COMS30127/COMSM2127 Computational Neuroscience

Lecture 13: Spike trains, analysing spike data (h)

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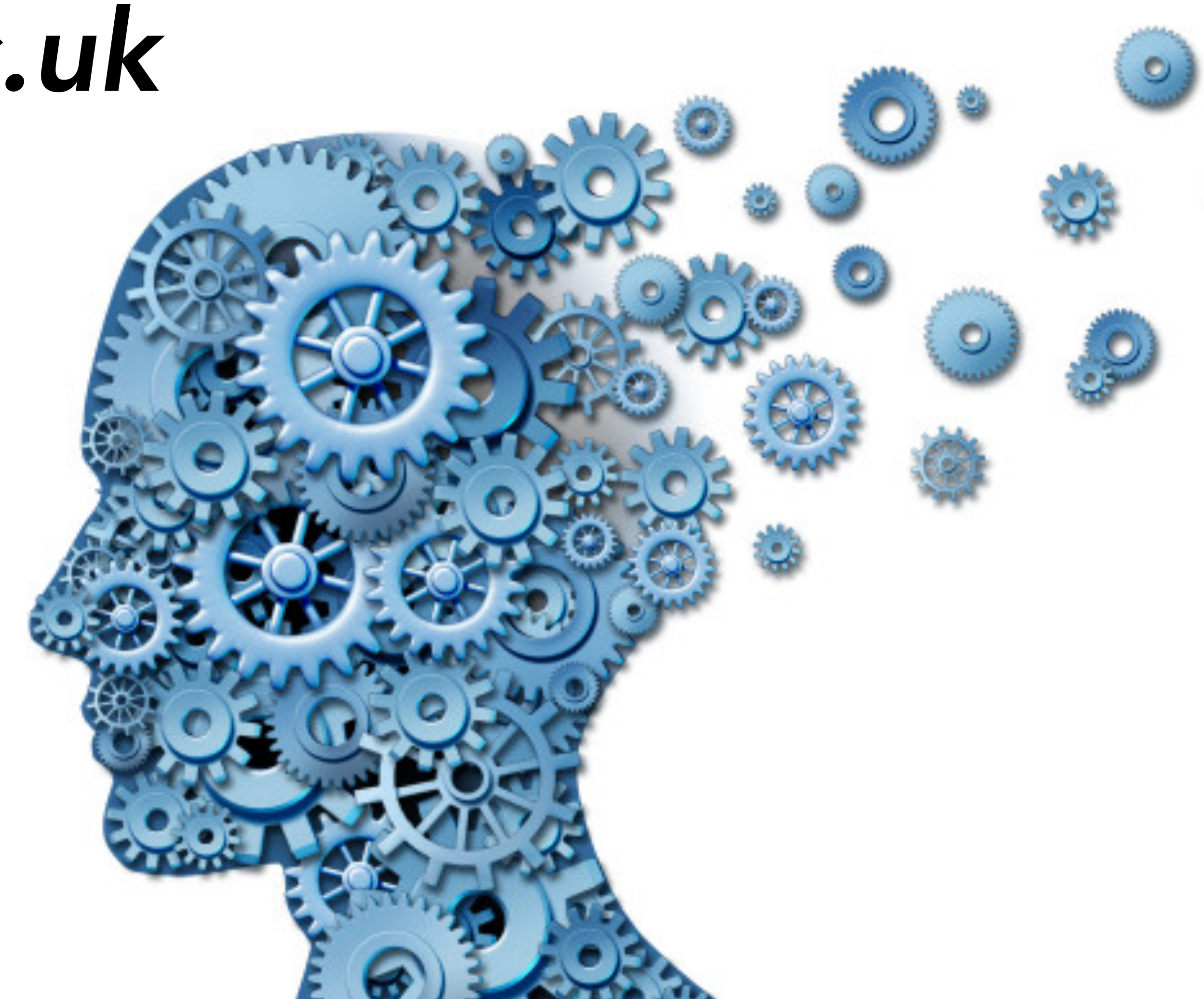


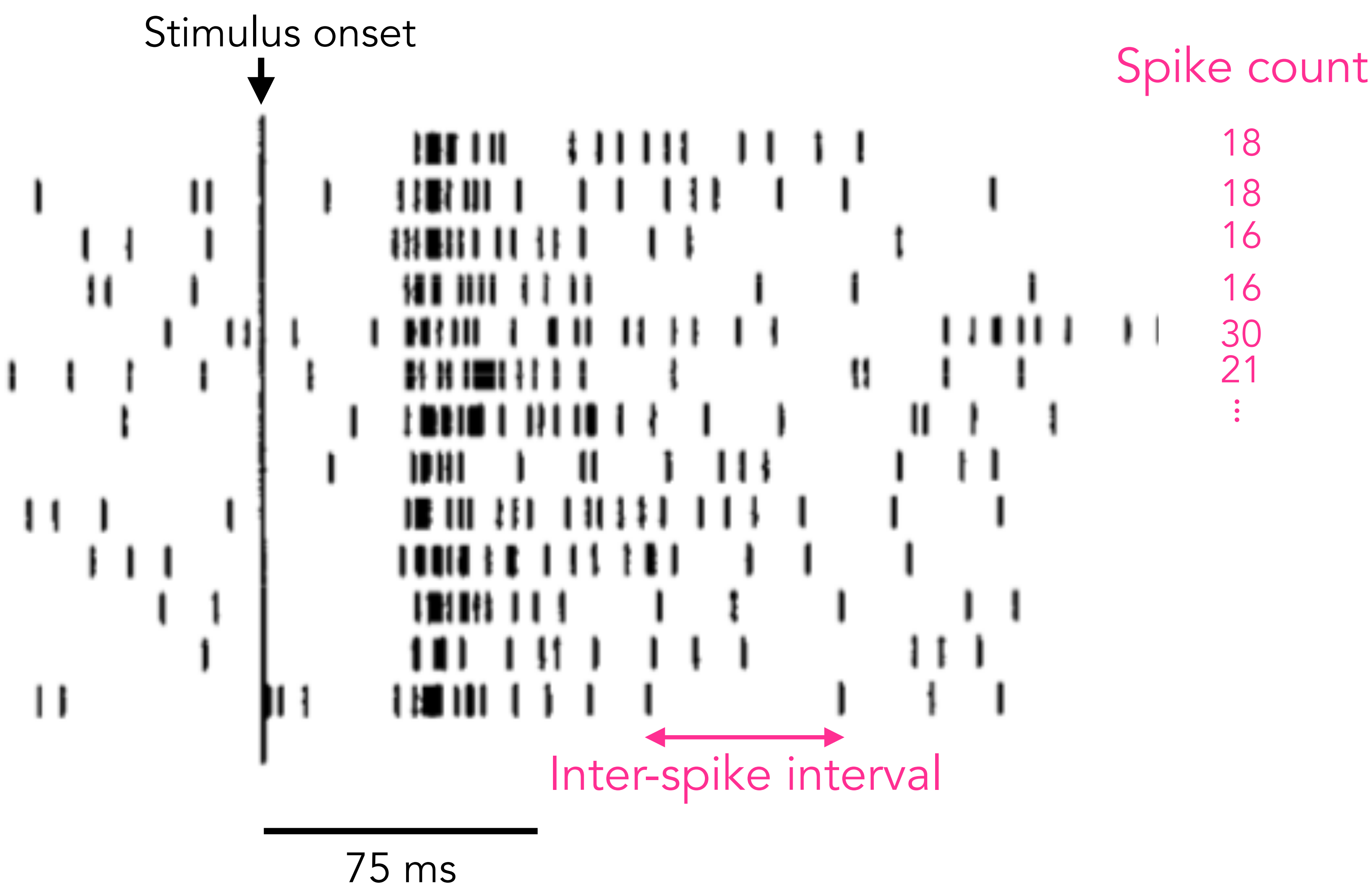
What we will cover today

- Recap on spike trains
  - Spike count
  - Inter-spike interval

- Spike train summary statistics
  - Fano factor
  - Coefficient of Variation (CV)

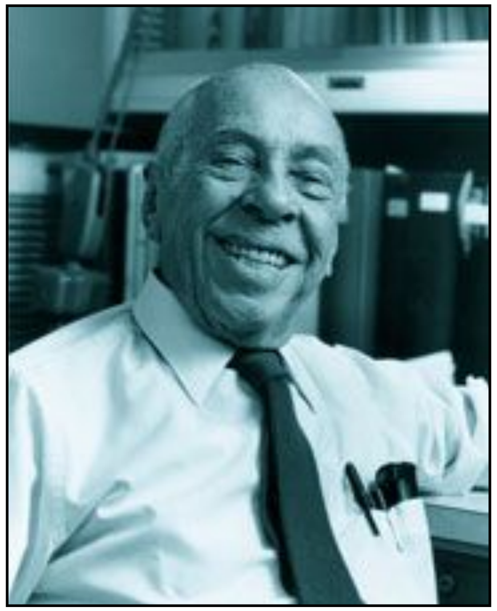
- Analysing spiking data
  - Peri-stimulus time histogram (PSTH)
  - Spike-triggered average (STA)
  - Autocorrelograms
  - Cross-correlograms
  - Decoding

Spike trains



[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:

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

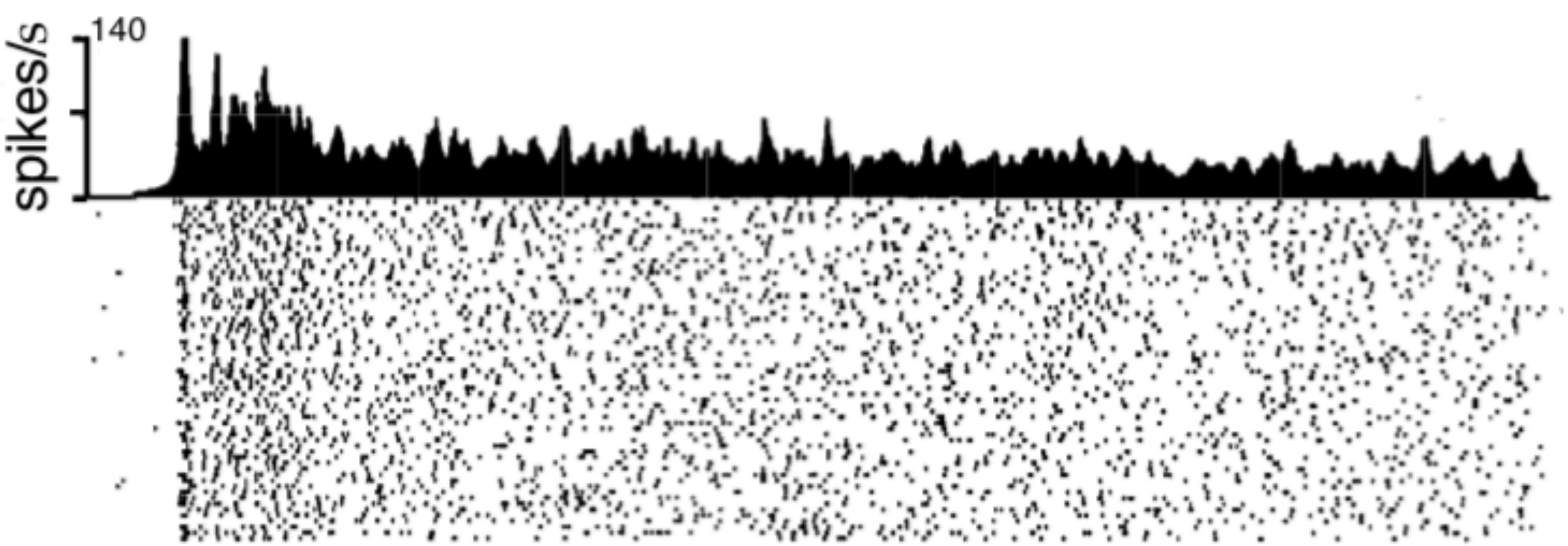
- In contrast to the Fano Factor, it is usually applied to the **interspike intervals** (not the spike counts).

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

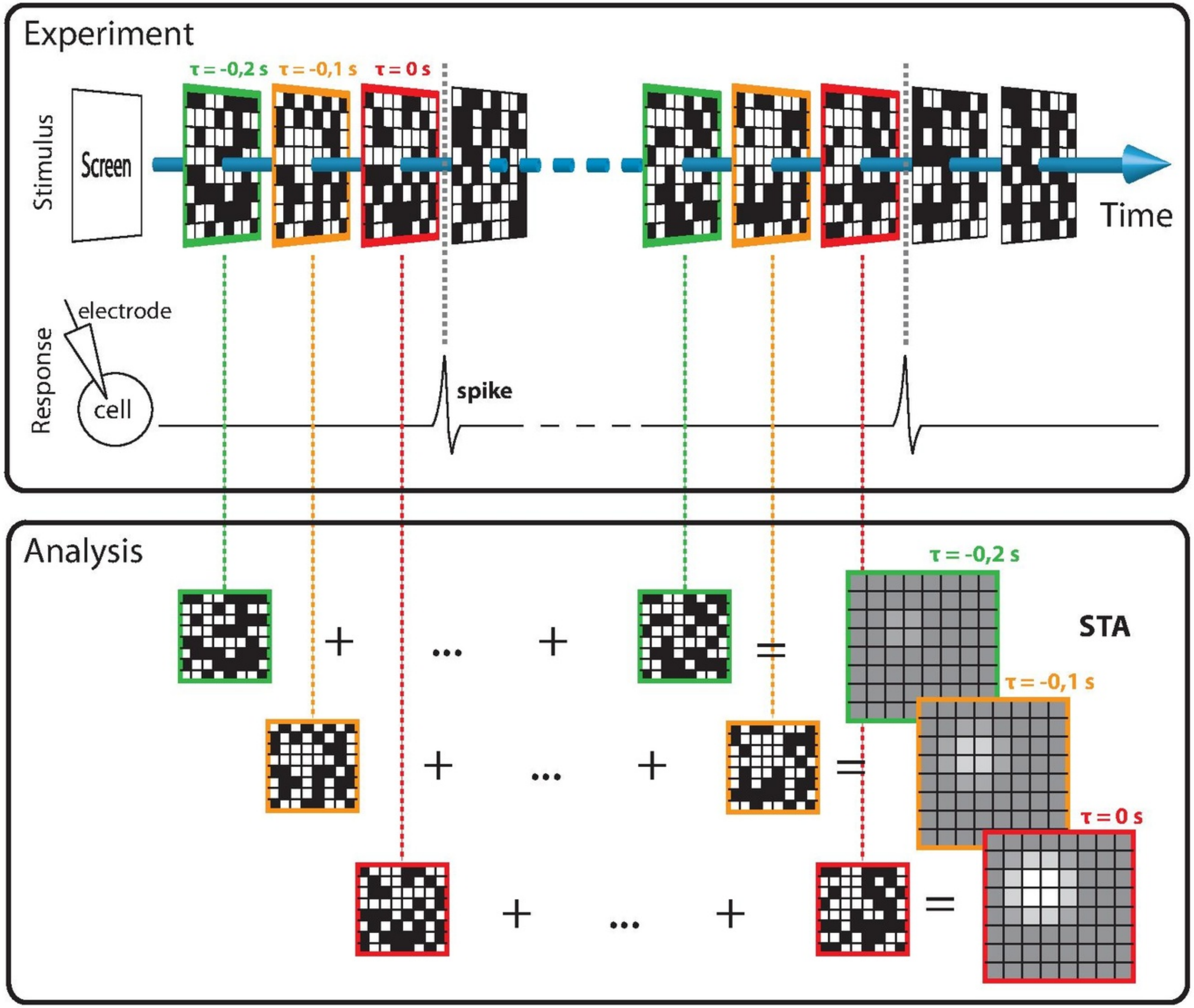
- Another way of analysing the data is to ask the question: what aspect of the stimulus caused the neuron to spike?

- 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 τ is a time interval.

Spike-triggered average (STA)



https://upload.wikimedia.org/wikipedia/commons/2/2c/Illustration_diagram_for_the_Spike-triggered_average.pdf

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

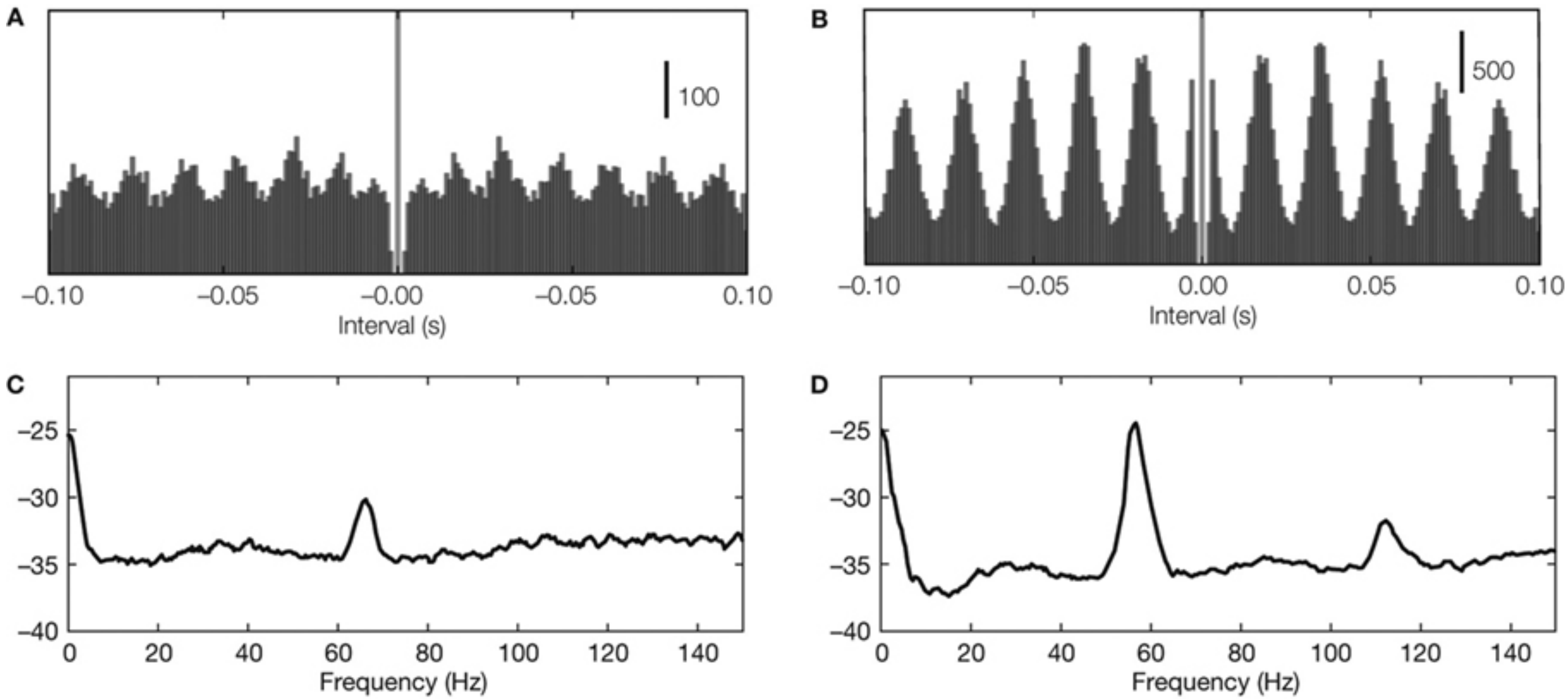
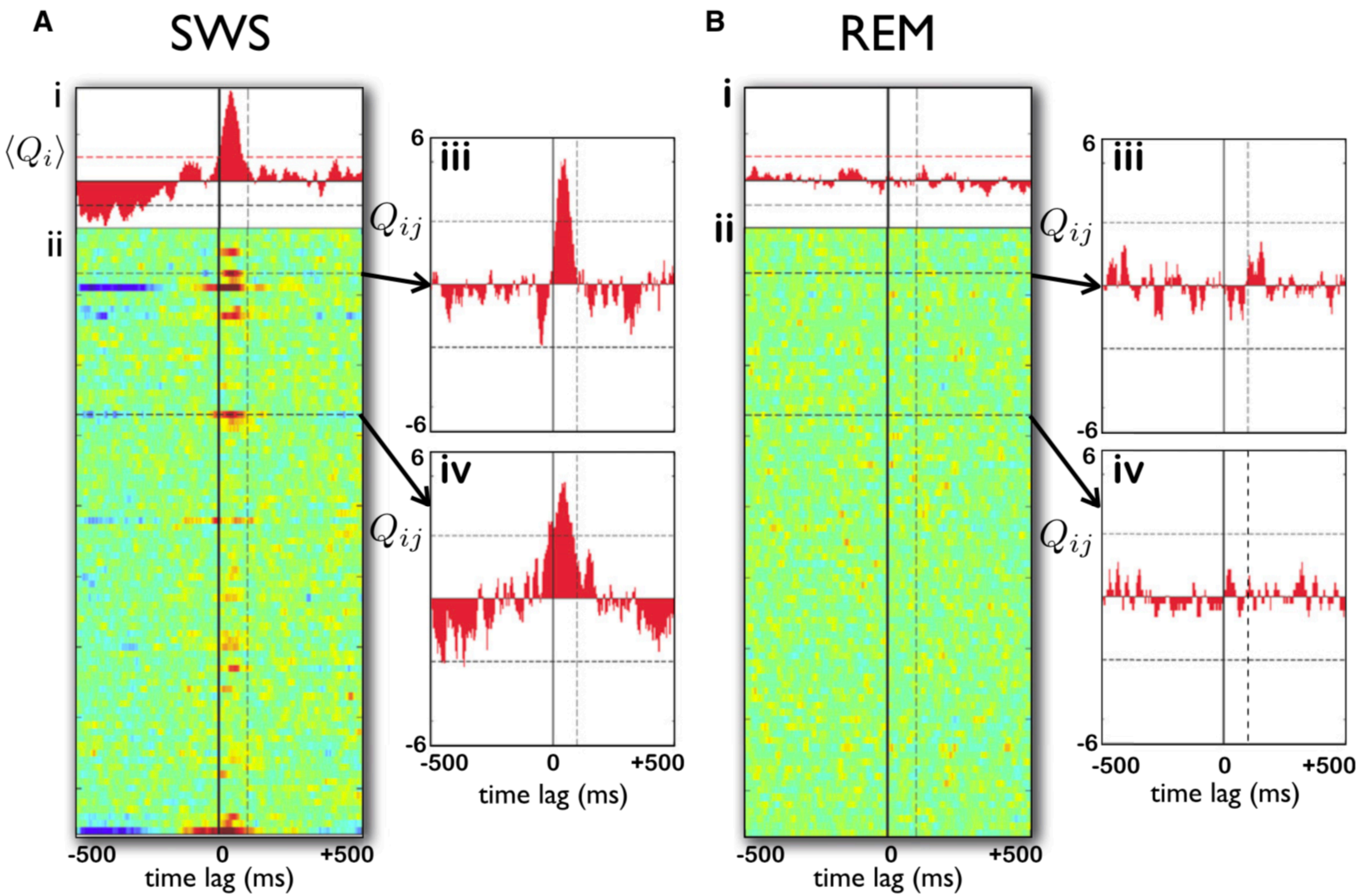


Figure 1. Detecting neural oscillations. (A,B) Oscillations in autocorrelations in two example recordings (spike trains recorded from LGN in cat) with oscillation score 10 and 29, respectively. **(C,D)** Oscillations in spectral power (same spike trains as used for panel **A**).

Koepsell, K., Wang, X., Hirsch, J.A., Sommer, F.T. (2010) Front Neurosci 4, 53

Cross correlograms

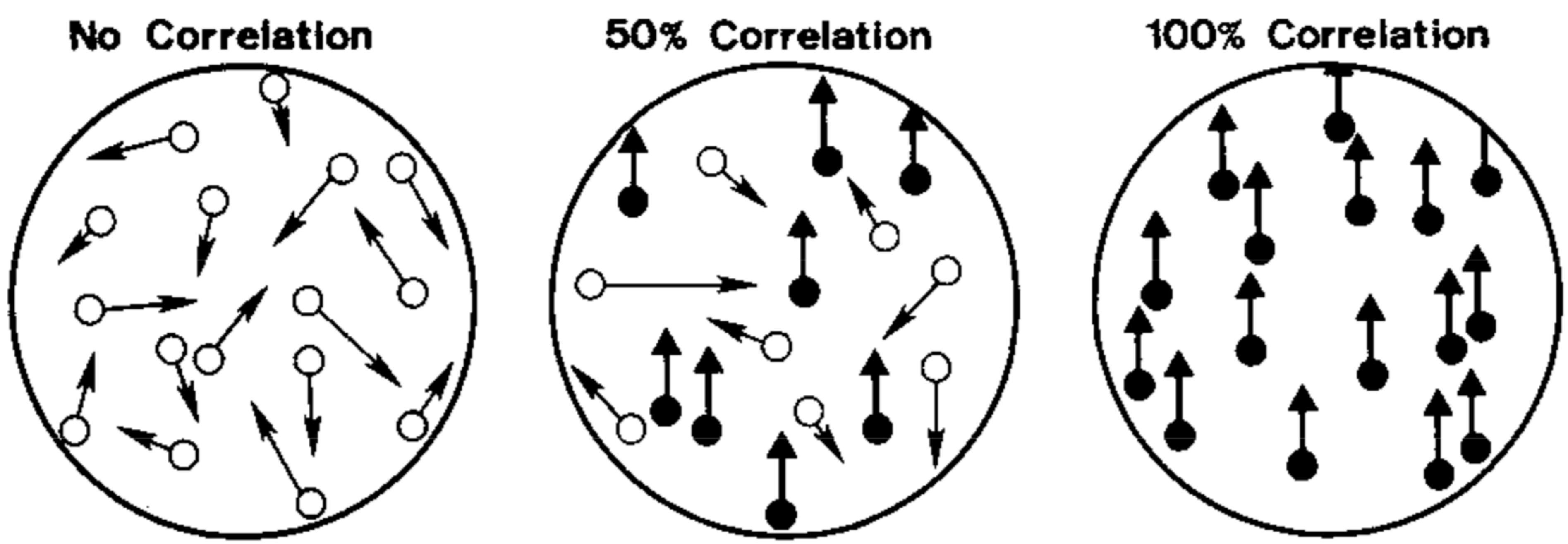


Wierzynski, C.M., Lubenov, E.V., Gu, M., Siapas, A.G. (2009) Neuron 61, 587–596.

Decoding from a single neuron

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

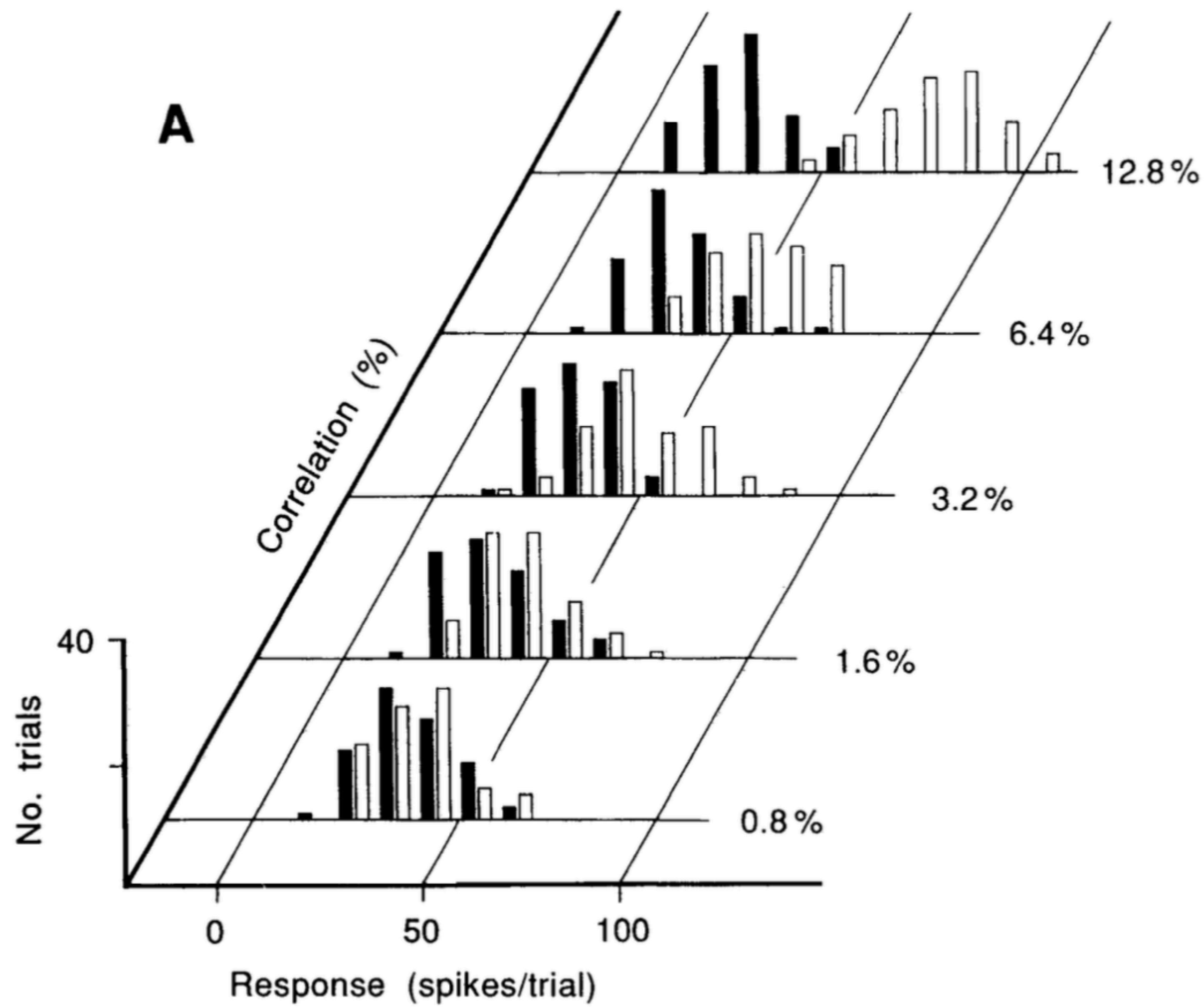
- As an example we can use signal detection theory to compute decoding quality for a moving dots task.



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

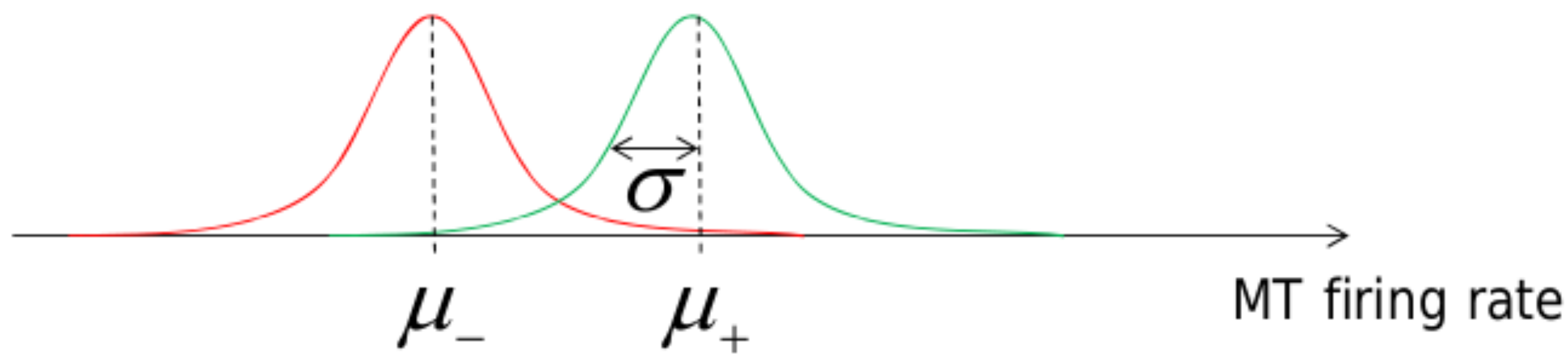


The firing rate distributions become more separated for higher moving dot image correlation levels

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.



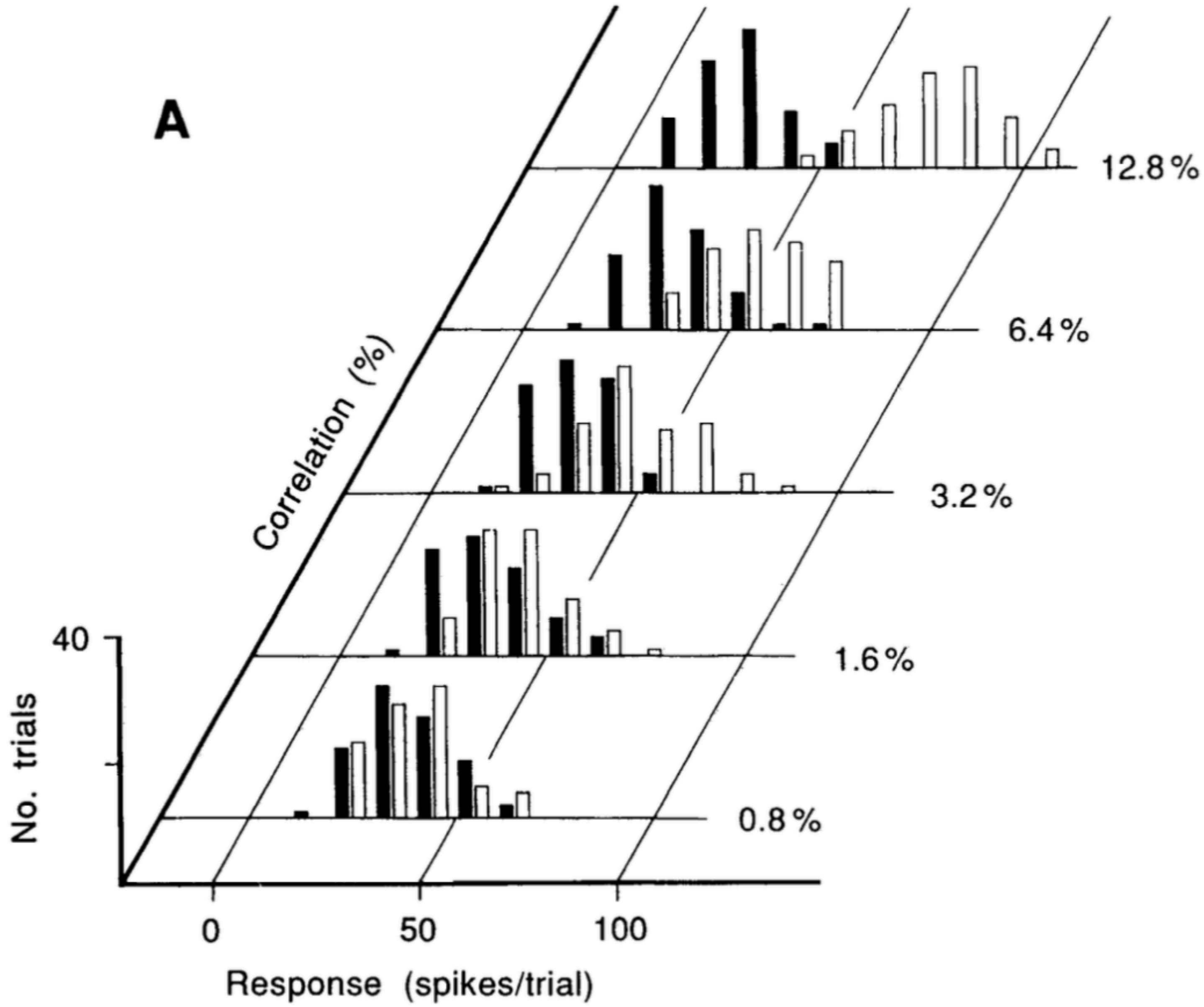
$$d' = \frac{\mu_+ - \mu_-}{\sigma}$$

Figure from Rafal Bogacz

$$\begin{aligned} P(\text{correct}) &= P(\mathcal{N}(\mu_+, \sigma) > \mathcal{N}(\mu_-, \sigma)) \\ &= \Phi(d'/\sqrt{2}) \end{aligned}$$

Where Φ is the cumulative distribution for the normal distribution

Decoding from a single neuron



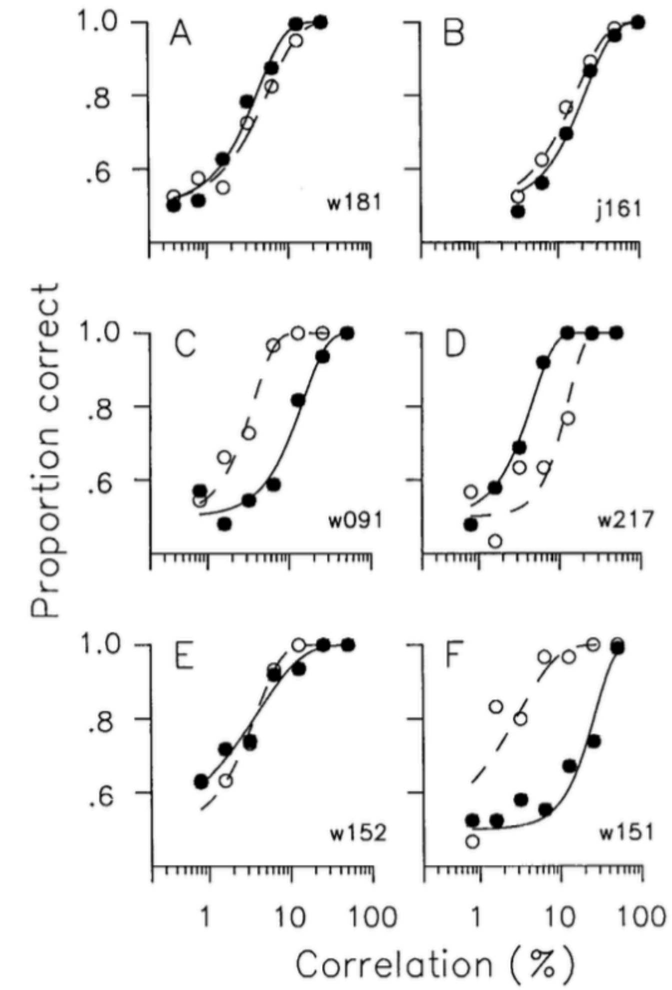


Figure 6. Psychometric and neurometric functions obtained in six experiments. The *open symbols* and *broken lines* depict psychometric data, while the *solid symbols* and *solid lines* represent neurometric data. The six examples illustrate the range of relationships present in our data. *A*, Results 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 α = 17.8% correlation, $\beta = 1.20$; neurometric α = 23.0% correlation, $\beta = 1.31$. *C*, An experiment in which psychophysical threshold was substantially lower than neuronal threshold. Psychometric α = 3.7% correlation, $\beta = 1.68$; neurometric α = 14.8% correlation, $\beta = 1.49$. *D*, An experiment in which neuronal threshold was substantially lower than psychophysical threshold. Psychometric α = 13.0% correlation, $\beta = 2.15$; neurometric α = 4.7% correlation, $\beta = 1.58$. *E*, An experiment in which thresholds were similar but slopes were dissimilar. Psychometric α = 3.9% correlation, $\beta = 1.36$; neurometric α = 4.0% correlation, $\beta = 0.79$. *F*, An experiment in which threshold and slope were dissimilar. Psychometric α = 3.1% correlation, $\beta = 0.91$; neurometric α = 27.0% 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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