# *COMS30127/COMSM2127*
# *Computational Neuroscience*

## Lecture 13: Spike trains, analysing spike data

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## Link to lecture video:

# What we will cover today

- Recap on spike trains

  - Spike count

  - Inter-spike interval

- Spike train summary statistics

  - Fano factor

  - Coefficient of Variation (CV)

- Analysing spiking data

  - Peri-stimulus time histogram (PSTH)

  - Spike-triggered average (STA)

  - Autocorrelograms

  - Cross-correlograms

  - Decoding

# Spike trains

Stimulus onset

Spike count

18
18
16
16
30
21
⋮

Inter-spike interval

75 ms

[Motter, *J Neurophysiol*, 1993]
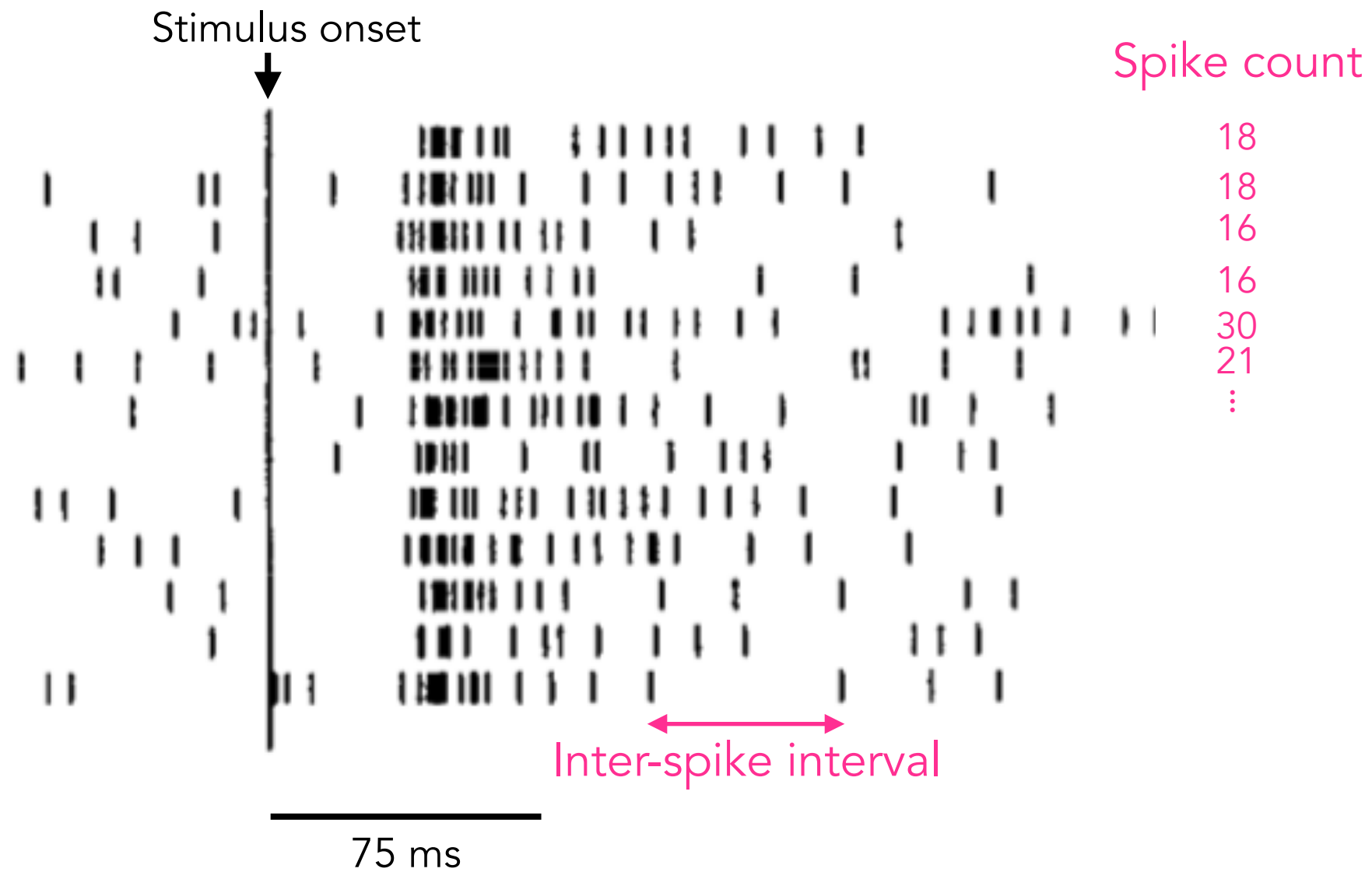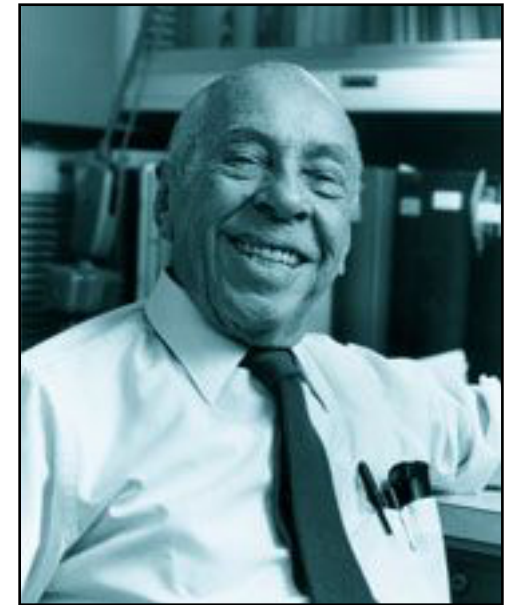
# Fano Factor


Ugo Fano

- The Fano Factor is a statistical measure of the *dispersion* of a probability distribution.

- In neuroscience it is typically used to quantify the variability of spike trains.

- It the variance of the spike count divided by the mean spike count:

$$F = \frac{\sigma^2}{\mu}$$

- Importantly it usually applied to the **spike counts** over some time interval (not the interspike intervals).

# Coefficient of variation (CV)

- A different measure of variability is the coefficient of variation (CV).

- It is the standard deviation of the interspike interval divided by the mean interspike interval:

$$CV = \frac{\sigma_{ISI}}{\mu_{ISI}}$$

- In contrast to the Fano Factor, it is usually applied to the **interspike intervals** (not the spike counts).

# Analysing spiking data

- Peri-stimulus time histogram (PSTH)

- Spike-triggered average (STA)

- Autocorrelograms

- Cross-correlograms

- Decoding

# Peri-stimulus time histogram (PSTH)

- Neural responses to stimuli are variable, meaning they are not always identical from trial to trial (repeated presentations of the same stimulus).

- The peri-stimulus time histogram is one way to represent the average spike response across trials.

- The idea is:
  - Superimpose the neuron's spike responses from multiple trials.
  - Bin time into small intervals (e.g. 2 ms).
  - Histogram the spike counts in each time bin.


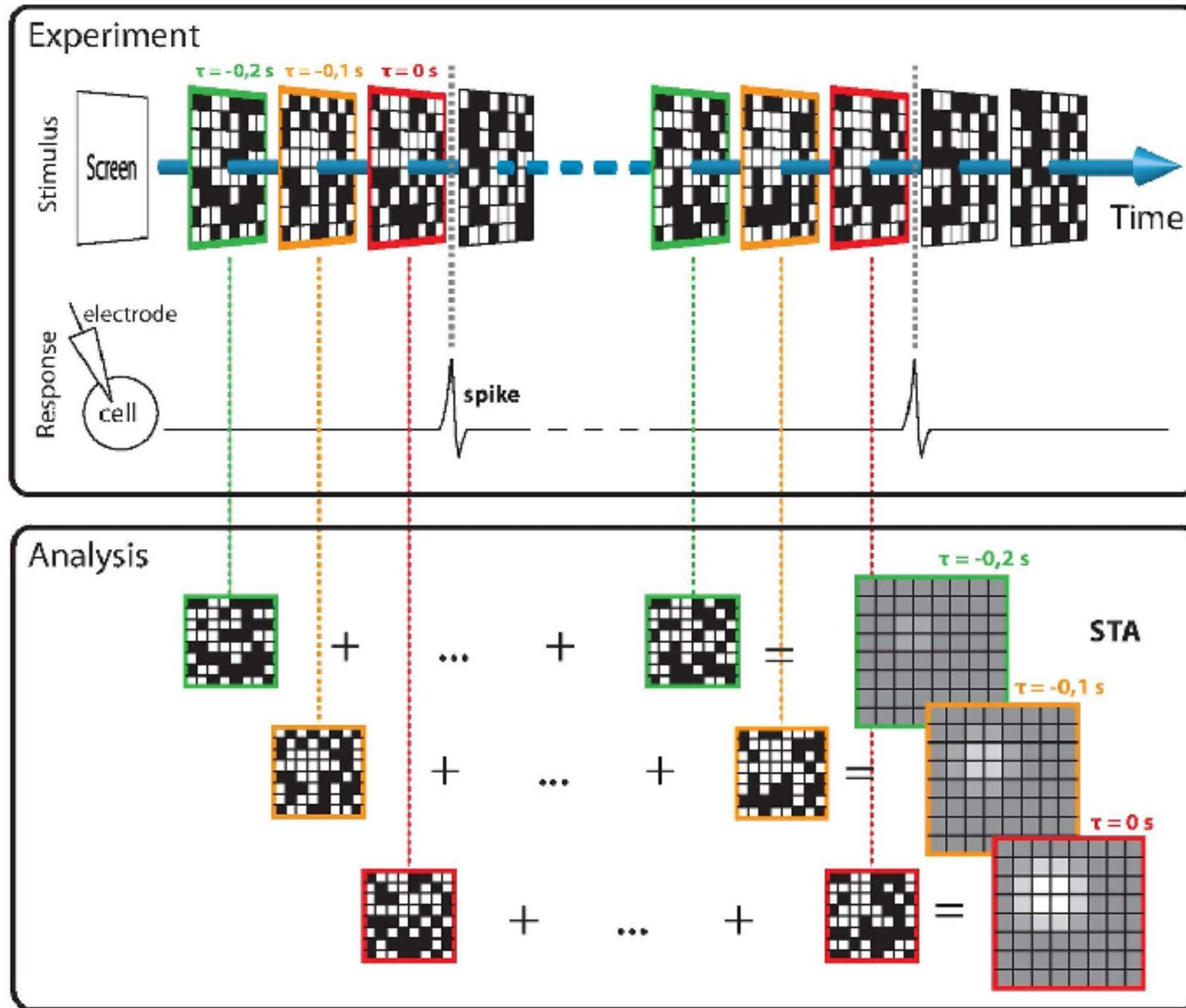
[Dayan & Abbott, 2001]
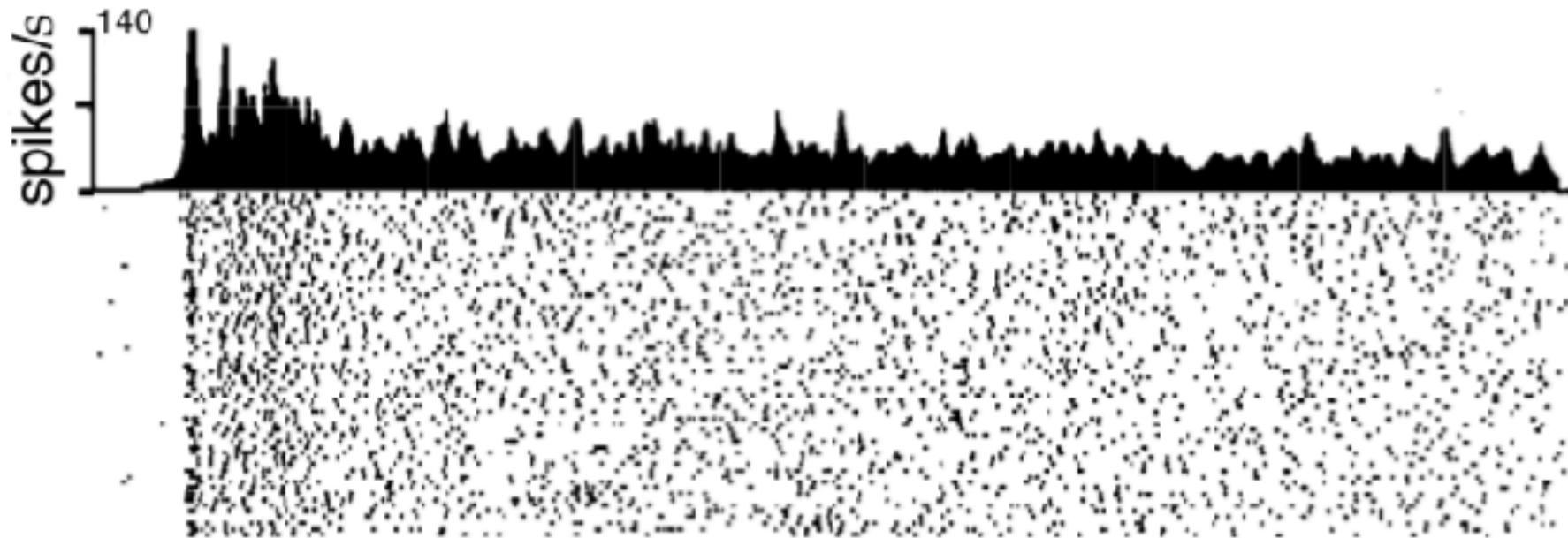
# Spike-triggered average

- Another way of analysing the data is to ask the question: what aspect of the stimulus caused the neuron to spike?

- One way of quantifying this is the spike-triggered average stimulus:

$$S(\tau) = \frac{1}{N} \sum_{i=1}^{N} s(t_i - \tau)$$

where $s(t)$ is the stimulus value, $t_i$'s are spike times and $\tau$ is a time interval.

# Spike-triggered average (STA)

# Auto and cross correlograms

- Both of the last measures were ways of quantifying a neuron's spiking response to a stimulus.

- But we can define other measures of a neuron's spike timings with respect to itself, or other neurons: the auto and cross correlograms, respectively.

- In both cases we:
  - take a spike in the train
  - ask how many other spikes occurred at each of a range of time intervals away
  - then repeat the process for all spikes
  - and average.

- Auto correlograms are useful for detecting oscillations in a neuron's spiking. They are symmetric between positive and negative time intervals.

- Cross-correlograms are used to discover a temporal relationship between two neurons. For example one neuron might tend to spike right before the other, perhaps indicating the first activated the second.

# Auto correlograms
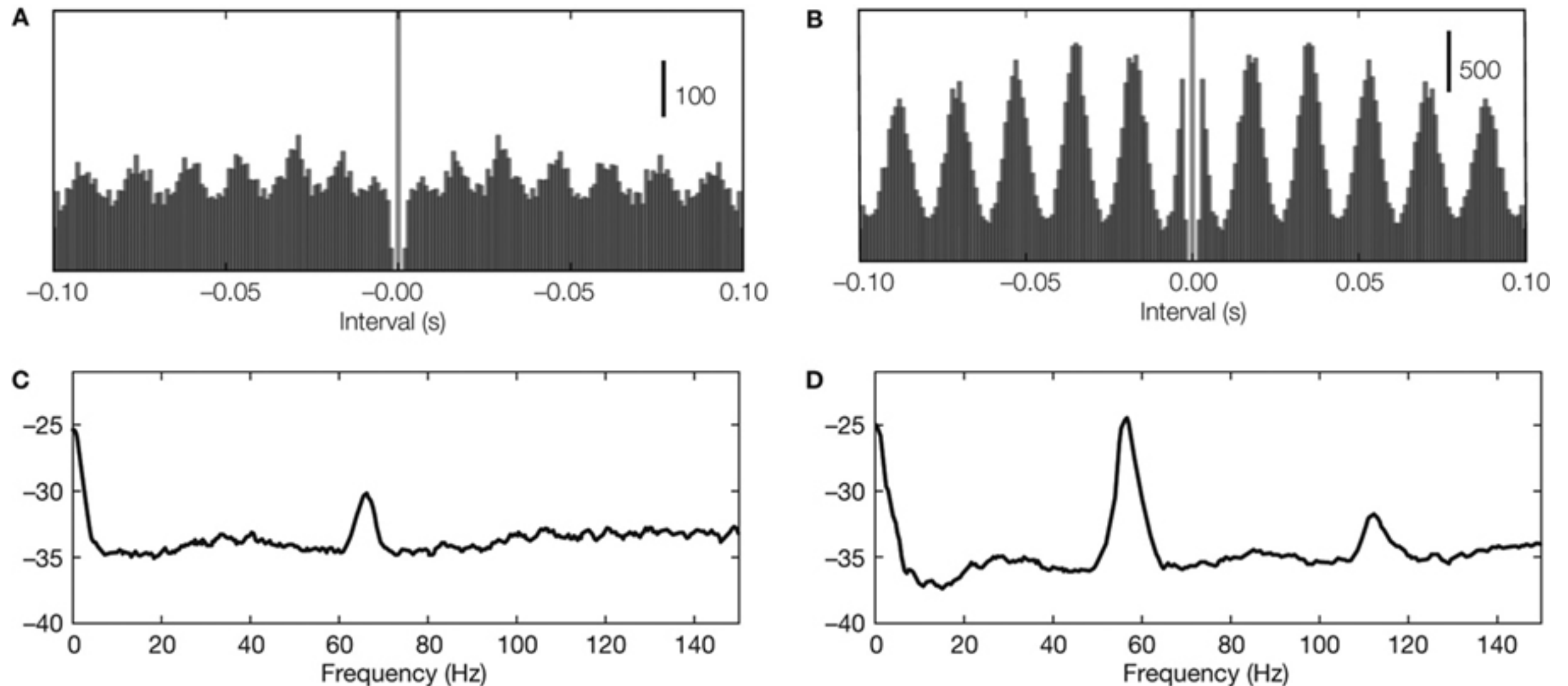


**Figure 1. Detecting neural oscillations. (A,B)** Oscillations in autocorrelations in two example recordings (spike trains recorded from LGN in cat) with oscillation score 10 and 29, respectively. **(C,D)** Oscillations in spectral power (same spike trains as used for panel **A**).

Koepsell, K., Wang, X., Hirsch, J.A., Sommer, F.T. (2010) Front Neurosci 4, 53
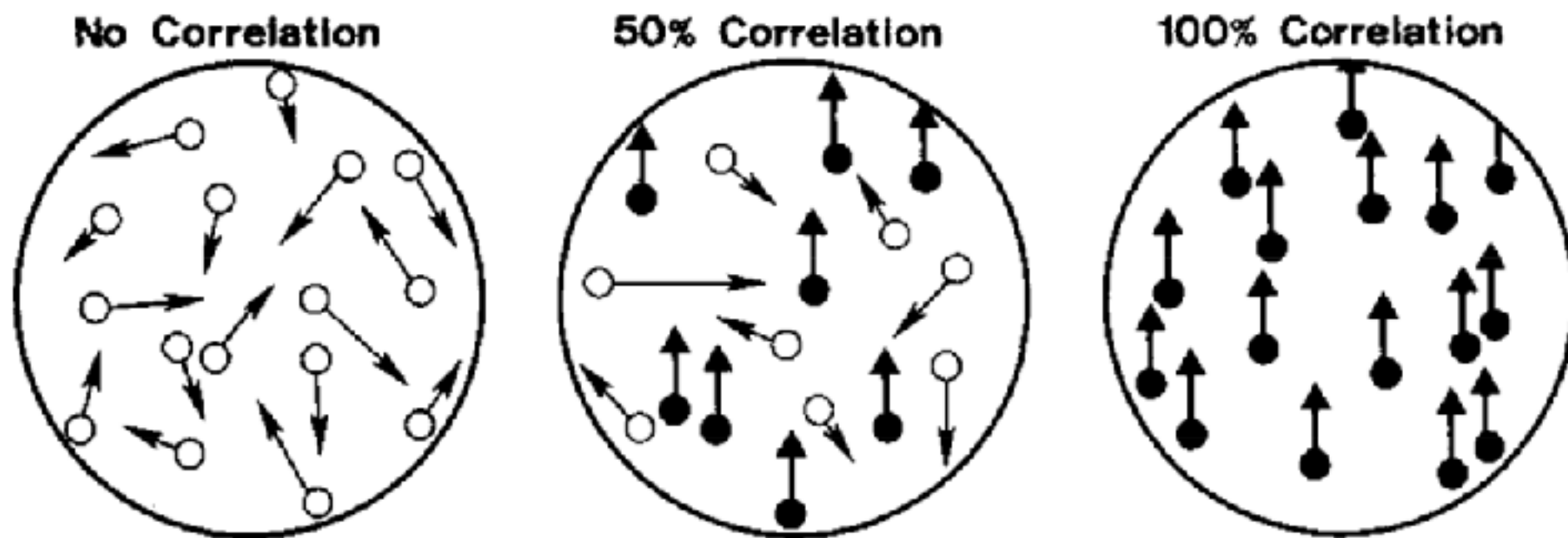
# Cross correlograms
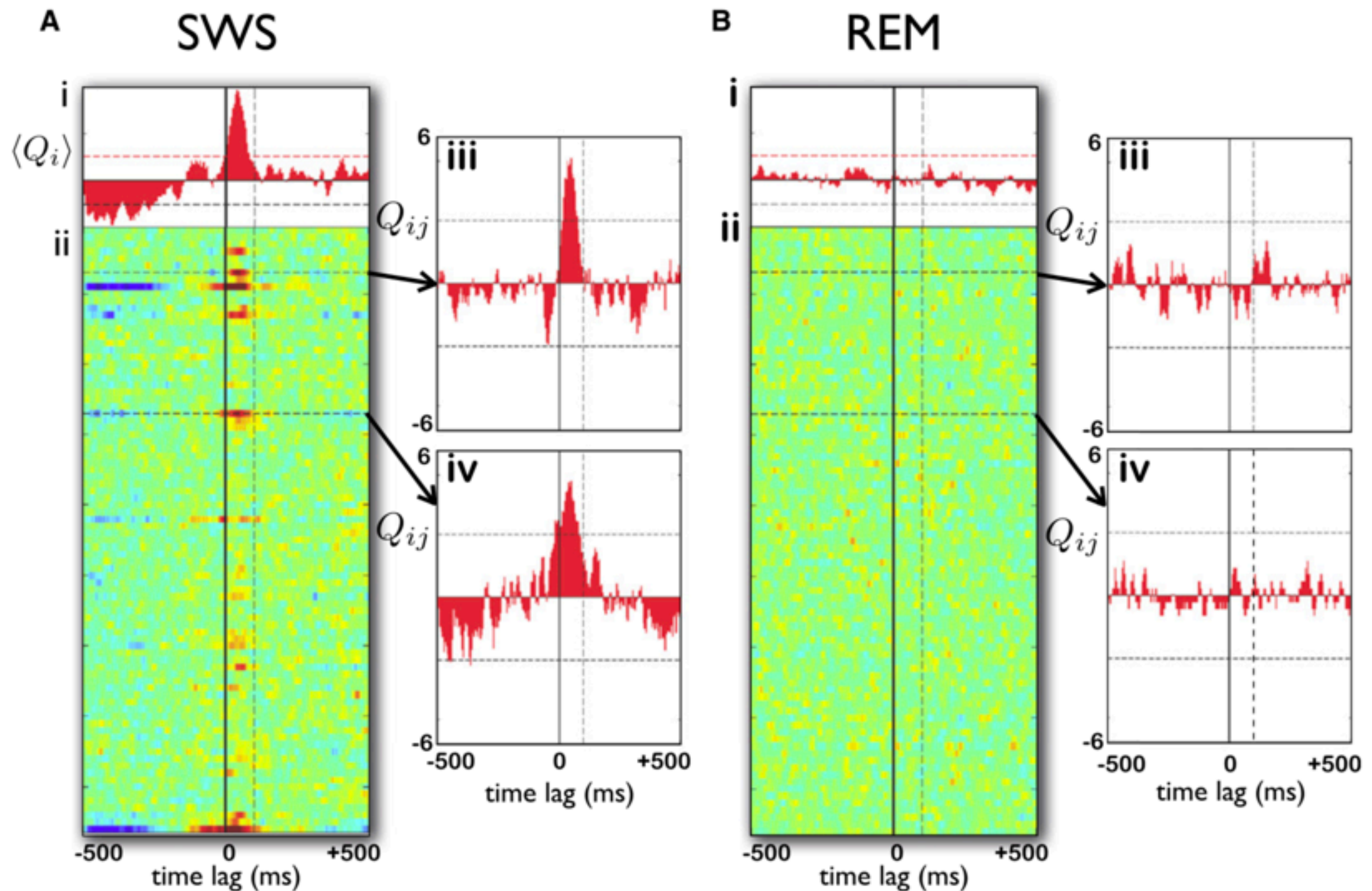
Wierzynski, C.M., Lubenov, E.V., Gu, M., Siapas, A.G. (2009) Neuron 61, 587–596.
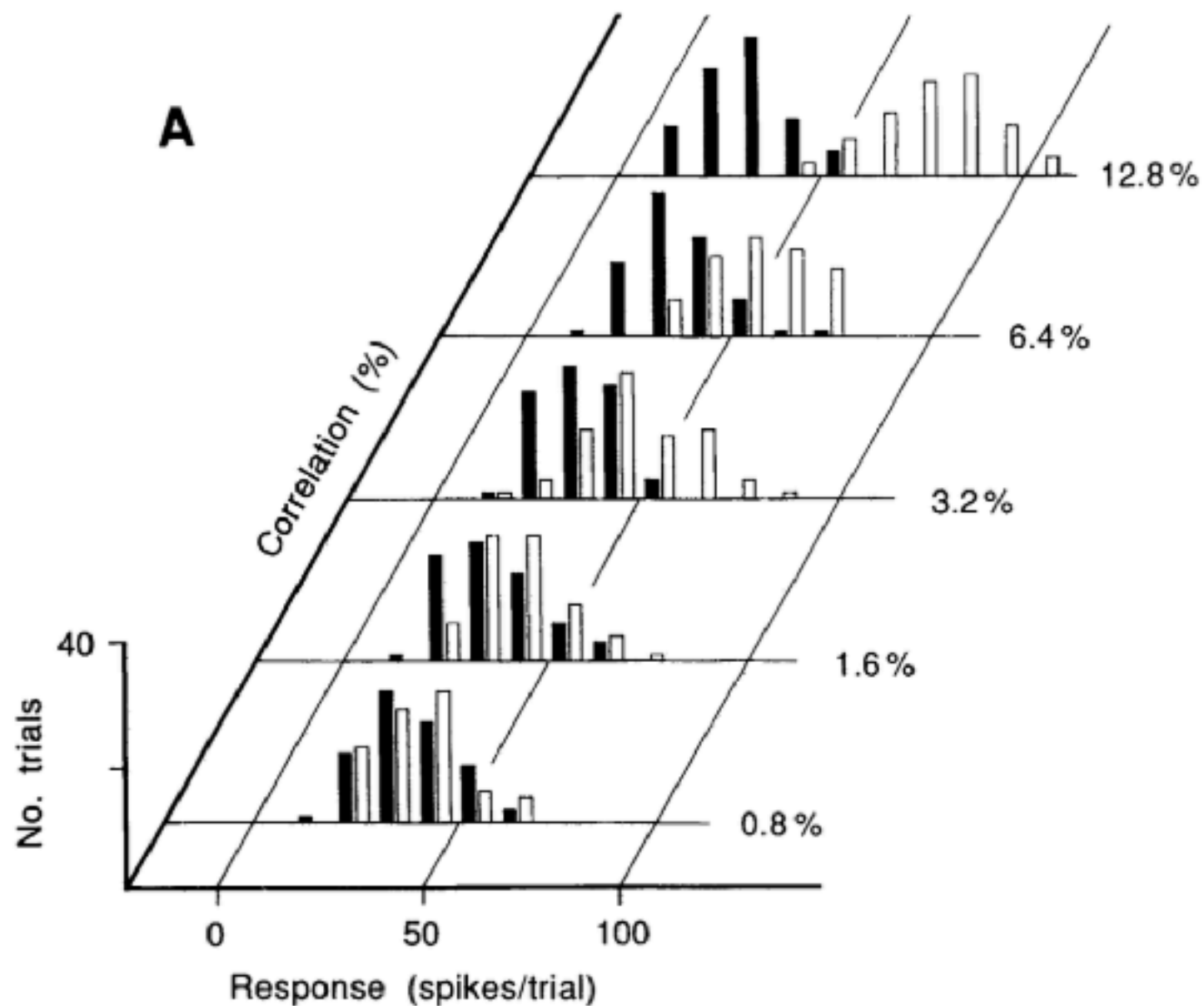
# Decoding from a single neuron

- Decoding is the process of inferring a stimulus from a neuron's spiking.

- As an example we can use signal detection theory to compute decoding quality for a moving dots task.



Example video: https://youtu.be/xUcwbjaGGNM?t=48

Britten, K.H., Shadlen, M.N., Newsome, W.T., Movshon, J.A., (1992). Journal of Neuroscience 12, 4745–4765.

# Decoding from a single neuron



The firing rate distributions become more separated for higher moving dot image correlation levels

Britten, K.H., Shadlen, M.N., Newsome, W.T., Movshon, J.A., (1992). Journal of Neuroscience 12, 4745–4765.

# Decoding from a single neuron

$d'$ (pronounced "dee-prime") is a measure of discriminability of two normal distributions.



$$d' = \frac{\mu_+ - \mu_-}{\sigma}$$
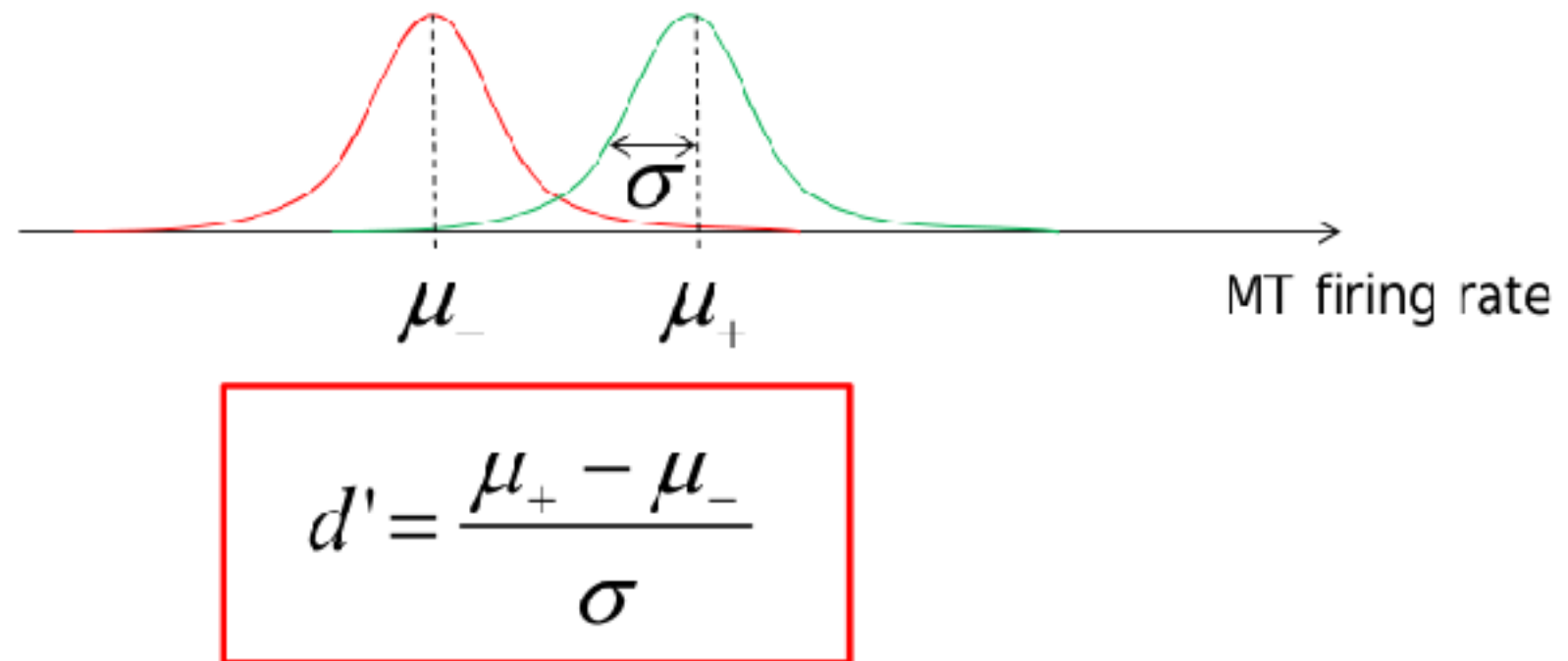
Figure from Rafal Bogacz

$$P(\text{correct}) = P(\mathscr{N}(\mu_+, \sigma) > \mathscr{N}(\mu_-, \sigma))$$
$$= \Phi(d'/\sqrt{2})$$

Where $\Phi$ is the cumulative distribution for the normal distribution
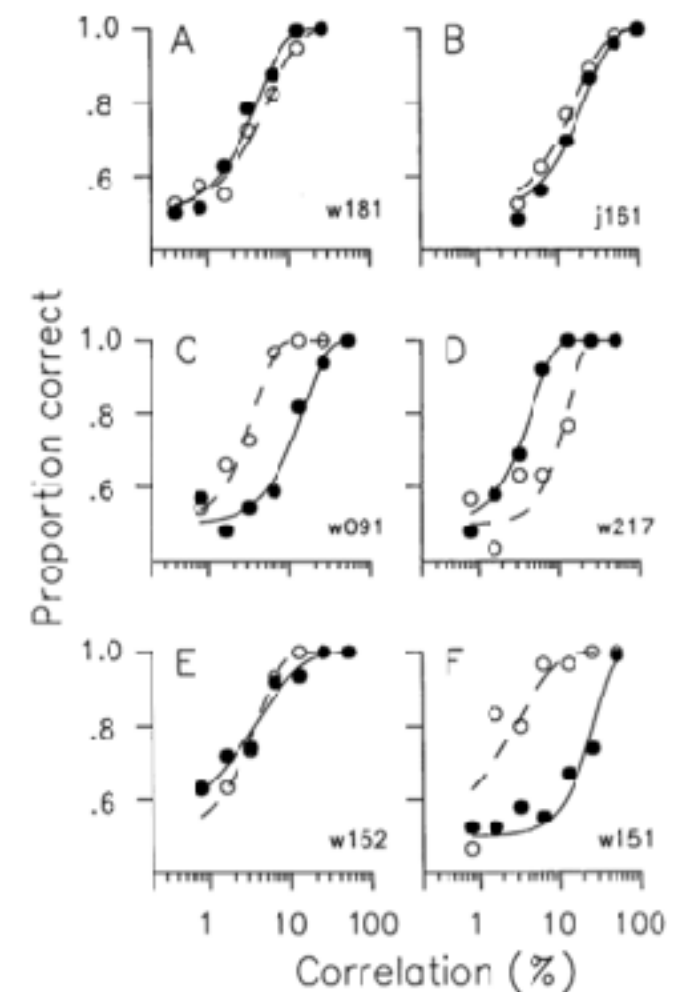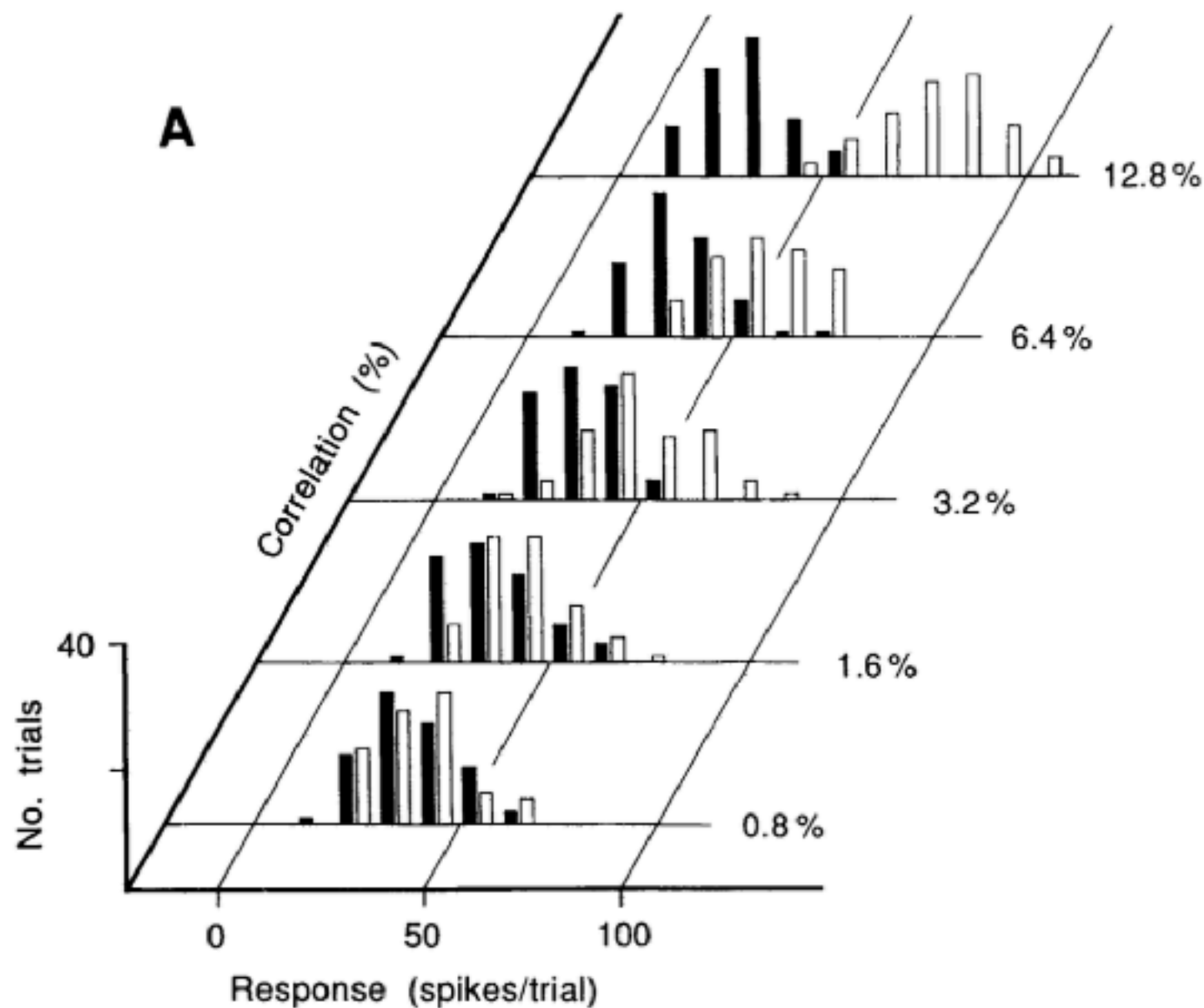
# Decoding from a single neuron



Figure 6  Psychometric and neurometric functions obtained in six experiments. The *open symbols* and *broken lines* depict psychometric data, while the *solid symbols* and *solid lines* represent neurometric data. The six examples illustrate the range of relationships present in our data. *A,* Results of the experiment illustrated in Figures 4 and 5. Psychophysical and neuronal data were statistically indistinguishable in this experiment. Thresholds and slope parameters are given in the captions for Figures 4 and 5. *B,* A second experiment in which psychometric and neurometric data were statistically indistinguishable. Psychometric $\alpha$ = 17.8% correlation, $\beta$ = 1.20; neurometric $\alpha$ = 23.0% correlation, $\beta$ = 1.31. *C,* An experiment in which psychophysical threshold was substantially lower than neuronal threshold. Psychometric $\alpha$ = 3.7% correlation, $\beta$ = 1.68; neurometric $\alpha$ = 14.8% correlation, $\beta$ = 1.49. *D,* An experiment in which neuronal threshold was substantially lower than psychophysical threshold. Psychometric $\alpha$ = 13.0% correlation, $\beta$ = 2.15; neurometric $\alpha$ = 4.7% correlation, $\beta$ = 1.58. *E,* An experiment in which thresholds were similar but slopes were dissimilar. Psychometric $\alpha$ = 3.9% correlation, $\beta$ = 1.36; neurometric $\alpha$ = 4.0% correlation, $\beta$ = 0.79. *F,* An experiment in which threshold and slope were dissimilar. Psychometric $\alpha$ = 3.1% correlation, $\beta$ = 0.91; neurometric $\alpha$ = 17.0% correlation, $\beta$ = 1.81.

Britten, K.H., Shadlen, M.N., Newsome, W.T., Movshon, J.A., (1992). Journal of Neuroscience 12, 4745–4765.

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