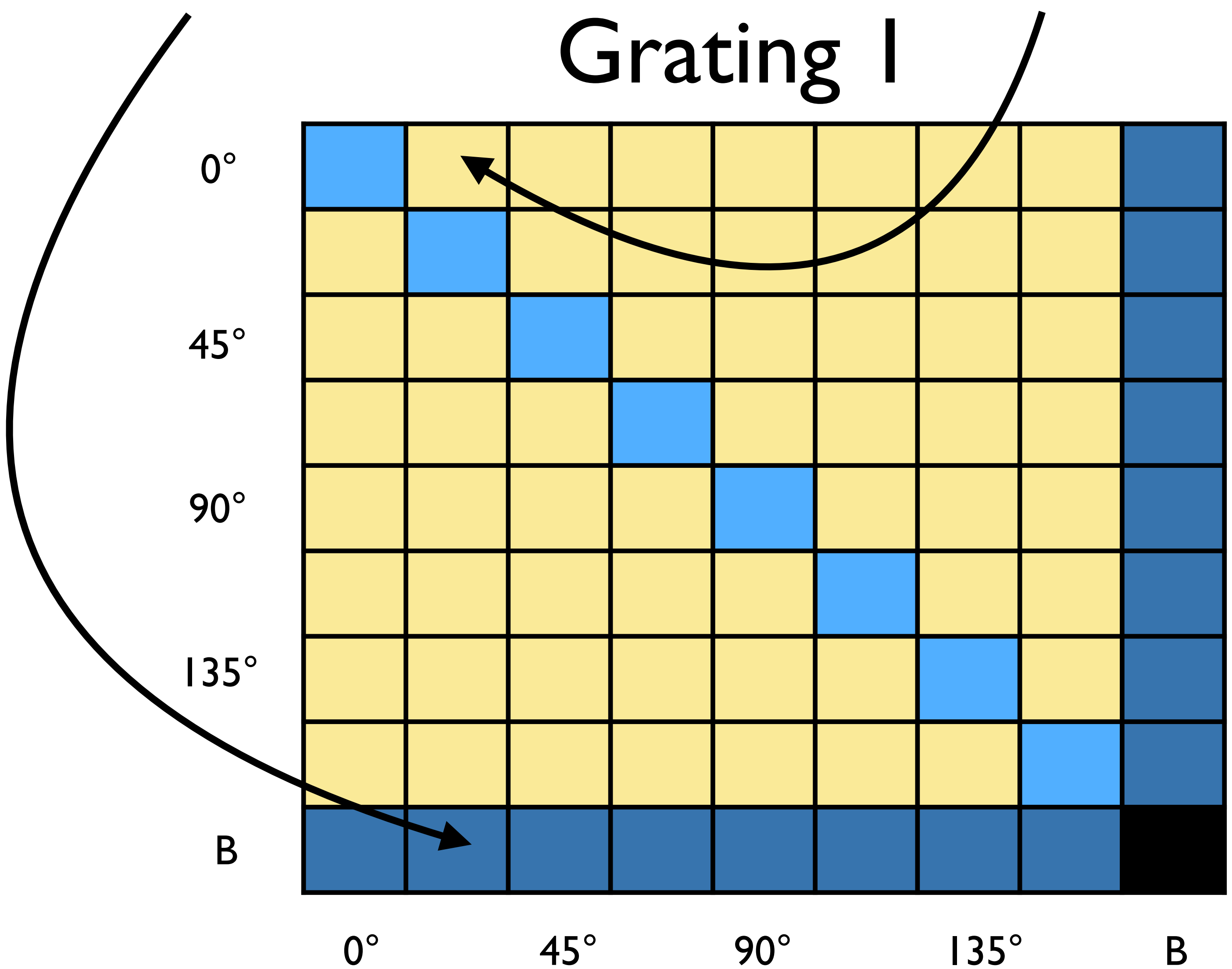
Plaid

8 orientations spaced by 22.5° (or a blank)





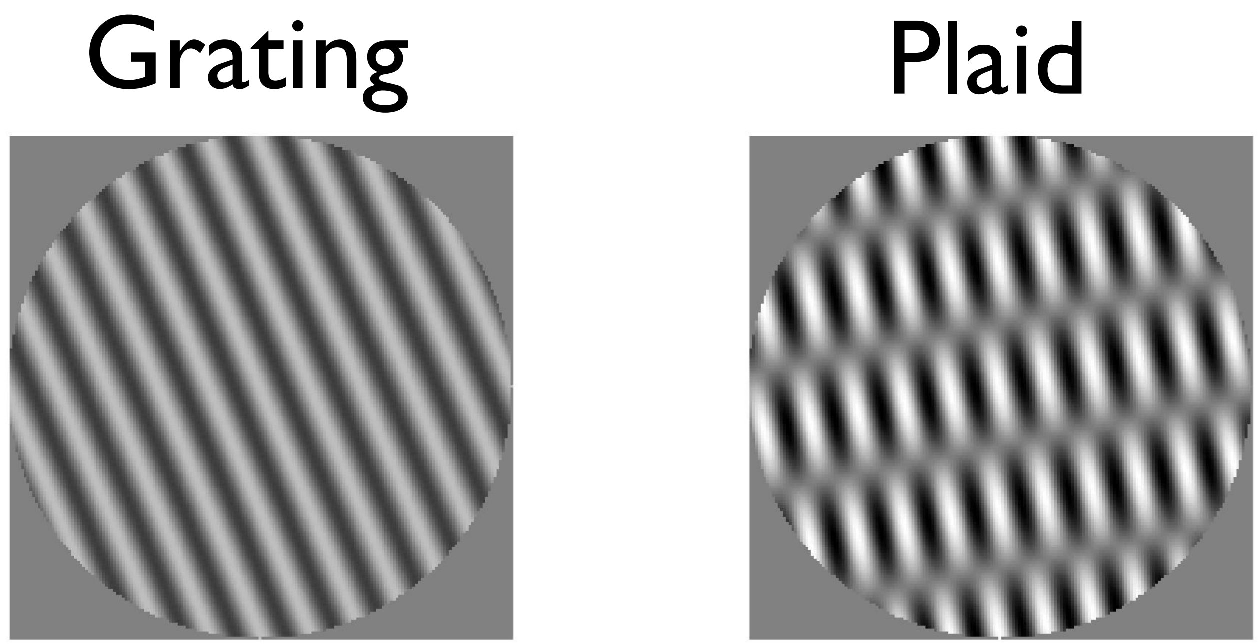
81 possible stimuli



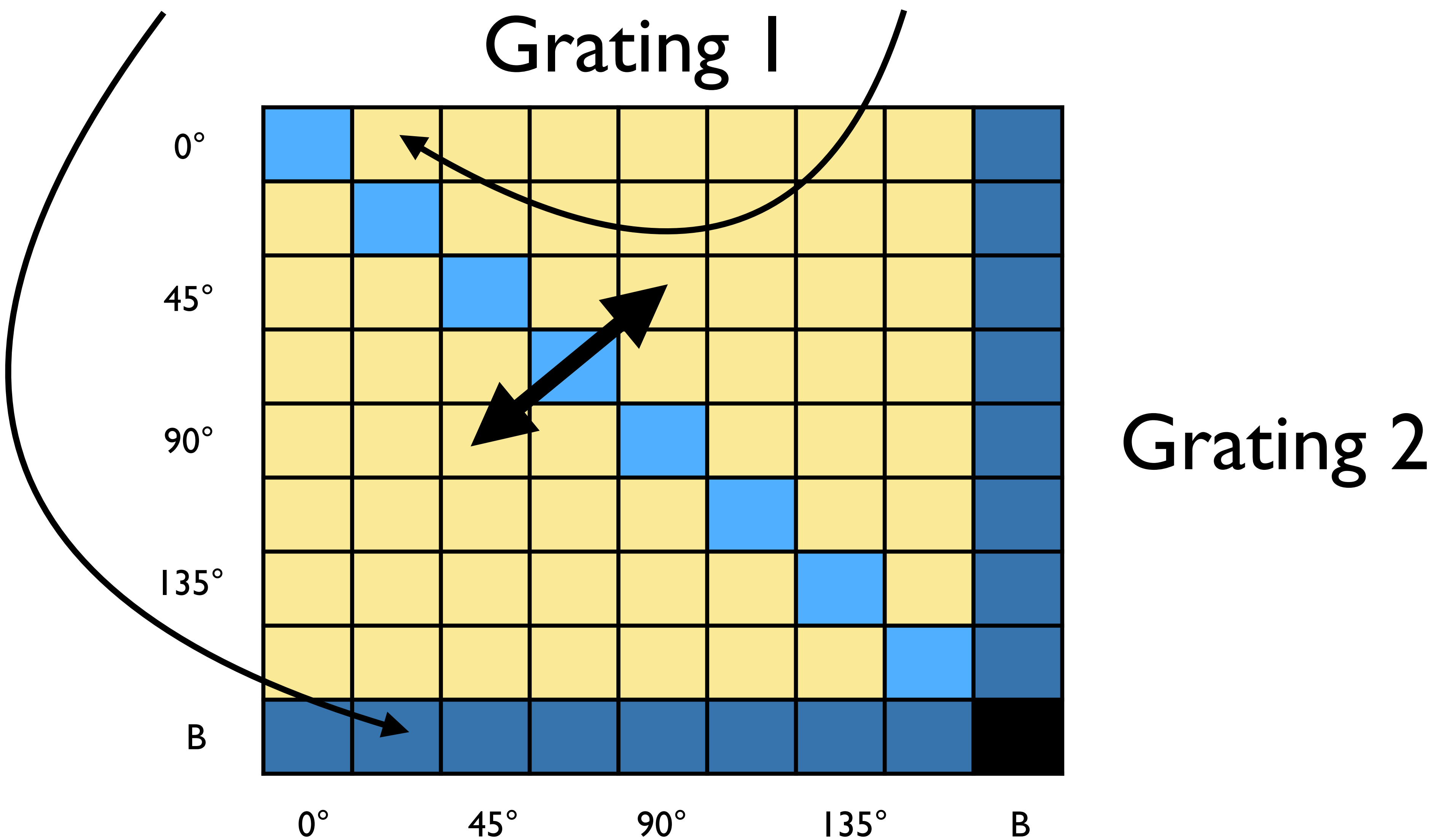
Grating 2

Visual stimuli

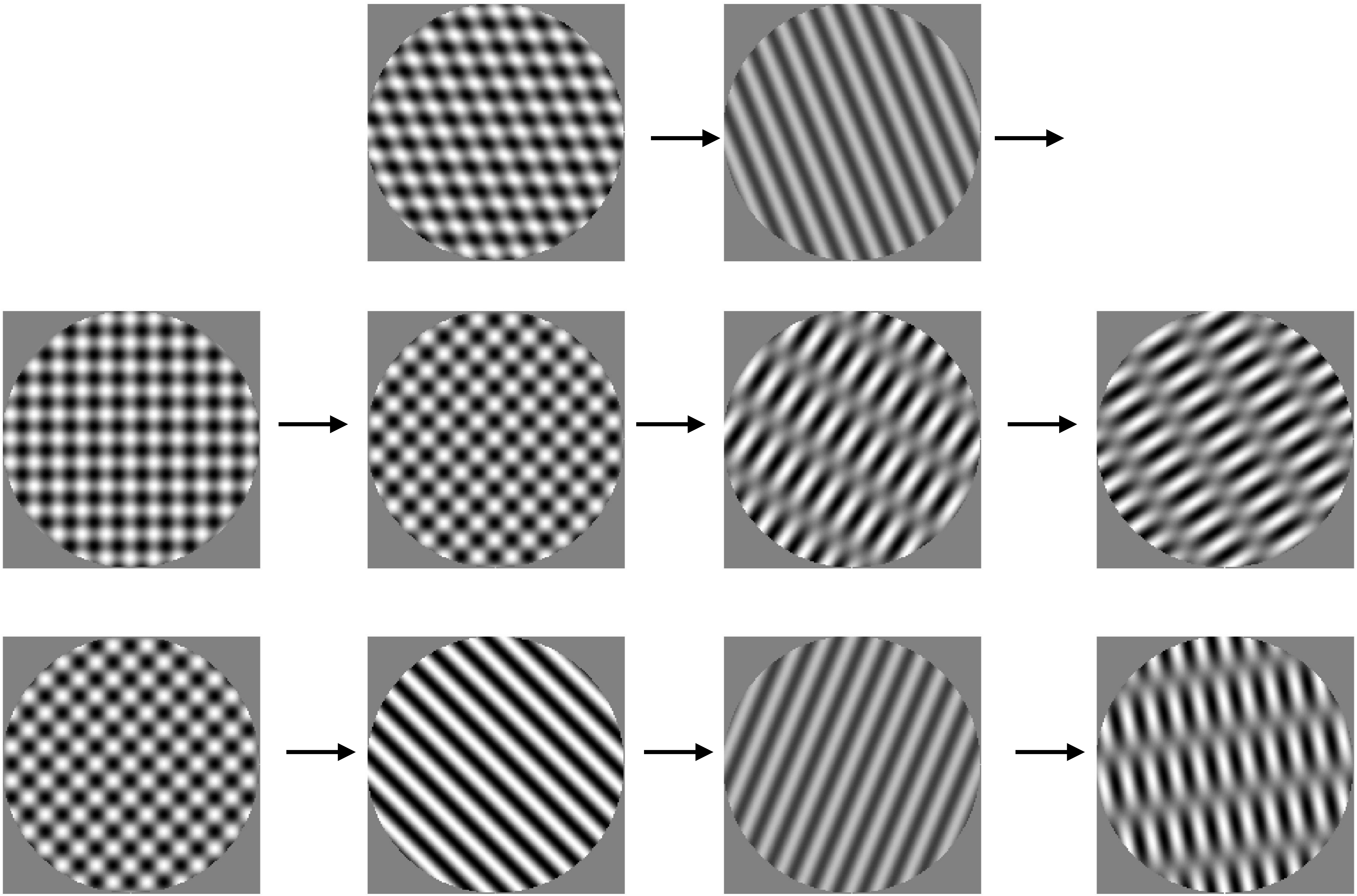
8 orientations spaced by 22.5° (or a blank)



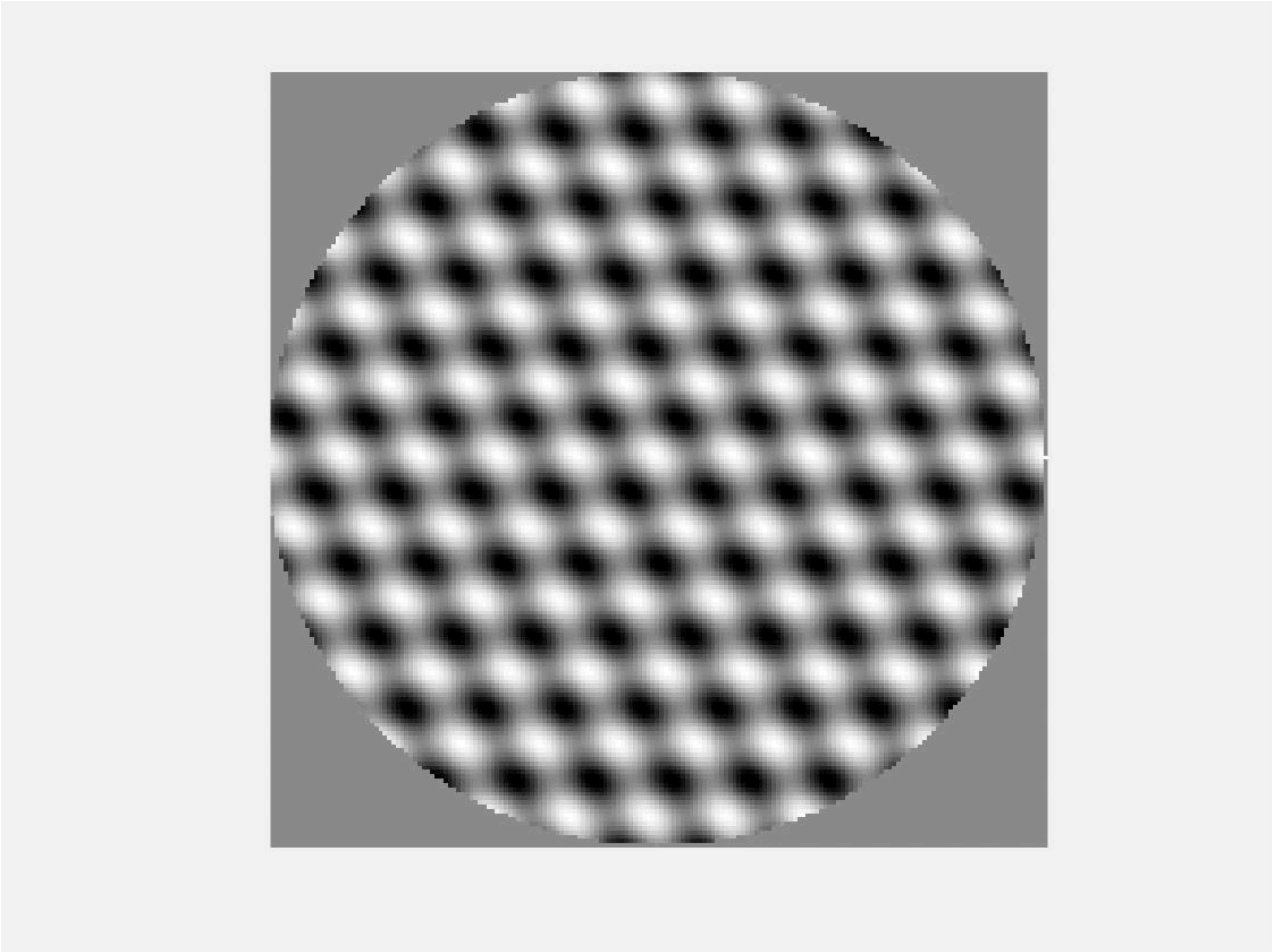
81 possible stimuli



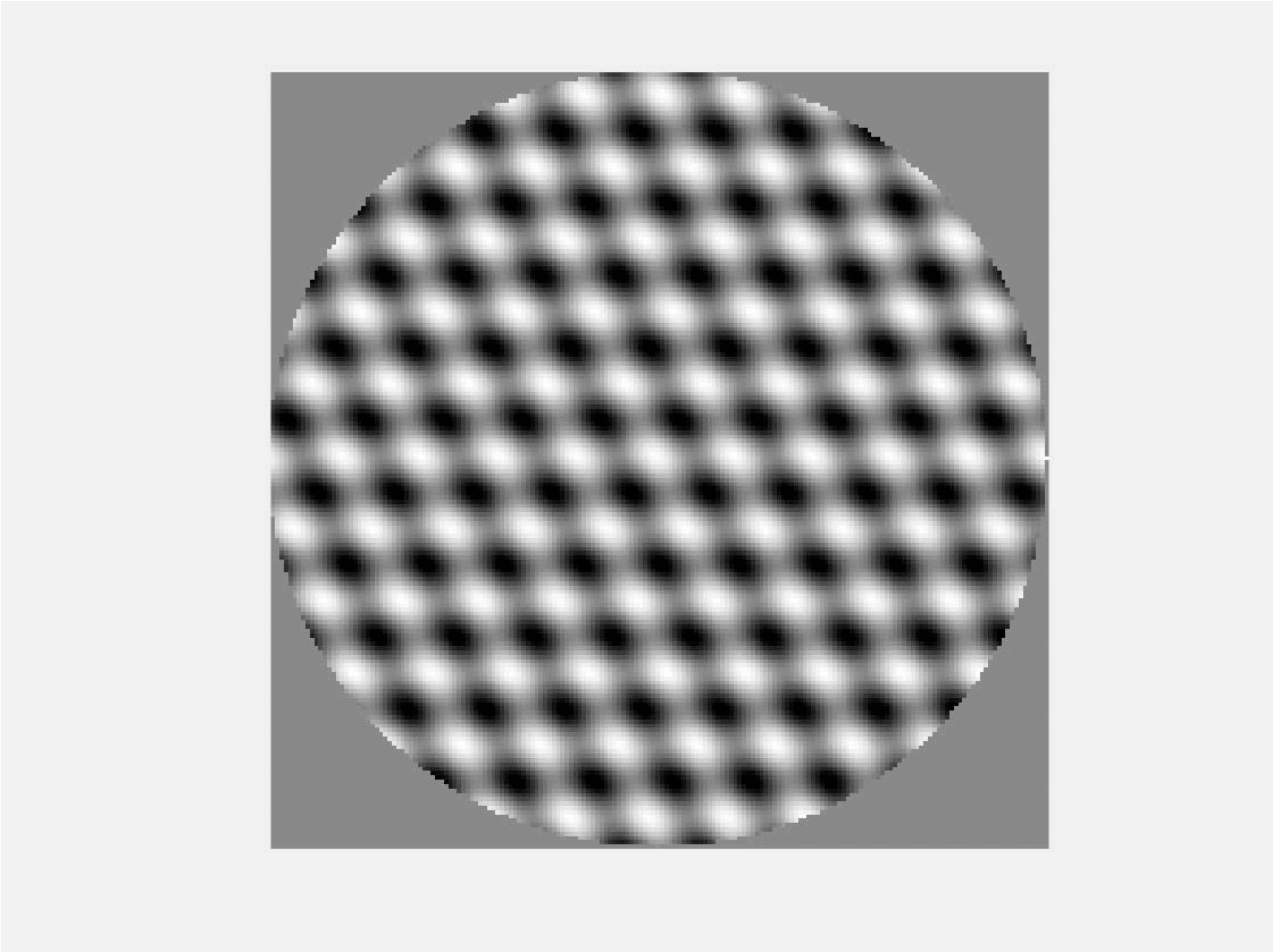
Visual stimuli (10 stimuli per fixation, 100 ms each)



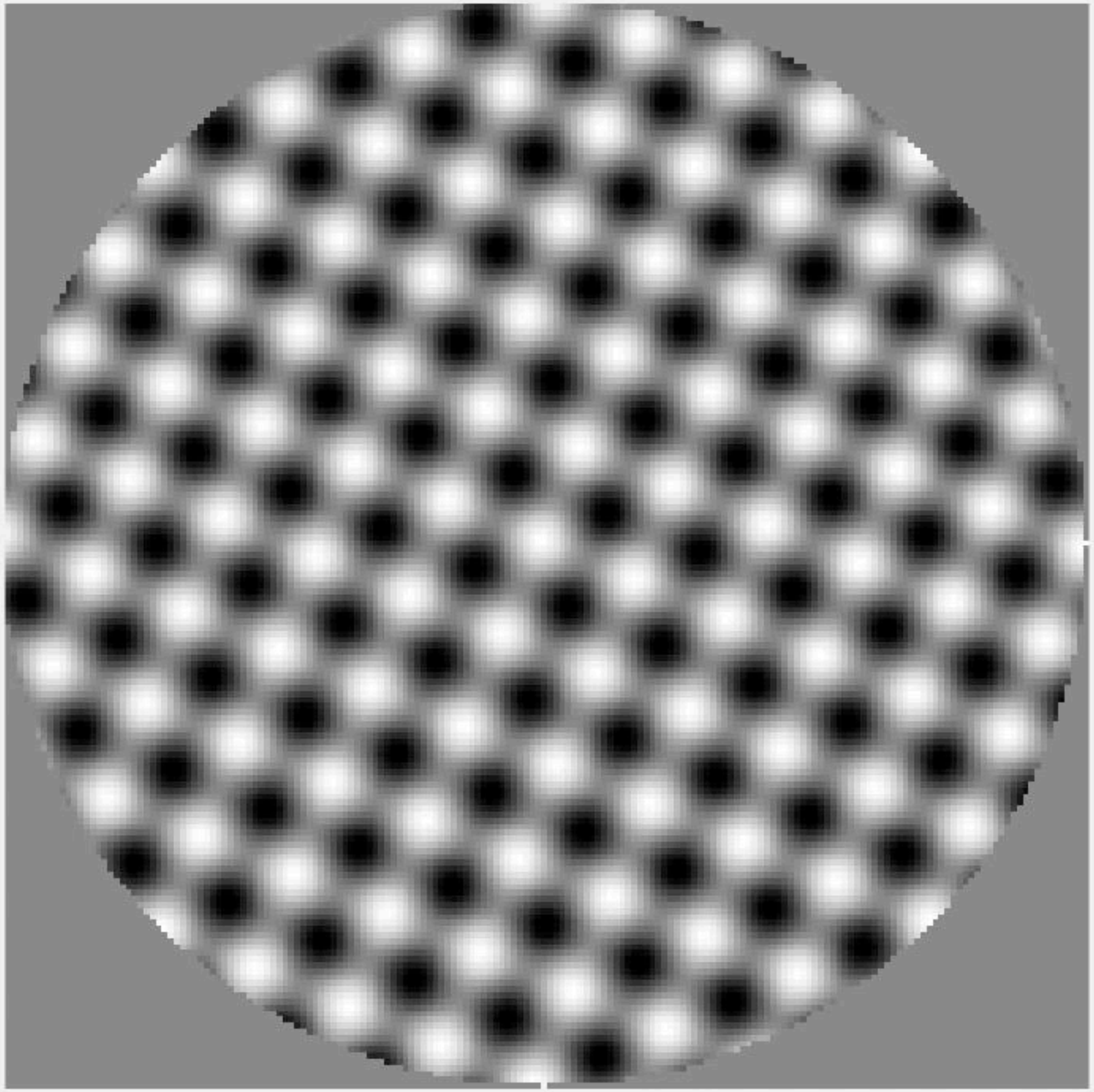
Visual Stimulus



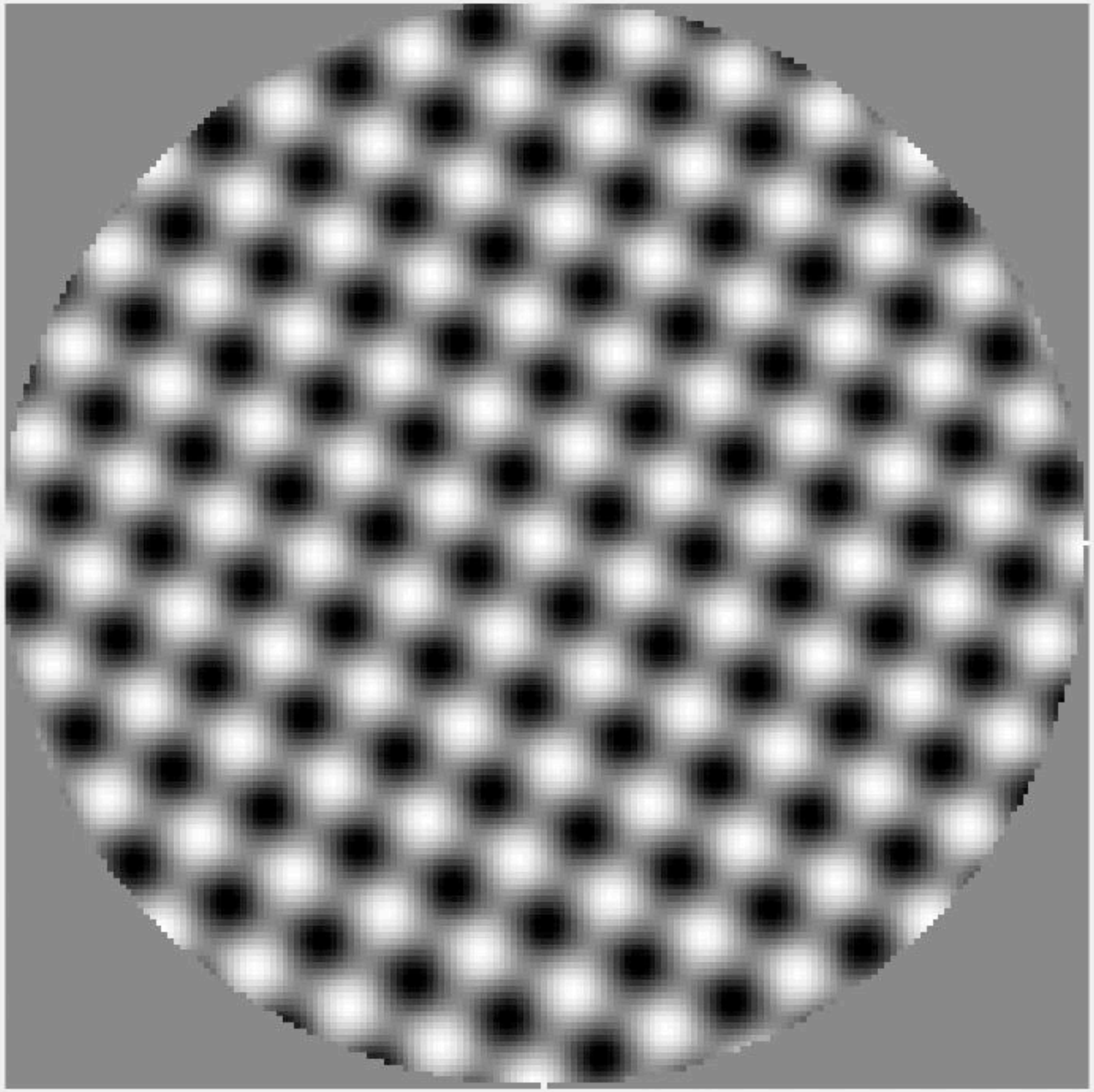
Visual Stimulus



Visual Stimulus

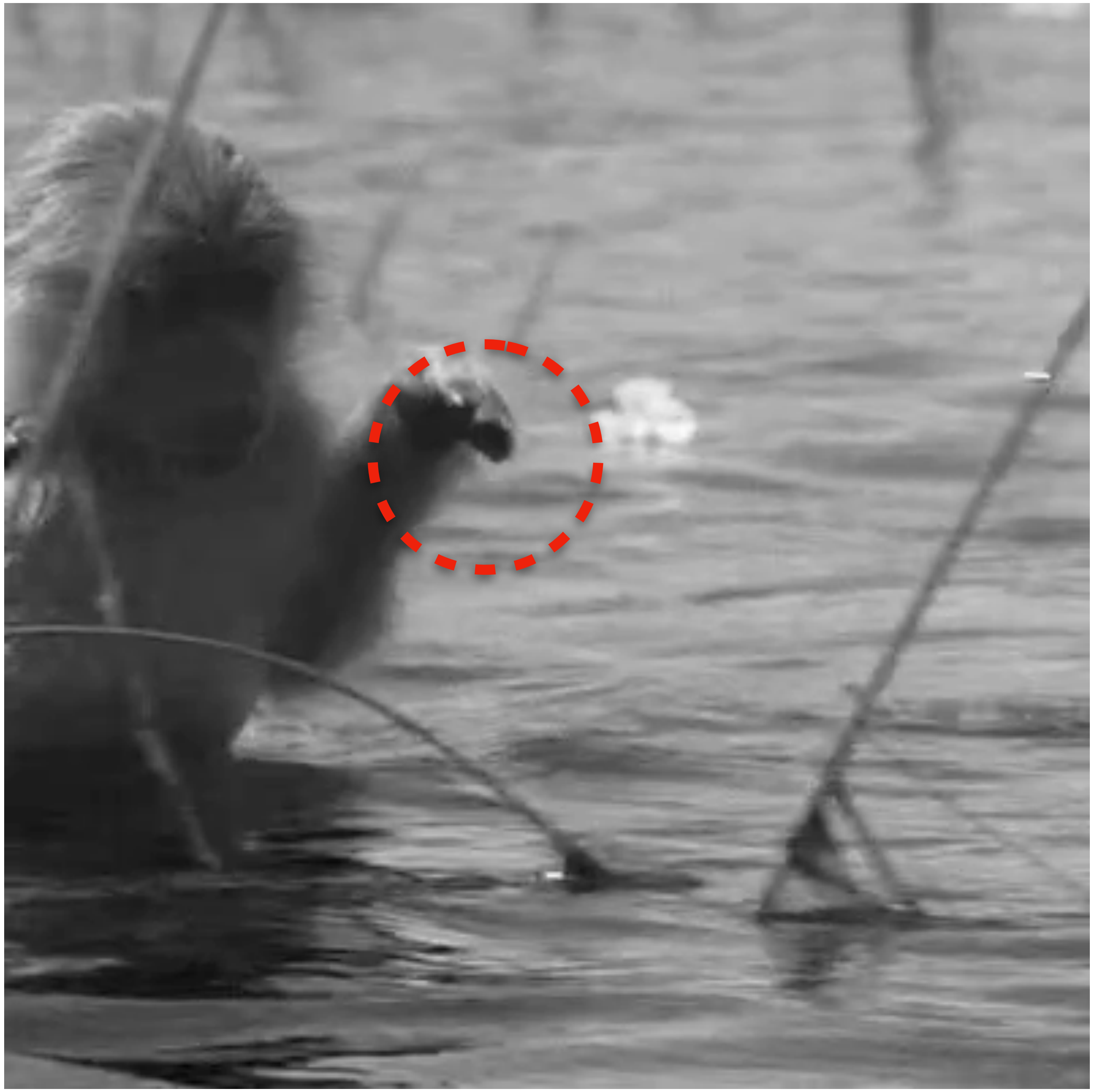


Visual Stimulus

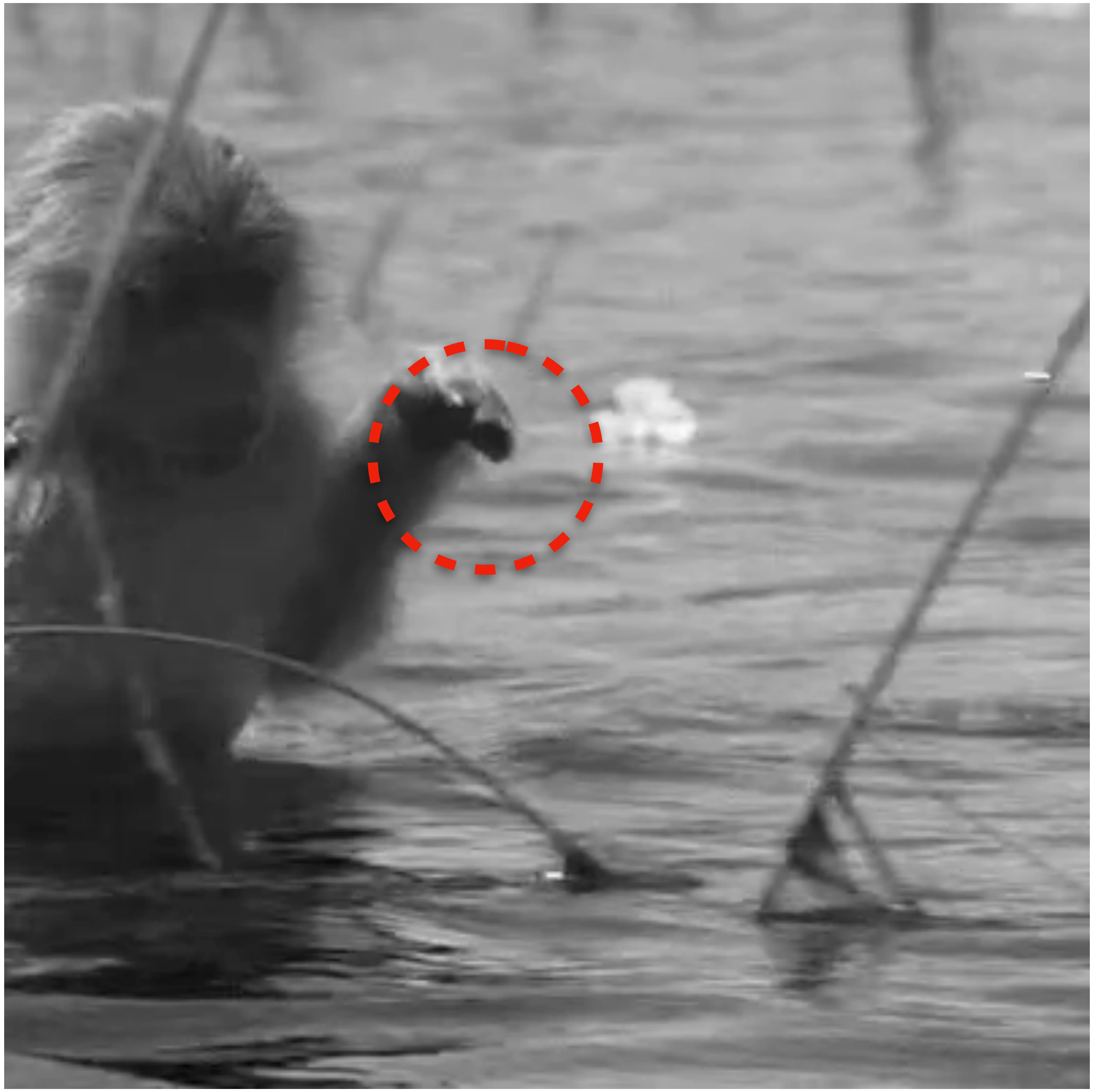


Neurons are noisy

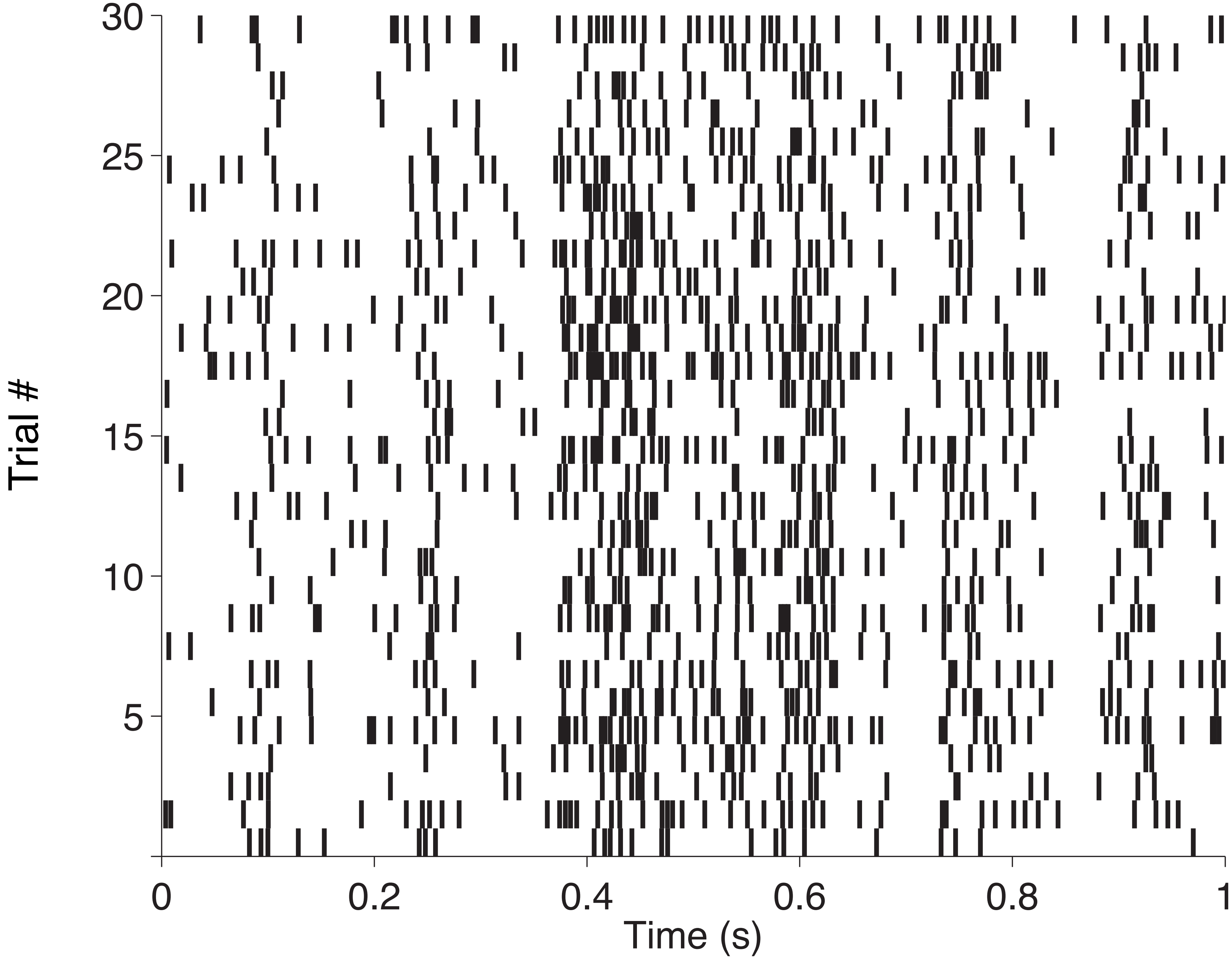
Neurons are noisy



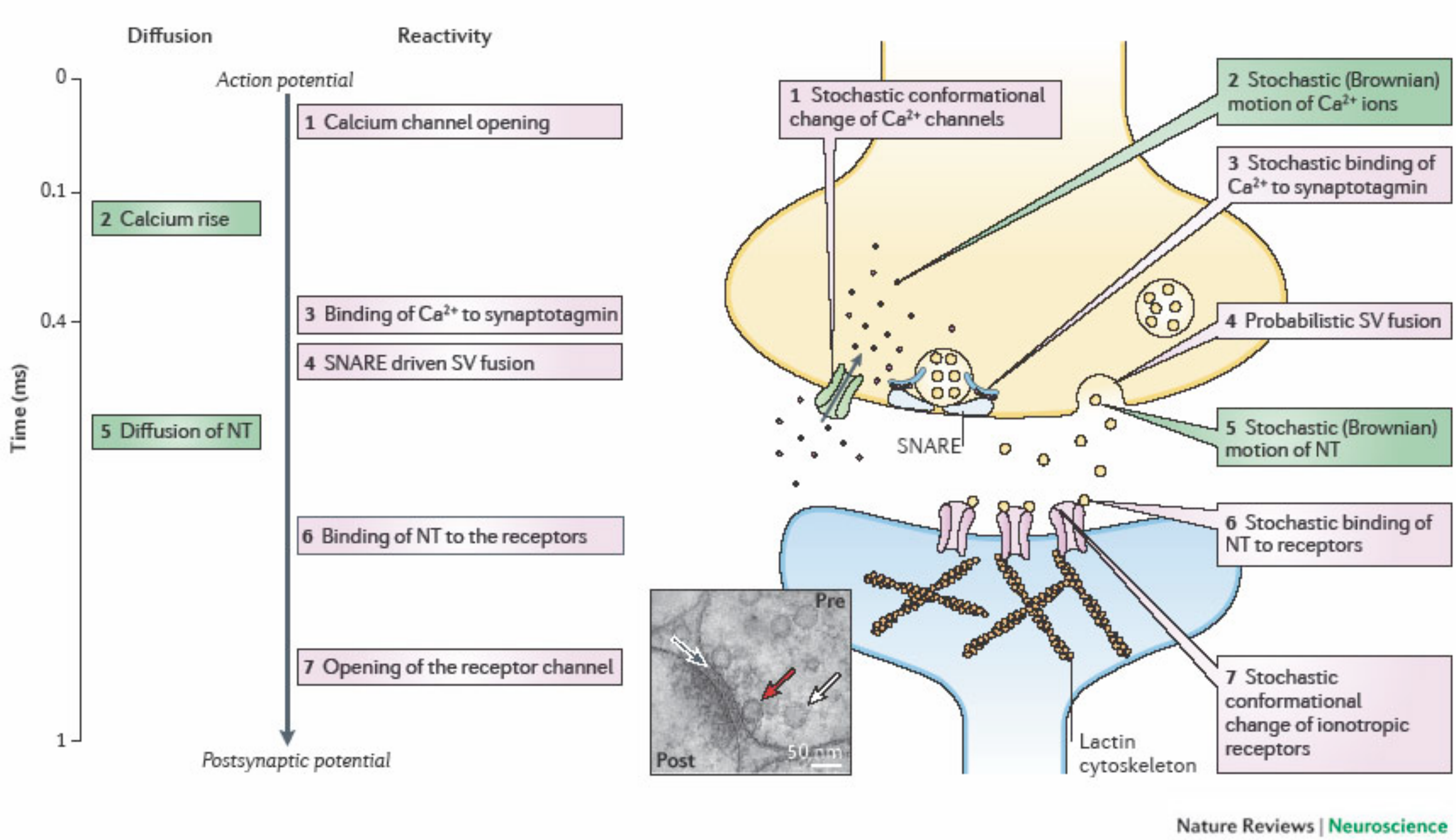
Neurons are noisy



Neurons are noisy

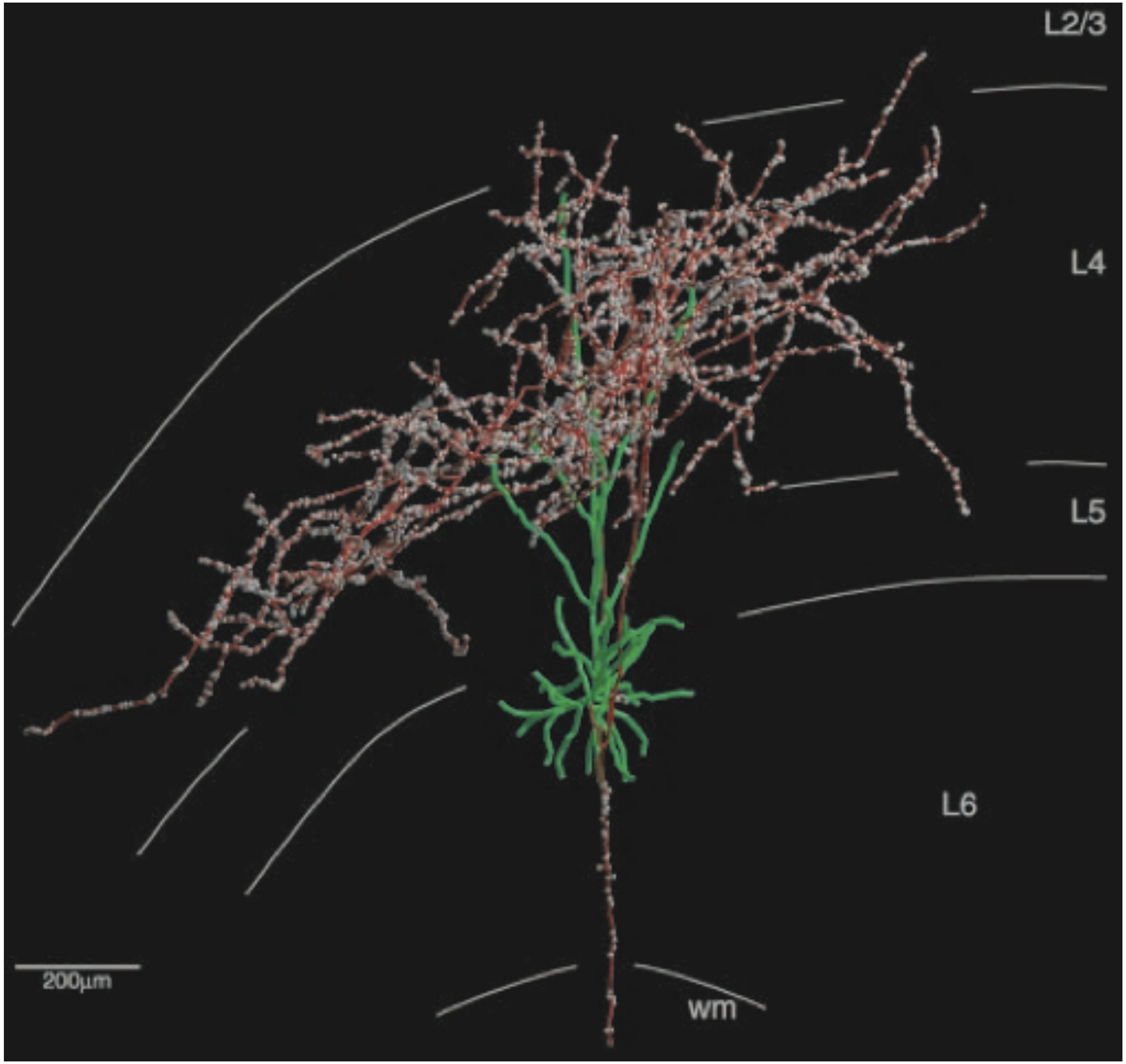


Neurons are noisy



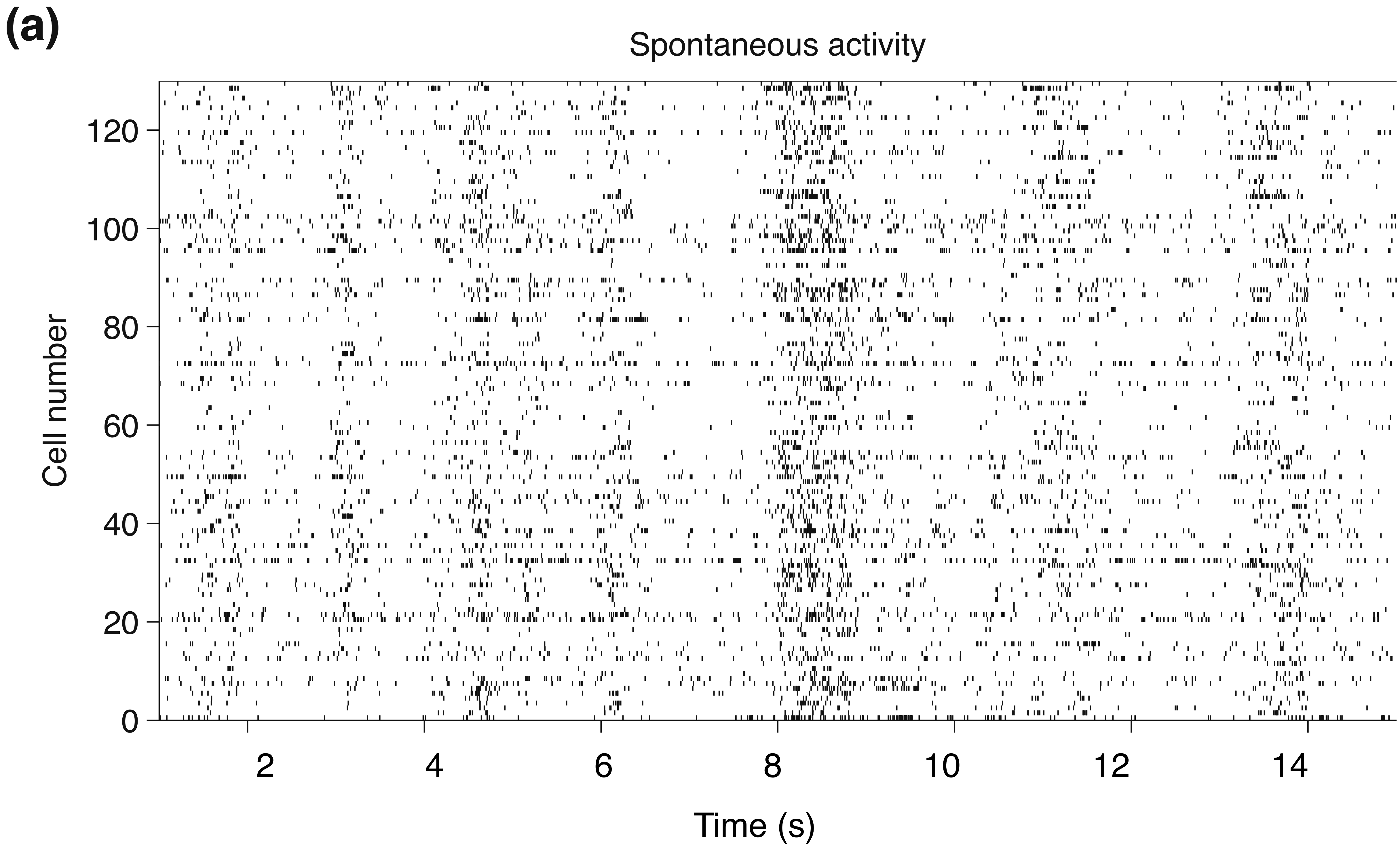
Ribrault, Sekimoto & Triller, 2011

Neurons are noisy



Binzegger, Douglas & Martin, 2004

Neuronal populations have correlated noise



Kelly, Smith, Kass & Lee (2010)

Correlation: a fundamental way to study interactions

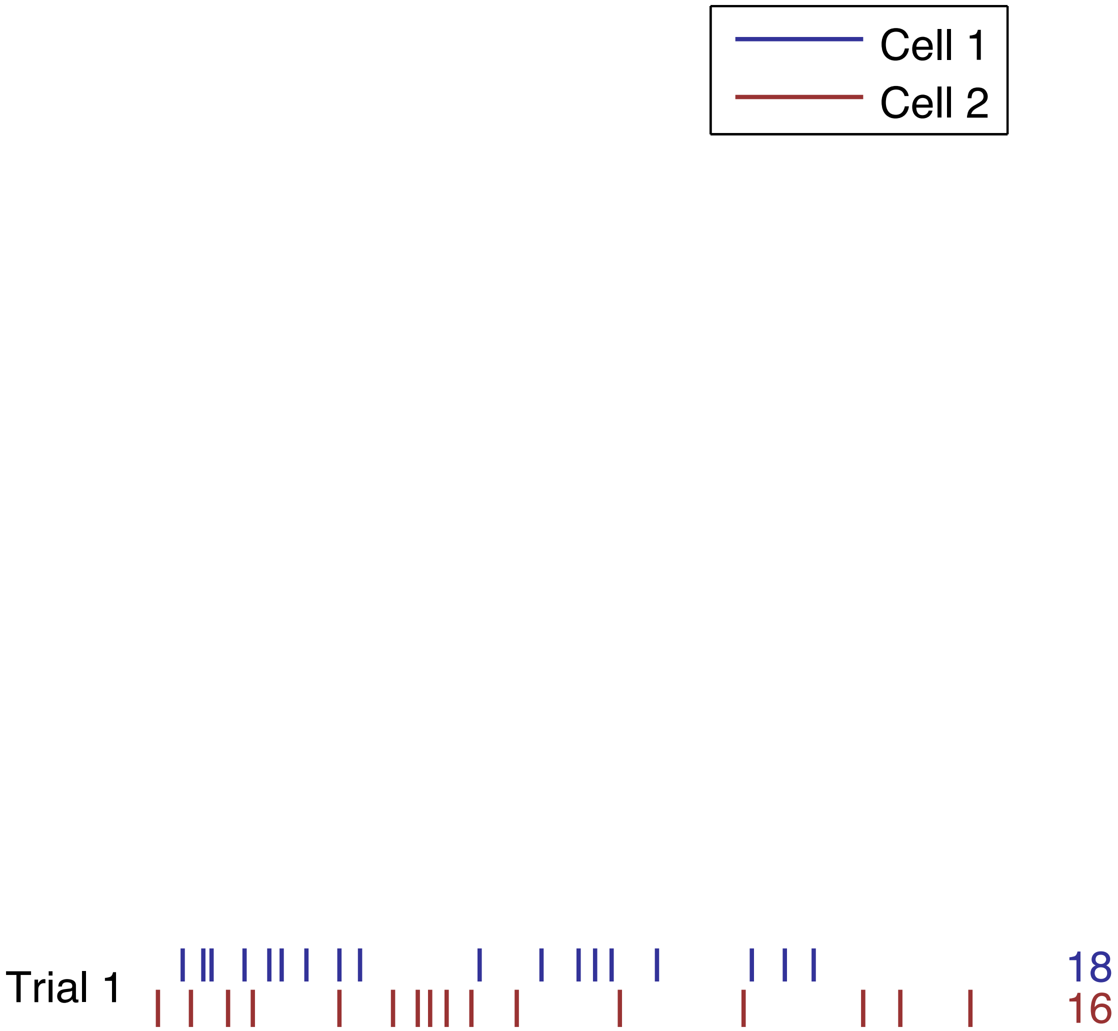
Covariation in X and Y

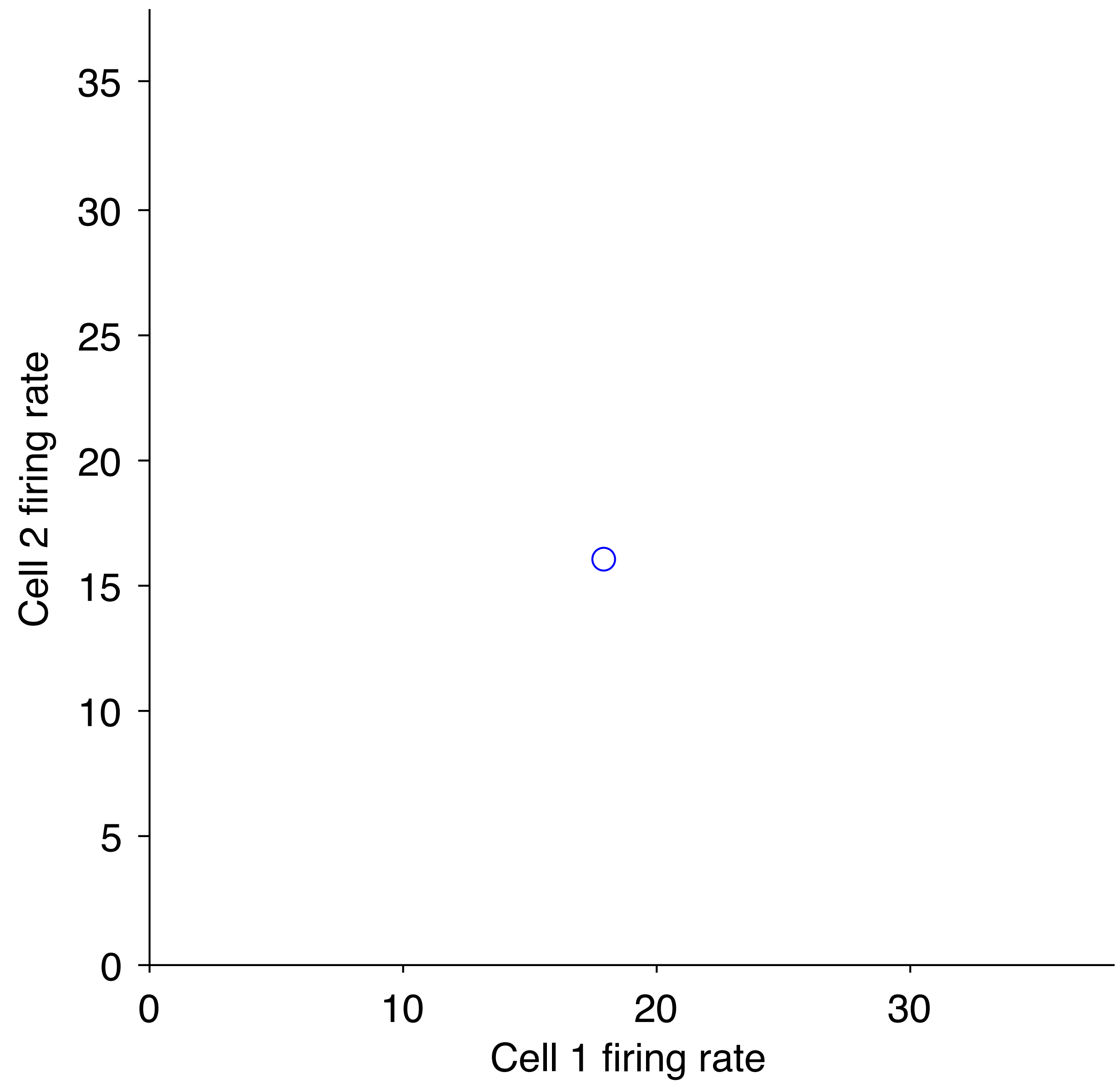
$$r = \frac{\sum_{i=1}^{n}\left(\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)\right)}{\sqrt{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2 \sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2}}$$

Variation in X

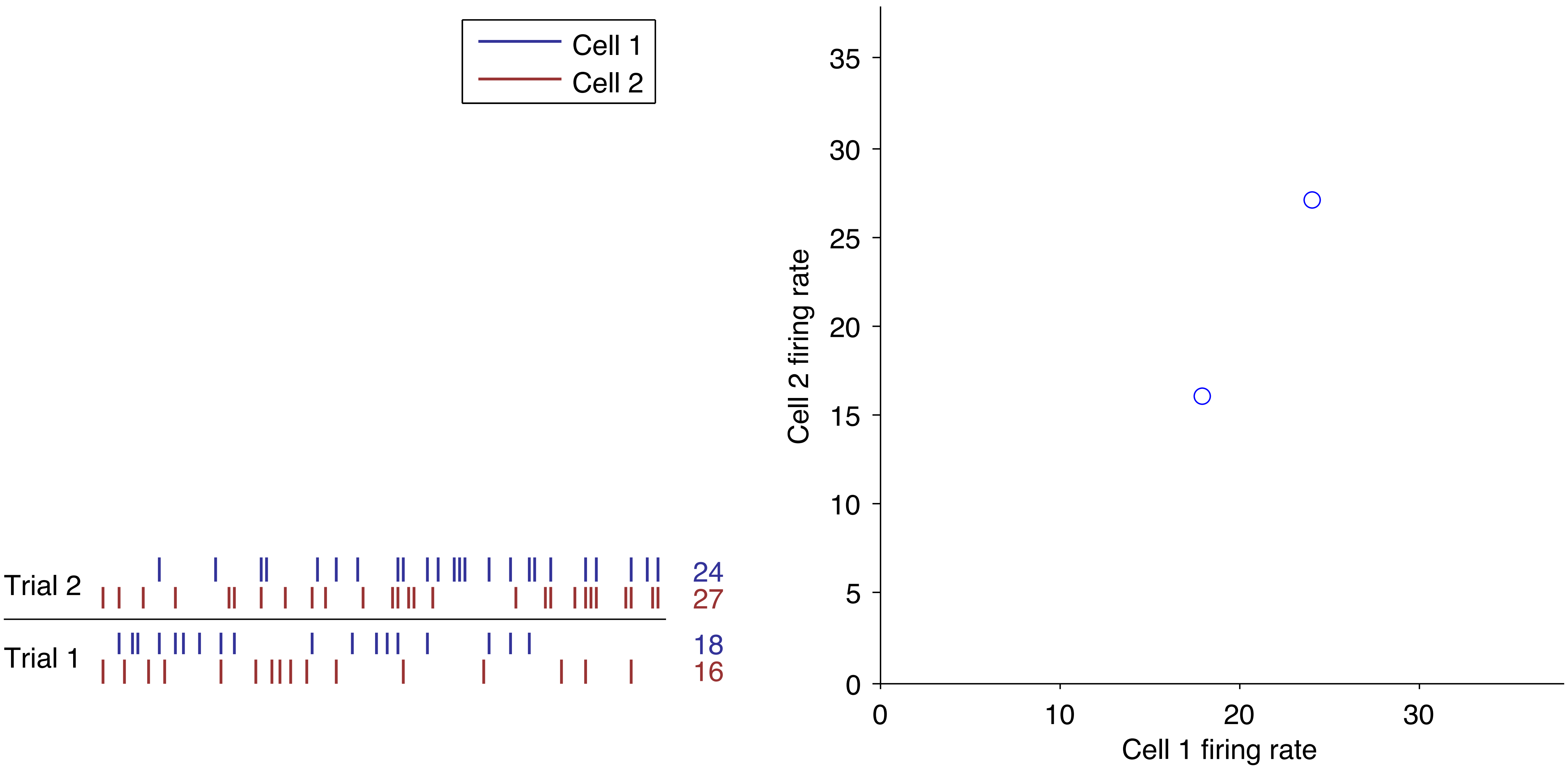
Variation in Y

Spike count correlation (r_{sc})

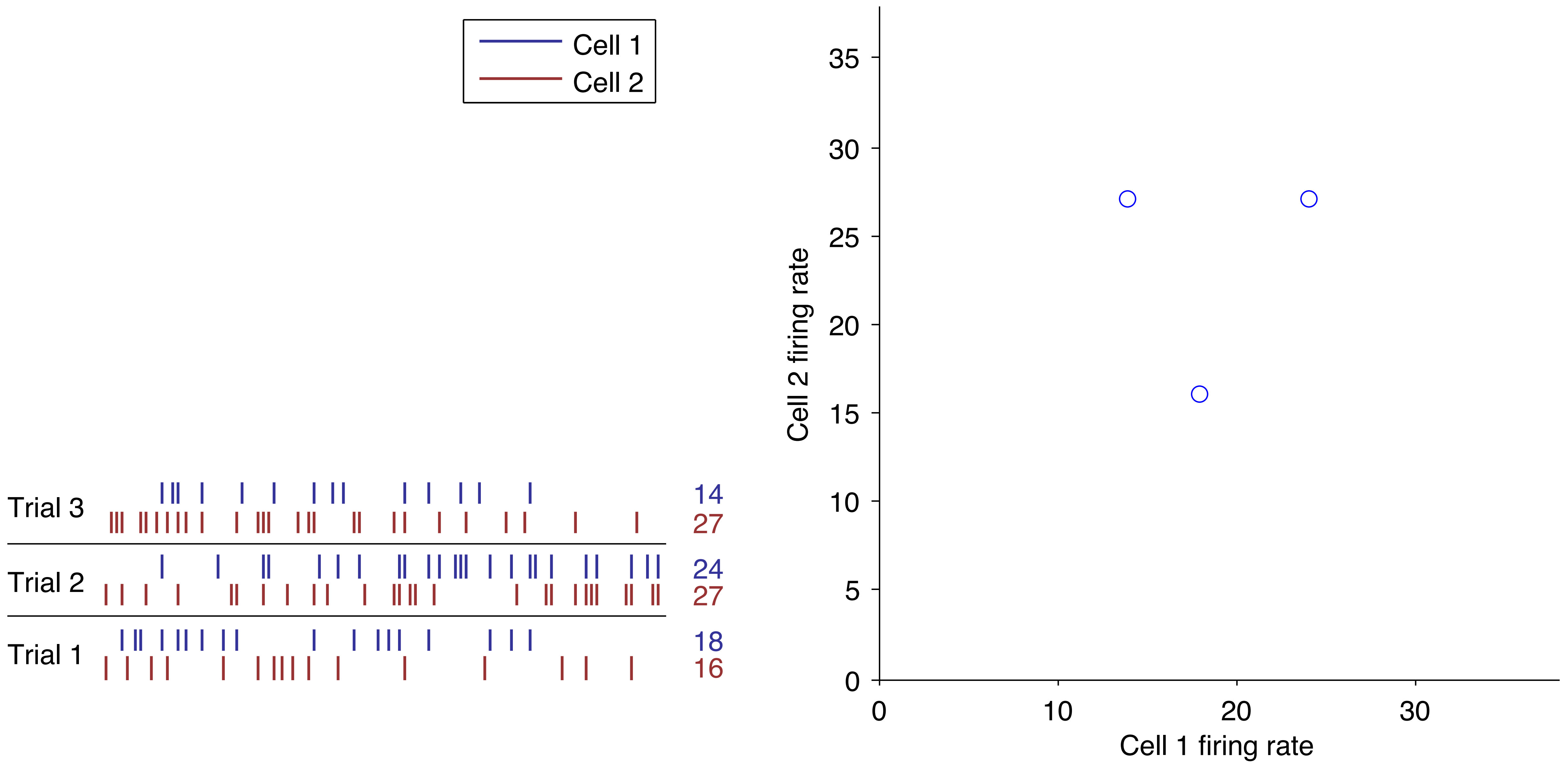




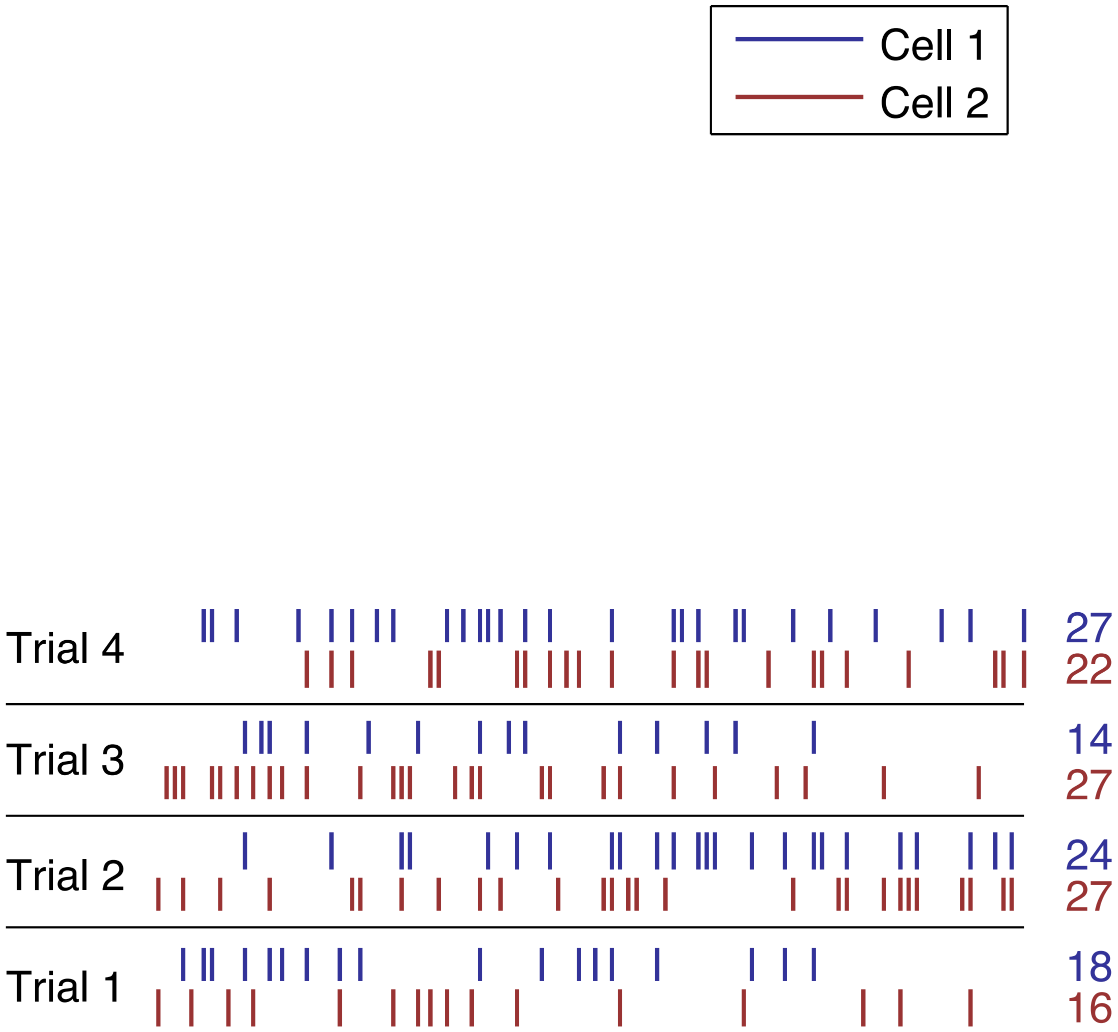
Spike count correlation (r_{sc})

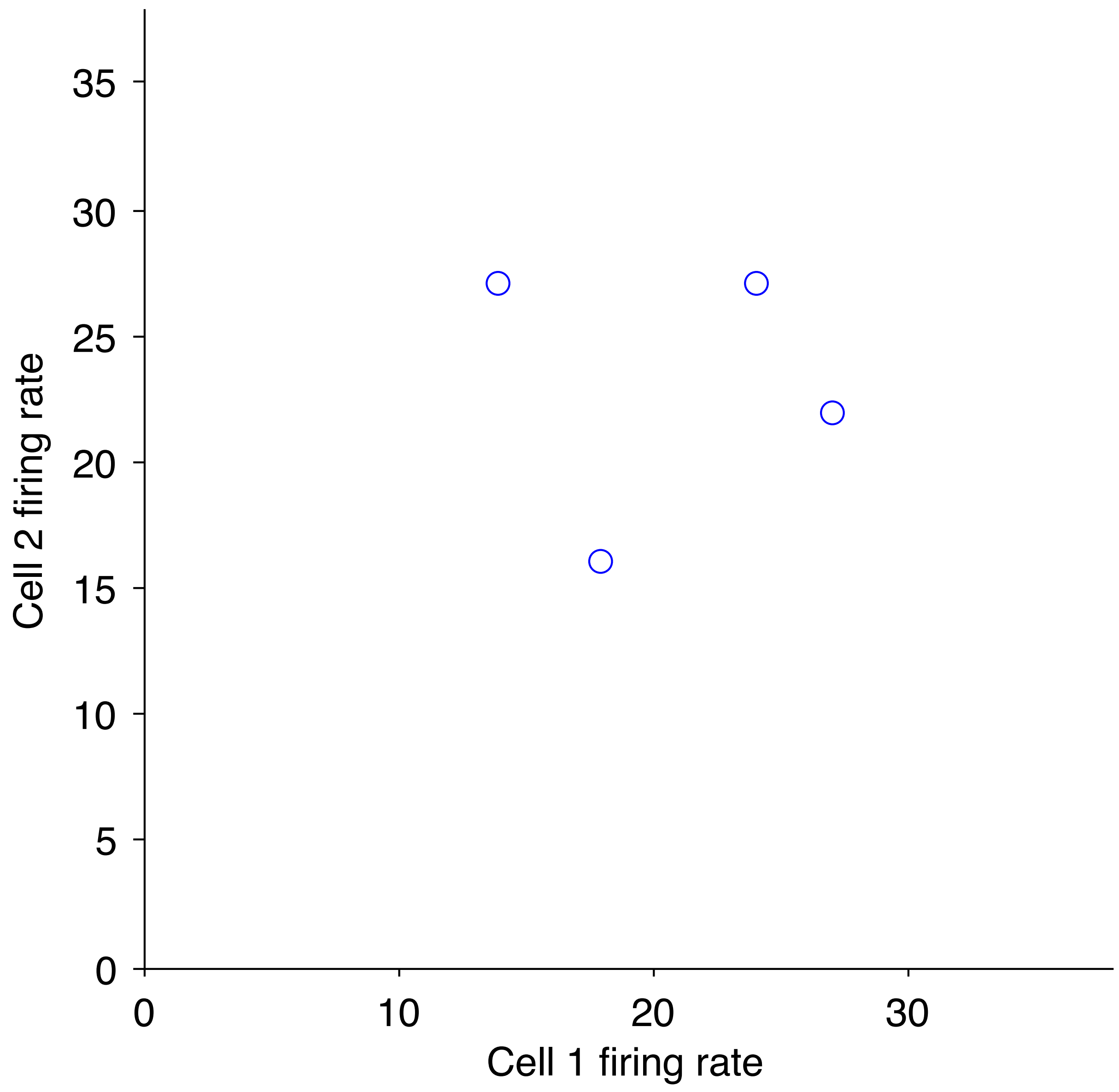


Spike count correlation (r_{sc})

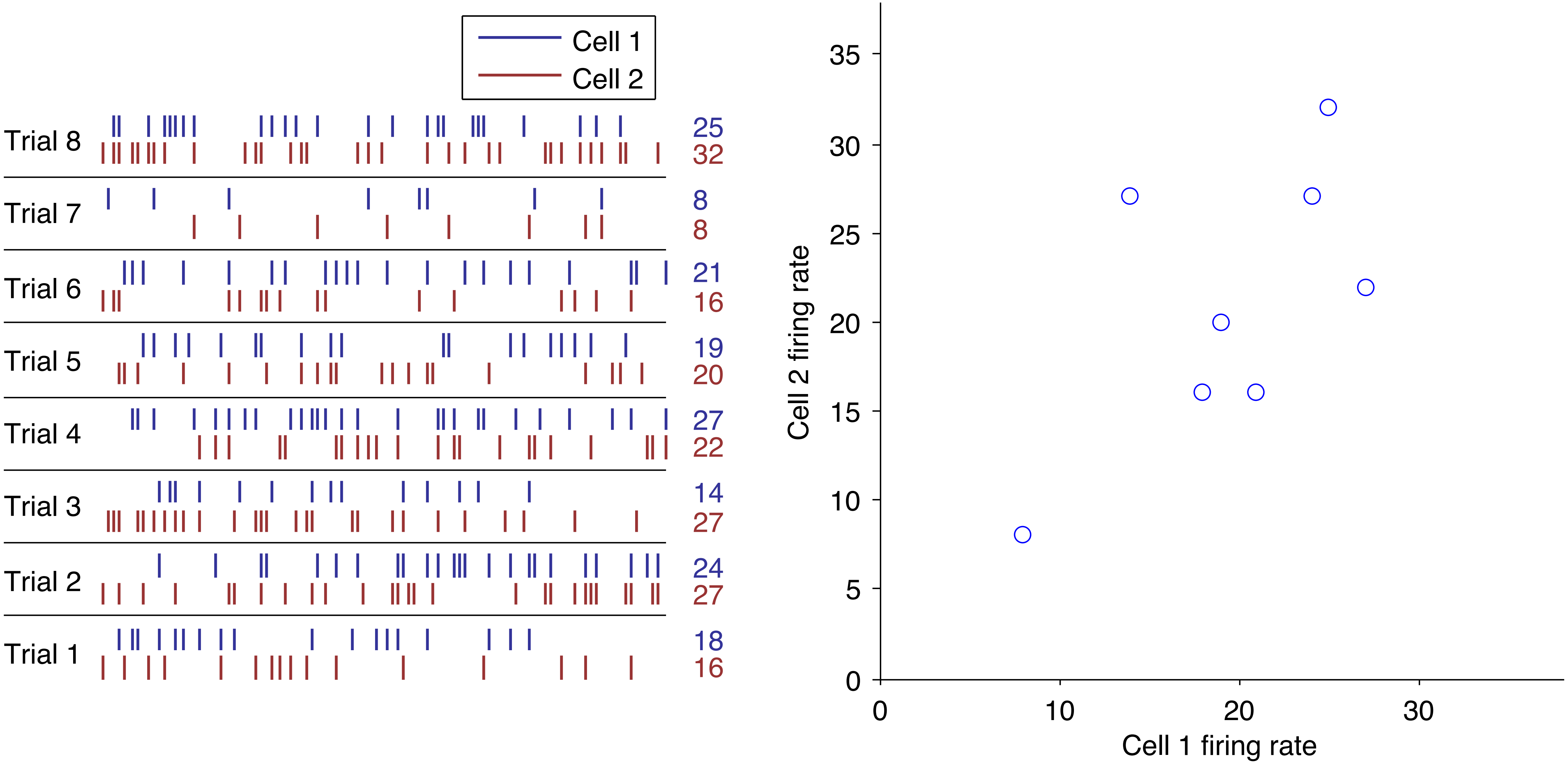


Spike count correlation (r_{sc})

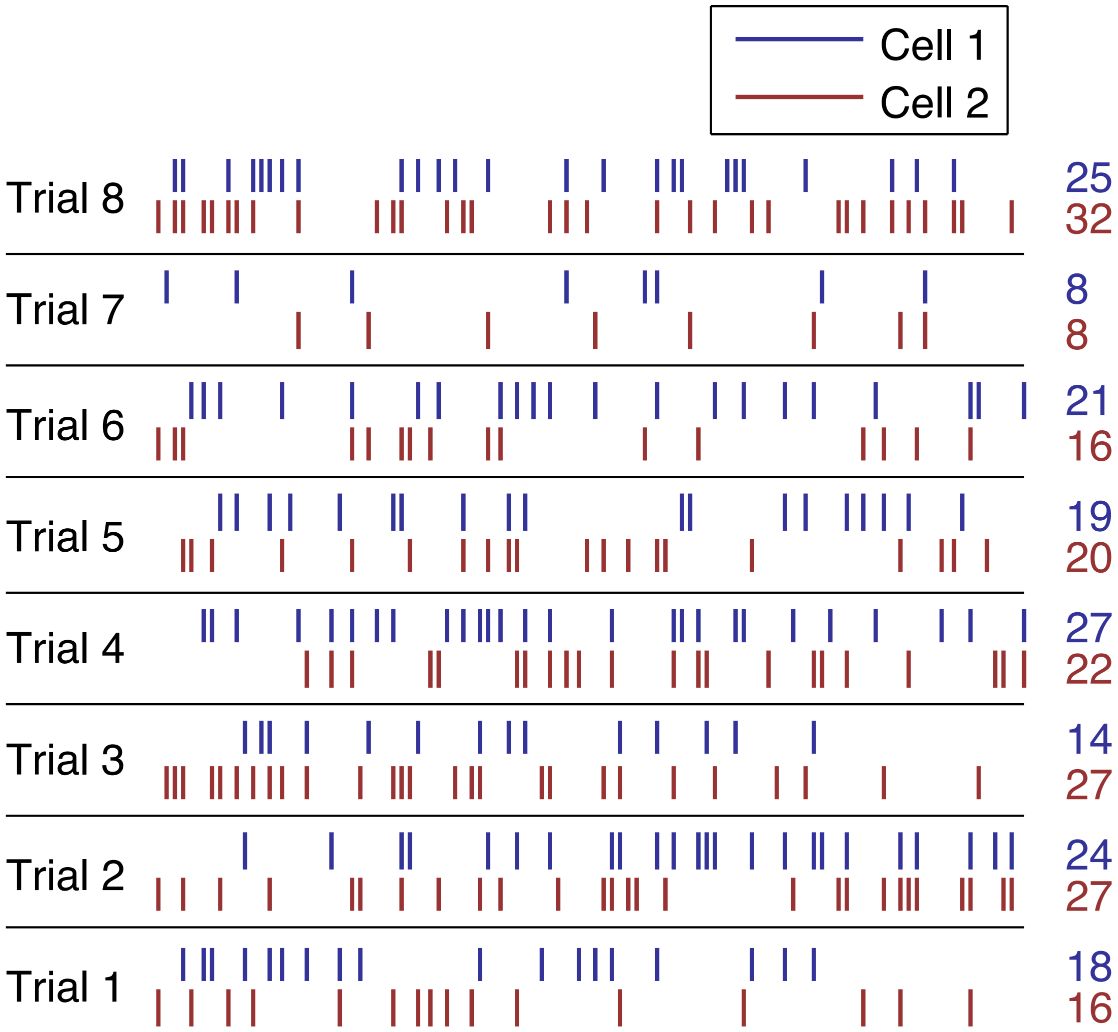


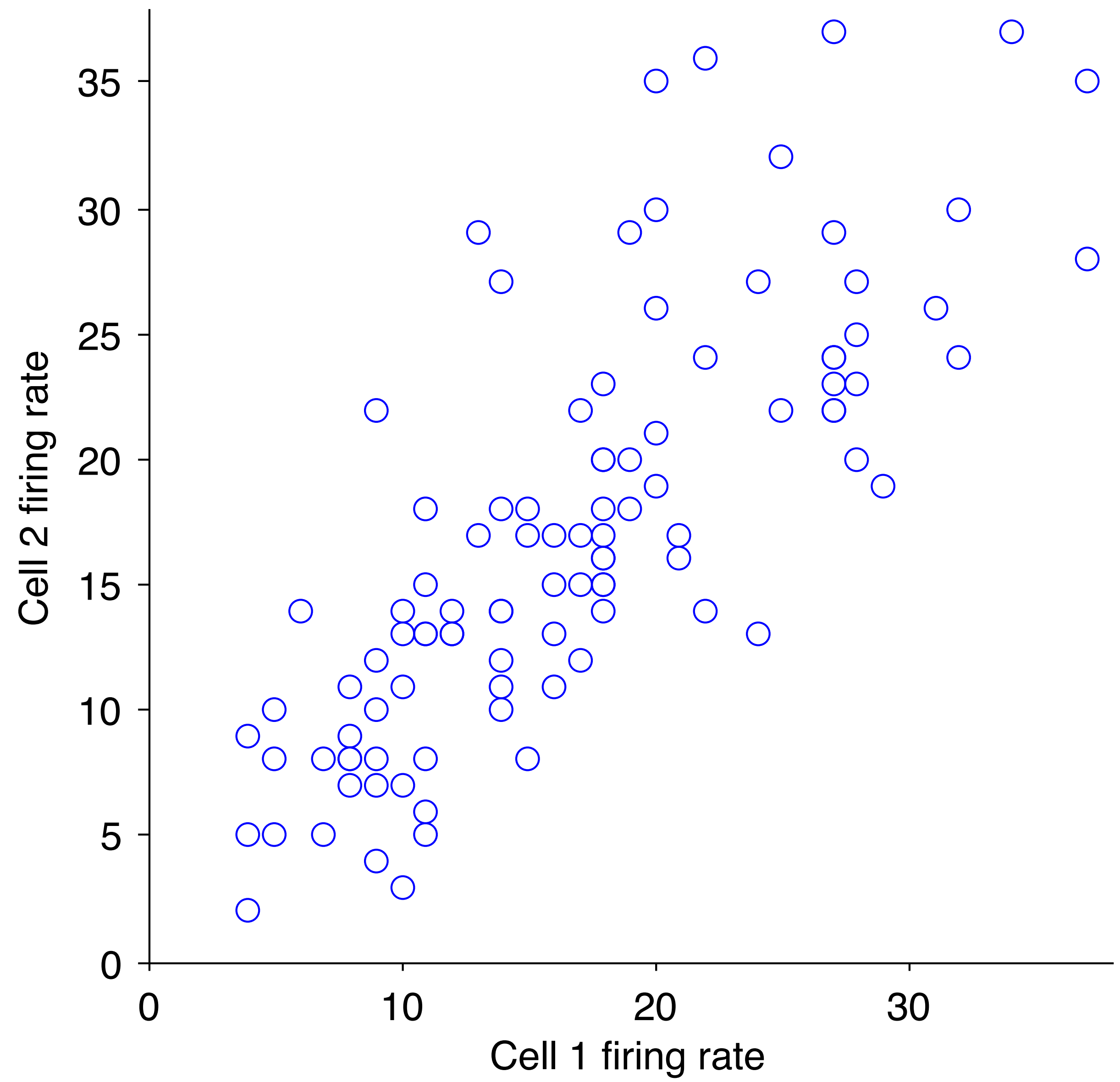


Spike count correlation (r_{sc})

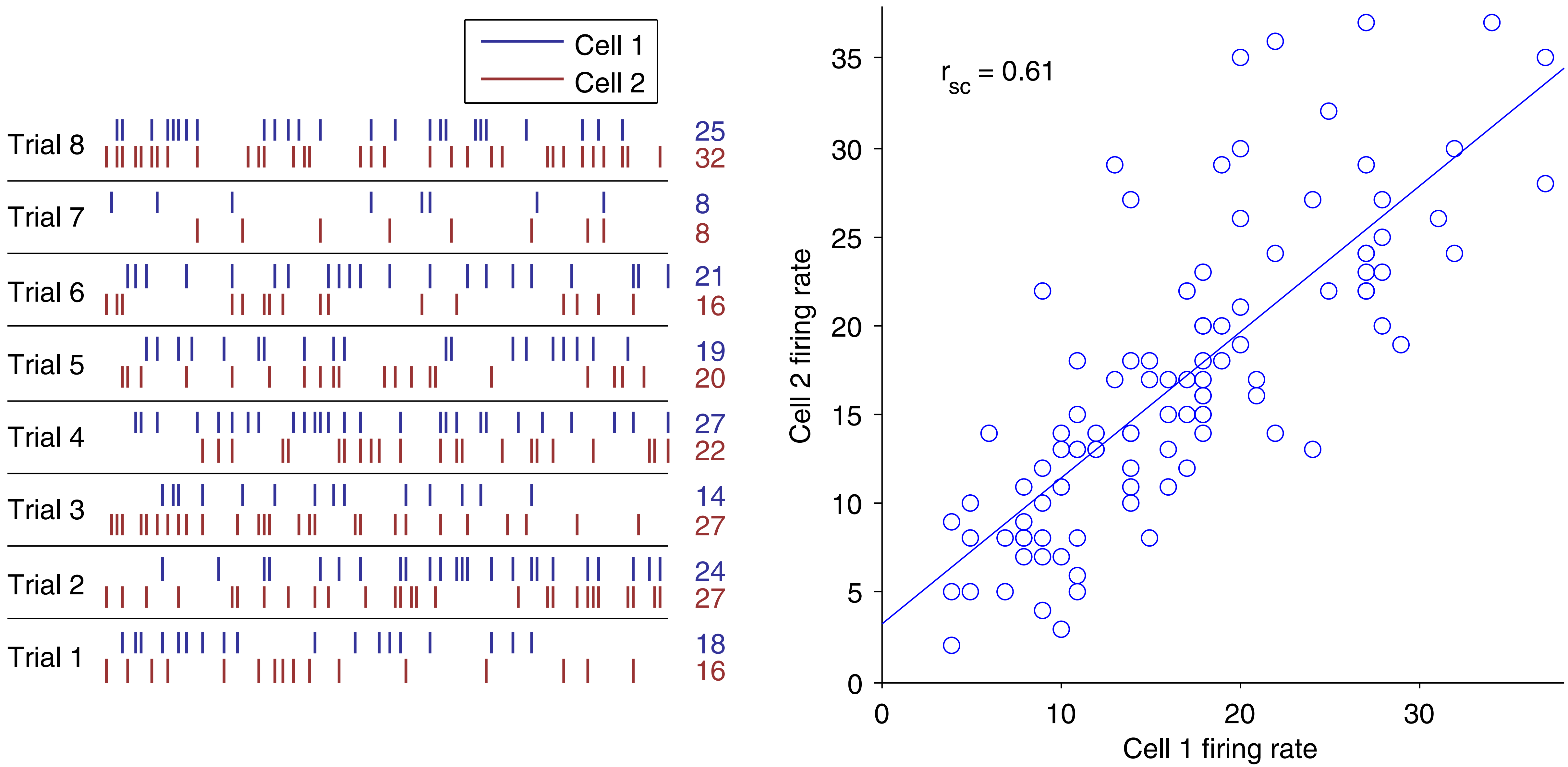


Spike count correlation (r_{sc})



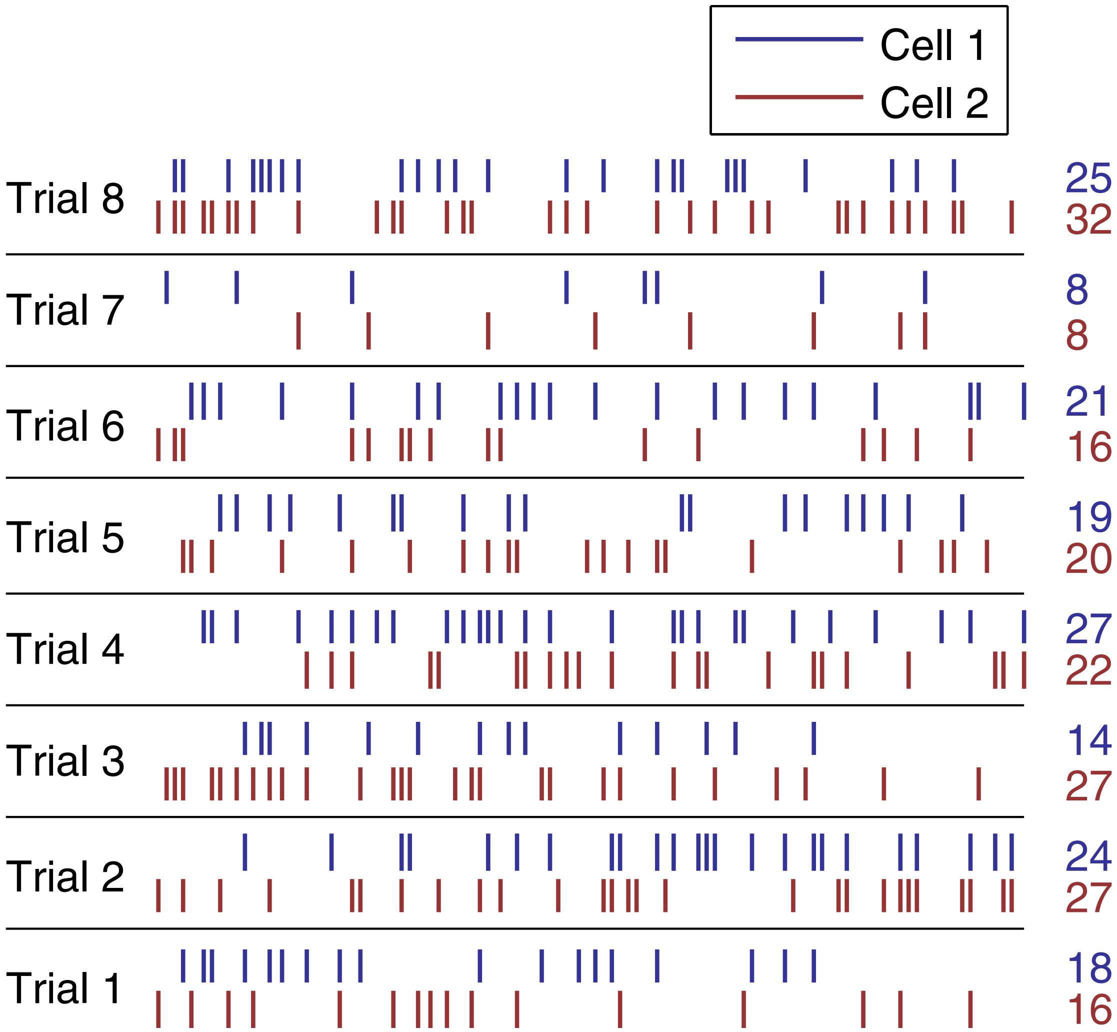


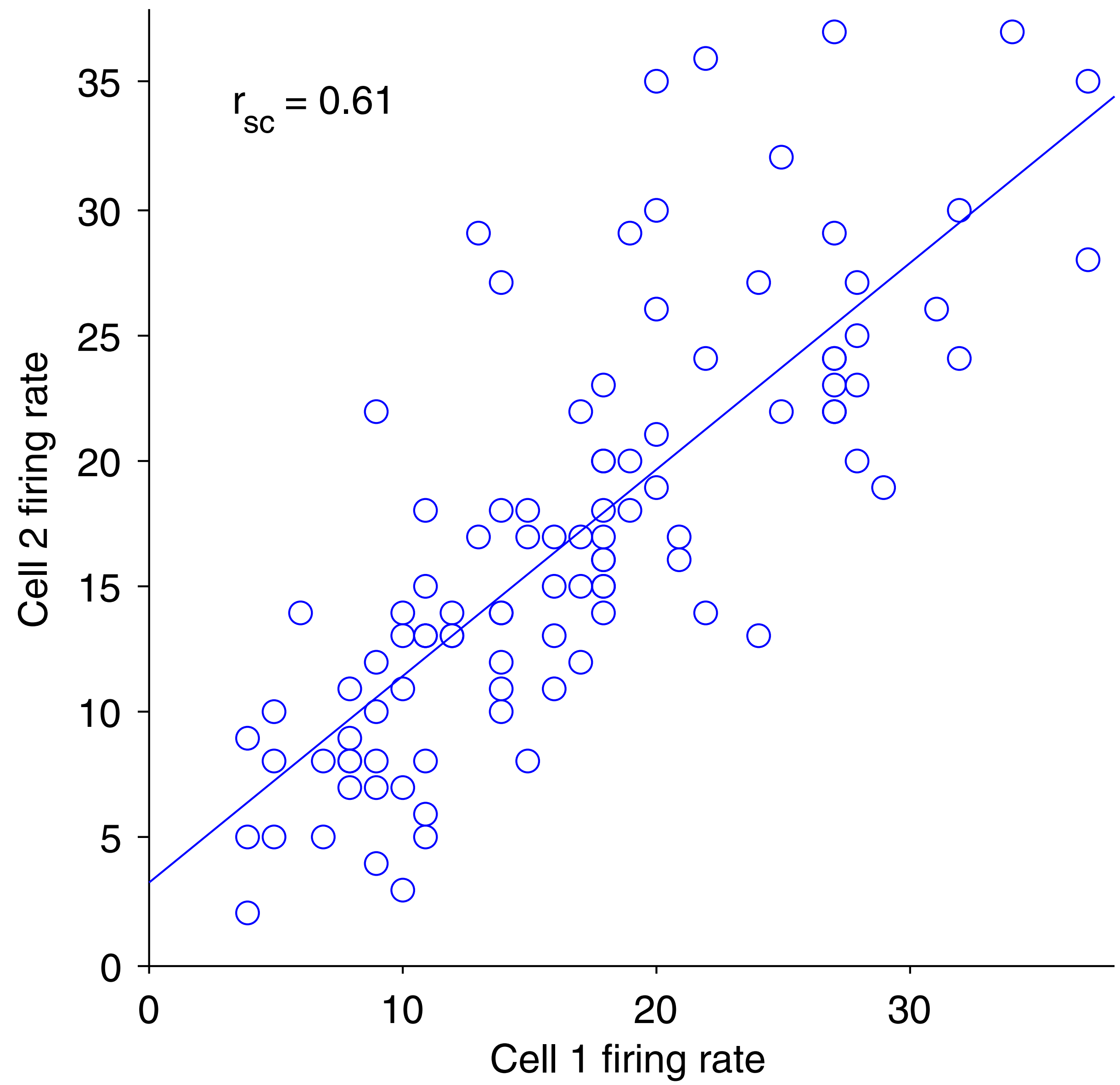
Spike count correlation (r_{sc})



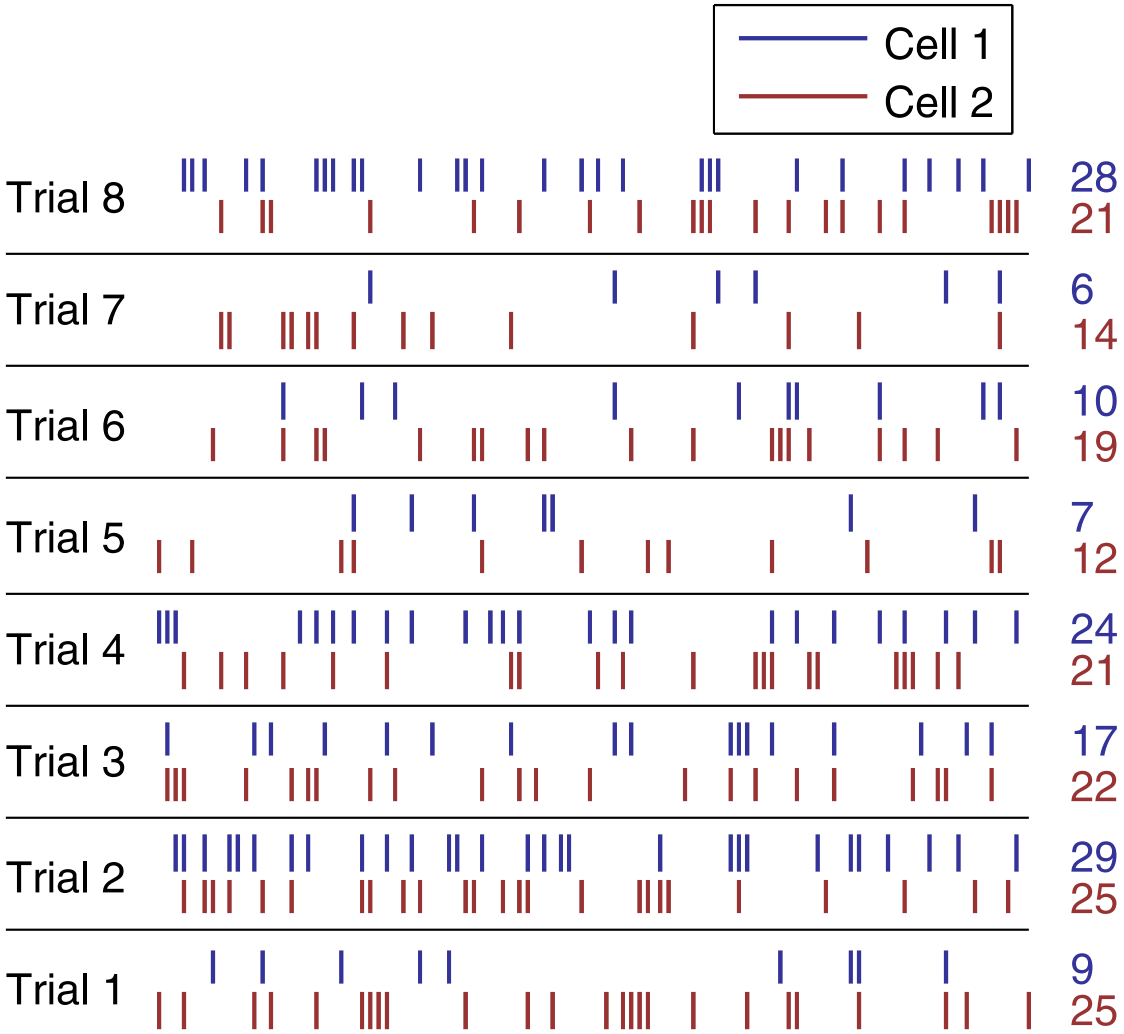
Spike count correlation (r_{sc})

Slow time scale correlation

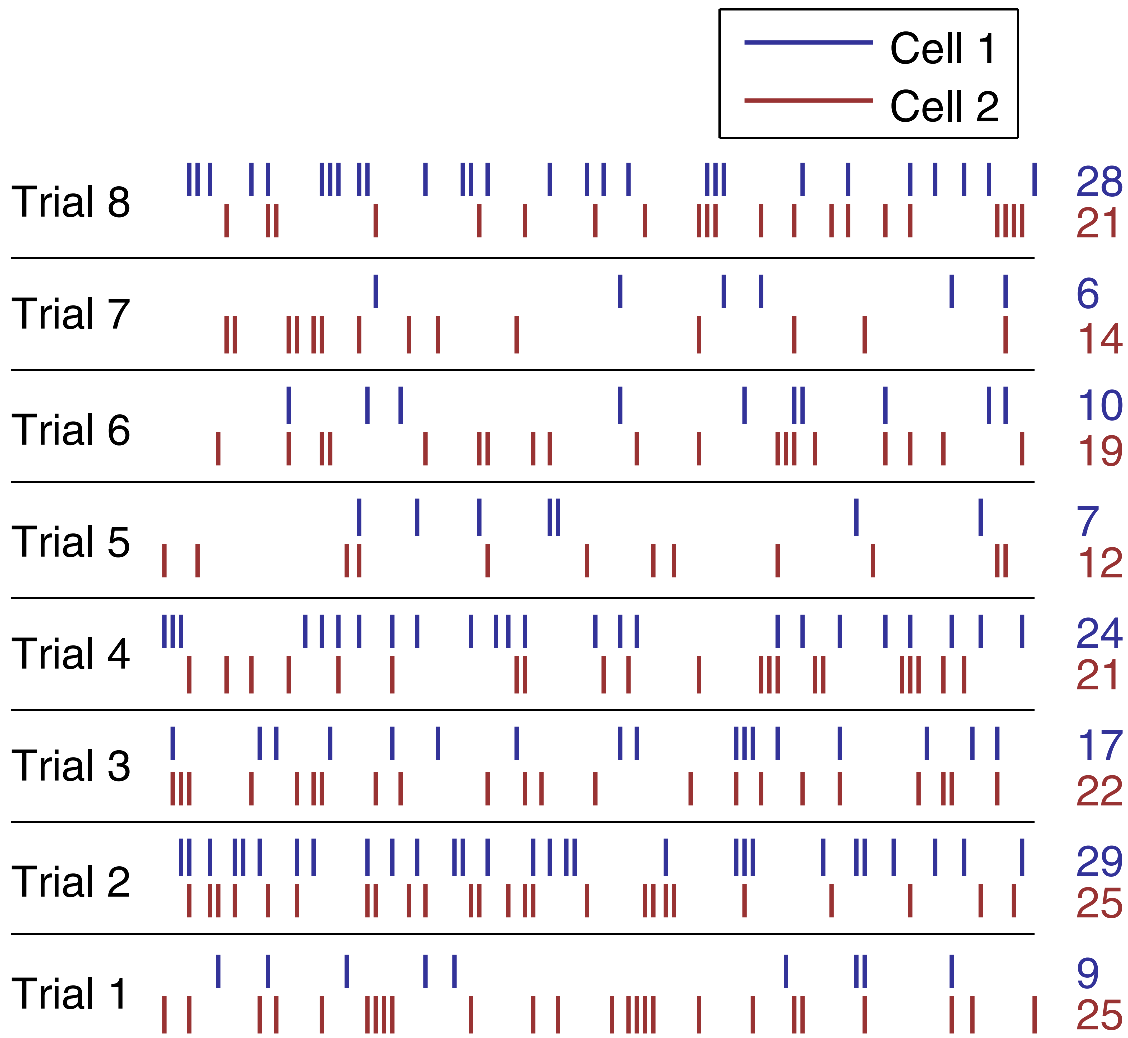


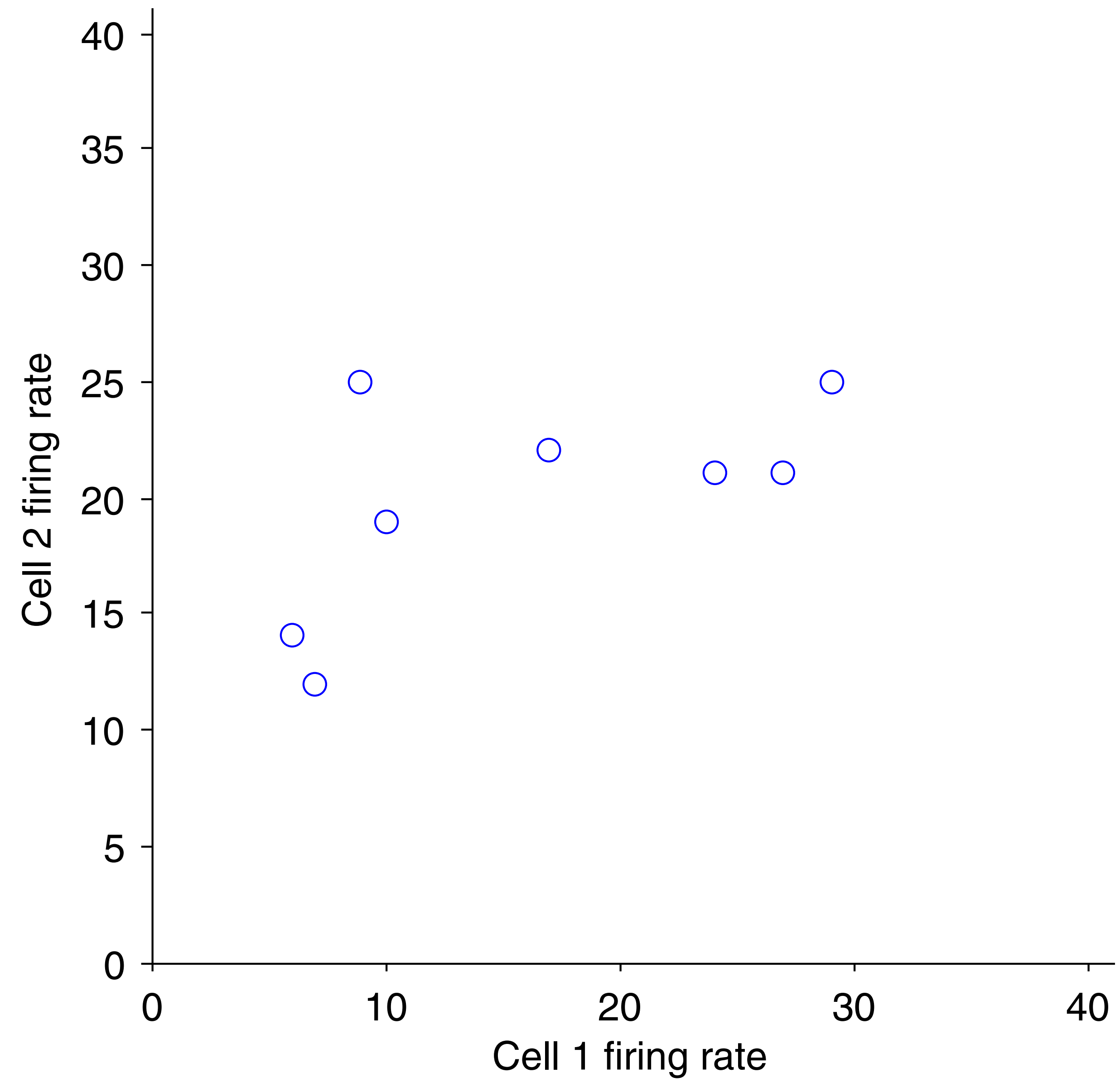


Spike count correlation (r_{sc})

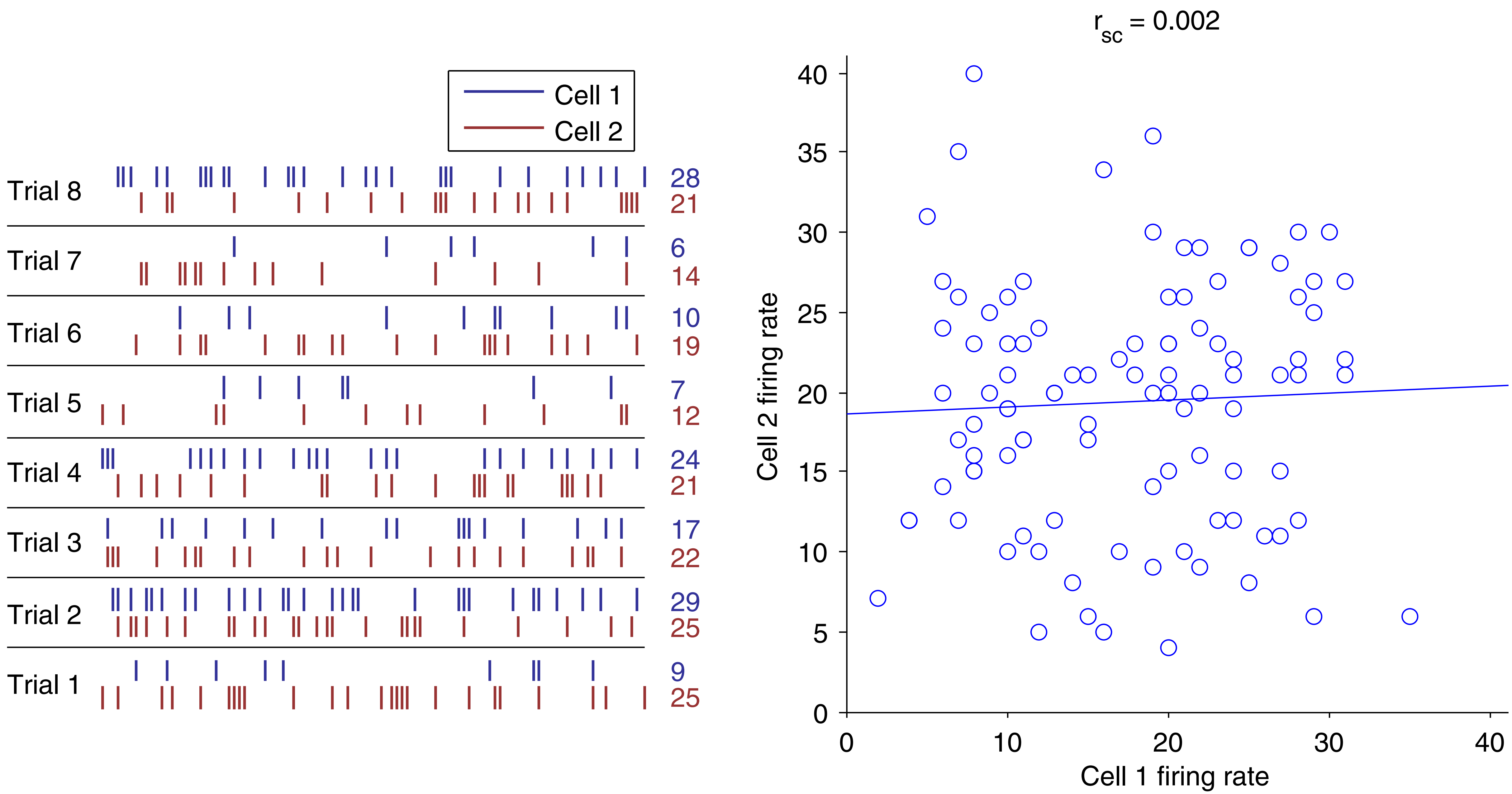


Spike count correlation (r_{sc})

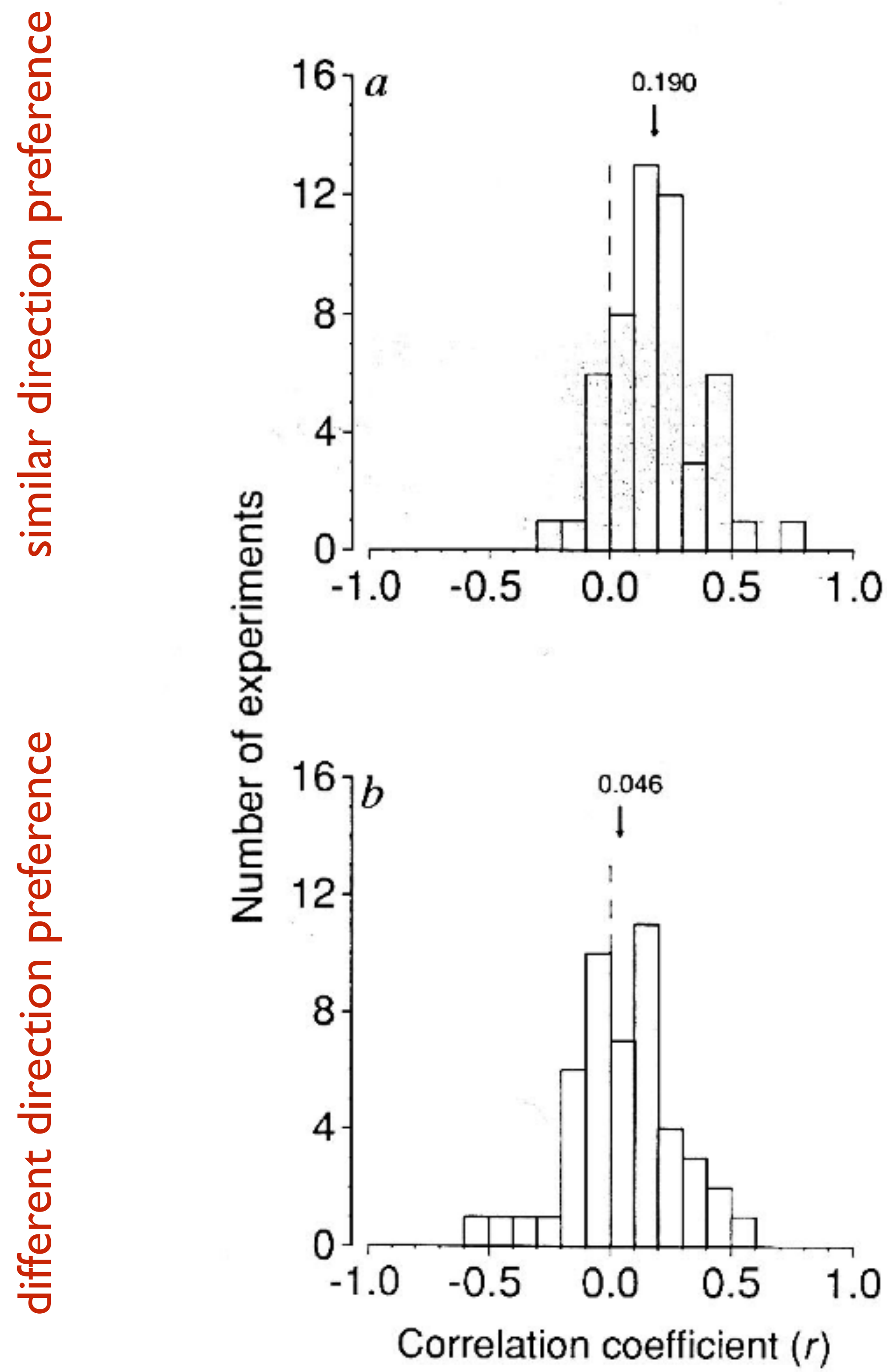




Spike count correlation (r_{sc})



Correlation: a fundamental way to study interactions

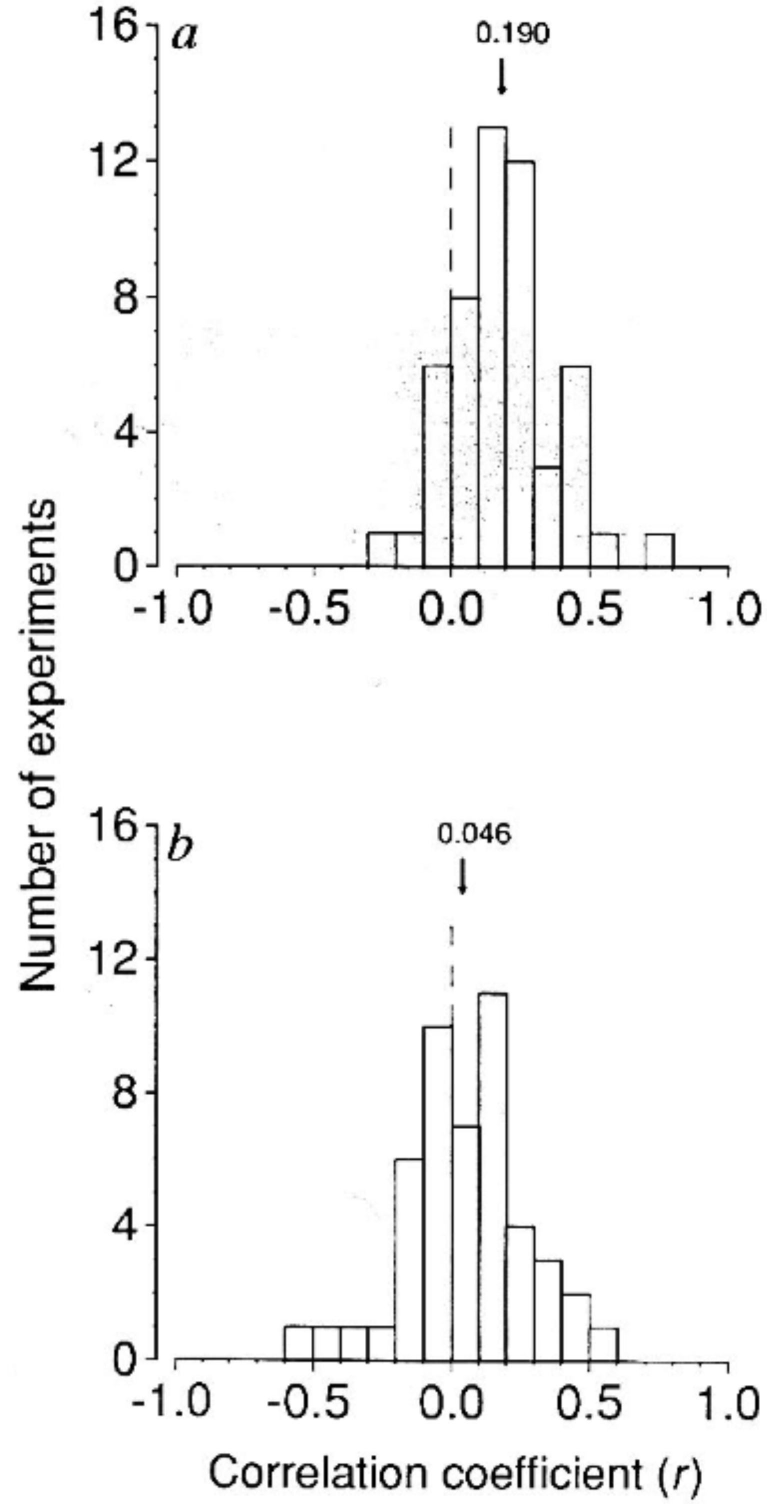


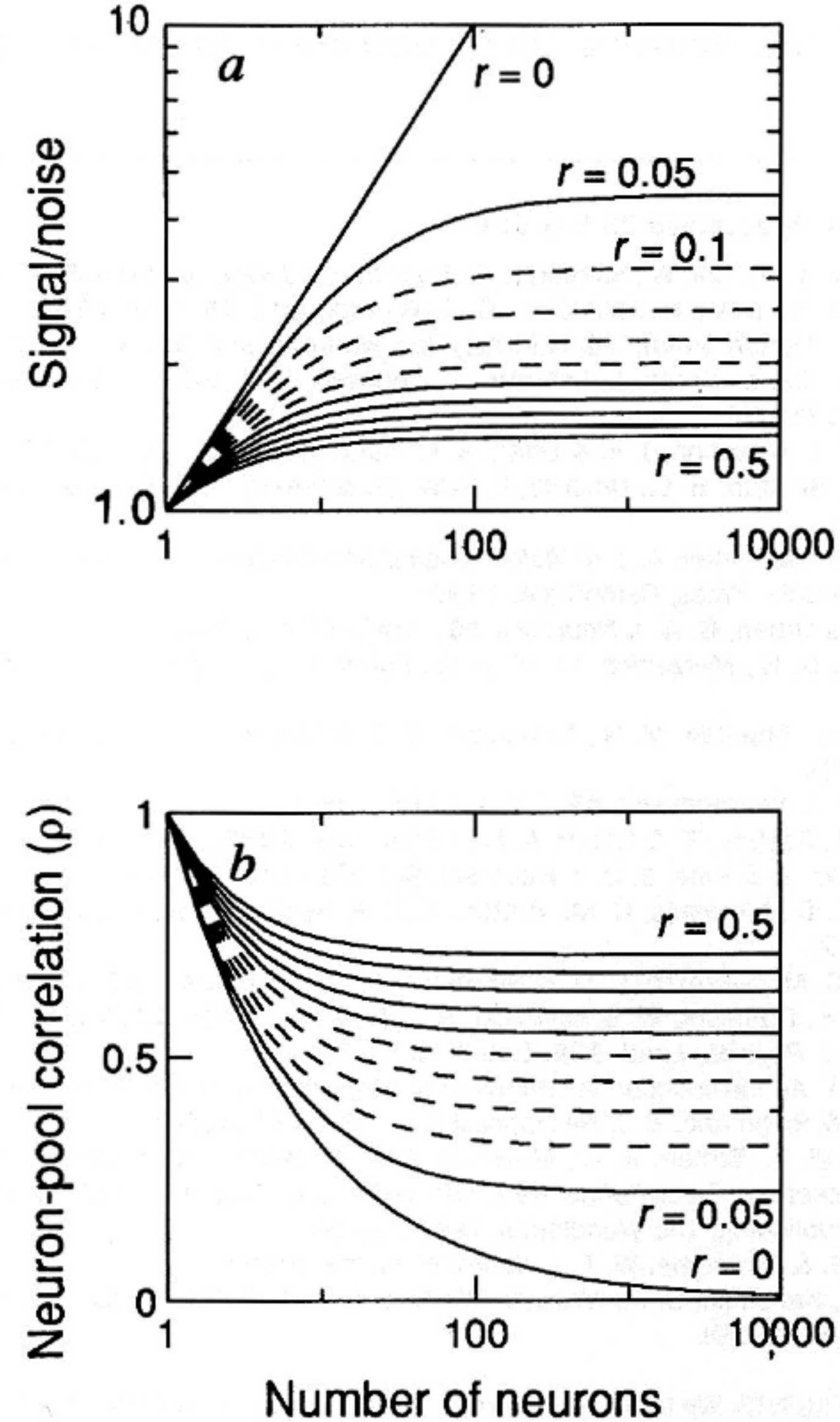
Zohary, Shadlen & Newsome (1994)

Correlation: a fundamental way to study interactions

similar direction preference

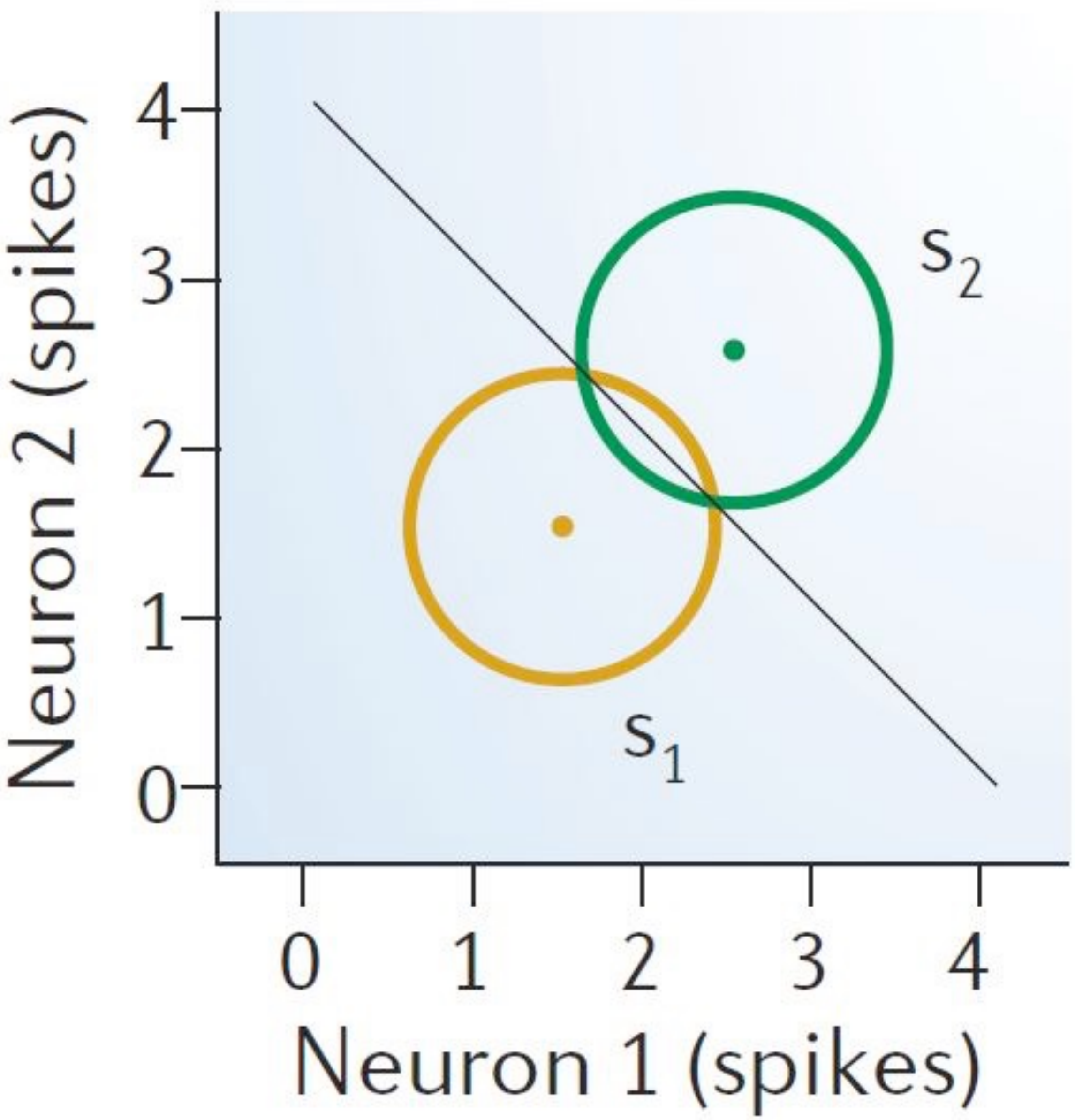
different direction preference





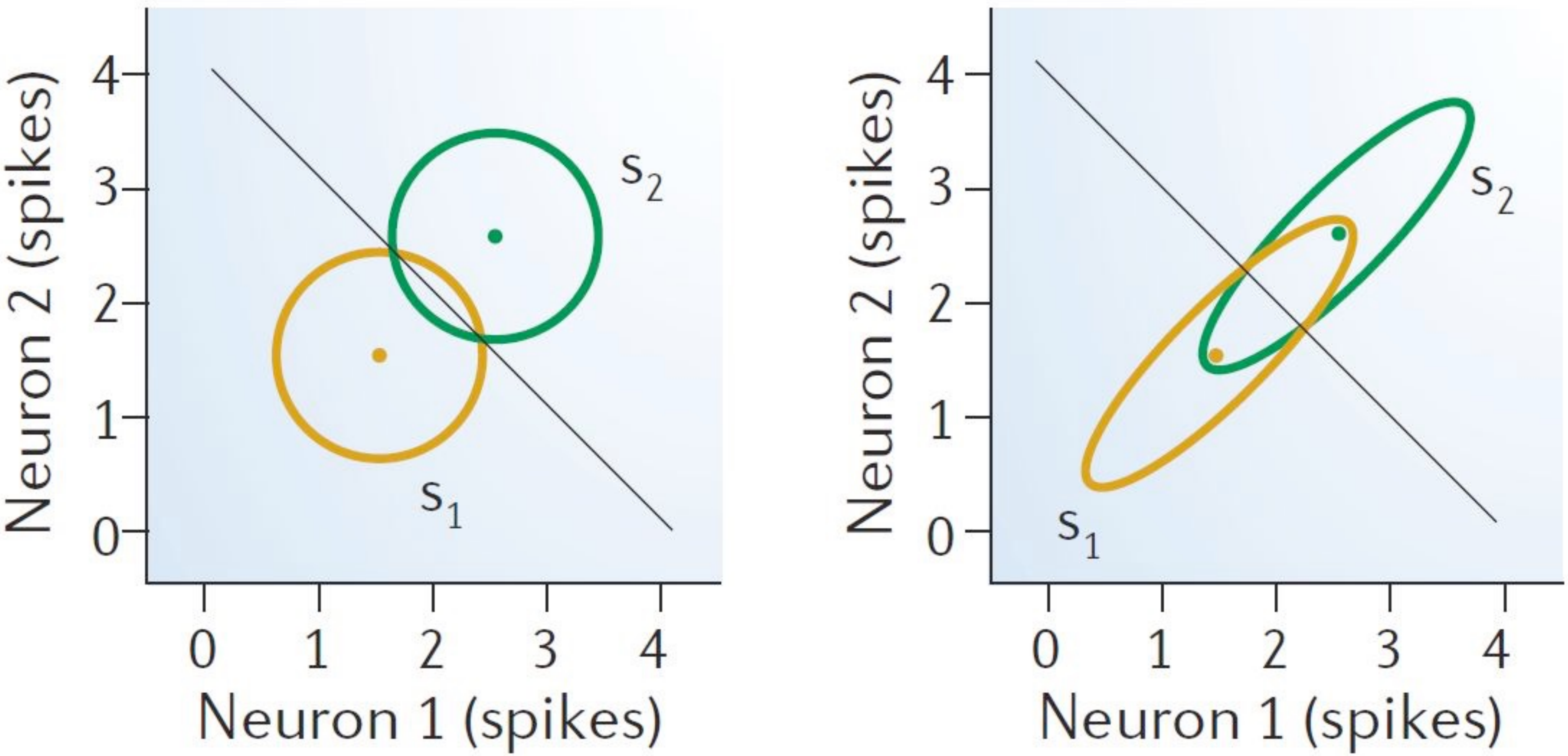
Zohary, Shadlen & Newsome (1994)

Correlated noise affects information capacity

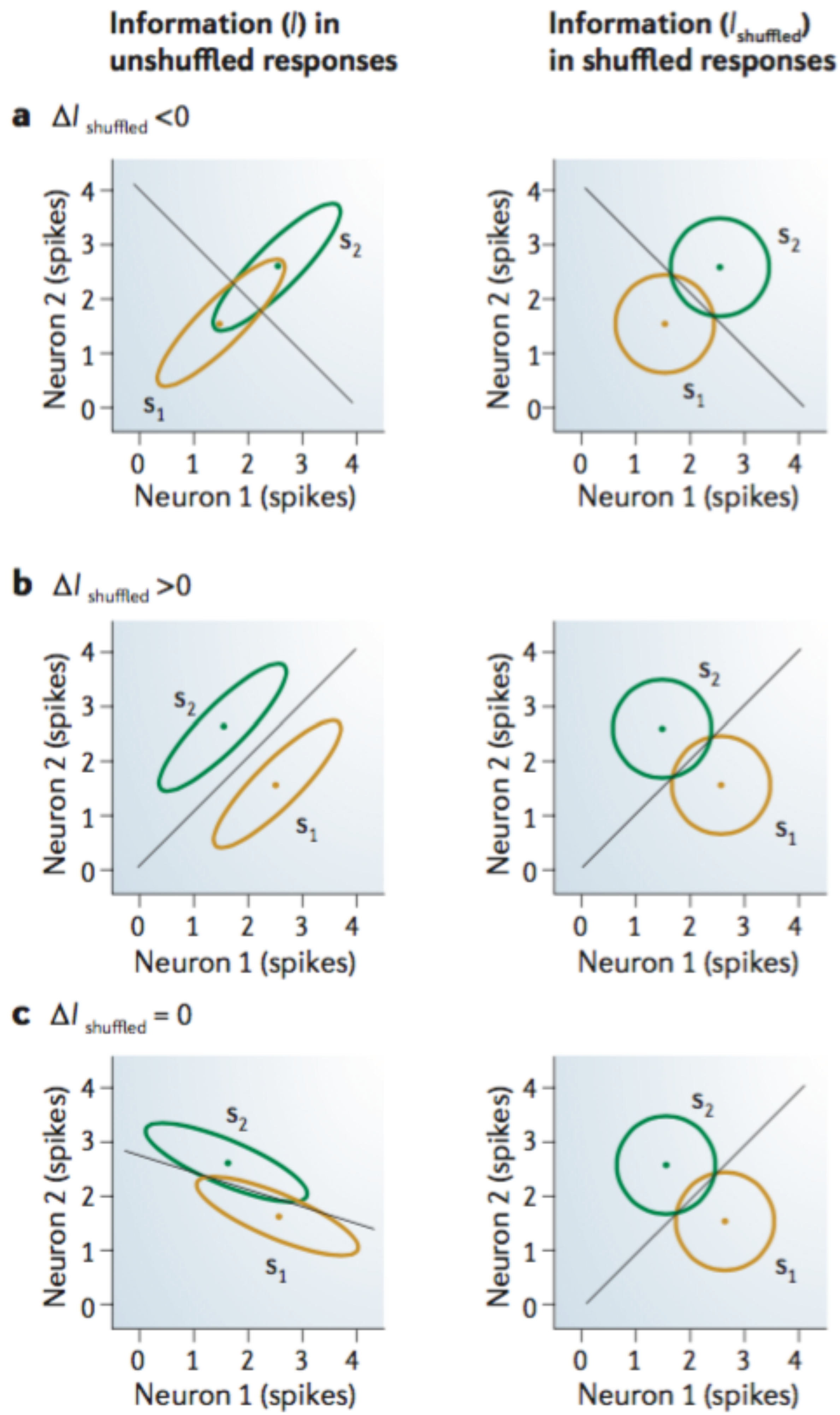


Averbeck et al (2006)

Correlated noise affects information capacity



Averbeck et al (2006)

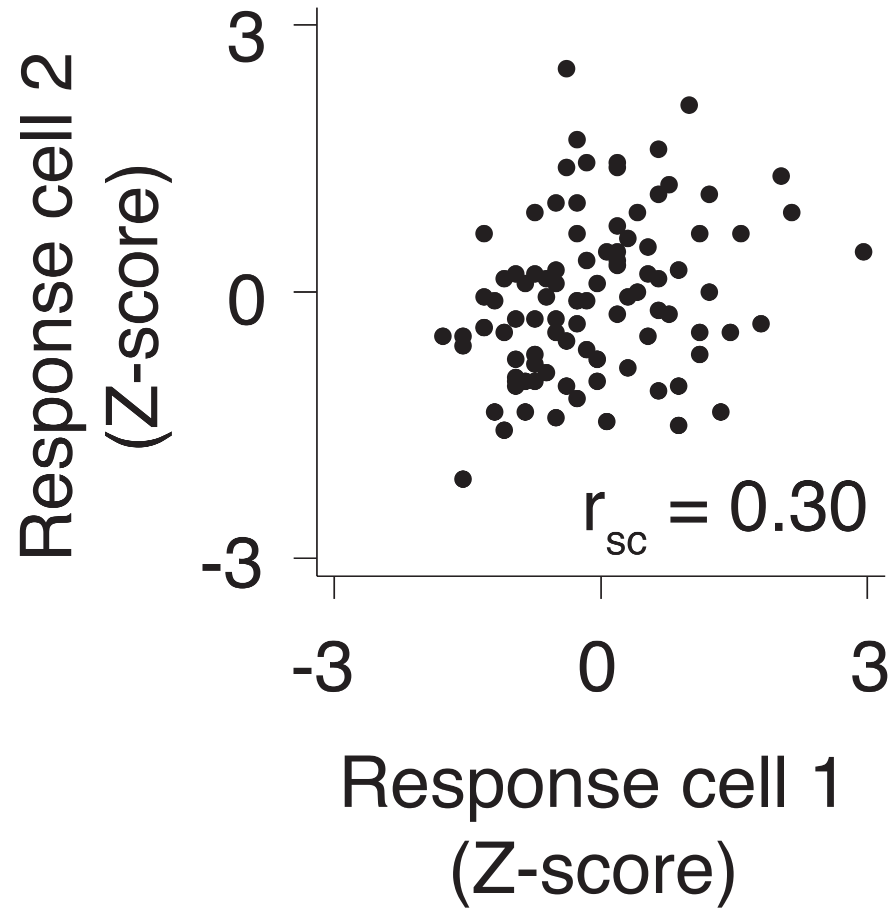


Averbeck et al (2006)

Other uses of correlation measures

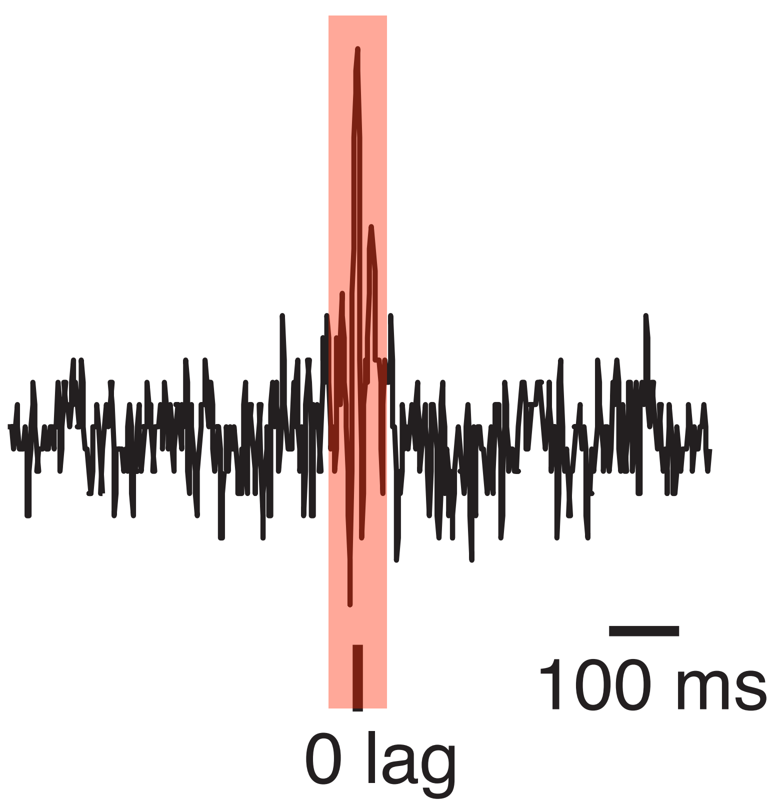
Correlation of trial-to-trial response variability (a.k.a. “noise correlation”, spike count correlation, r_{sc})

Slow time scale



Synchronous spiking (CCG or cross-correlogram)

Fast time scale

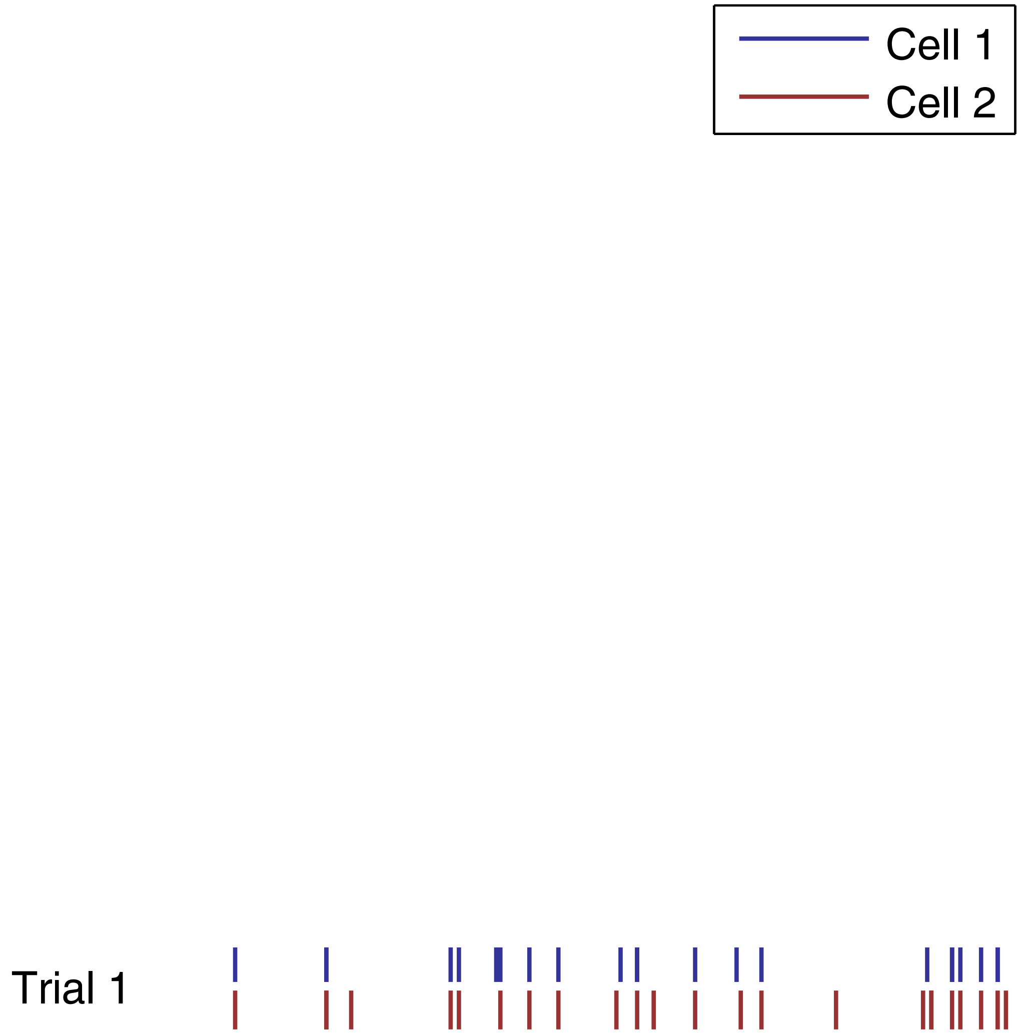


Spike timing correlation (synchrony)

Fast time scale correlation

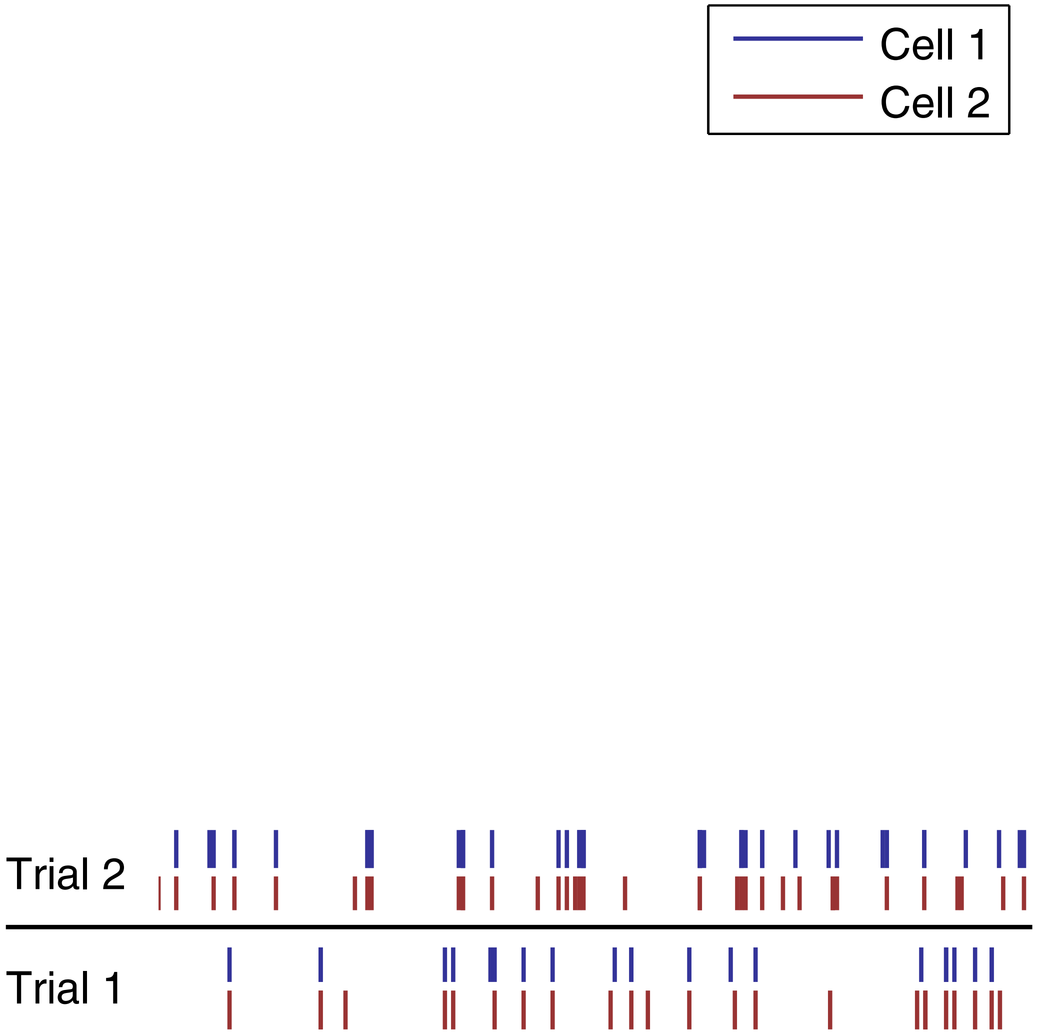
Spike timing correlation (synchrony)

Fast time scale correlation



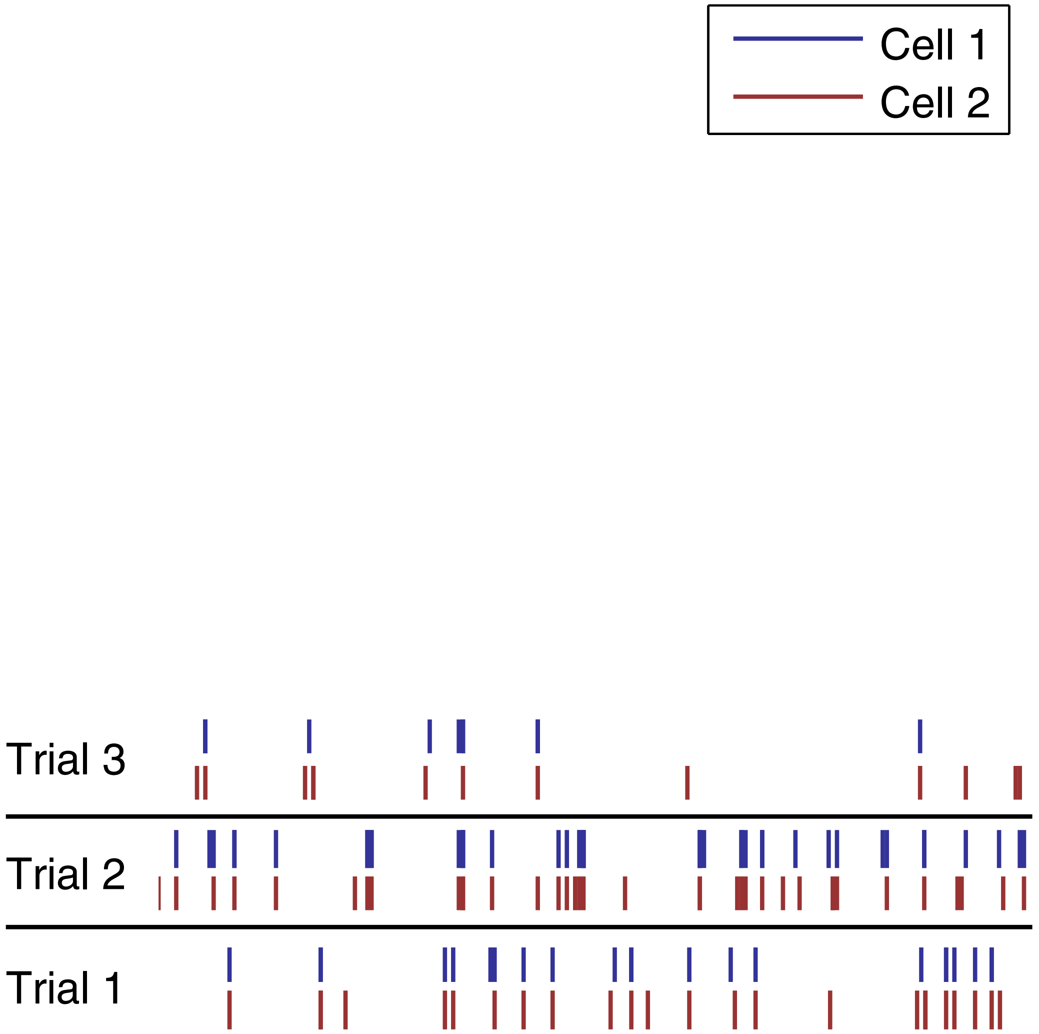
Spike timing correlation (synchrony)

Fast time scale correlation



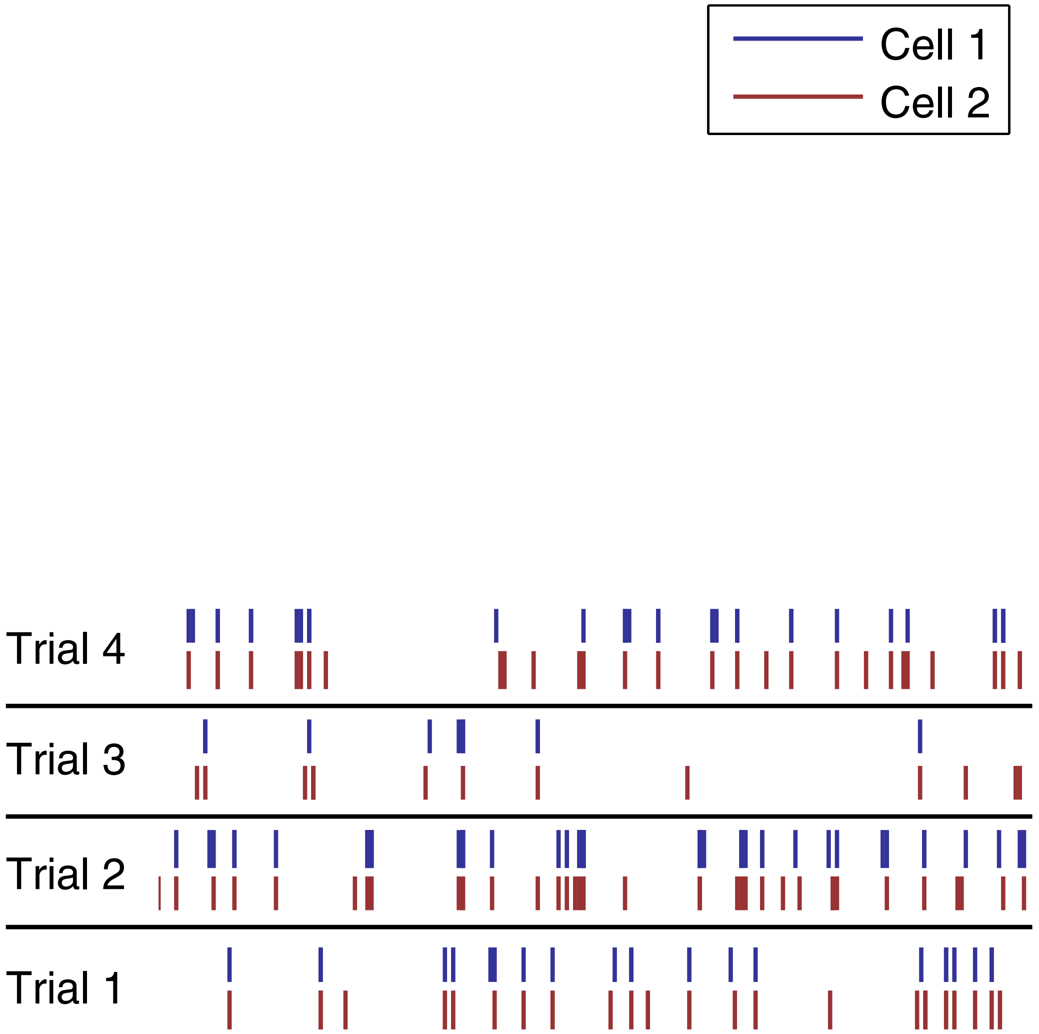
Spike timing correlation (synchrony)

<u>Fast</u> time scale correlation



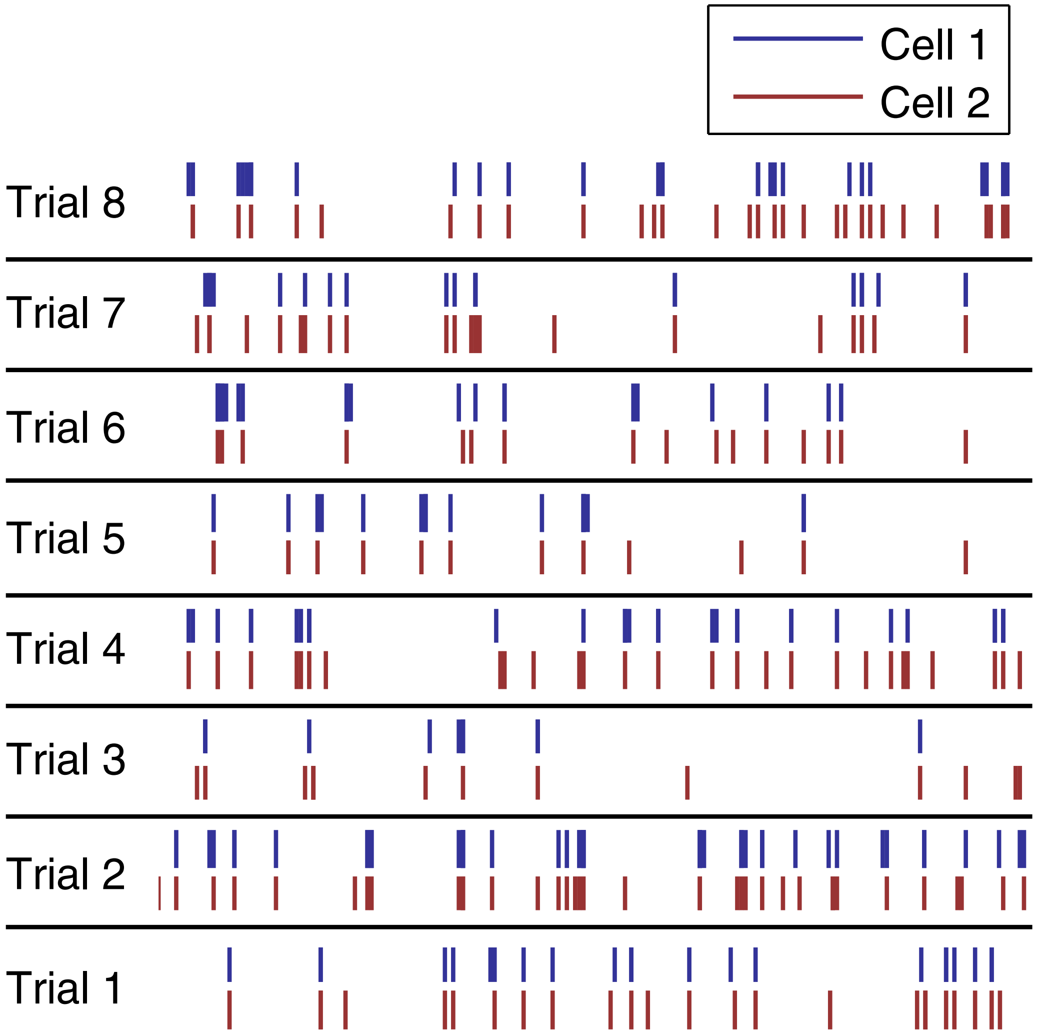
Spike timing correlation (synchrony)

Fast time scale correlation



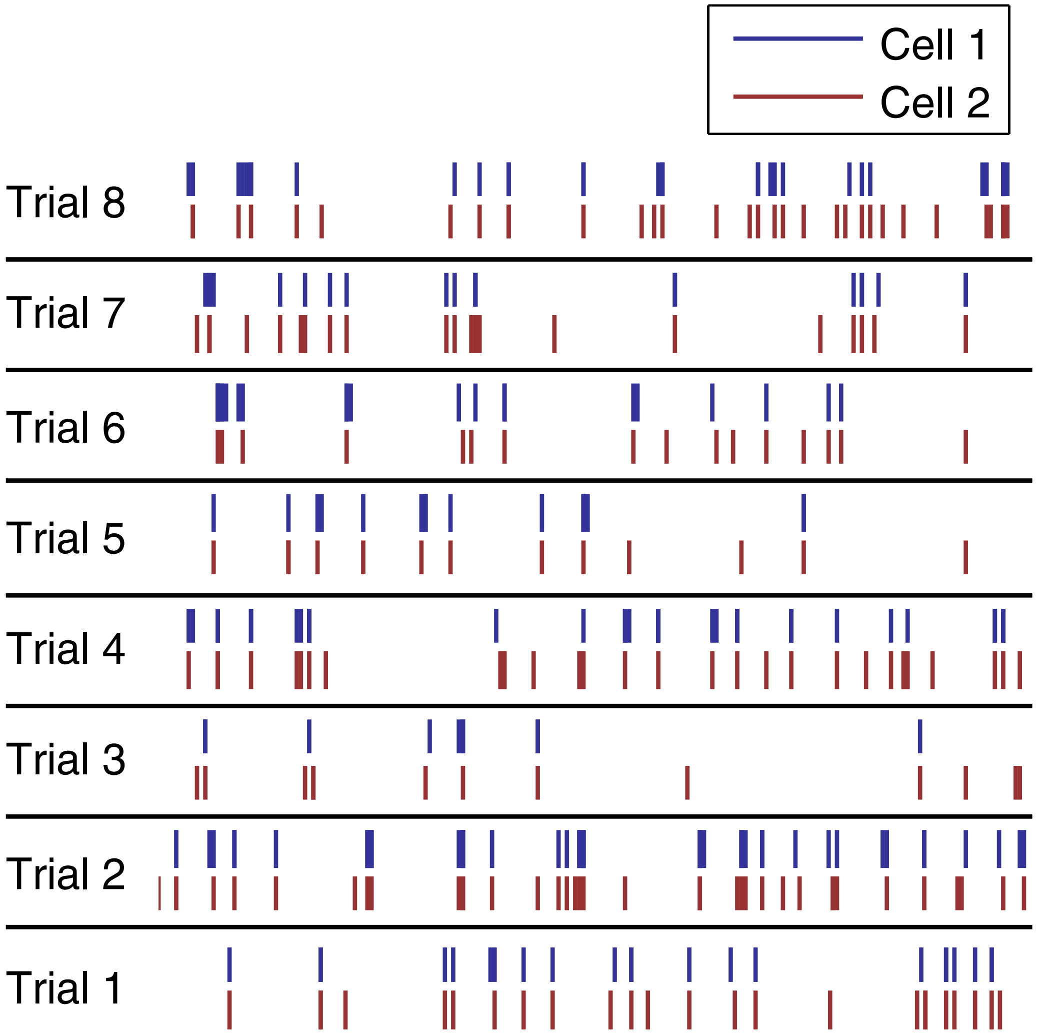
Spike timing correlation (synchrony)

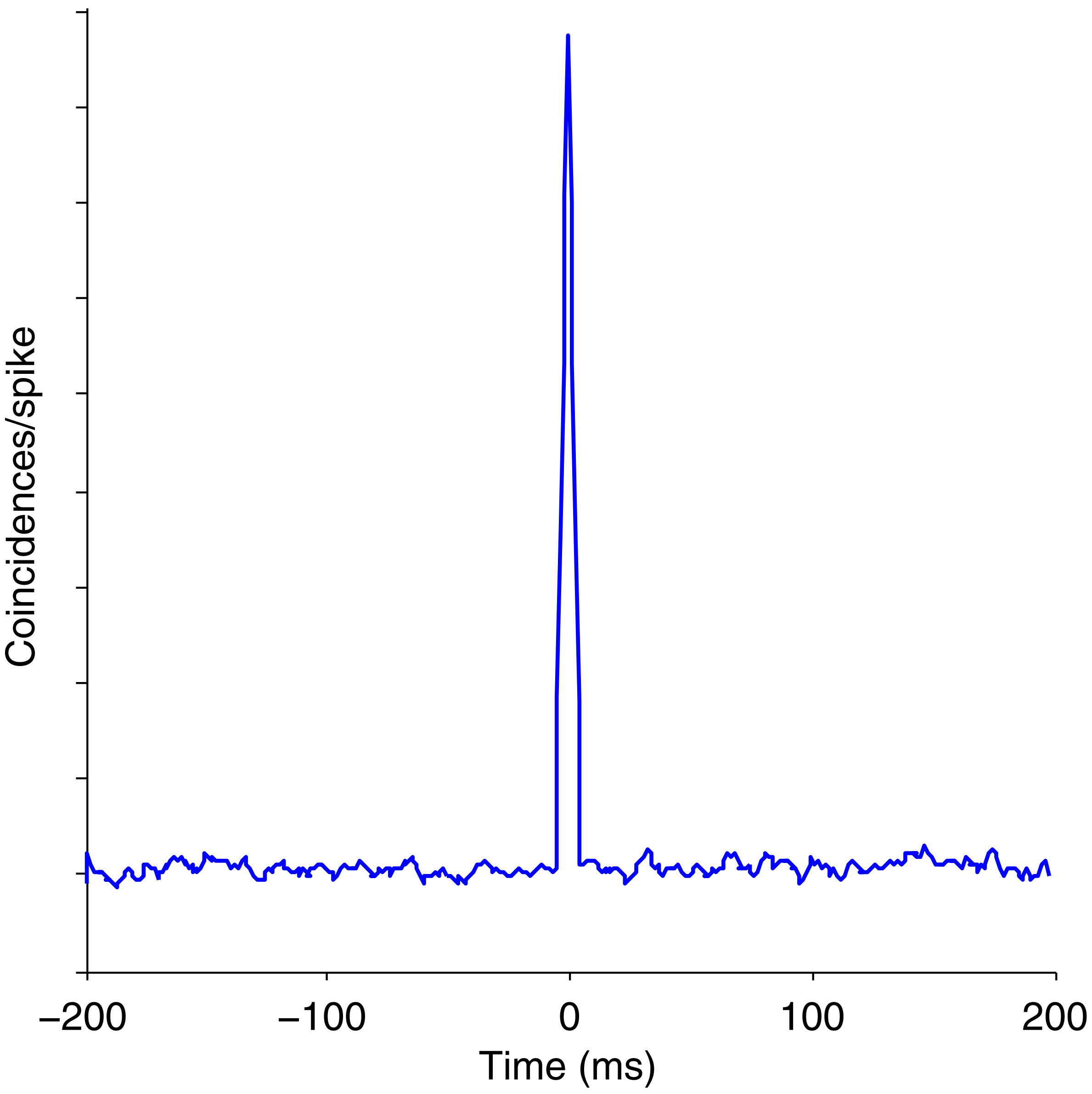
<u>Fast</u> time scale correlation



Spike timing correlation (synchrony)

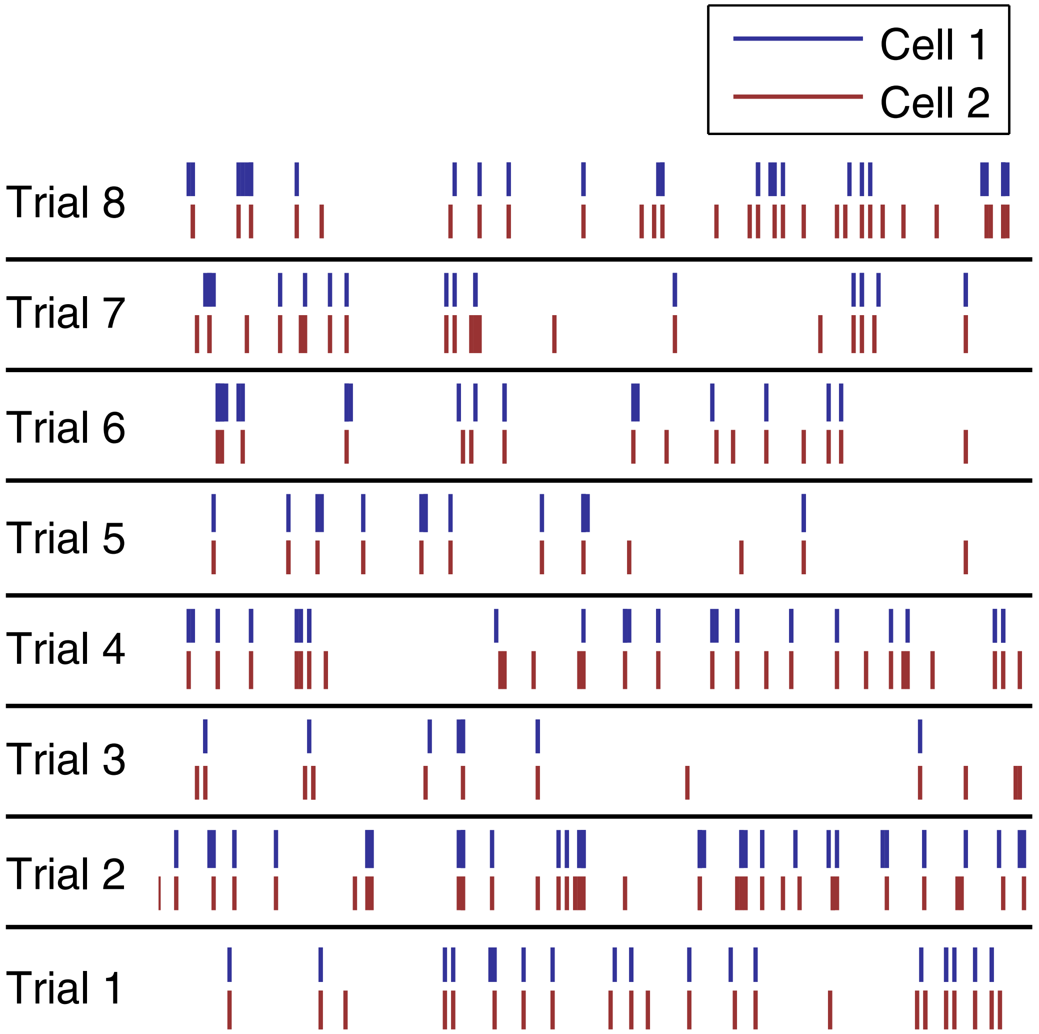
Fast time scale correlation

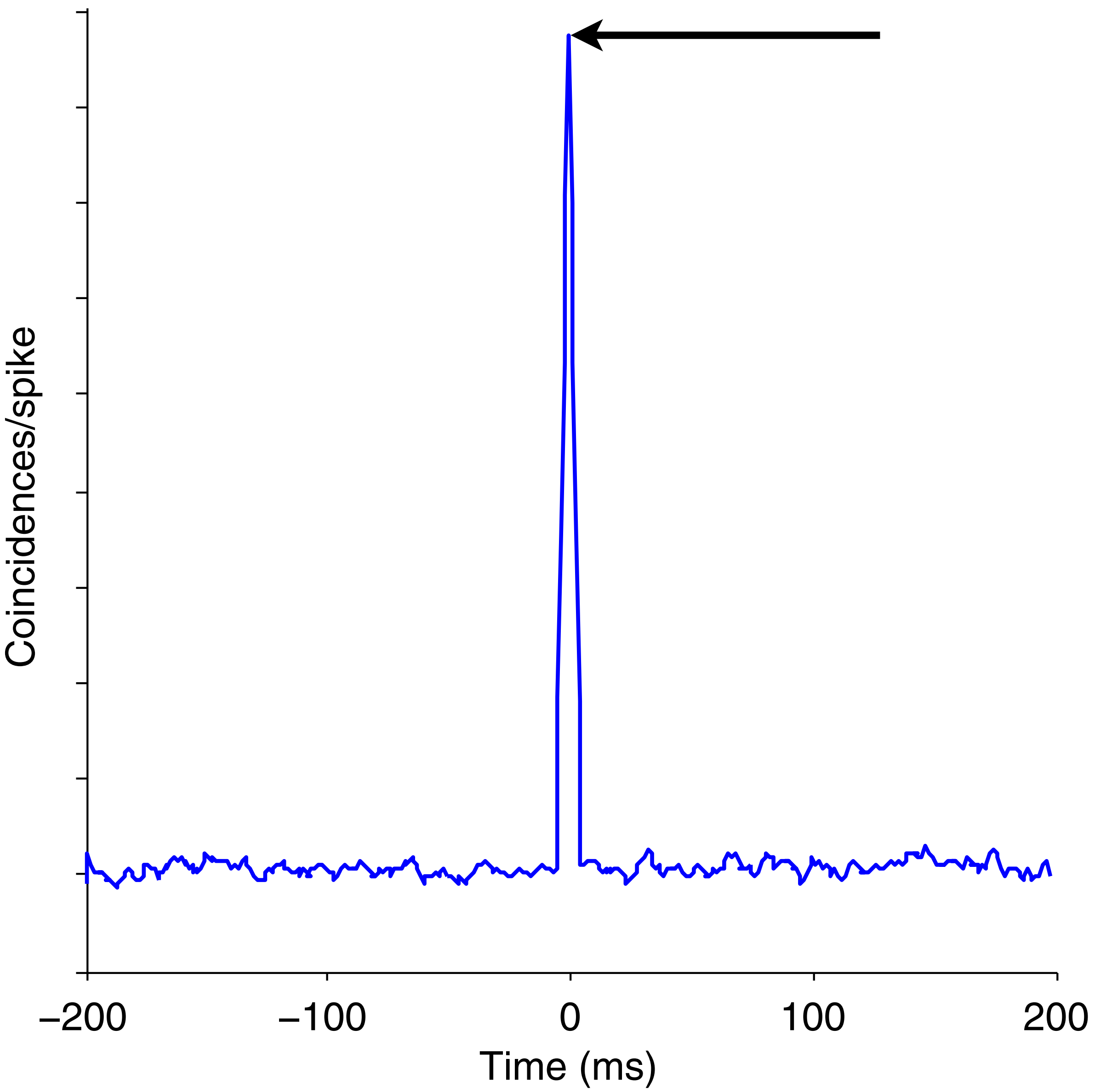




Spike timing correlation (synchrony)

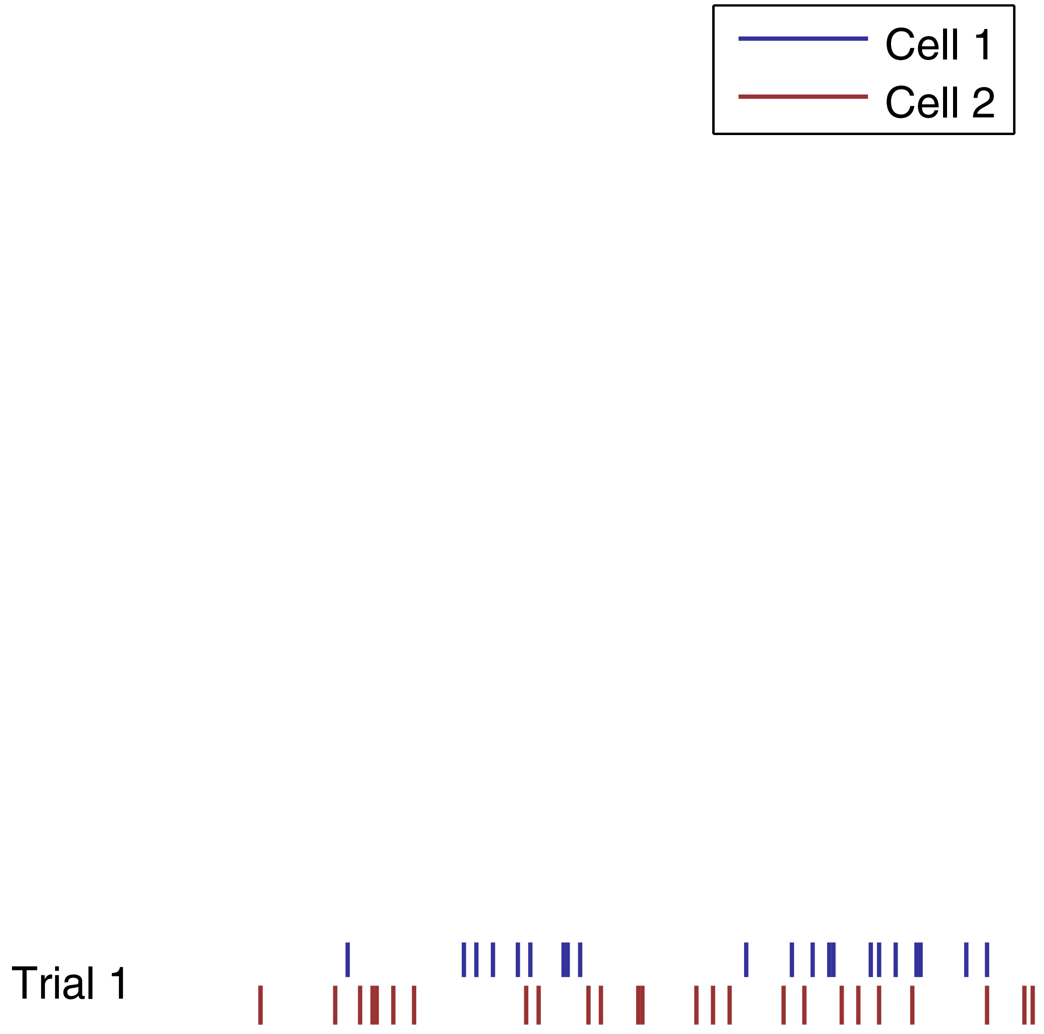
Fast time scale correlation



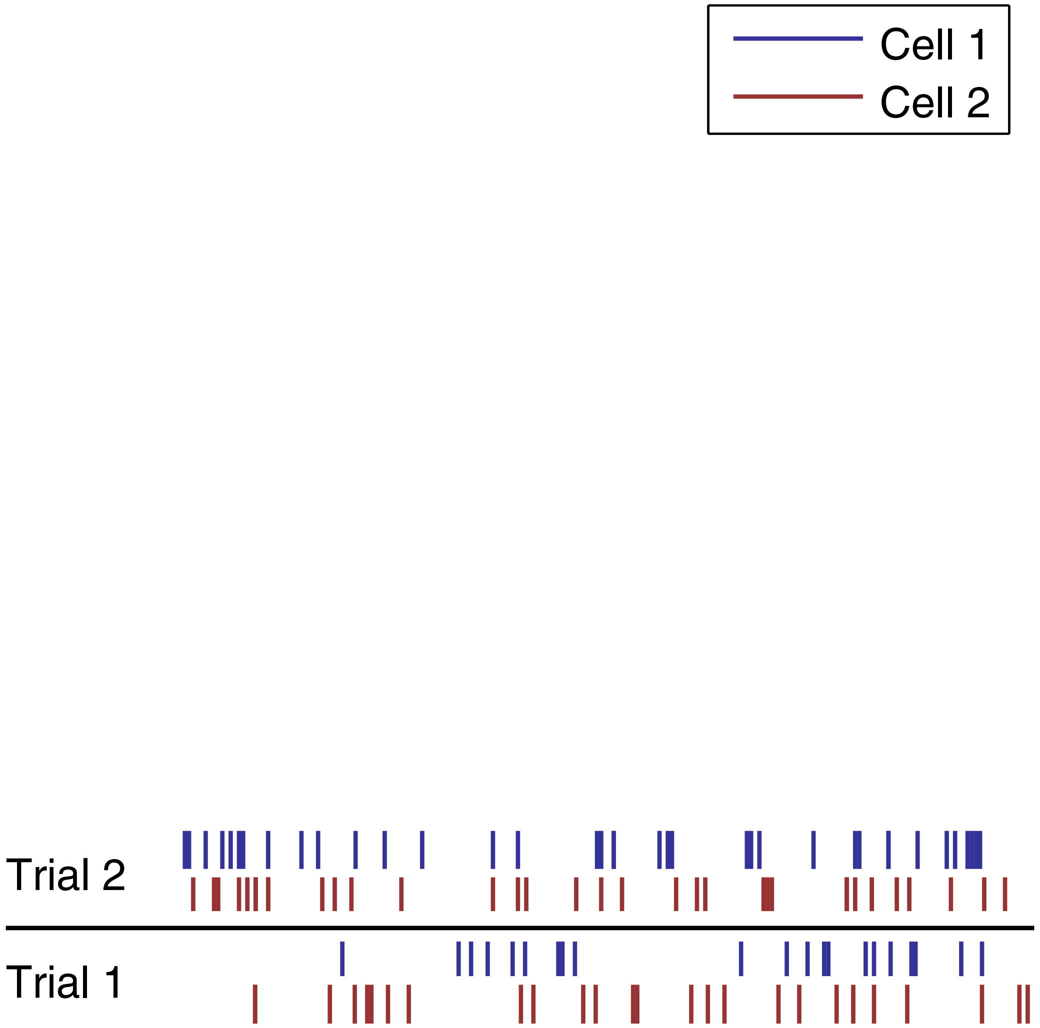


Spike timing correlation (synchrony)

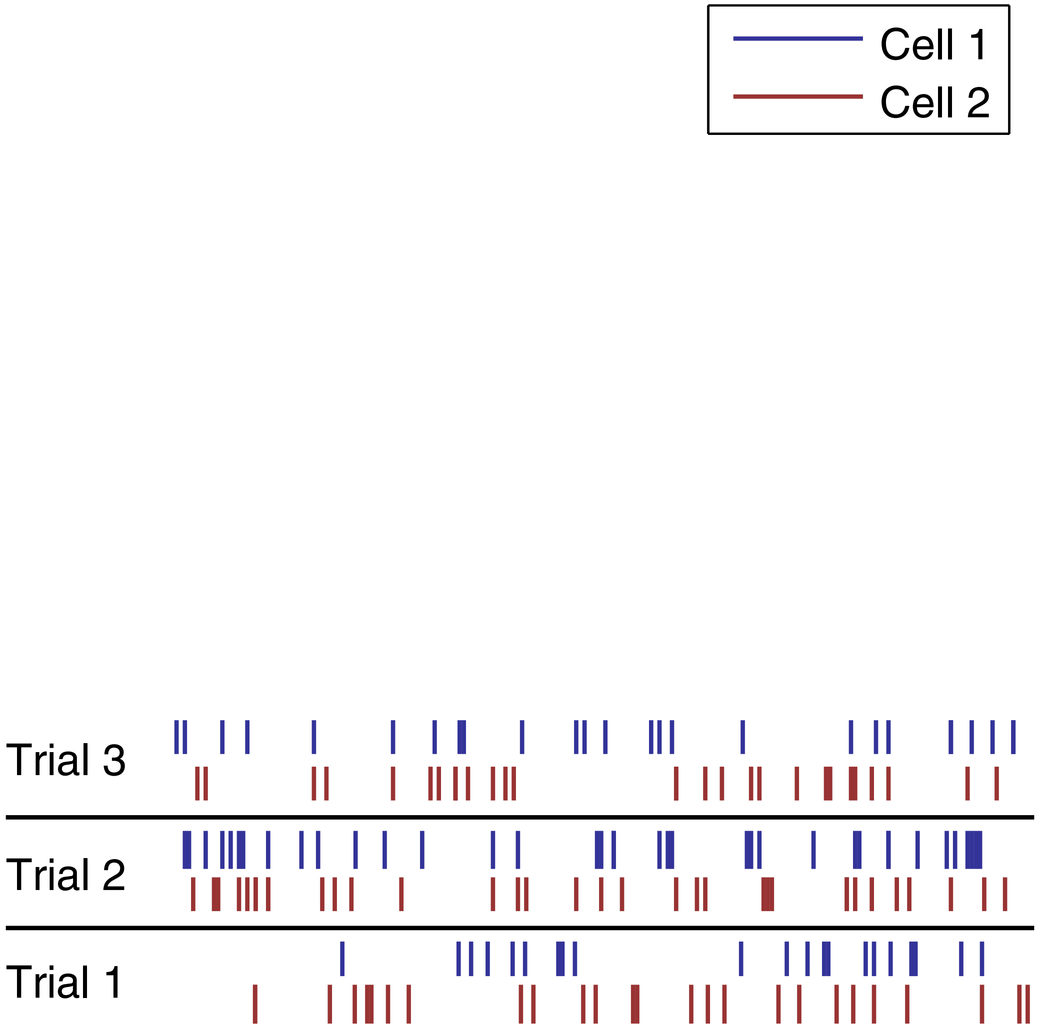
Spike timing correlation (synchrony)



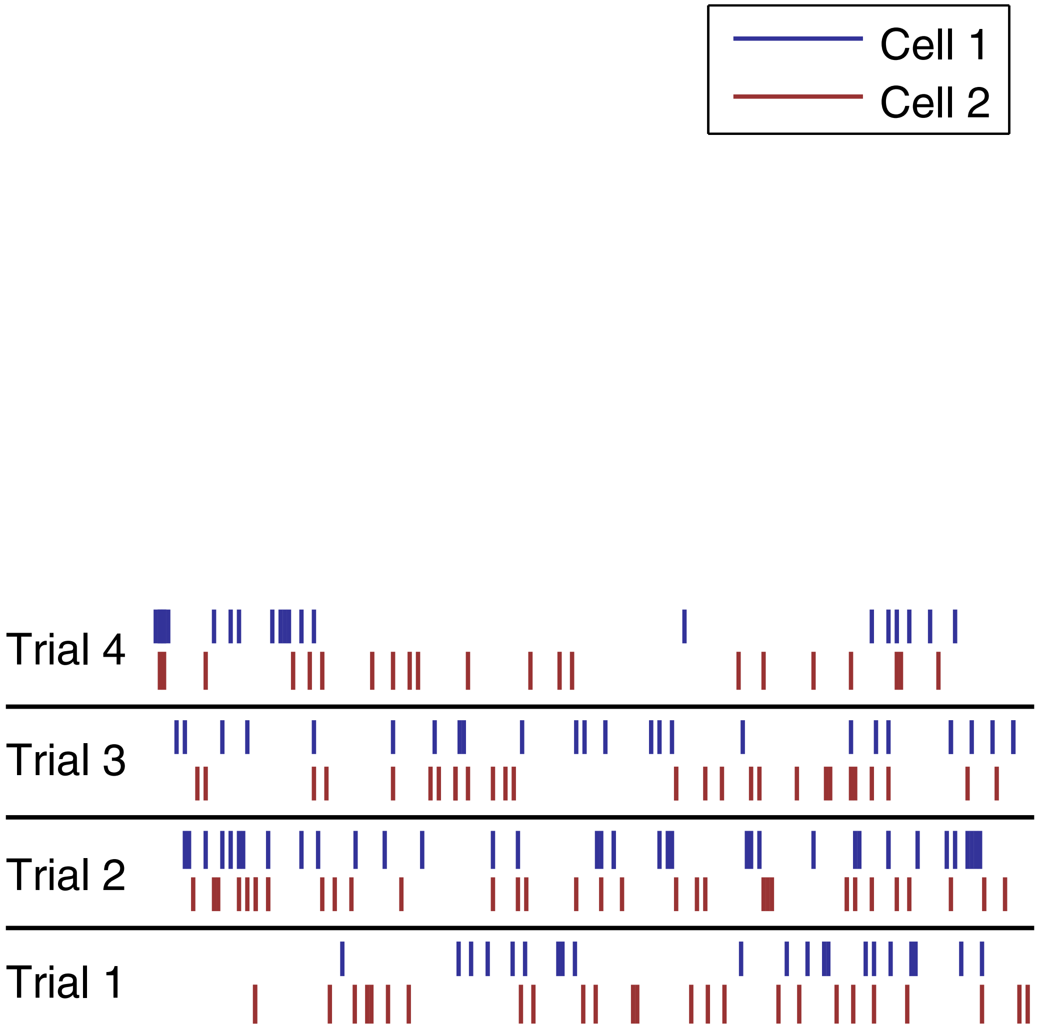
Spike timing correlation (synchrony)



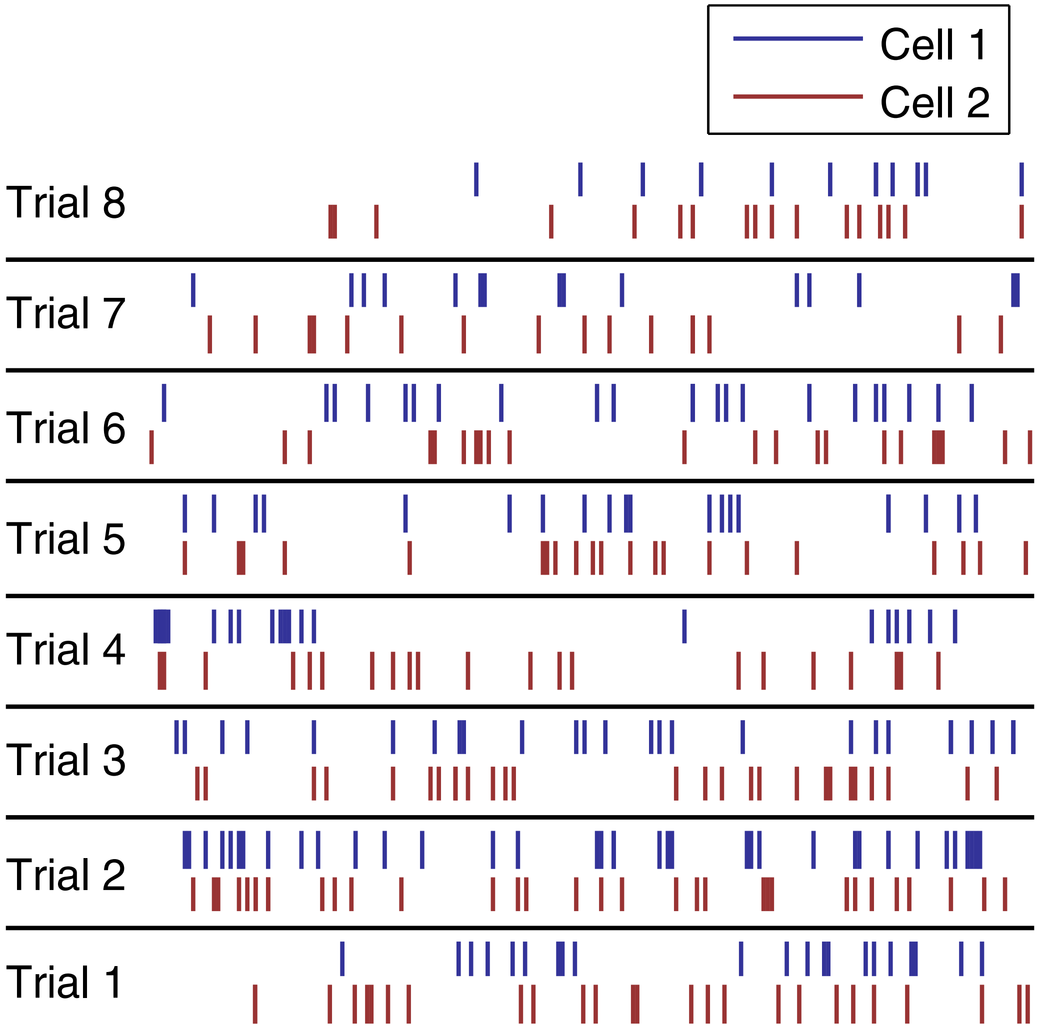
Spike timing correlation (synchrony)



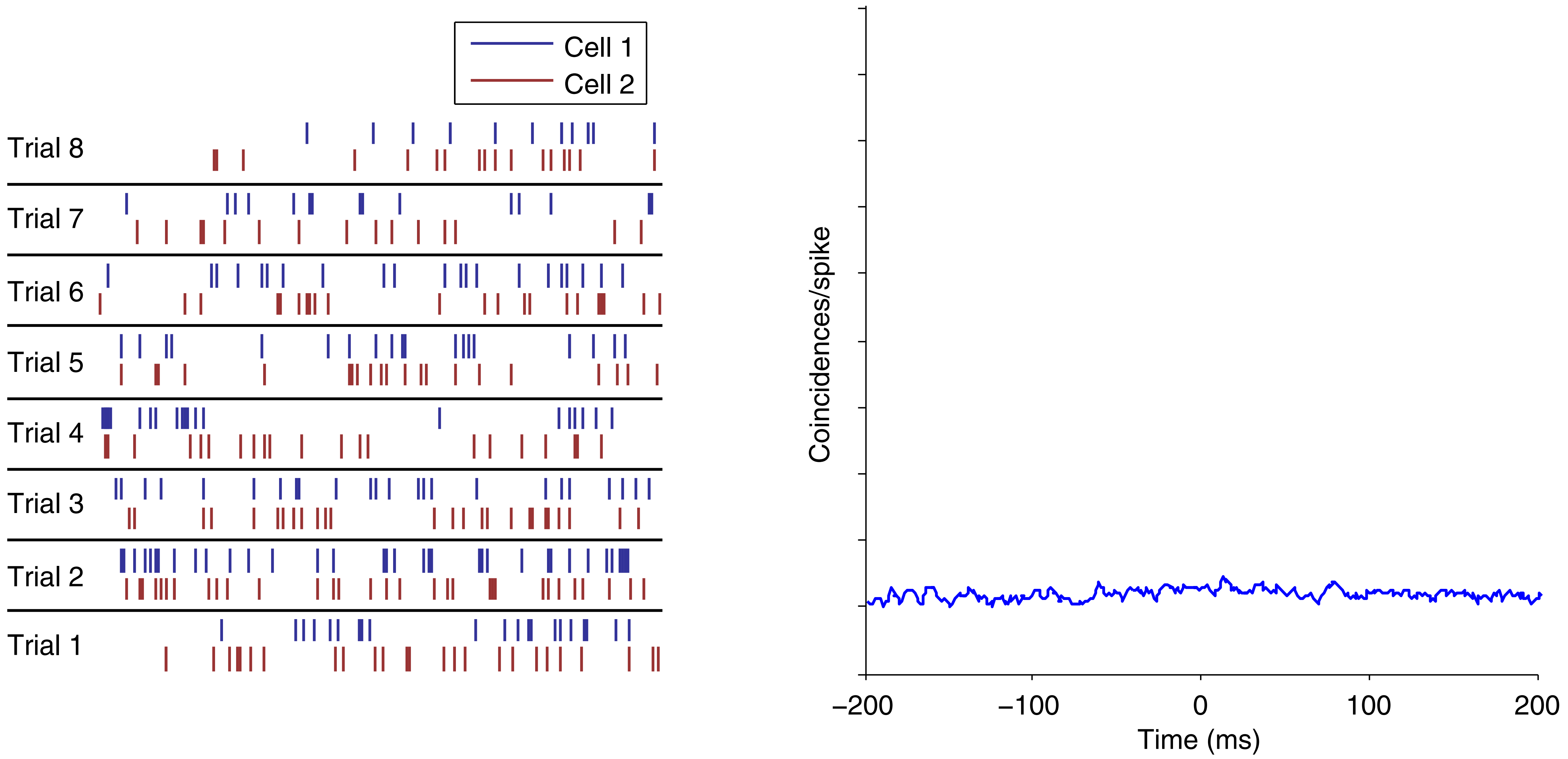
Spike timing correlation (synchrony)



Spike timing correlation (synchrony)



Spike timing correlation (synchrony)



Cross-correlogram (CCG)

trials

bins

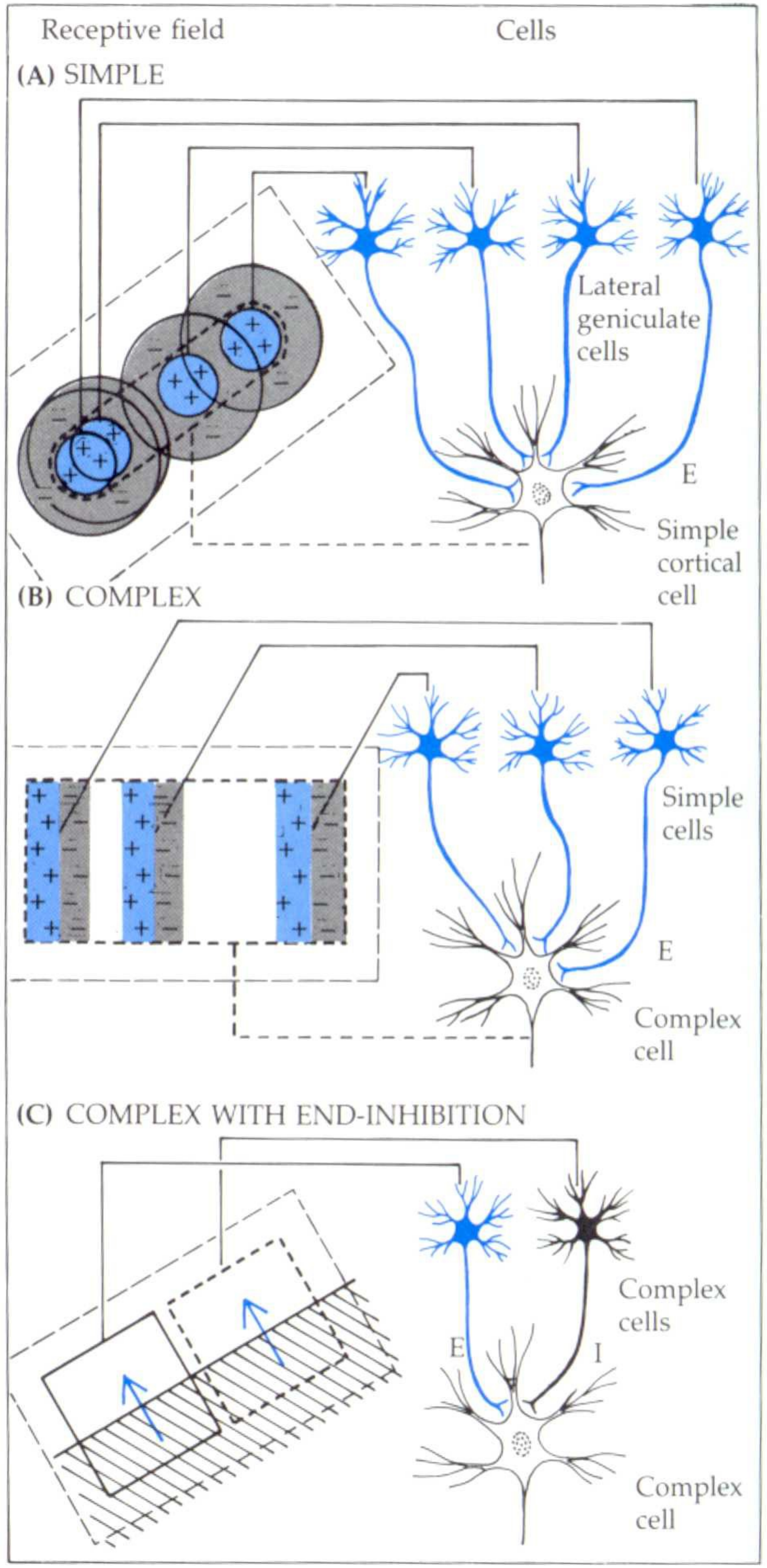
spike trains

$$CCG(\tau) = \frac{\frac{1}{M}\sum_{i=1}^{M}\sum_{t=1}^{N} x_1^i(t)\, x_2^i(t+\tau)}{\theta(\tau)\,\sqrt{\lambda_1\lambda_2}},$$

triangular function

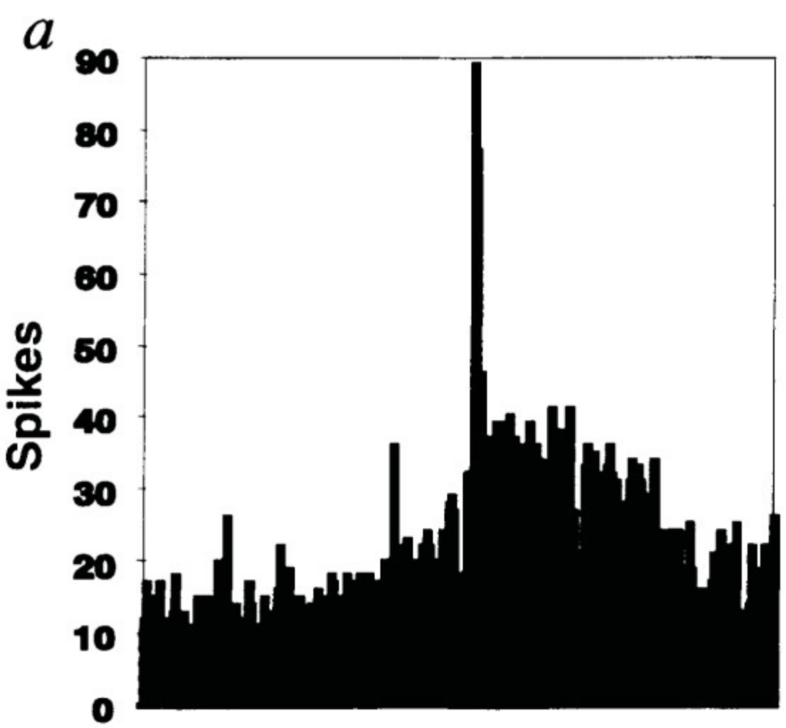
time lag

mean f.r.

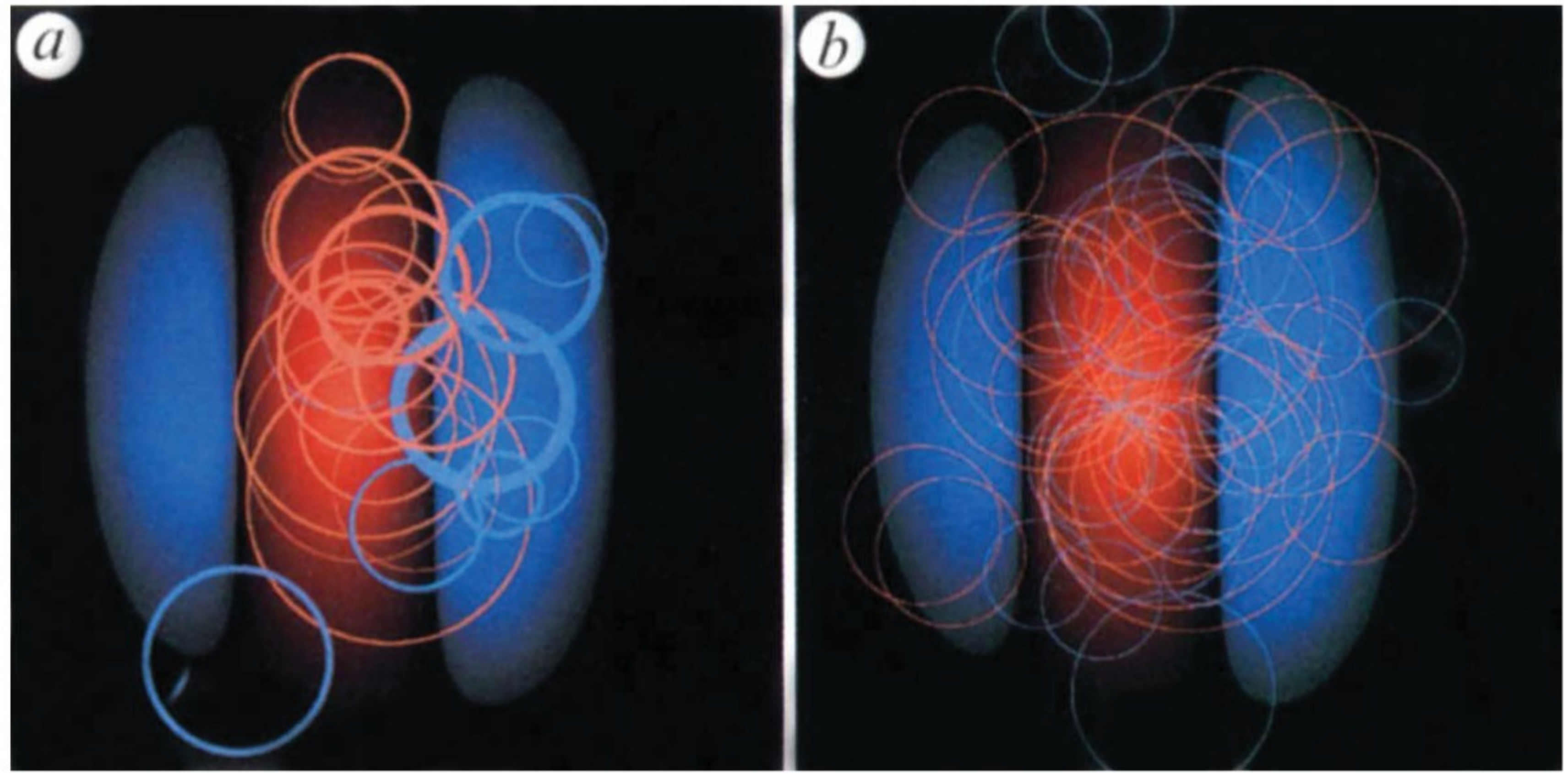


Using the cross-correlogram to infer circuits

Using the cross-correlogram to infer circuits



Time (ms)
Cross-correlogram



Reid and Alonso (1995) Nature 378: 281

Correcting the cross-correlogram

raw CCG - surrogate data

=

corrected CCG

Correcting the cross-correlogram

raw CCG - surrogate data

=

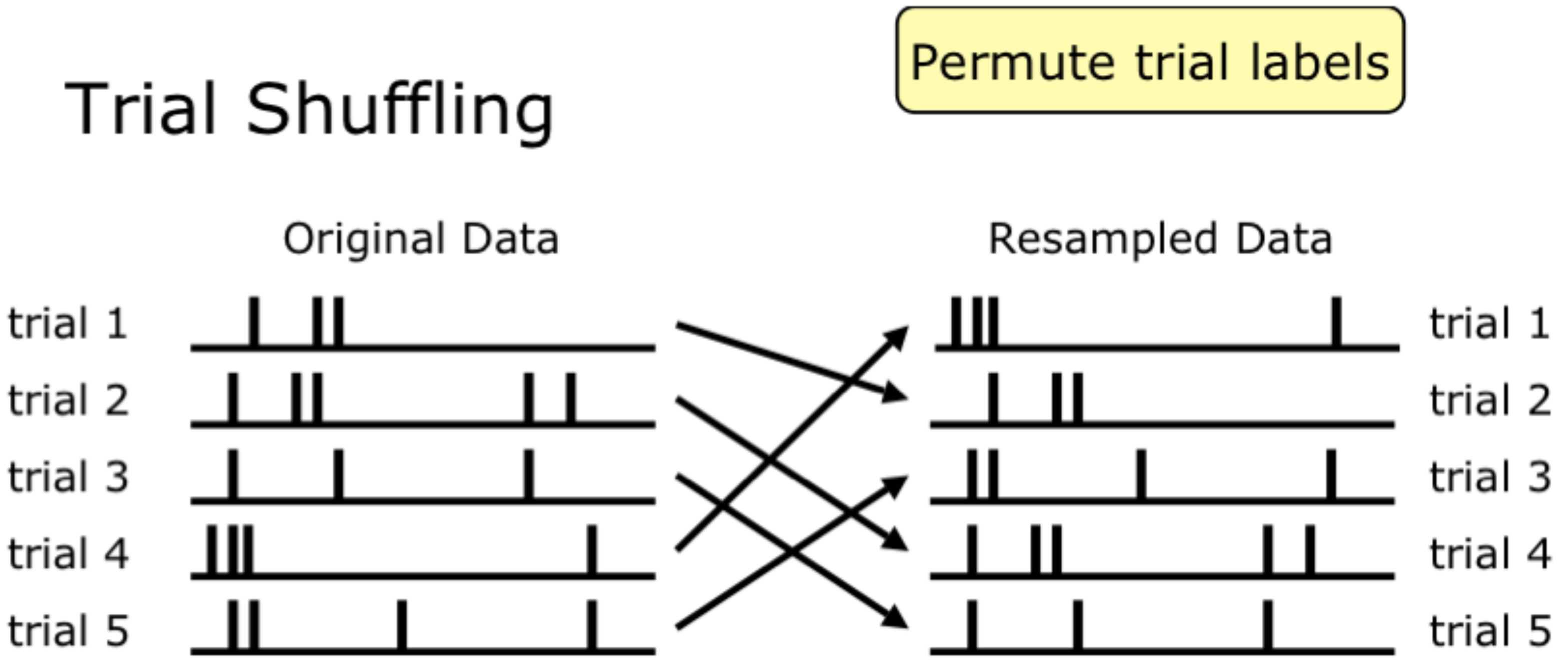
corrected CCG

surrogates=

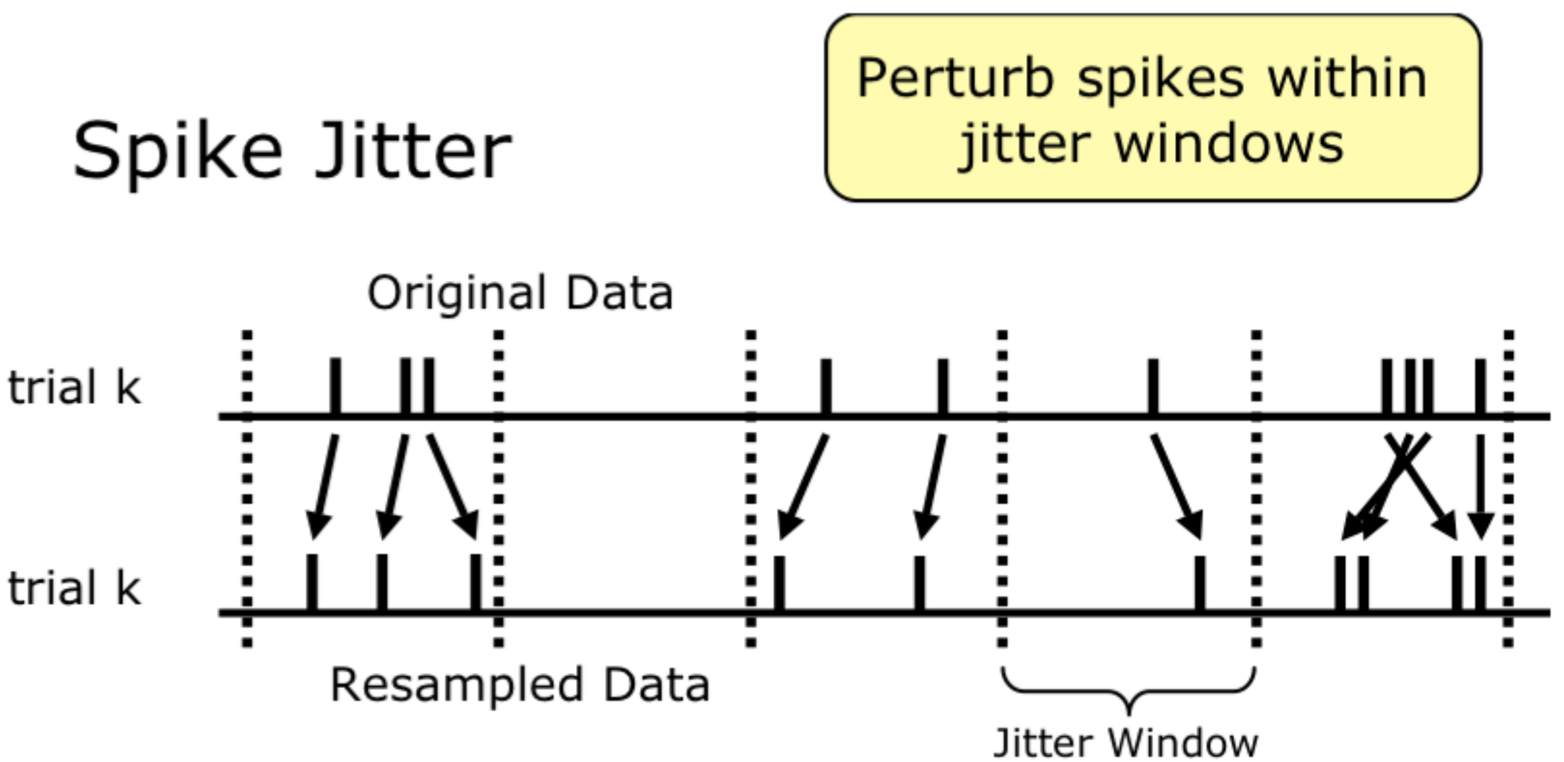
shuffle, shift, jitter, ?

How do we isolate fast correlation?

Removes event-locked correlation

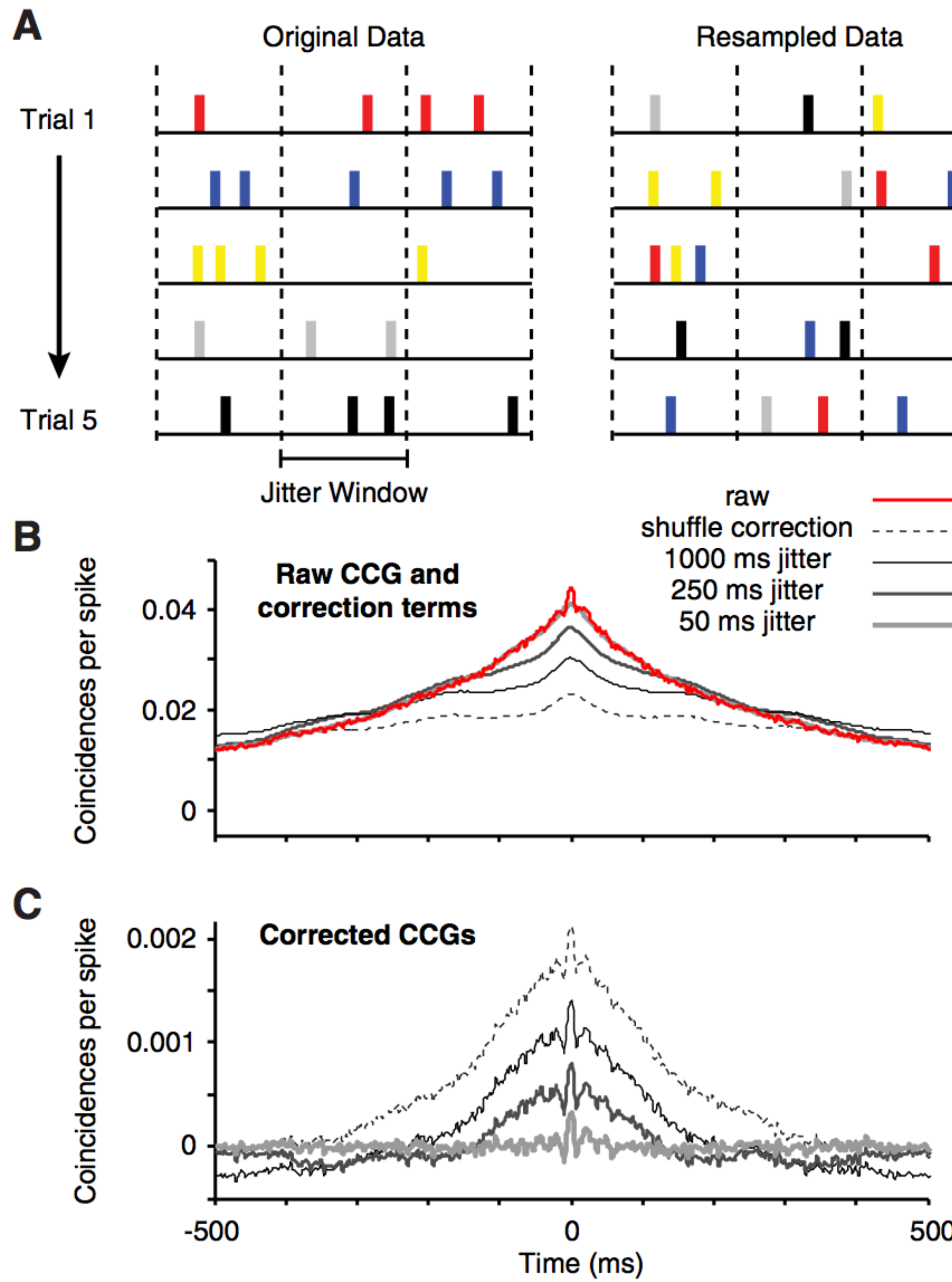


Removes all correlation on time scale < jitter window



Harrison, Amarasingham & Geman, Cosyne 2007

Correcting the cross-correlogram



Smith & Kohn, 2008

CCGs can allow us to infer anatomy

Autocorrelogram (ACG)

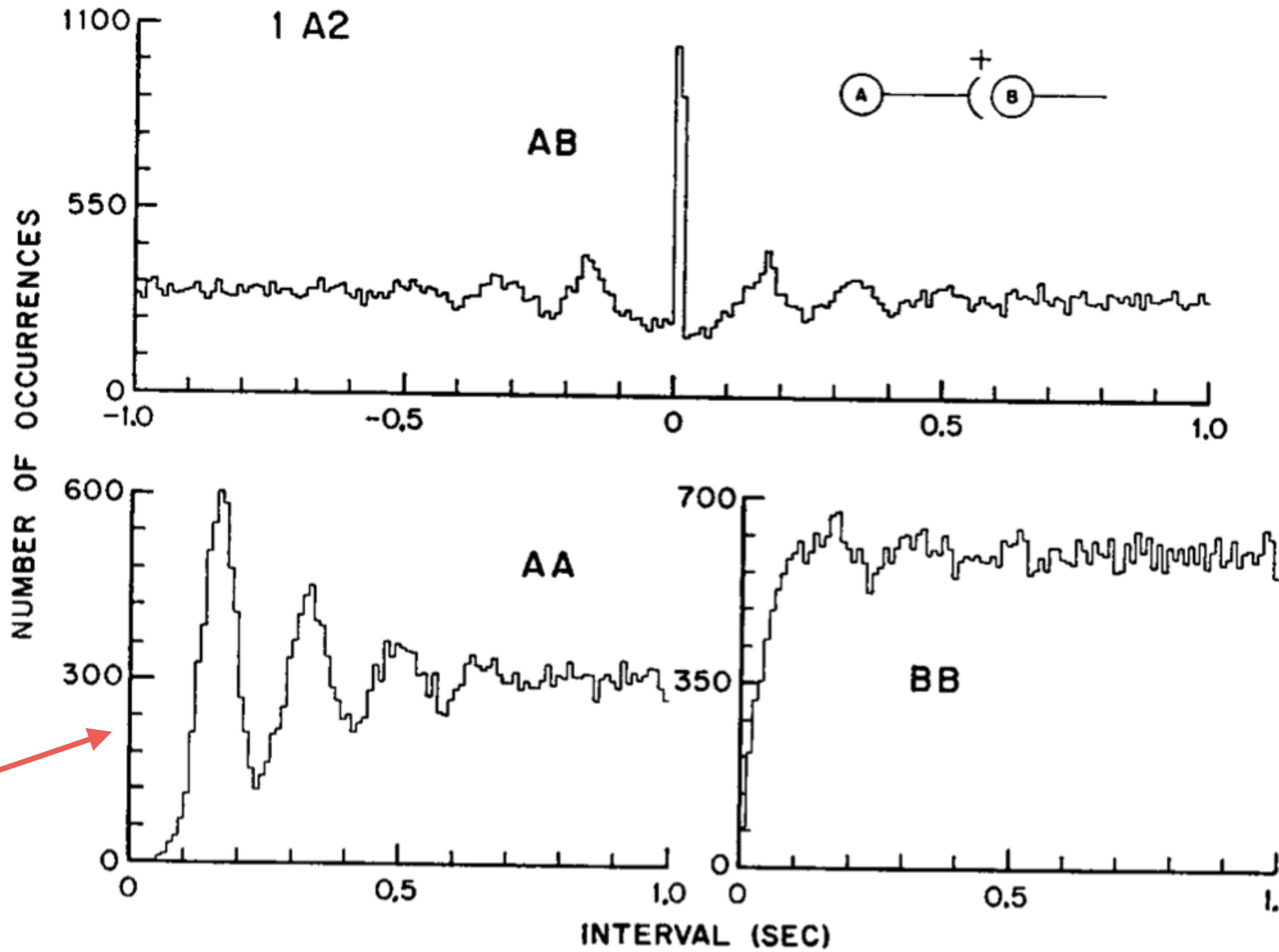


FIGURE 1 Monosynaptic excitation. Periodic presynaptic cell. In this and Figs. 2–6 the *A* cell is always the presynaptic cell, *B* the postsynaptic cell. Top: *AB* cross-correlation. Bottom, left: cell *A* autocorrelation. Right: *B* autocorrelation (run 1A2).

Moore, Segundo, Perkel & Levitan (1970)

CCGs can allow us to infer anatomy

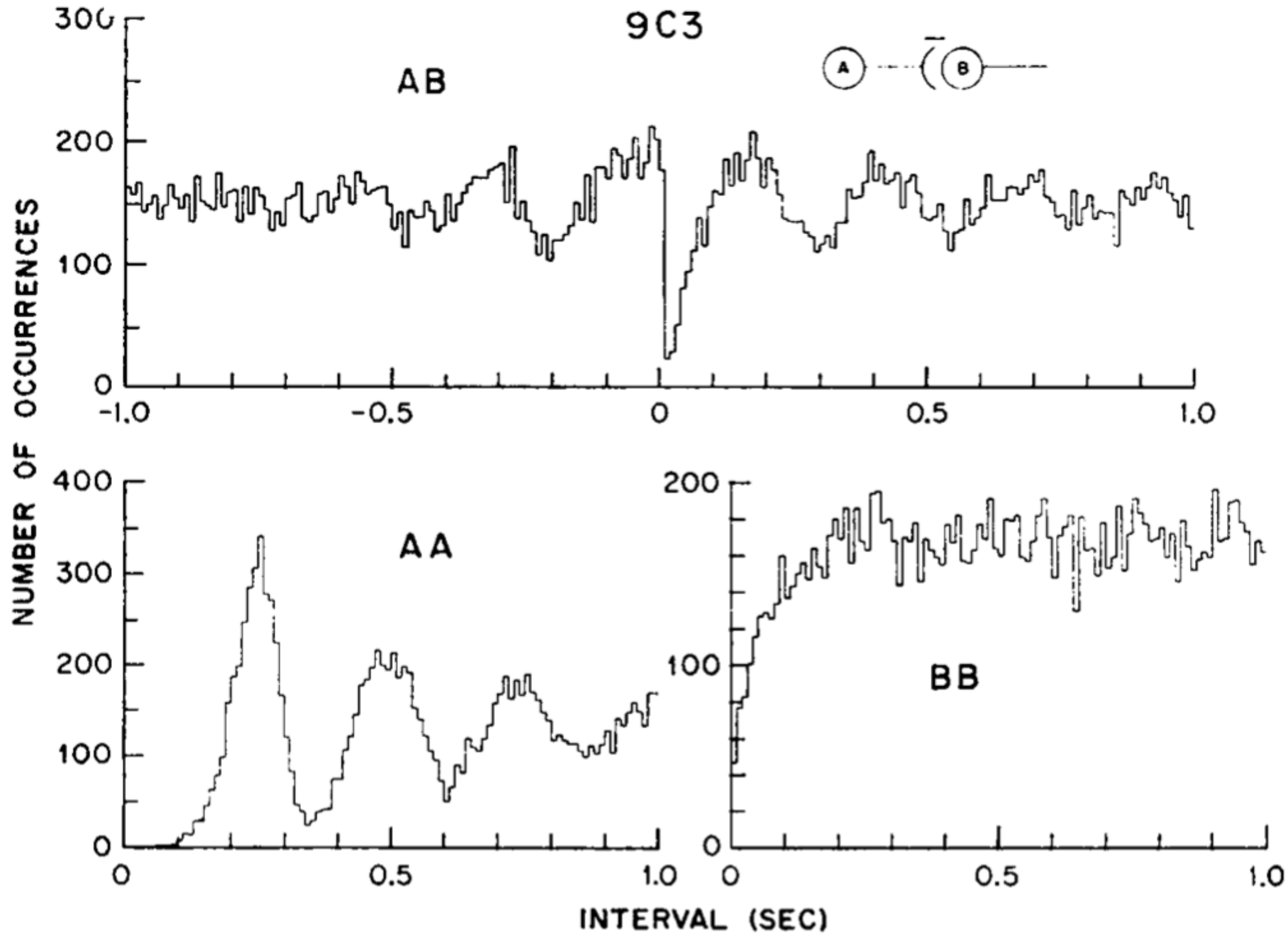


FIGURE 5 Monosynaptic inhibition. Periodically firing presynaptic cell. Top: *AB* cross-correlation. Initial trough is primary sign of monosynaptic inhibition. Bottom: *A* and *B* cell autocorrelations. Note appearance of input cell's periodicity in cross-correlation for positive and negative τ (run 9C3).

Moore, Segundo, Perkel & Levitan (1970)

… but we're limited in that inference

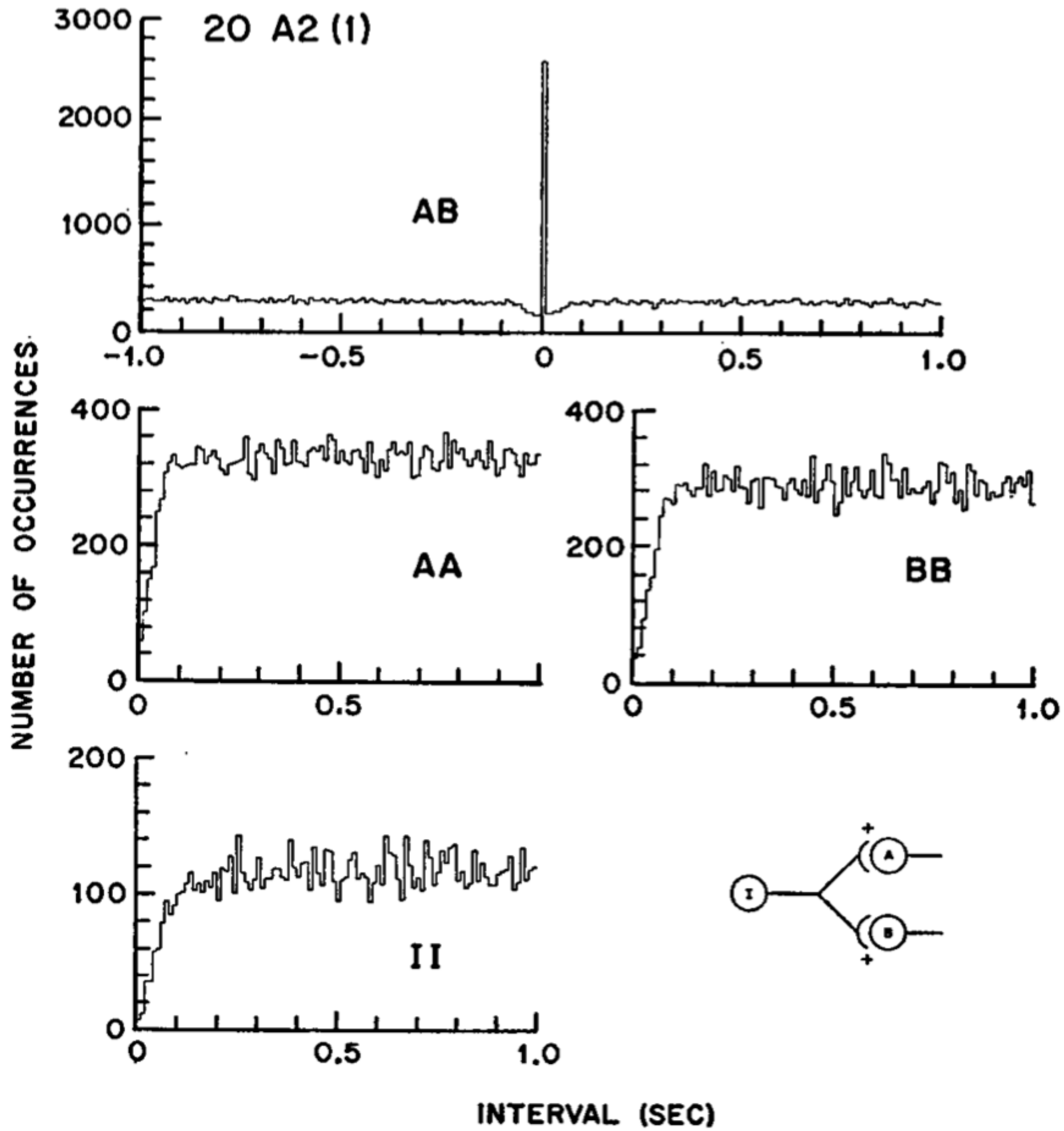


FIGURE 7 Shared excitatory synaptic input. Basic case in which common excitatory source and both postsynaptic cells have flat autocorrelations.

Moore, Segundo, Perkel & Levitan (1970)

… but we're limited in that inference

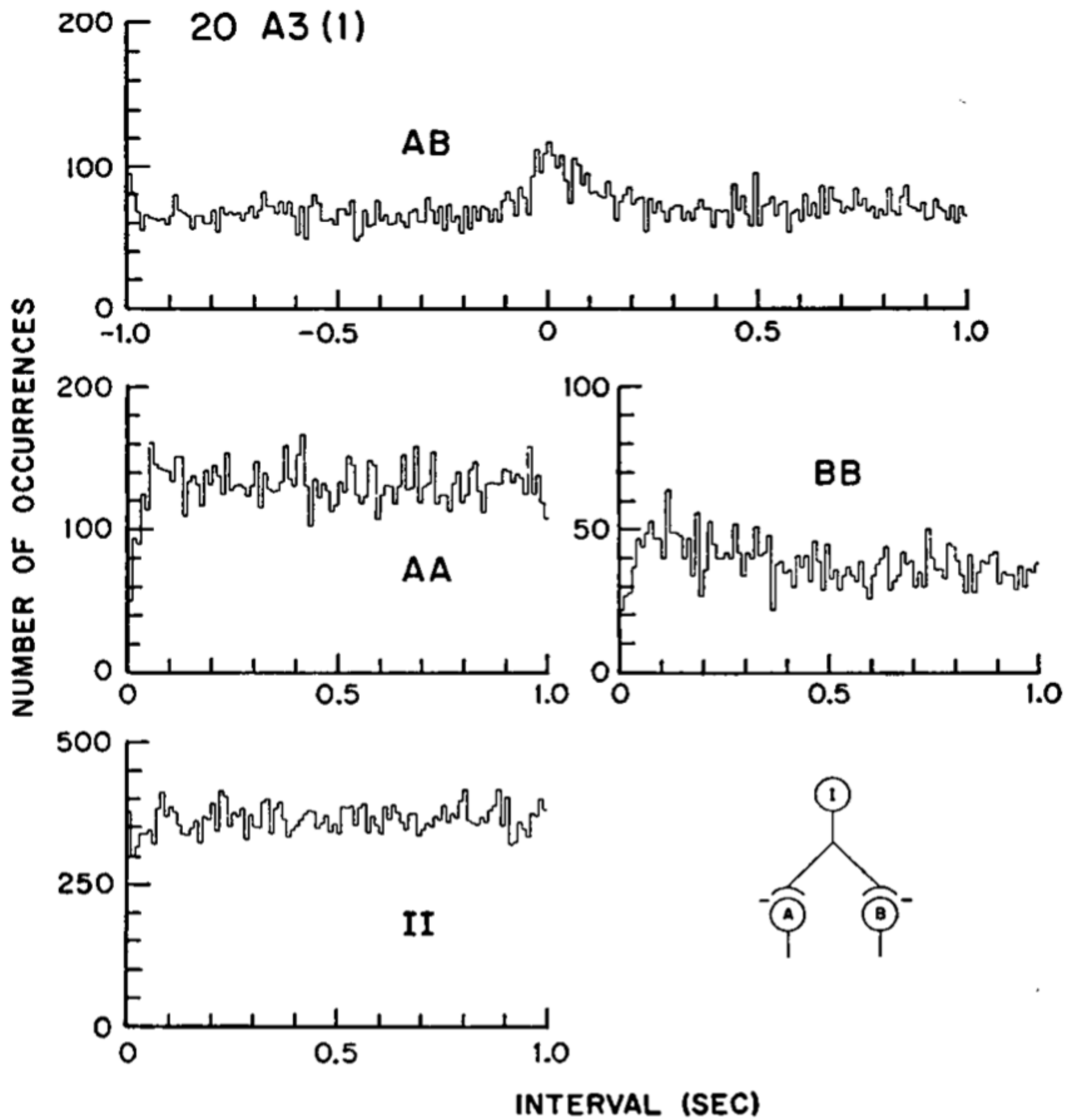
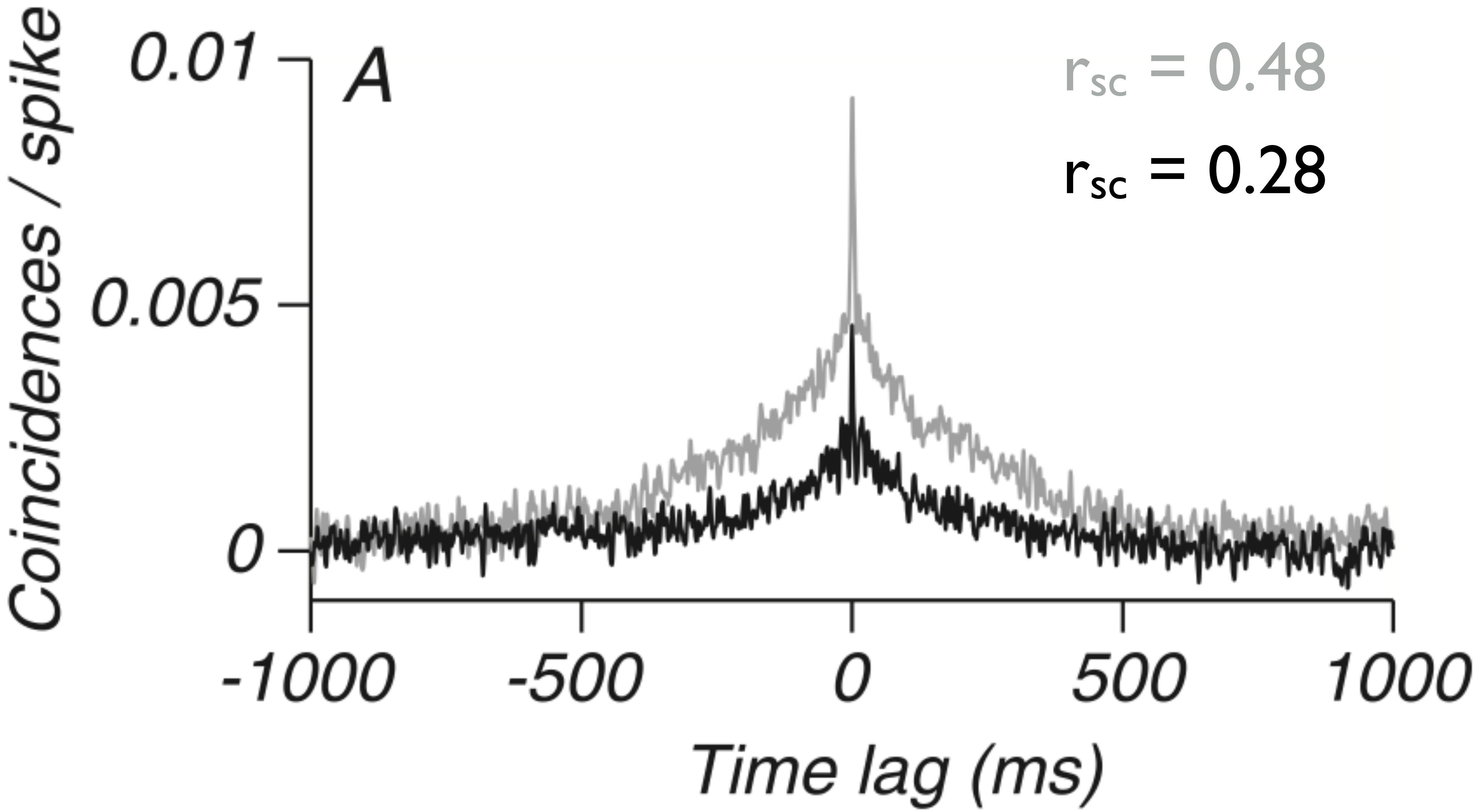


FIGURE 9 Shared inhibitory synaptic input. Basic case of shared inhibition in which all three cells have flat autocorrelation functions. Central broad peak is primary characteristic of the shared inhibition.

Moore, Segundo, Perkel & Levitan (1970)

The CCG and r_{sc} are linked



Kohn & Smith, 2005