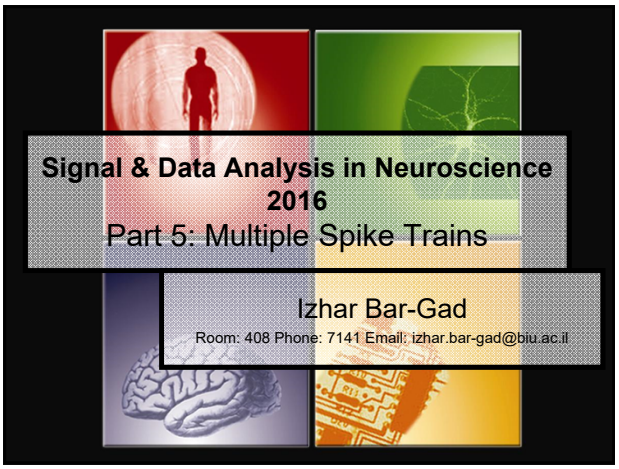
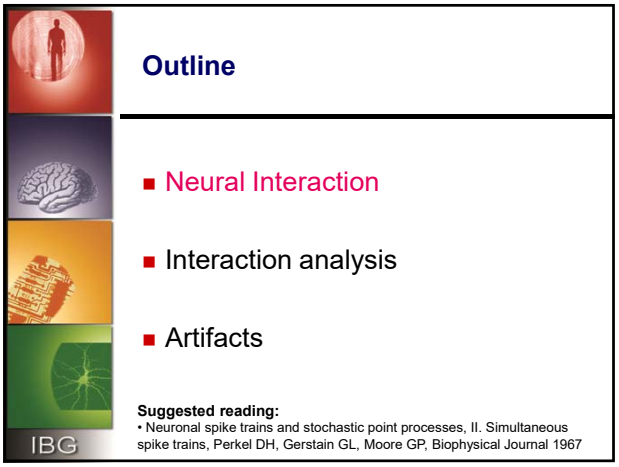

Signal & Data Analysis in Neuroscience 2016
Part 5: Multiple Spike Trains
Izhar Bar-Gad
Room: 408 Phone: 7141 Email: izhar.bar-gad@biu.ac.il


Outline
Neural Interaction
Interaction analysis
Artifacts
Suggested reading:
• Neuronal spike trains and stochastic point processes, II. Simultaneous spike trains, Perkel DH, Gerstain GL, Moore GP, Biophysical Journal 1967
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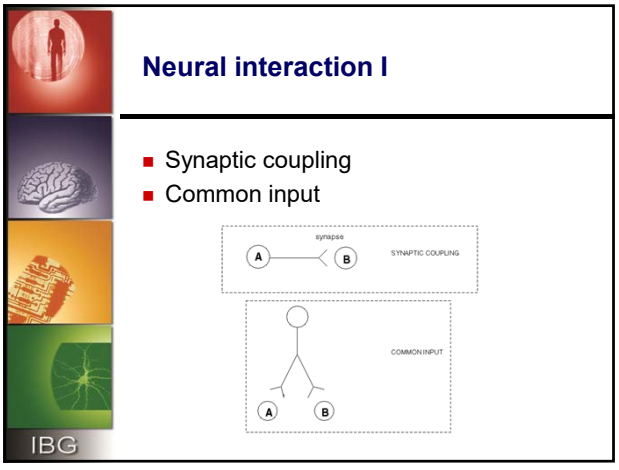
Neural interaction I
Synaptic coupling
Common input
synapse
A
B
SYNAPTIC COUPLING
COMMON INPUT
A
B
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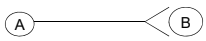
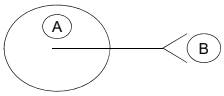
Neural Interaction II

- Single neuron interaction



- Population interaction



- Global co-activation (arousal, task, …)

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Common input

- Symmetric
- Input from the same neuron.
  - Inhibitory
  - Excitatory
- Input from the same group or network of neurons which have common properties.

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Synaptic coupling

- Asymmetric
- The 1st neuron de/activates the 2nd neuron
  - Excitatory
  - Inhibitory
- The 1st neuron belongs to a group de/activating the 2nd neuron

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Outline

- Neural Interaction
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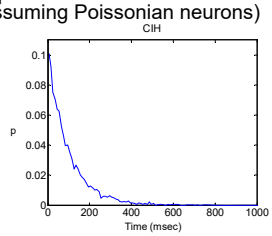
CIH

- CIH (cross interval histogram)
- Spikes for neuron A are the renewal points for neuron B
- Exponential distribution if no interaction (assuming Poissonian neurons)



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Cross-correlation practicalities

- Count $Q_{C_{1,2}}(\tau) = \sum_{i=1}^{n_1} \rho_1(t_{1,i}) \cdot \rho_2(t_{1,i} + \tau)$
- Probability $Q_{P_{1,2}}(\tau) = \frac{1}{n} \cdot \sum_{i=1}^{n_1} \rho_1(t_{1,i}) \cdot \rho_2(t_{1,i} + \tau)$
- Rate $Q_{R_{1,2}}(\tau) = \frac{1}{n \cdot \Delta t} \cdot \sum_{i=1}^{n_1} \rho_1(t_{1,i}) \cdot \rho_2(t_{1,i} + \tau)$

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Cross-correlation (rate normalized)

- Count

$$Q_{C_{1,2}}(\tau) = \sum_{i=1}^{n_1} [\rho_1(t_{1,i}) - r_1] \cdot [\rho_2(t_{1,i} + \tau) - r_2]$$

- Probability

$$Q_{P_{1,2}}(\tau) = \frac{1}{n} \cdot \sum_{i=1}^{n_1} [\rho_1(t_{1,i}) - r_1] \cdot [\rho_2(t_{1,i} + \tau) - r_2]$$

- Rate

$$Q_{R_{1,2}}(\tau) = \frac{1}{n \cdot \Delta t} \cdot \sum_{i=1}^{n_1} [\rho_1(t_{1,i}) - r_1] \cdot [\rho_2(t_{1,i} + \tau) - r_2]$$

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(A) Symmetry

- Reference neuron
- Target neuron
- Autocorrelation
  - $C_{ii}(t) = C_{ii}(-t)$
- Cross-correlation
  - $C_{ij}(t) \neq C_{ji}(t)$
  - $C_{ij}(t) = \alpha\, C_{ji}(-t)$

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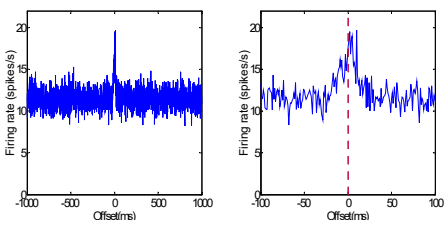
Cross-correlation: common input



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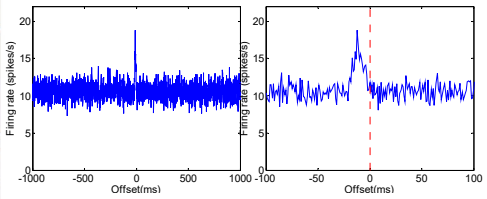
Cross-correlation: synaptic coupling



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Oscillatory correlation

- Depends on frequency of the two neurons.
- Depends on phase of the two neurons.
- Phase and frequency slips will destroy global correlations.
- Spectral analysis reveals such correlations much better.

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Outline

- Neural Interaction
- Interaction analysis
- Artifacts

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GP cross-correlations

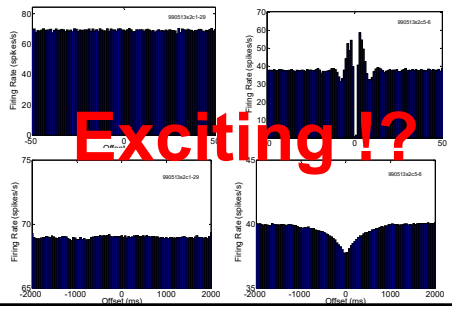
Remote (>500µm)

Neighbors (<100µm)

Short-term (50ms)

Long-term (2000ms)

Exciting !?



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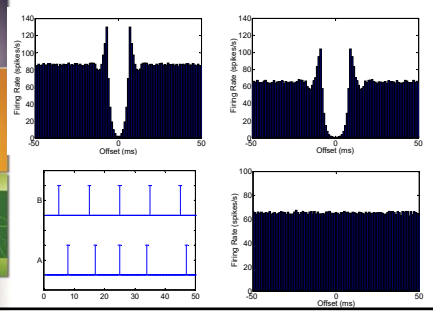
Cross-correlation artifact I



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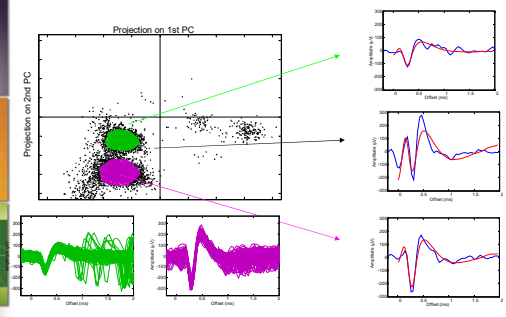
Cross-correlation artifact II



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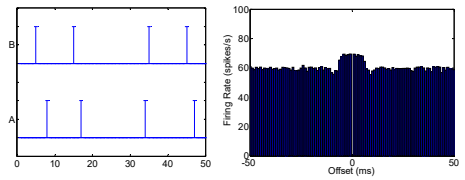
Cross-correlation artifact – Simple case



S=[1]

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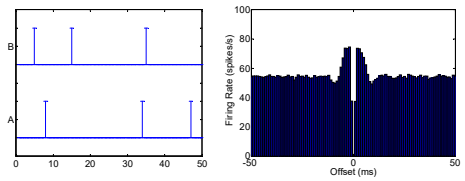
Cross-correlation artifact – Complex case



S=[0.5 1 0.5]

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Intuition ☺

- During the refractory period one of the cells does not fire so the other cell does not 'lose' spikes and therefore reflect the original firing rate of the cell and not the rate after removal of common spikes.
- More generally, the probability of 'losing' a spike depends on the shape of the autocorrelation functions.

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Analysis – simple case

(1) $$p_n^* = p_n \cdot (1 - p_m)$$

(2) $$c_{n,m}^*(t) = (1 - a_n(t)) \cdot (1 - a_m(t)) \cdot \frac{p_n}{1 - p_n}$$

Analysis – complex case

(1) $$p_n^* = p_n \cdot (1 - p_m \cdot \sum_{u=-\alpha}^{\alpha} S_{m,n}(u))$$

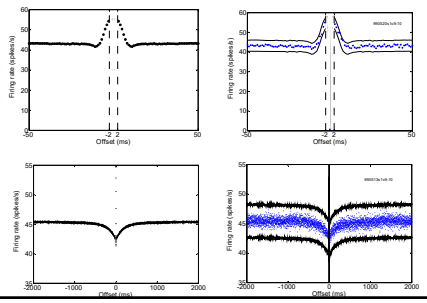
(2) $$c_{n,m}^*(t) = (1 - \sum_{u=-\alpha}^{\alpha} S_{n,m}(u) \cdot a_n(t+u)) \cdot (1 - \sum_{u=-\alpha}^{\alpha} S_{n,m}(u) \cdot a_m(t-u)) \cdot \frac{p_n}{1 - p_n \cdot \sum_{u=-\alpha}^{\alpha} S_{n,m}(u)}$$

Size of peak in different brain areas

	Observed Firing rate (spikes/s)	Original Firing rate (spikes/s)	$\Delta\lambda$ (Hz)	$\Delta\lambda/\lambda_\infty$ (%)
Pallidum	60	78.5	42.6	71.1
STN	25	27.2	4.6	18.6
Cortex	5	5.1	0.2	3.1

$S_{n,m}=S_{m,n}=[0.25\ 0.75\ 1\ 0.75\ 0.25]$

Correlations in the pallidum



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Summary

- Cross correlations are the most common tool for testing neural connectivity and functional relations between and within brain areas.
- Cross correlations provide a very limited ability to research the neural connectivity.
- Stronger methods exist which look at the spike sequences using measures such as mutual information.

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