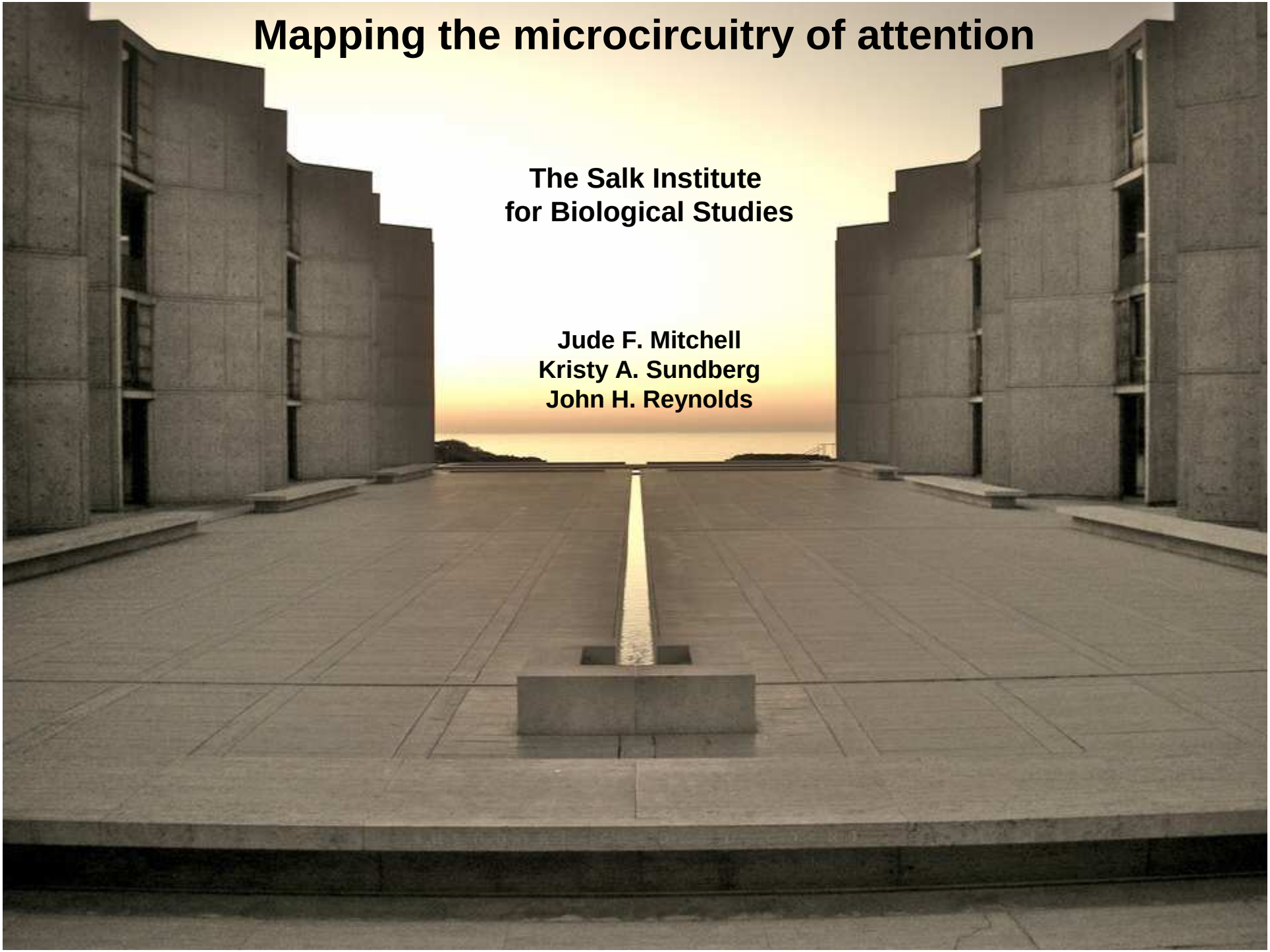
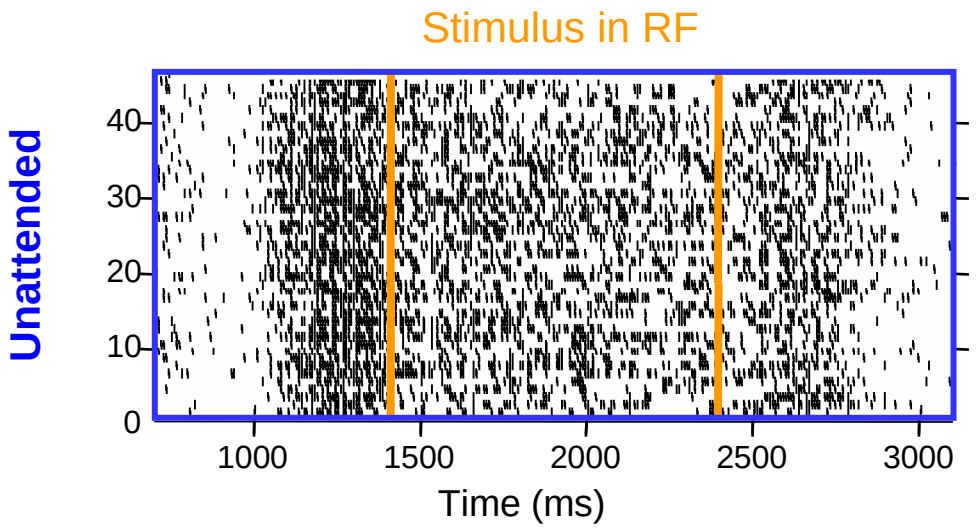
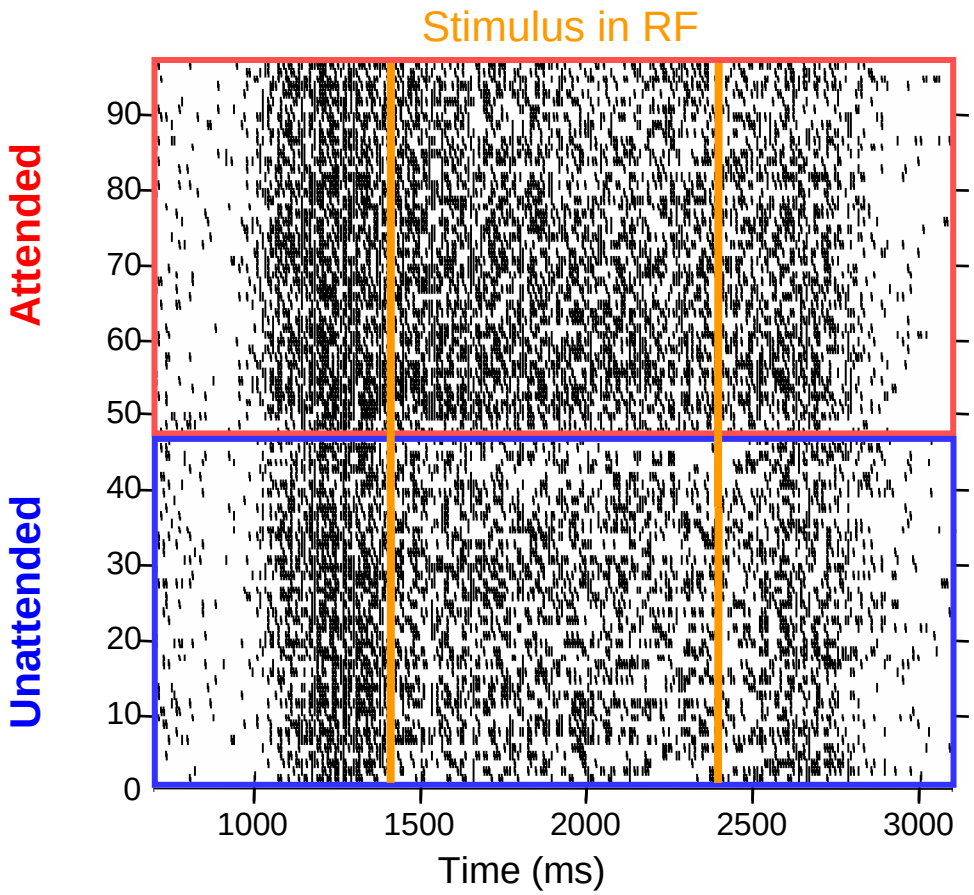
Mapping the microcircuitry of attention

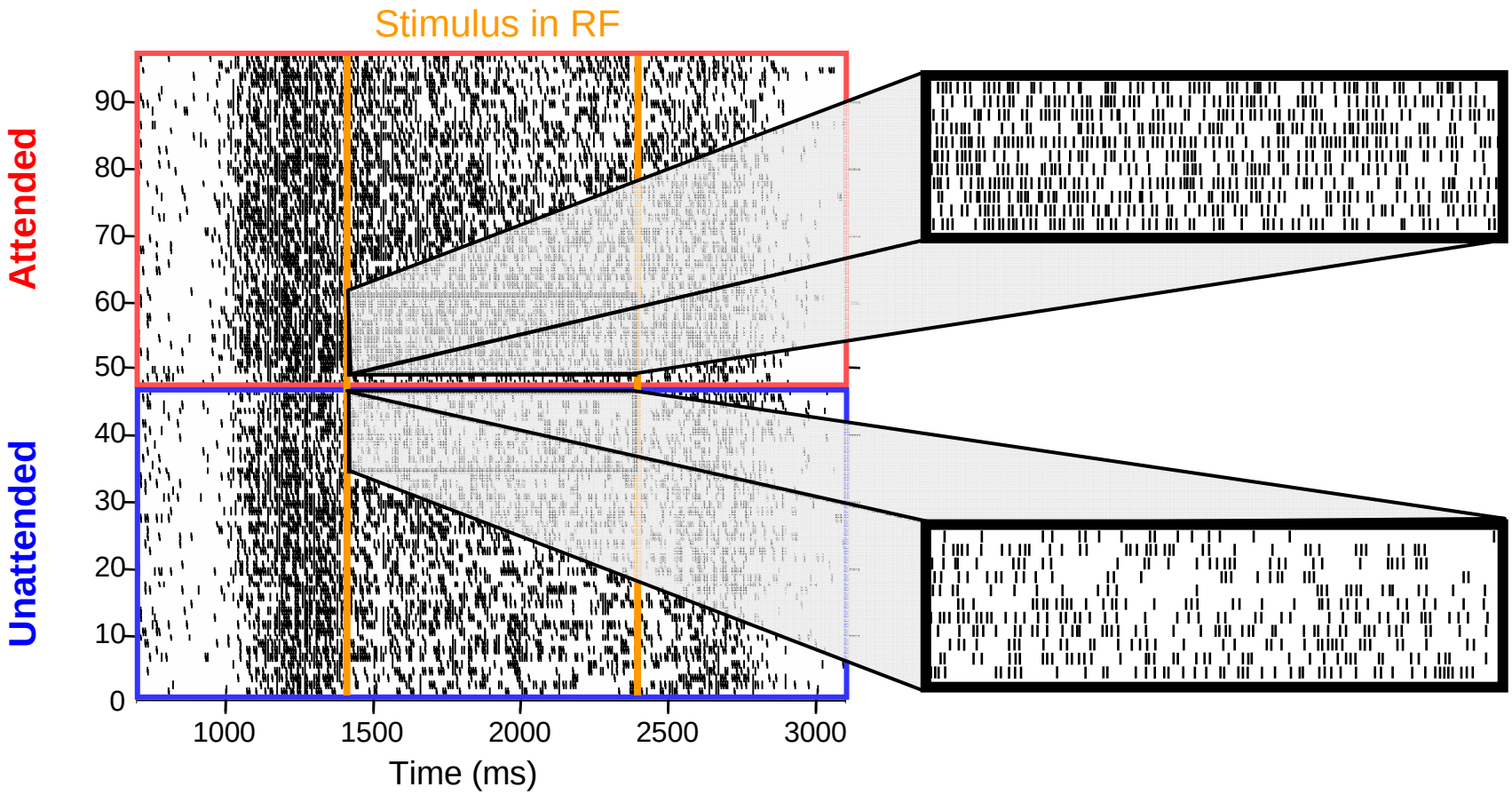


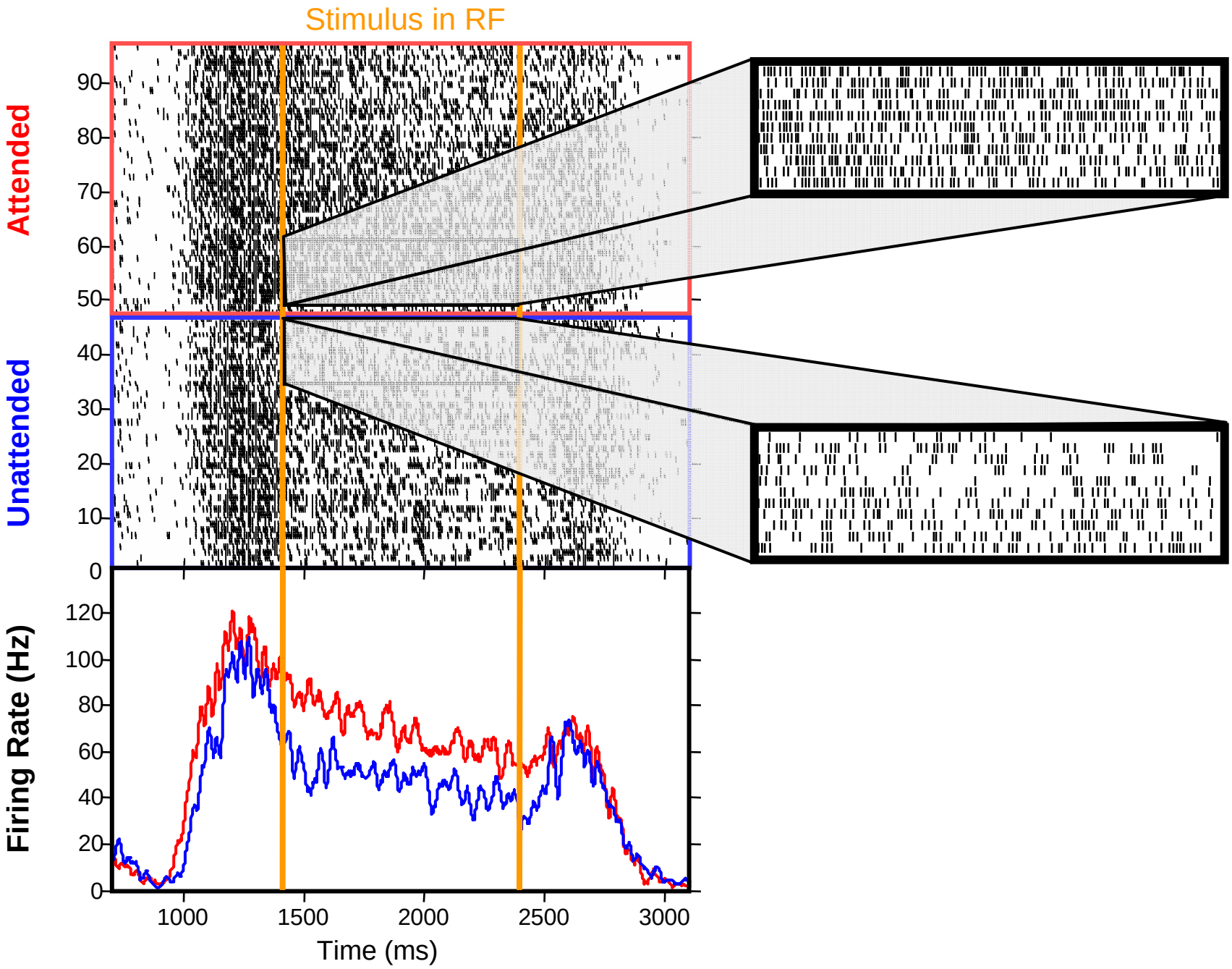
The Salk Institute
for Biological Studies

Jude F. Mitchell
Kristy A. Sundberg
John H. Reynolds

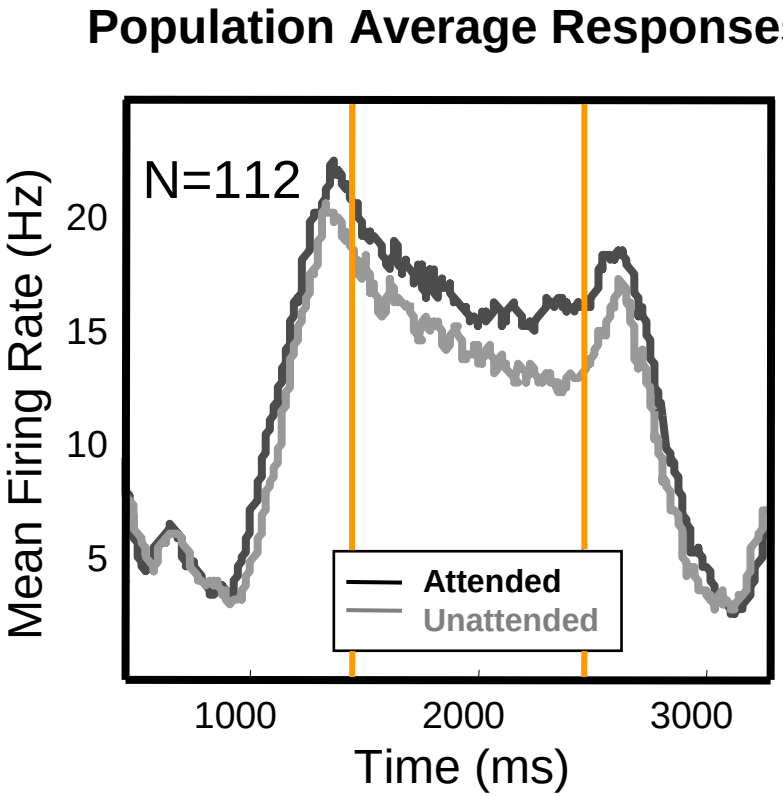

Stimulus in RF
Unattended
40
30
20
10
0
1000
1500
2000
2500
3000
Time (ms)


Stimulus in RF
Attended
Unattended
90
80
70
60
50
40
30
20
10
0
1000
1500
2000
2500
3000
Time (ms)

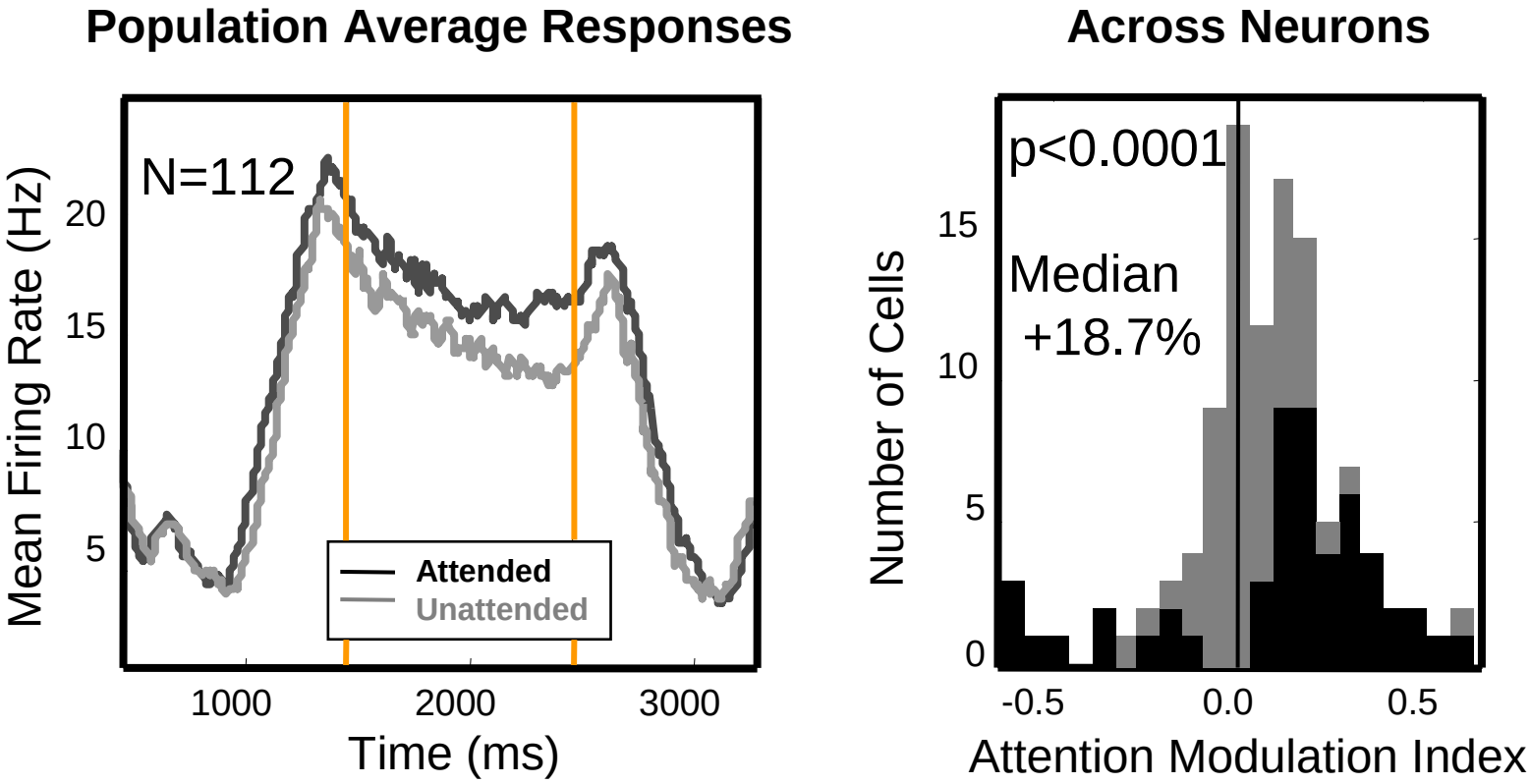

Stimulus in RF
Attended
Unattended
90
80
70
60
50
40
30
20
10
0
1000
1500
2000
2500
3000
Time (ms)

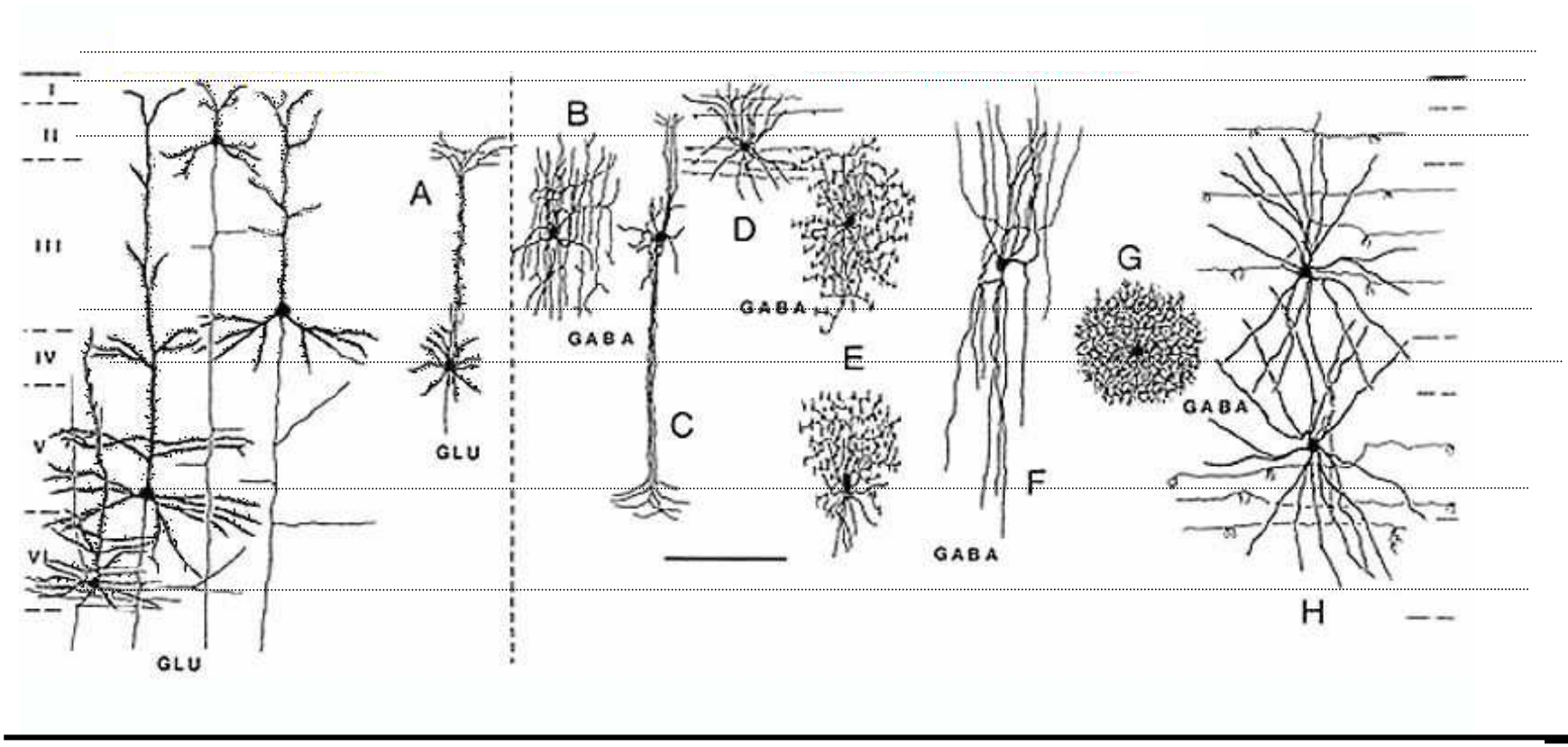

Stimulus in RF
Attended
Unattended
90
80
70
60
50
40
30
20
10
0
120
100
80
60
40
20
0
Firing Rate (Hz)
1000
1500
2000
2500
3000
Time (ms)

Attention-dependent modulation of firing rate

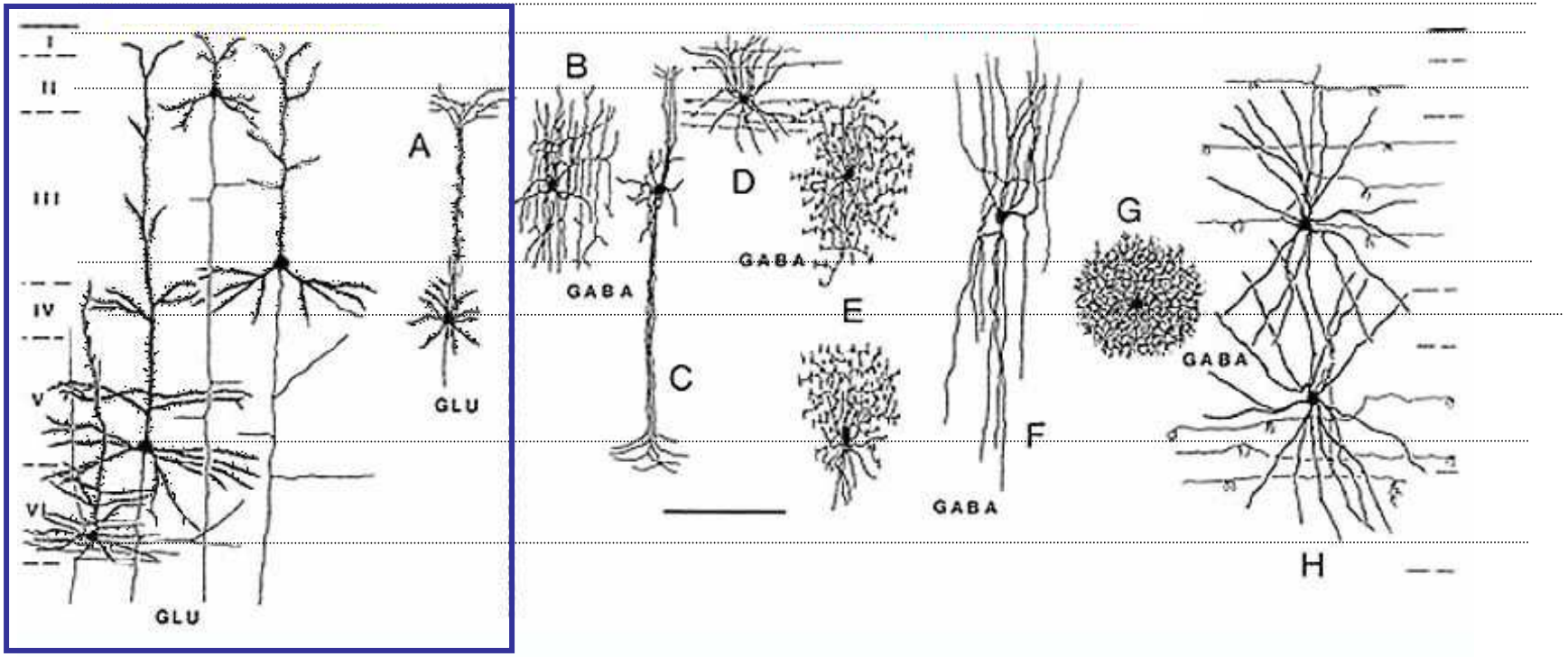


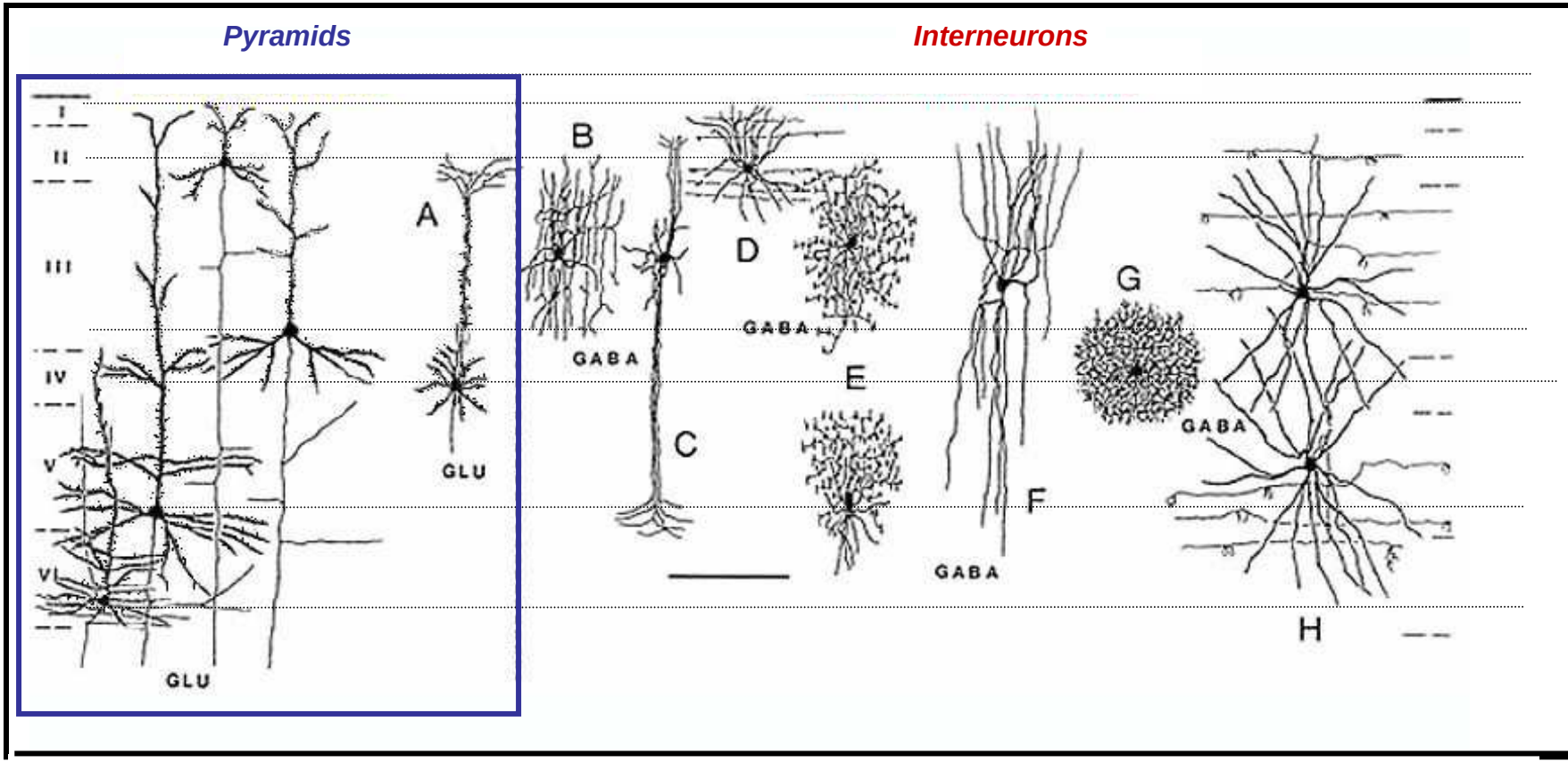
Attention-dependent modulation of firing rate

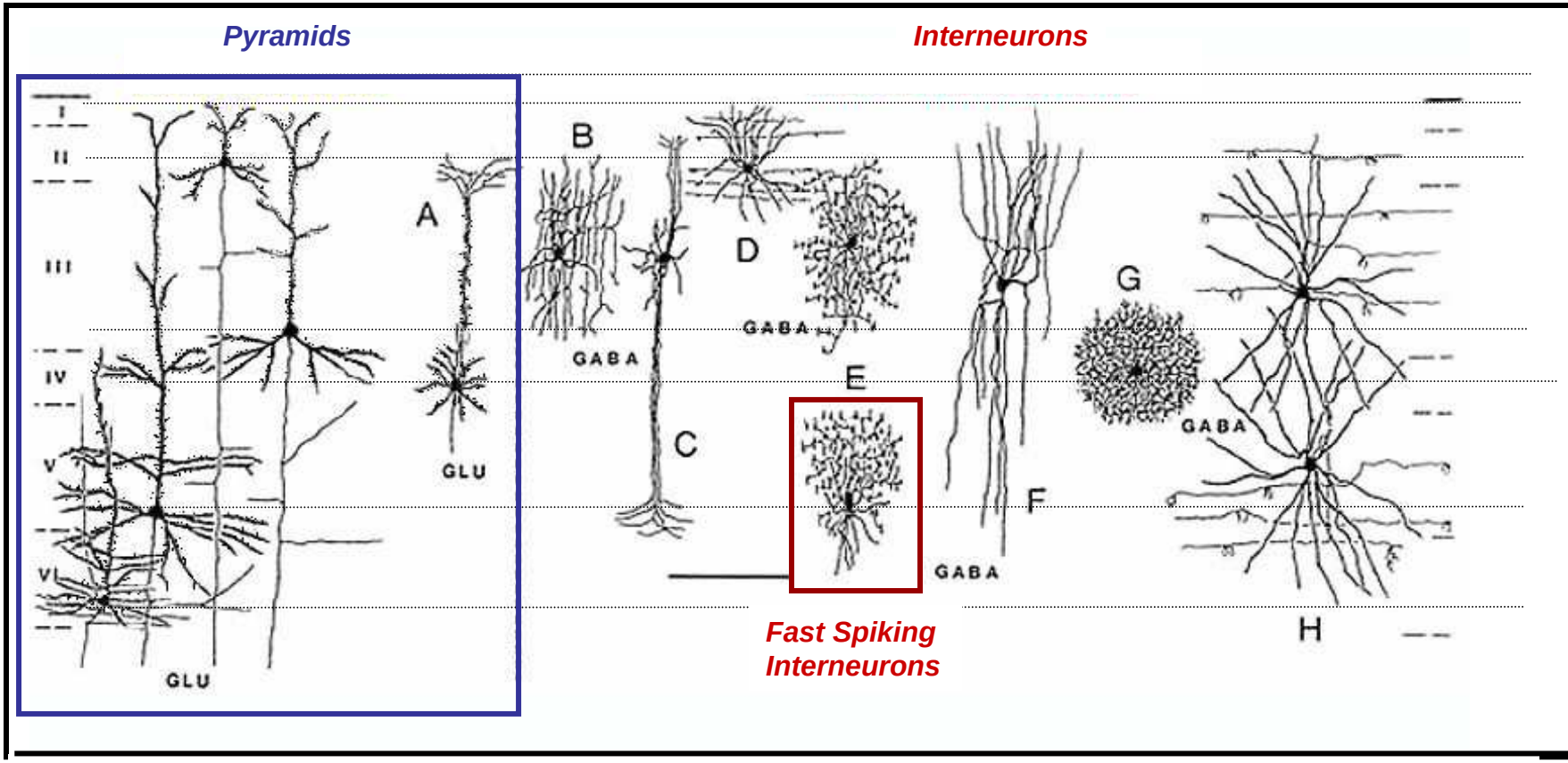



I
II
III
IV
V
VI
GLU
A
GLU
B
GABA
C
D
GABA
E
F
GABA
G
GABA
H

Pyramids

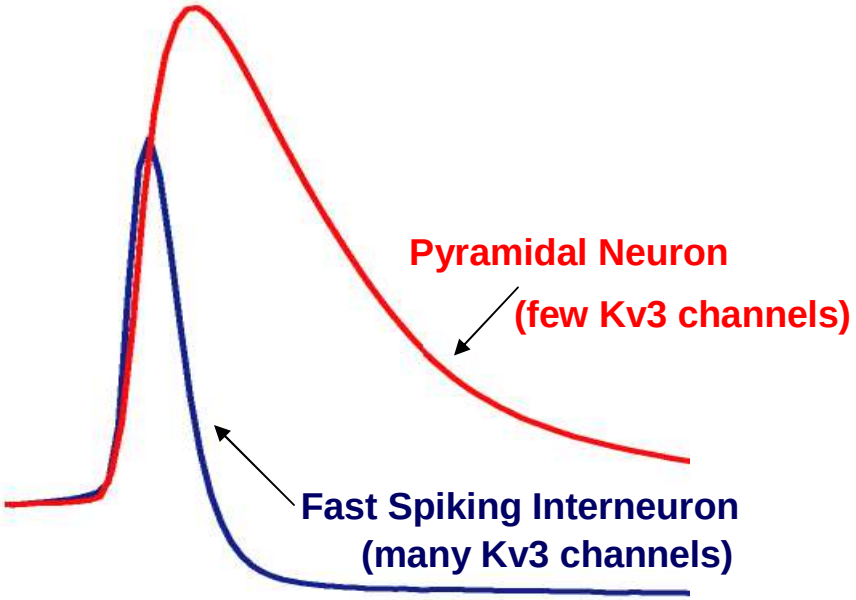


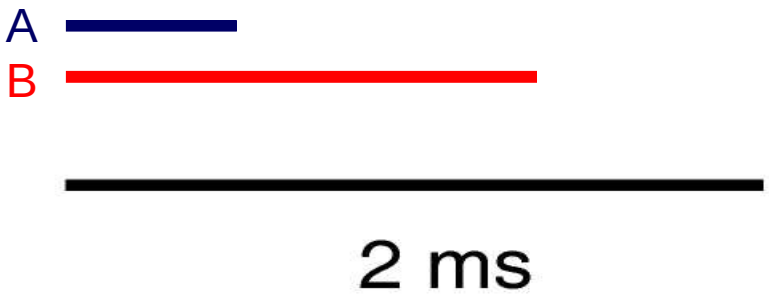

Pyramids
Interneurons
I
II
III
IV
V
VI
A
GLU
GLU
B
GABA
C
D
GABA
E
F
GABA
G
GABA
H


Pyramids
Interneurons
I
II
III
IV
V
VI
A
GLU
GLU
B
GABA
C
D
GABA
E
F
GABA
G
GABA
H
Fast Spiking
Interneurons

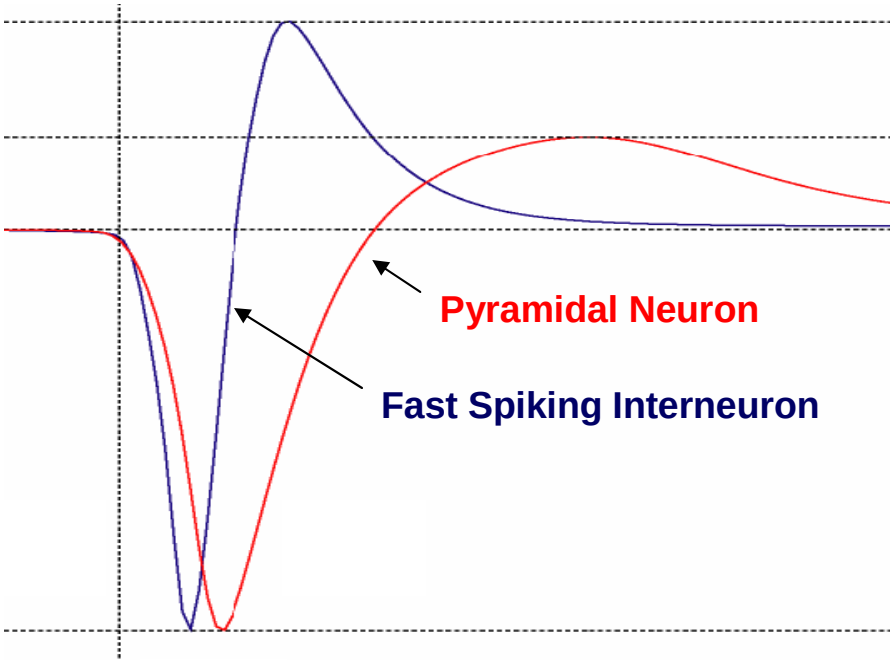
Pyramidal and Fast Spiking Inhibitory Interneuron Action Potentials

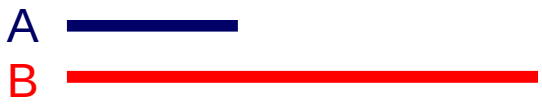
Intracellular action potential





Extracellular action potential

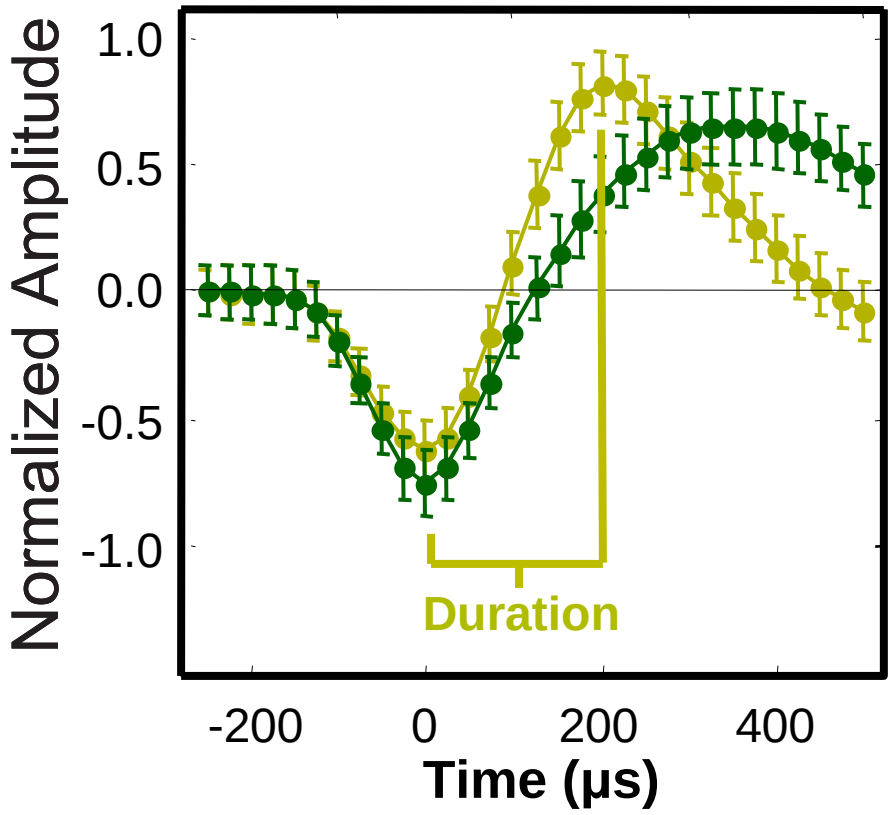




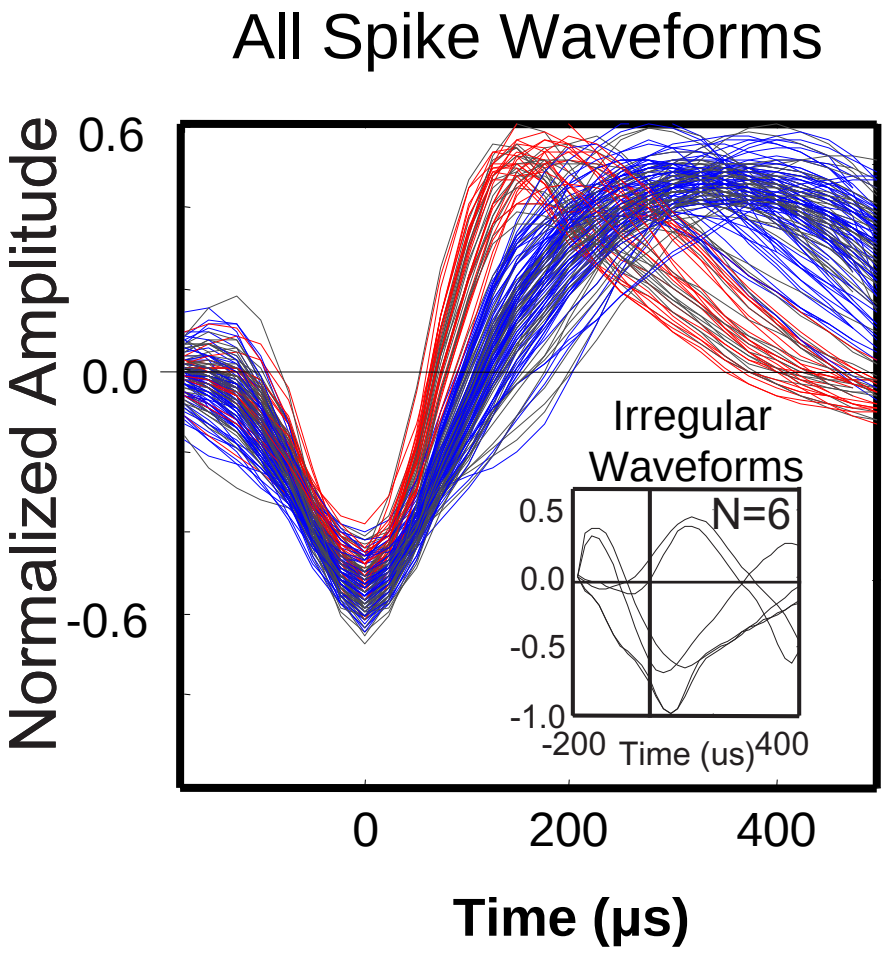
Hasenstaub et al., 2005

c.f. Henze et al., 1999
Goldman-Rakic et al.

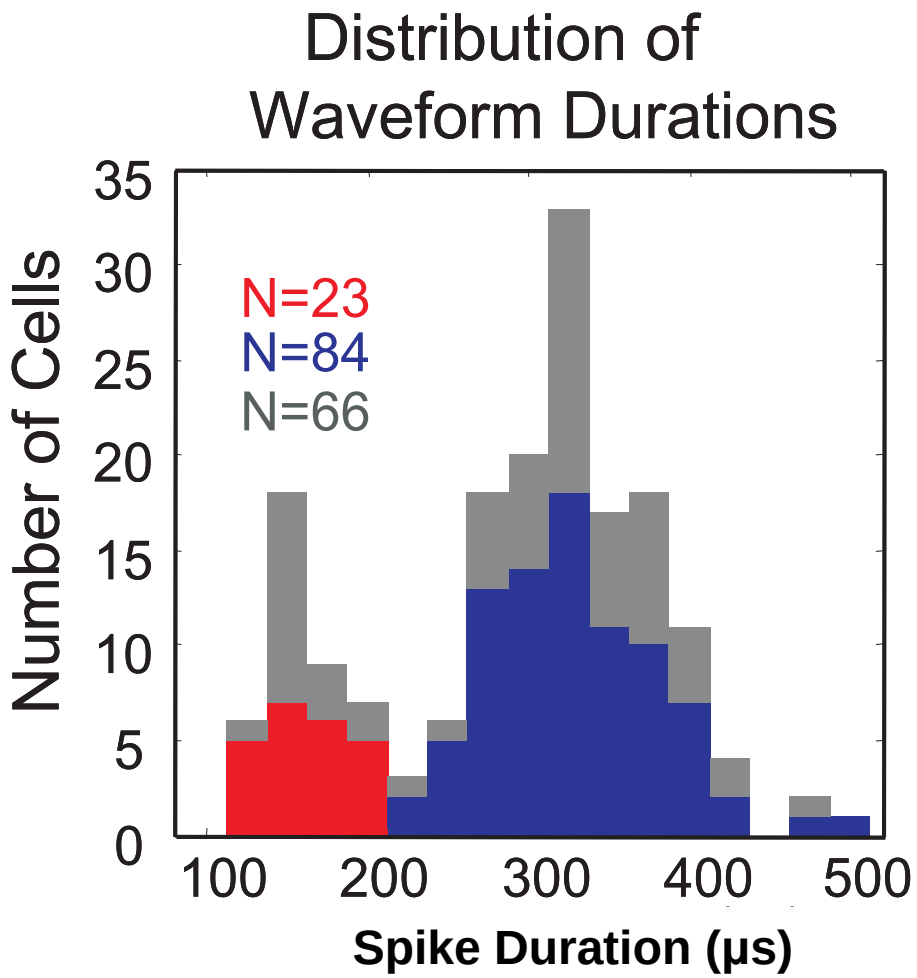
Two Mean Neuronal Waveforms (+/- one standard deviation)



Mitchell, Sundberg and Reynolds (2007) *Neuron*



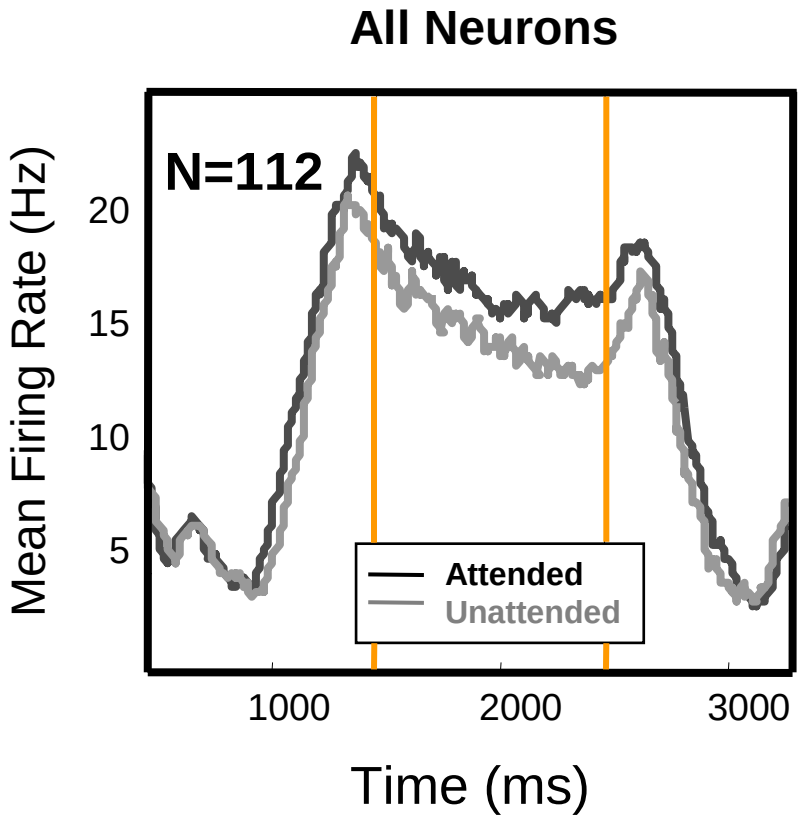
Mitchell, Sundberg and Reynolds (2007) *Neuron*



Mitchell, Sundberg and Reynolds (2007) *Neuron*

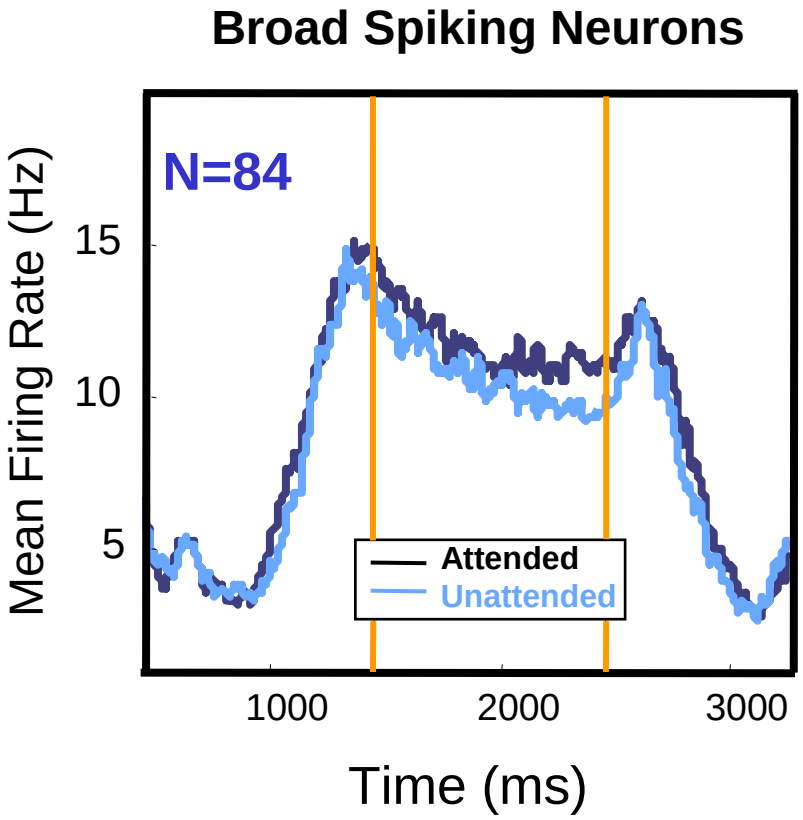
Hartigan's Dip test p=0.015

Attention-dependent modulation of firing rate



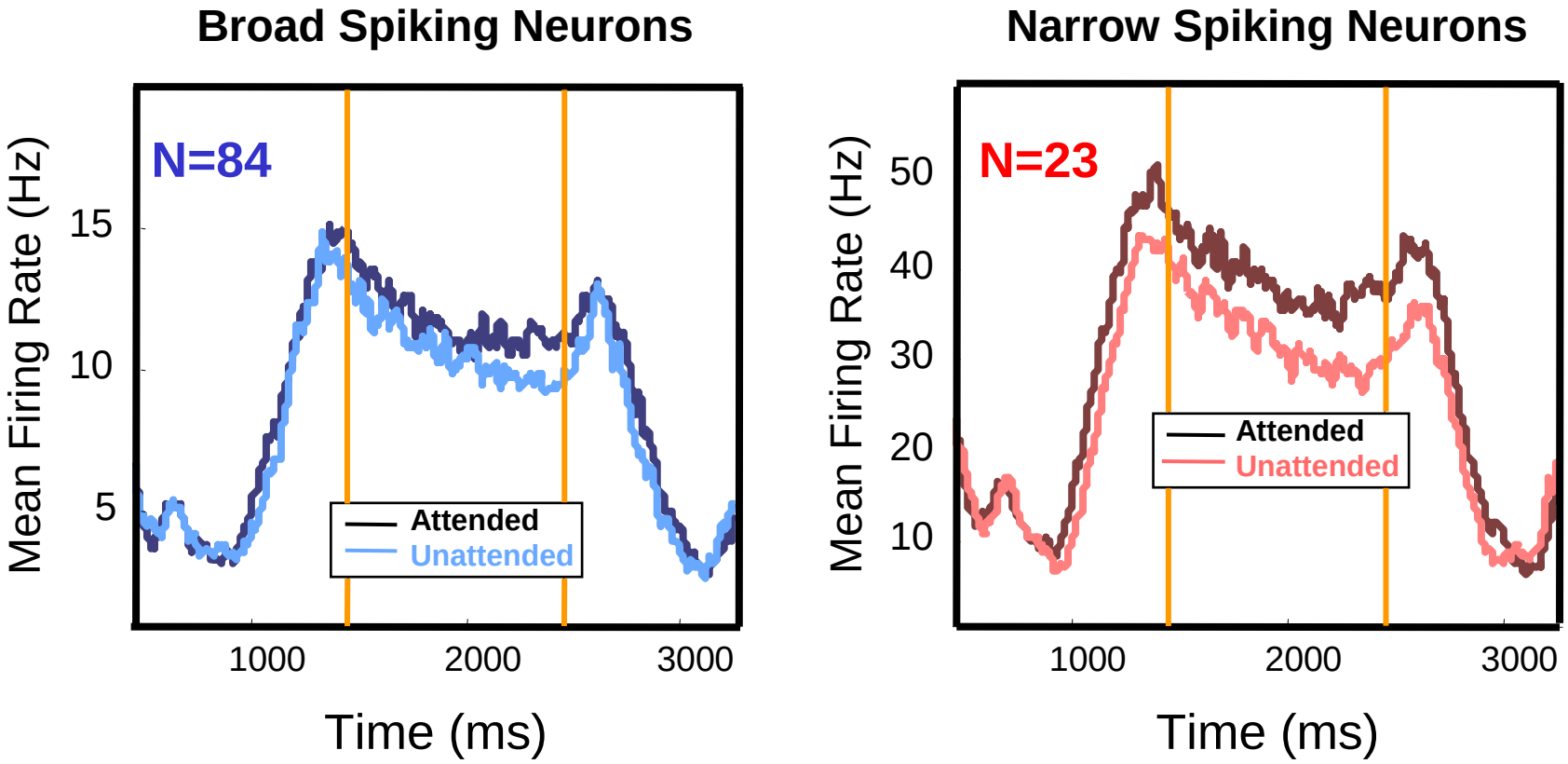
Mitchell, Sundberg and Reynolds (2007) *Neuron*

Attention-dependent modulation of firing rate



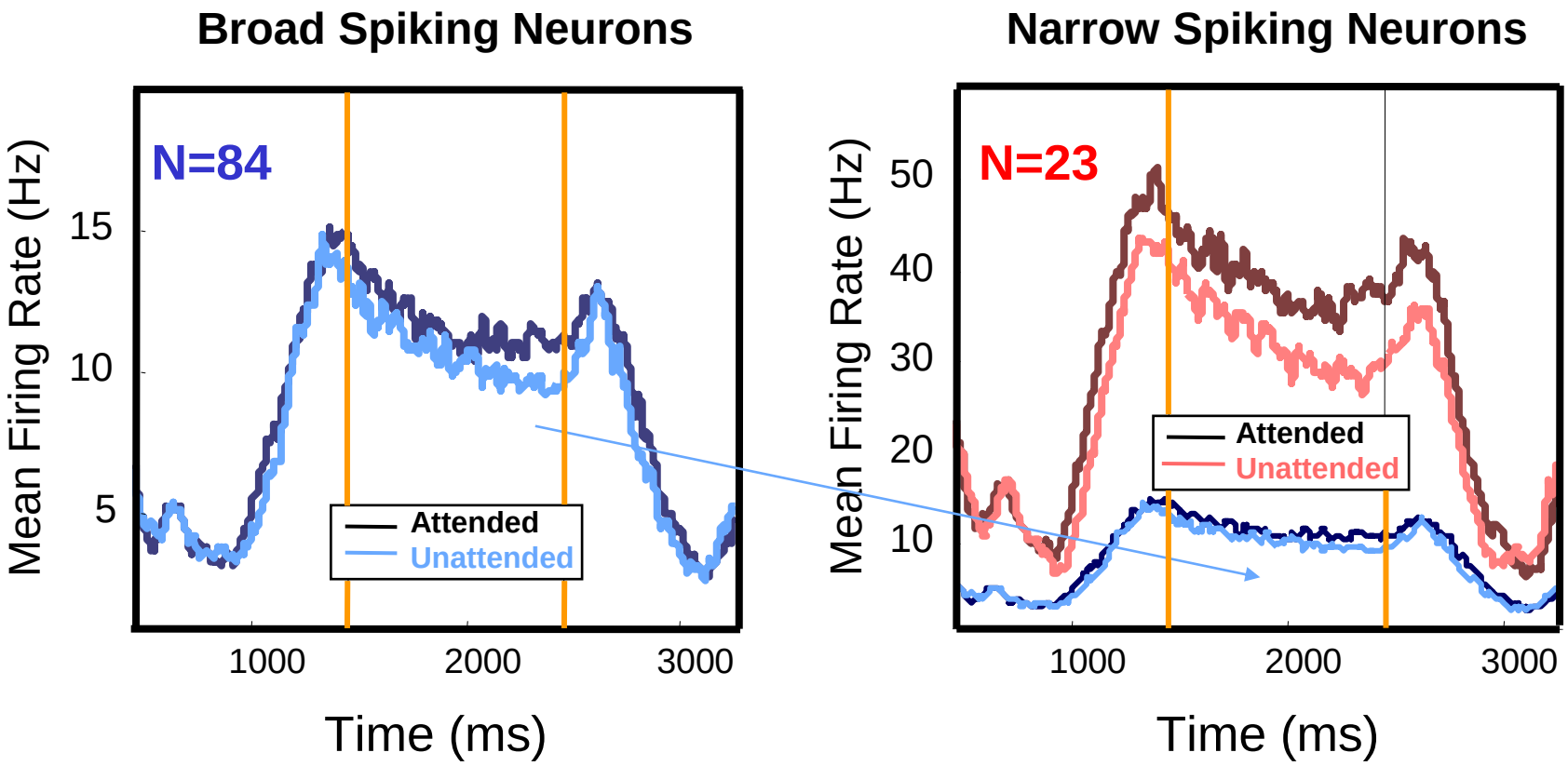
Mitchell, Sundberg and Reynolds (2007) *Neuron*

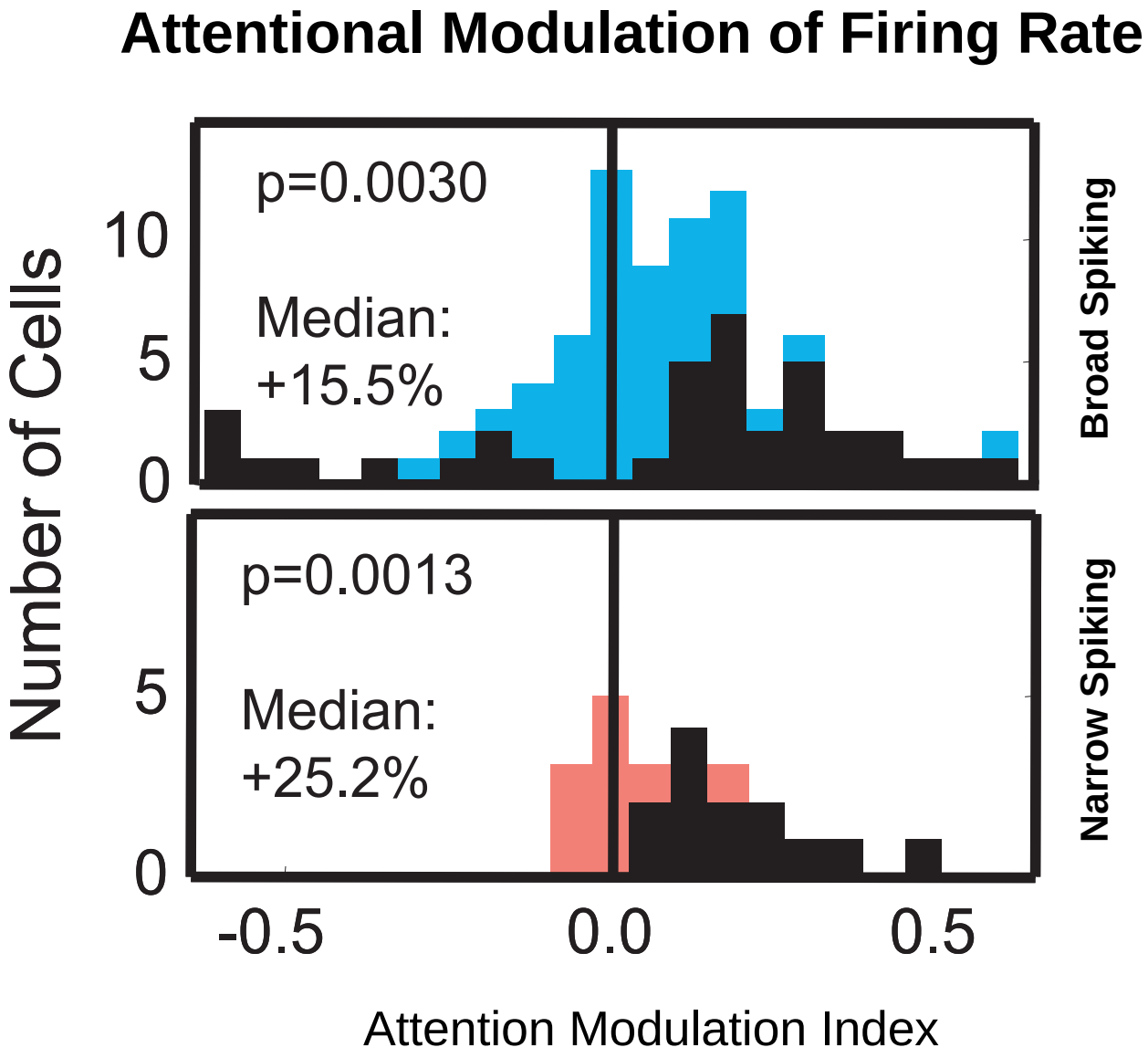
Attention-dependent modulation of firing rate



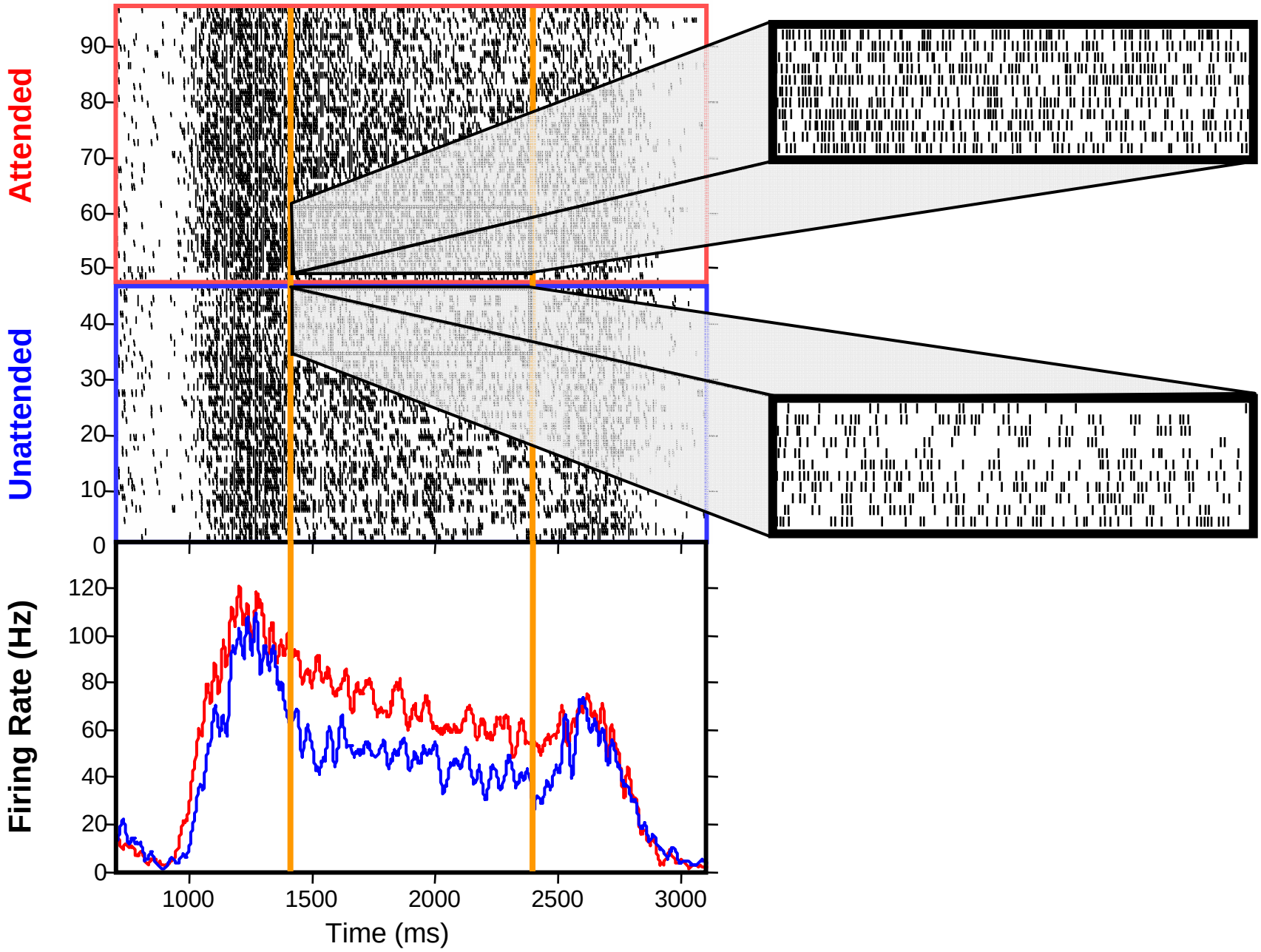
Mitchell, Sundberg and Reynolds (2007) *Neuron*

Attention-dependent modulation of firing rate

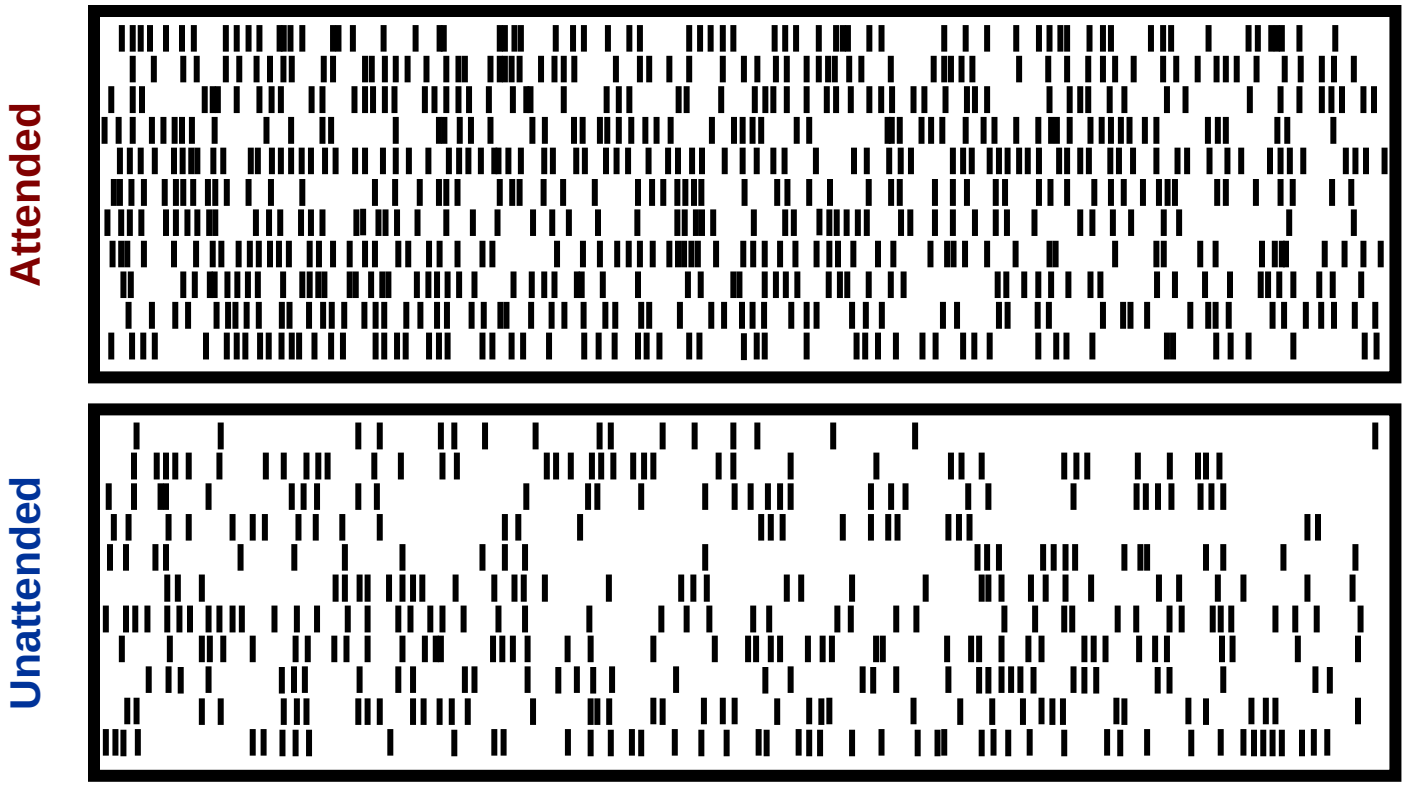



Attentional Modulation of Firing Rate
p=0.0030
Median:
+15.5%
10
5
0
Broad Spiking
p=0.0013
Median:
+25.2%
5
0
Narrow Spiking
Number of Cells
-0.5
0.0
0.5
Attention Modulation Index

Attention-dependent modulation of response reliability

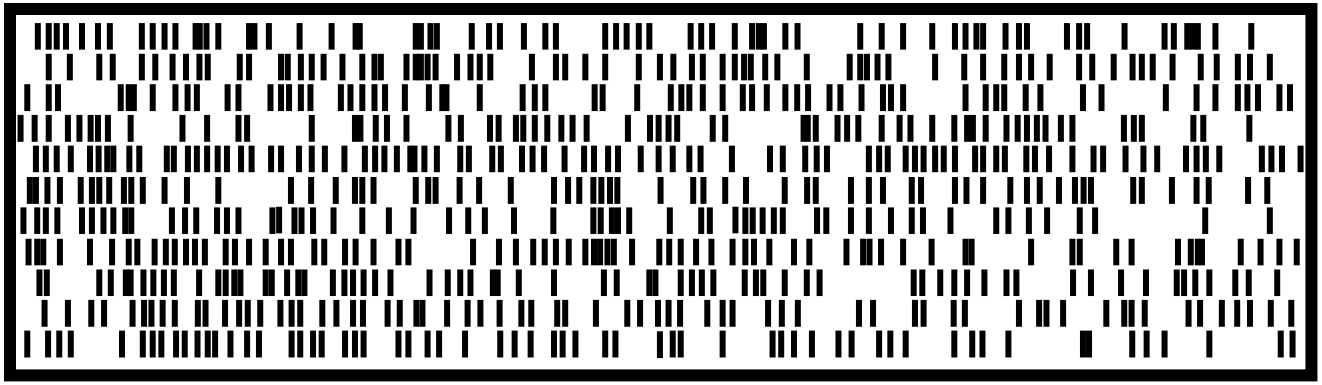


Attention-dependent modulation of response reliability



Attention-dependent modulation of response reliability

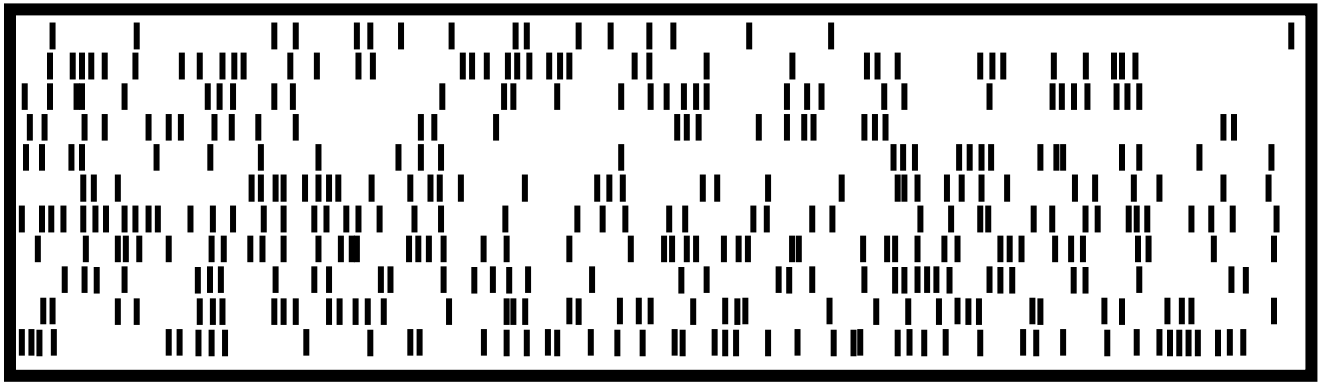
Attended



68
71
66
64
85
63
60
72
67
67
61

σ=6.9 spikes

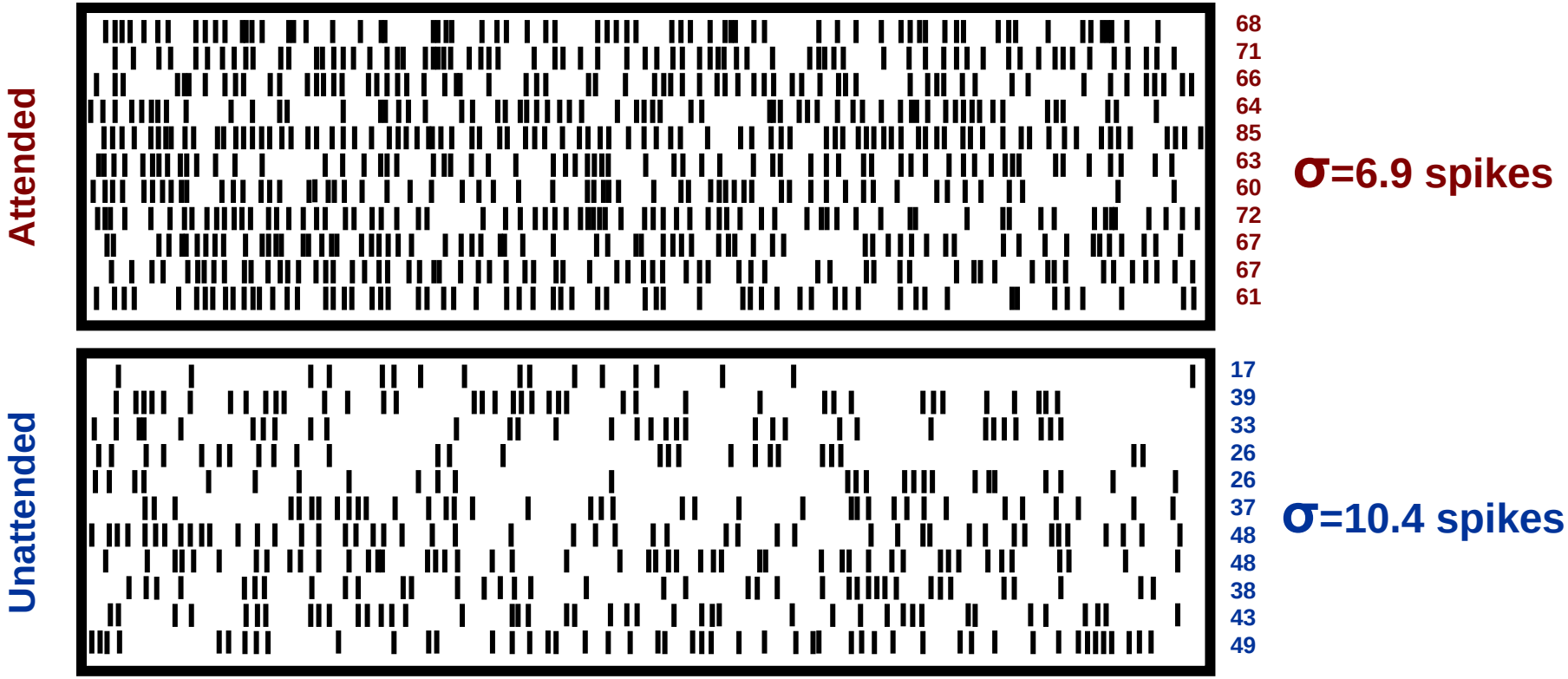
Unattended



17
39
33
26
26
37
48
48
38
43
49

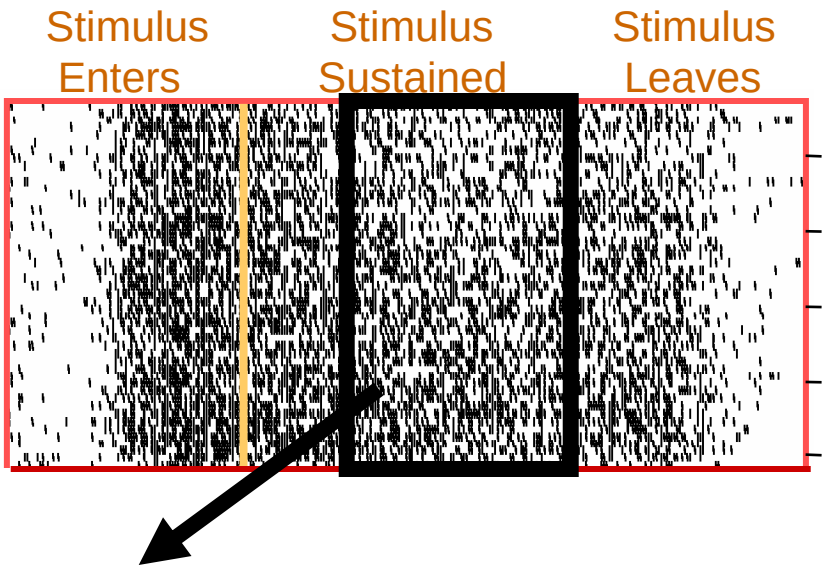
σ=10.4 spikes

Attention-dependent modulation of response reliability

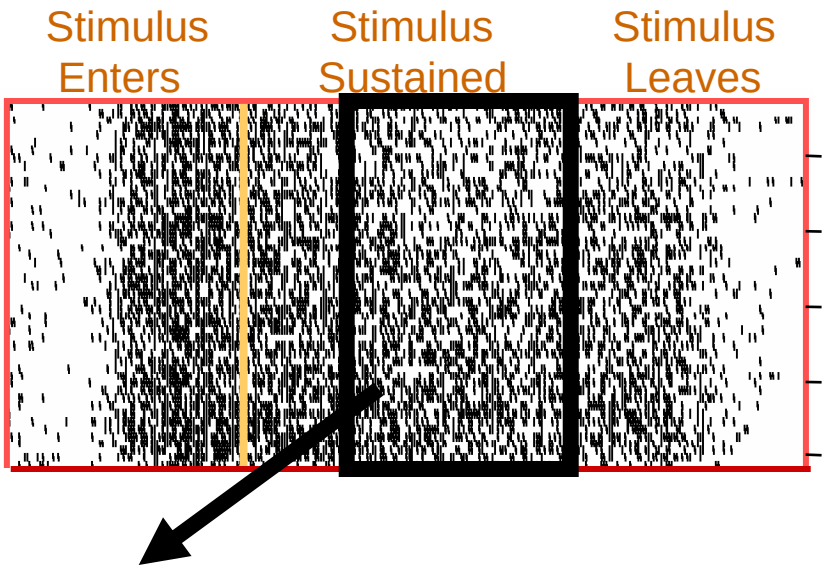


$$\text{Fano Factor} = \frac{\sigma^2}{\mu}$$

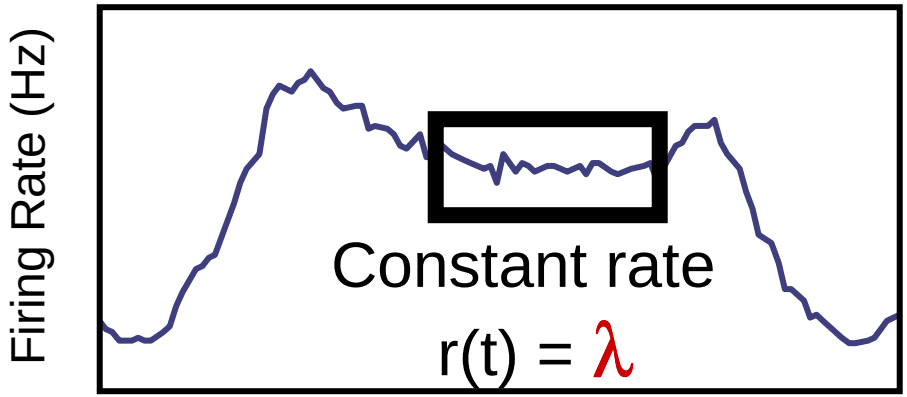
Fano Factor

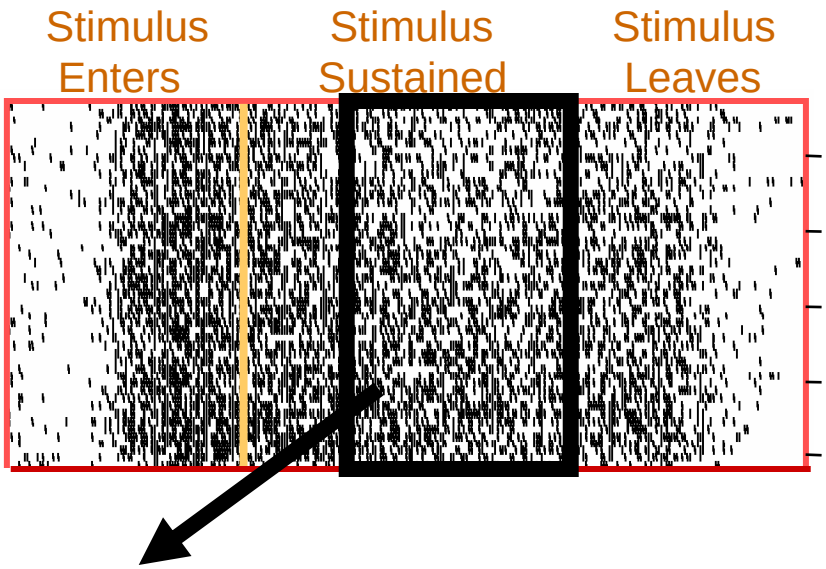


Poisson Spiking:

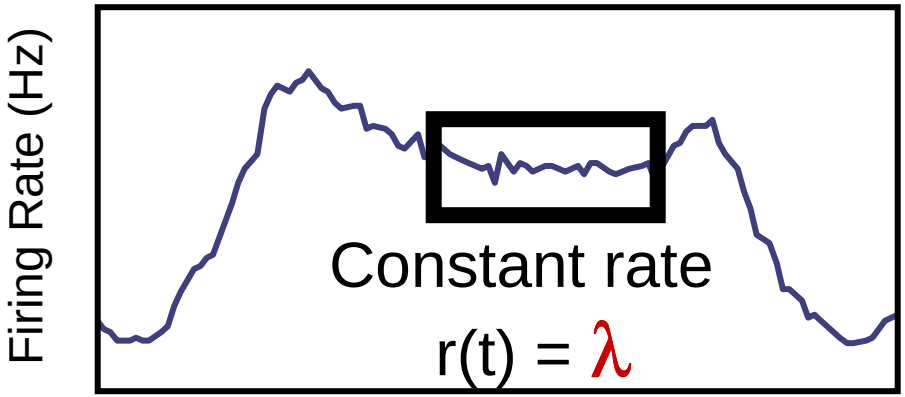


Poisson Spiking:

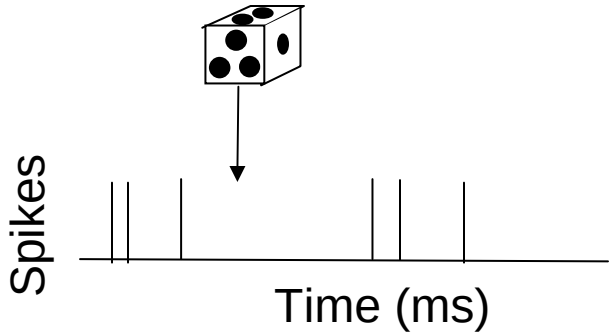


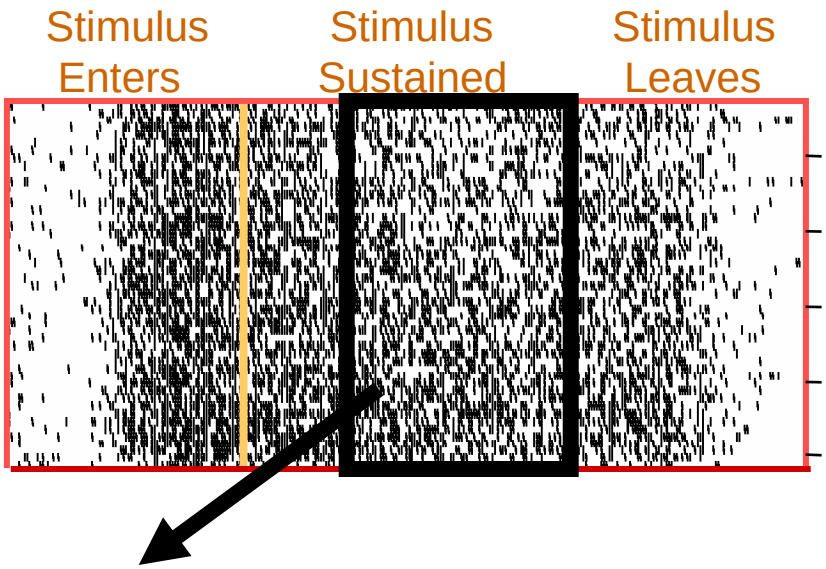


Poisson Spiking:

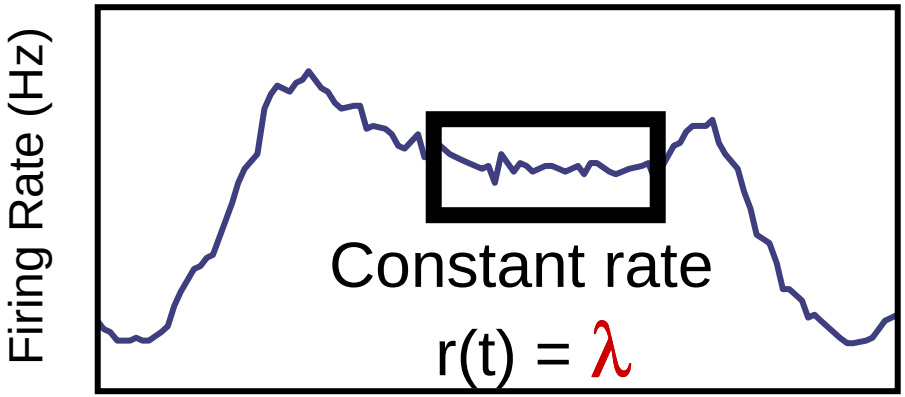


$$\text{Spike}(t) = \begin{cases} 1 & \text{with probability } \lambda \\ 0 & \text{else} \end{cases}$$





Poisson Spiking:



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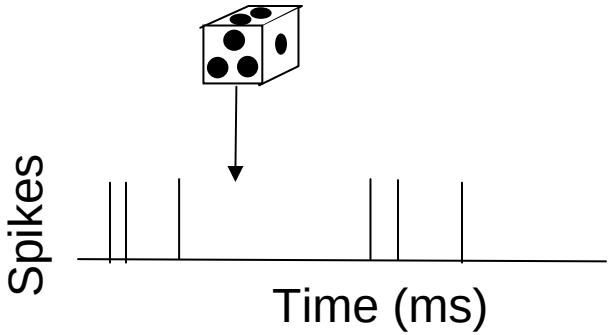
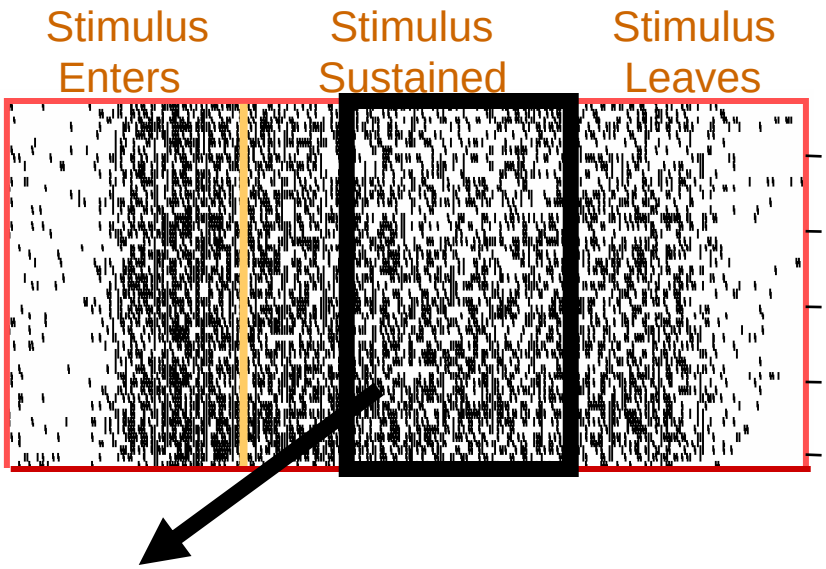
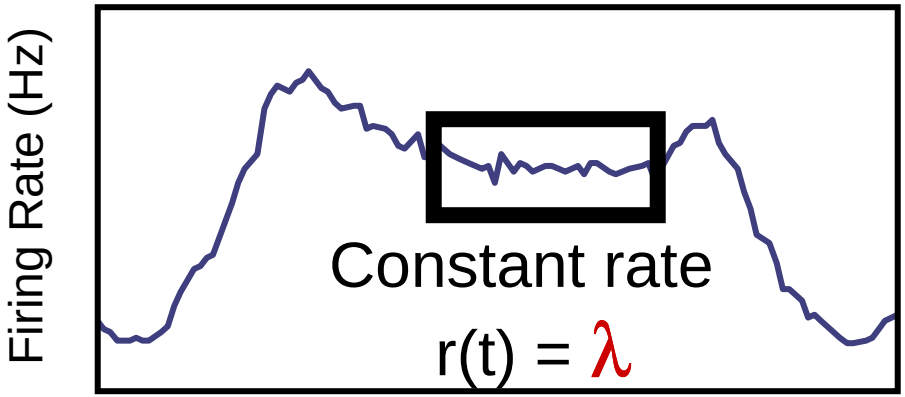
Some Properties of Poisson Spiking:





Poisson Spiking:

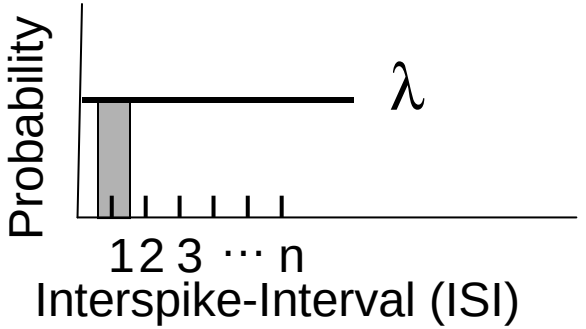


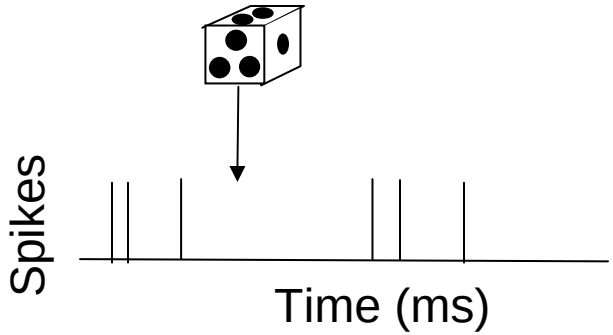
$$\text{Spike}(t) = \begin{cases} 1 & \text{with probability } \lambda \\ 0 & \text{else} \end{cases}$$

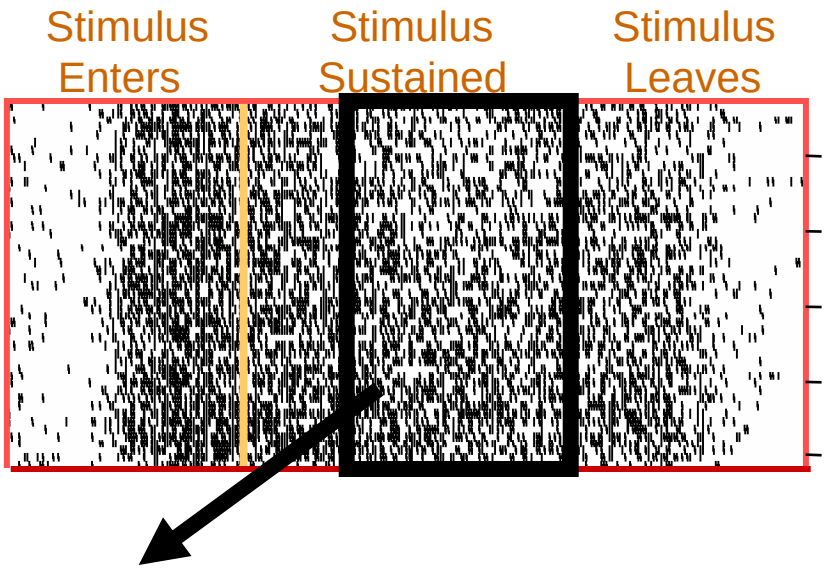
Some Properties of Poisson Spiking:

Flat Autocorrelation Function:

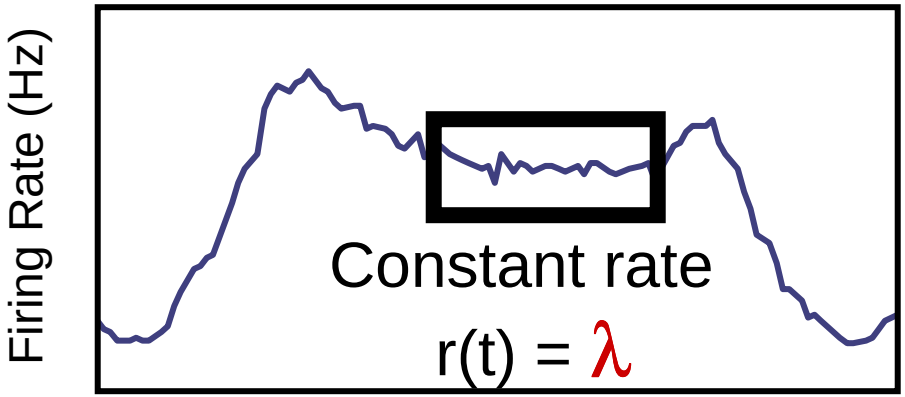
Prob(Spike(t) | Spike(0)) = λ







Poisson Spiking:



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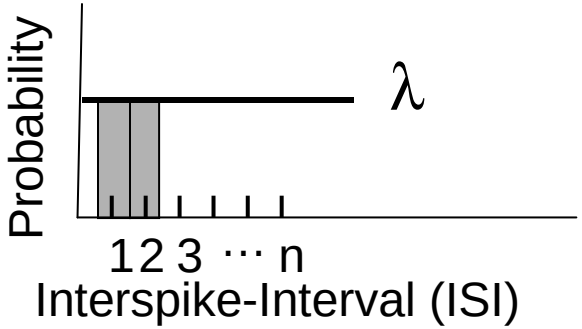
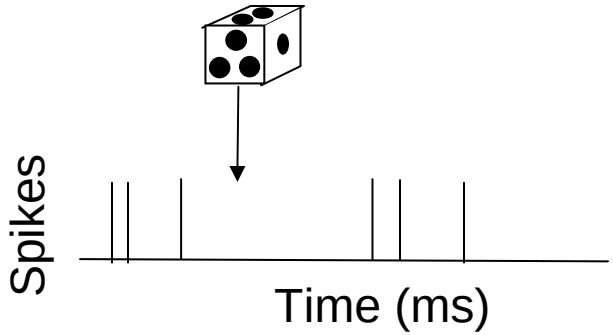
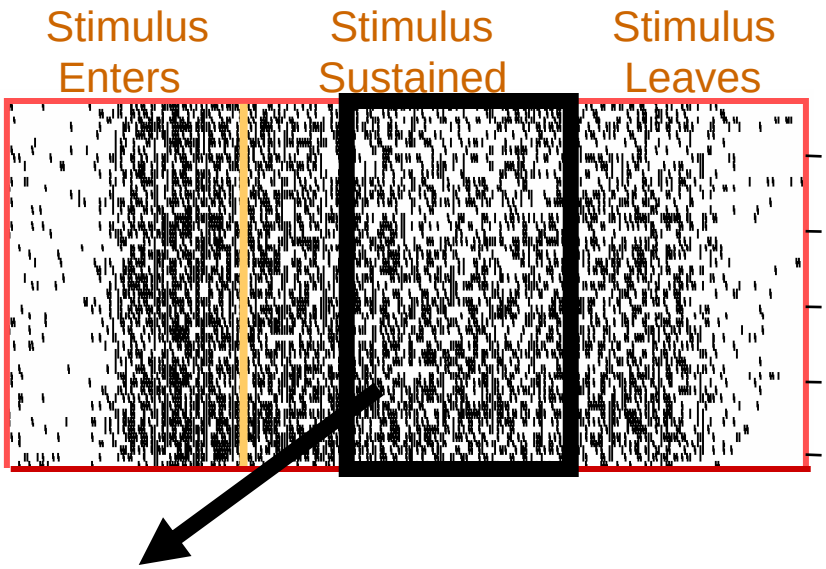
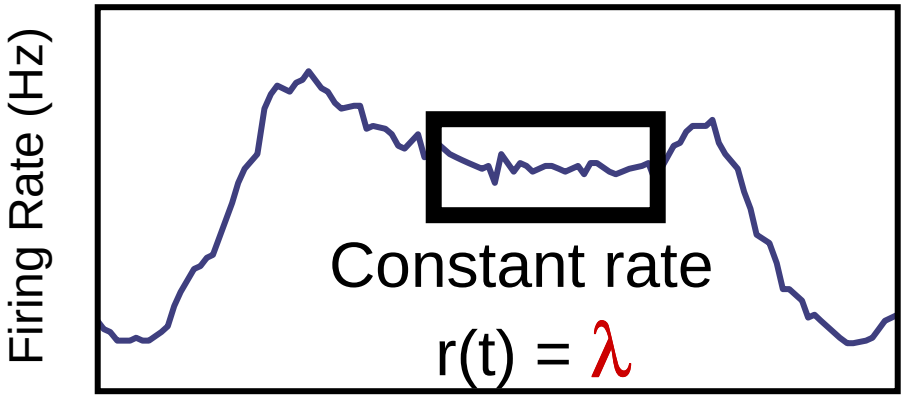






Poisson Spiking:



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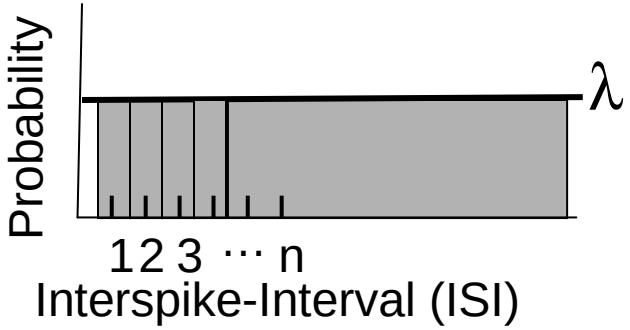
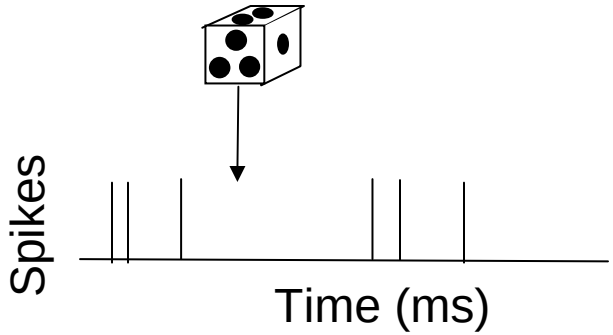
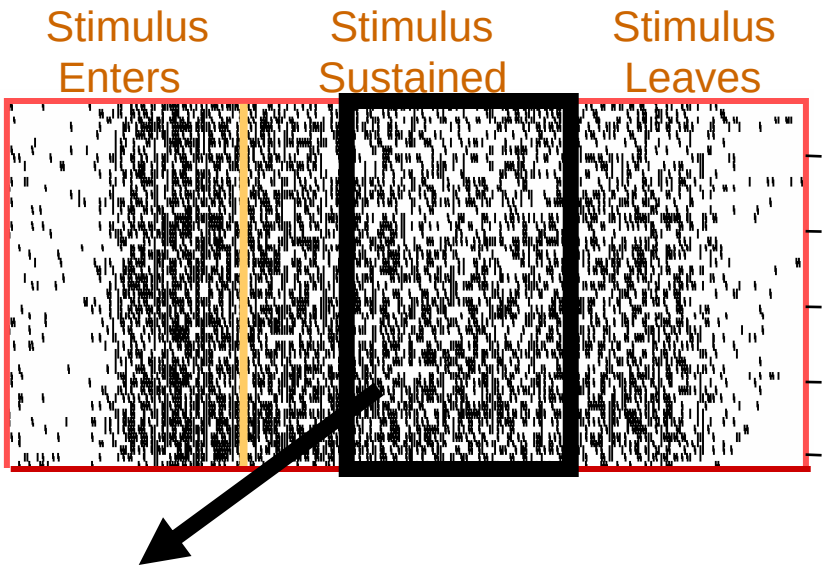
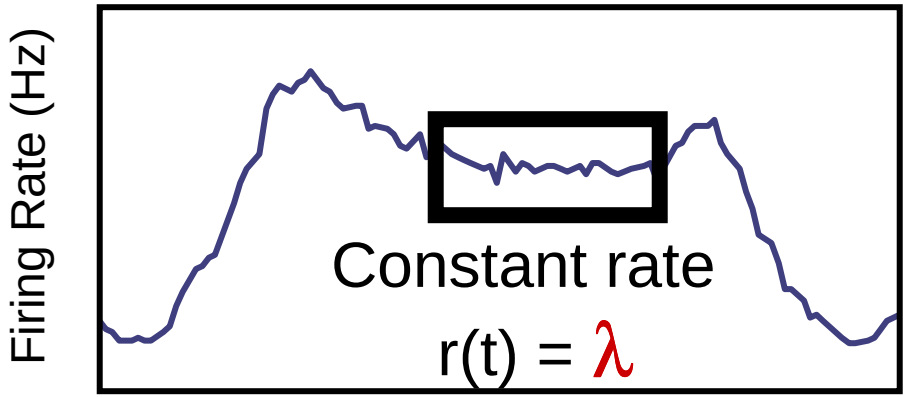






Poisson Spiking:



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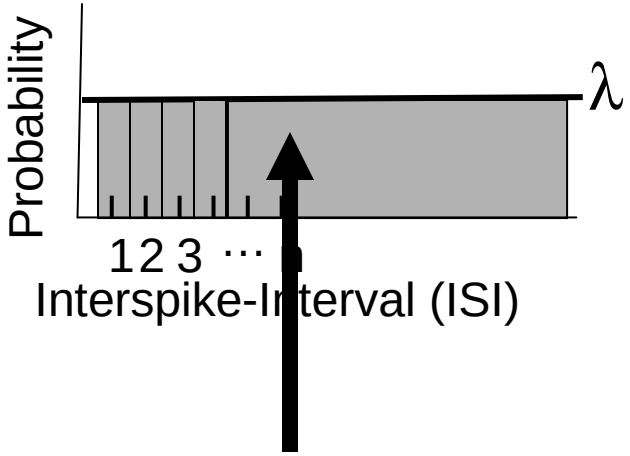
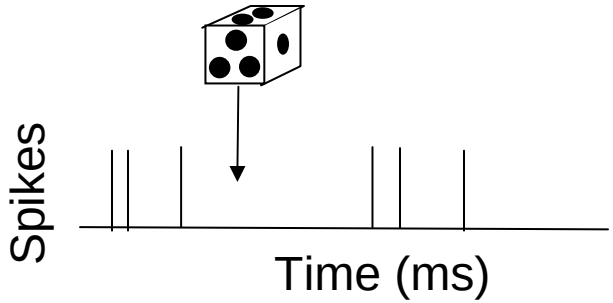
Some Properties of Poisson Spiking:

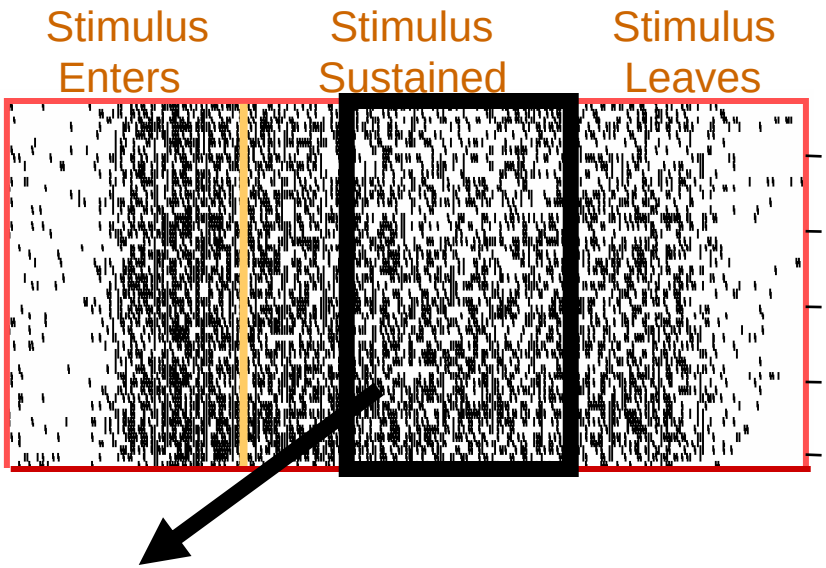
Flat Autocorrelation Function:

Prob(Spike(t) | Spike(0)) = λ

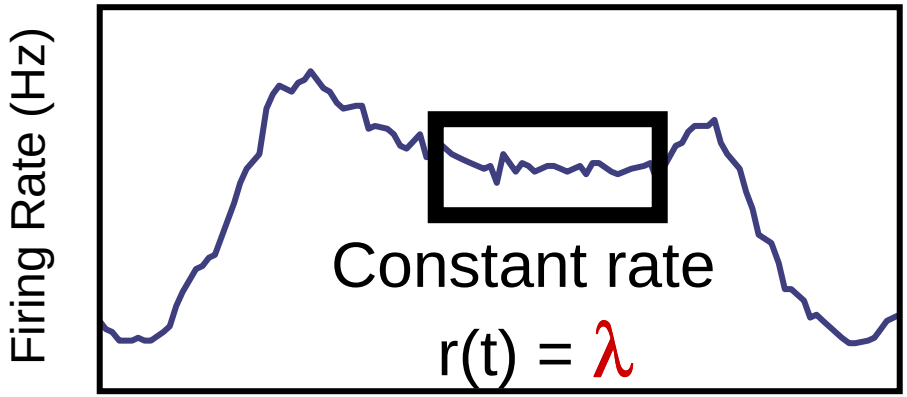


Probability of Firing is Independent of History





Poisson Spiking:



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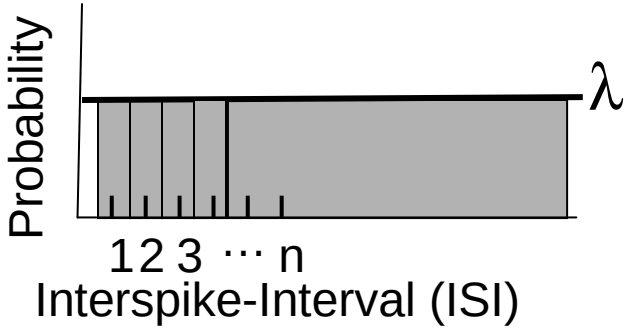

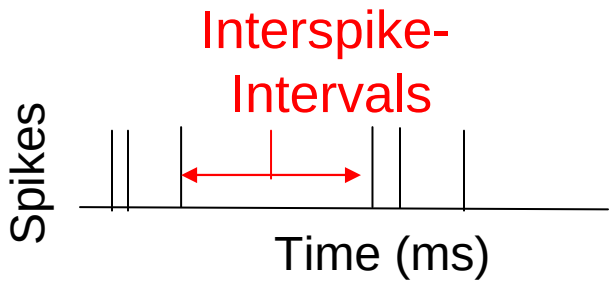

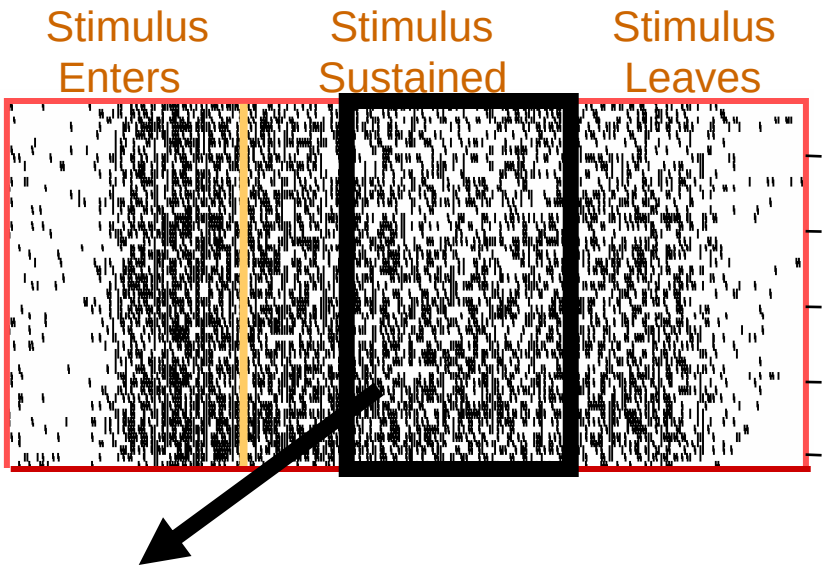

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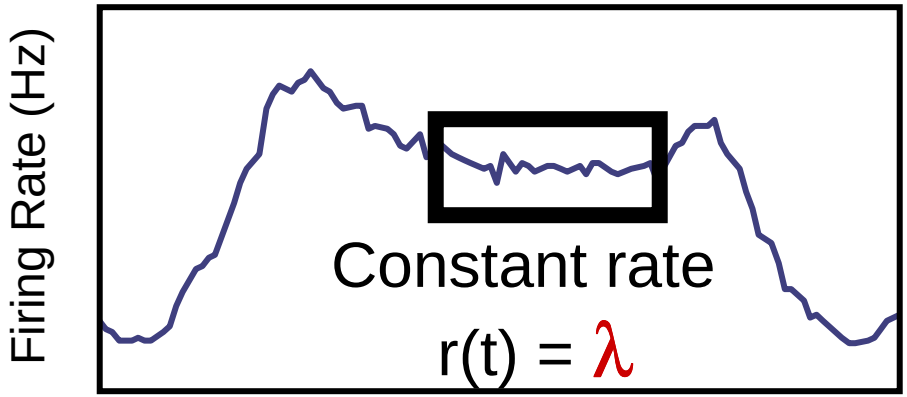

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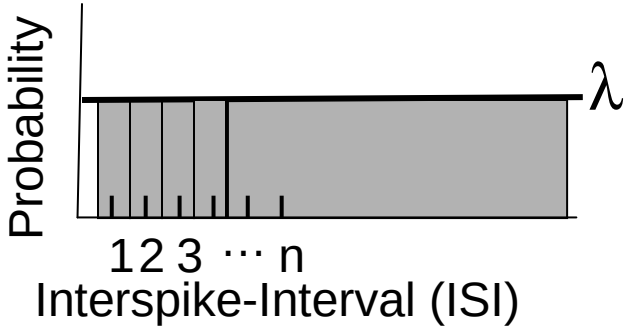
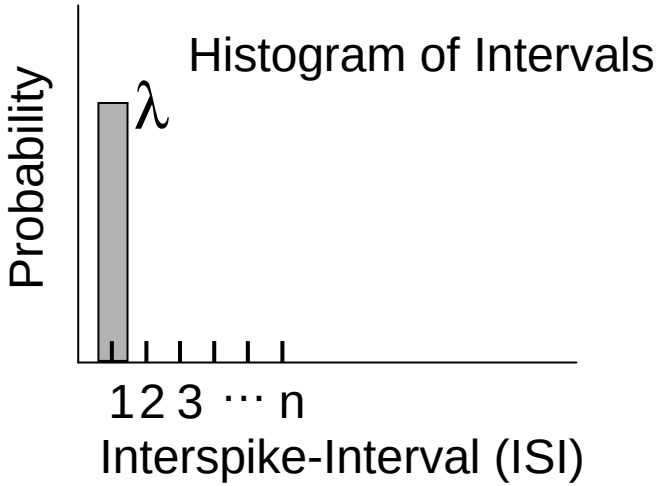
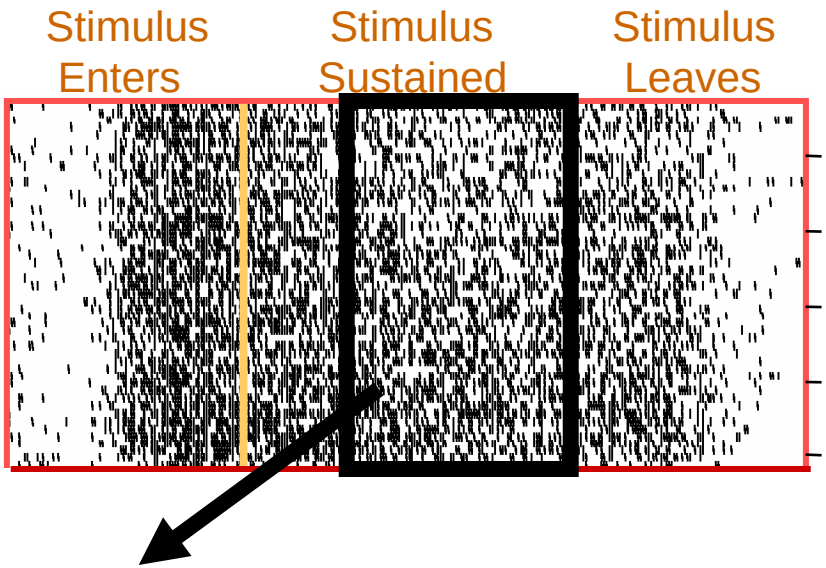


Exponential ISI Distribution:





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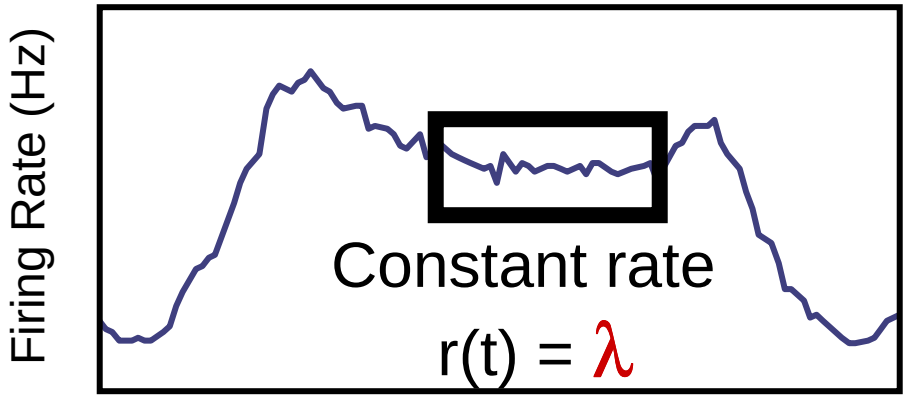

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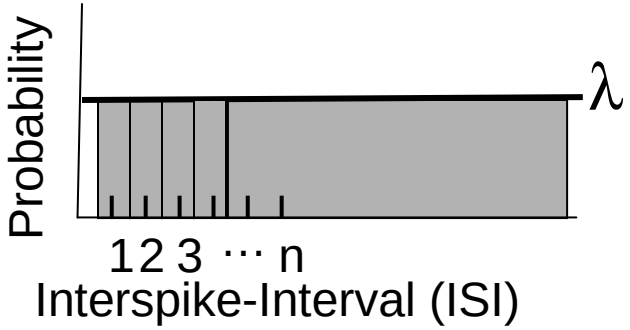

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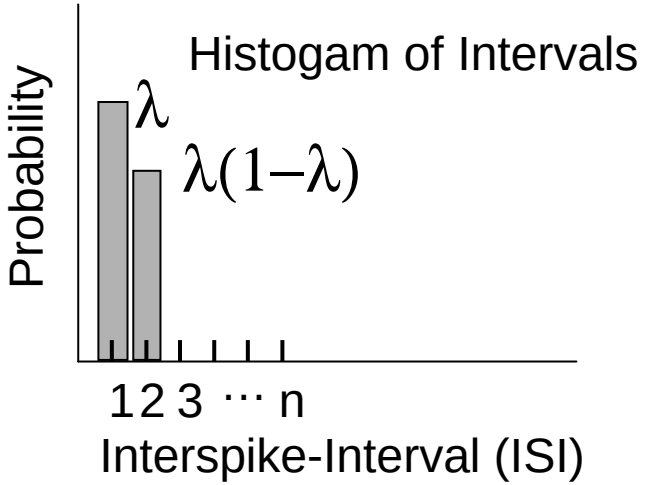

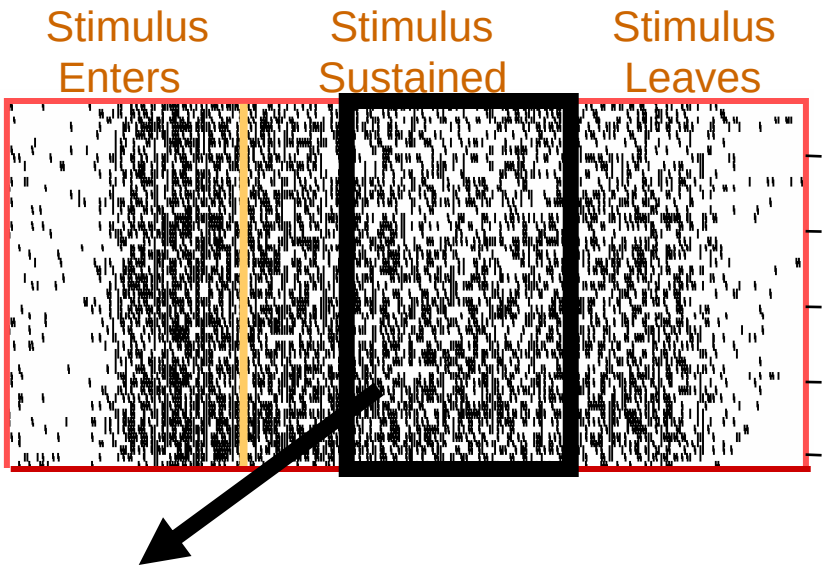

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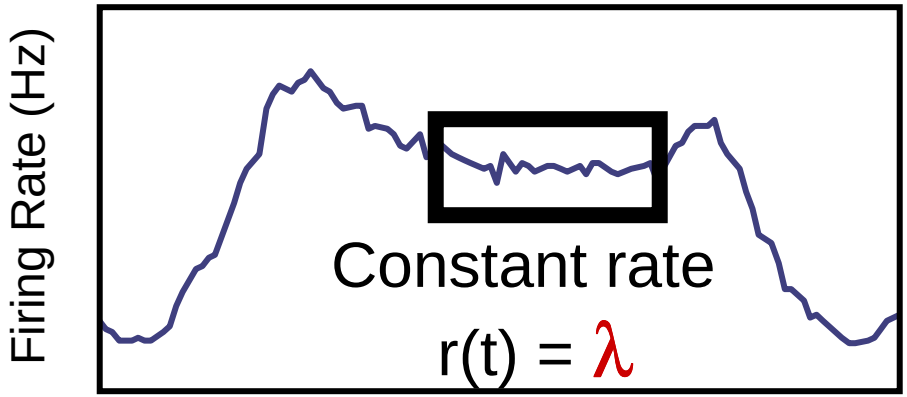

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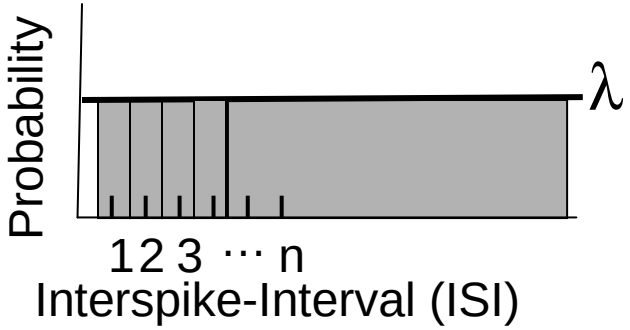

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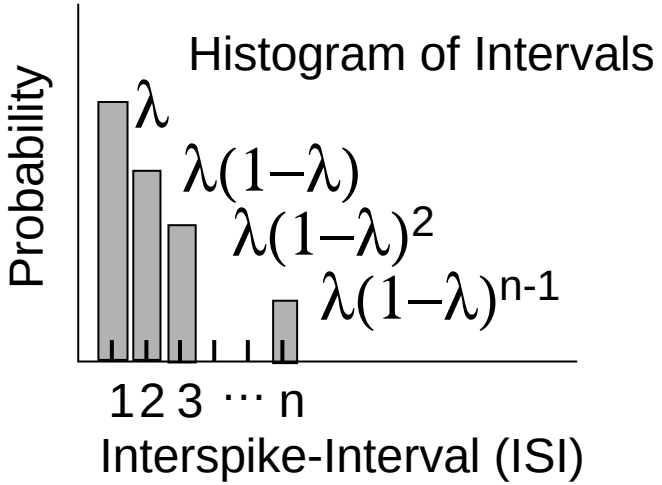

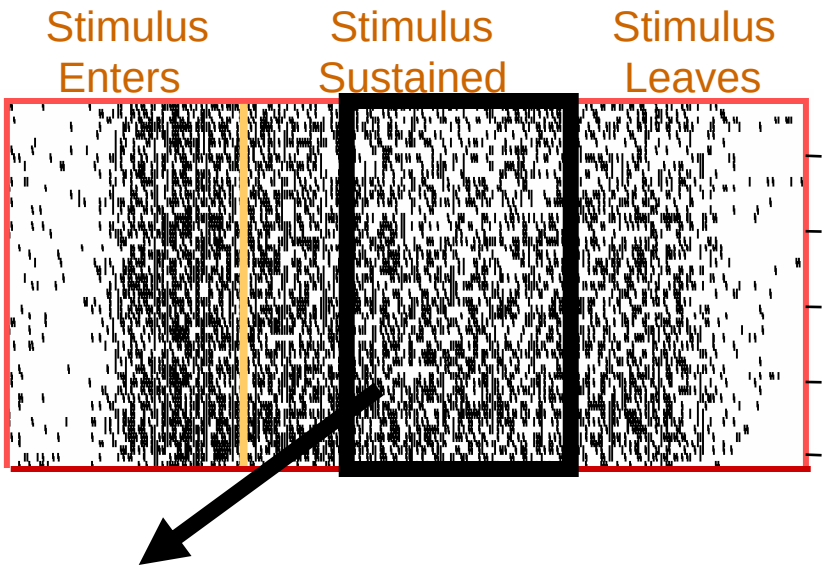

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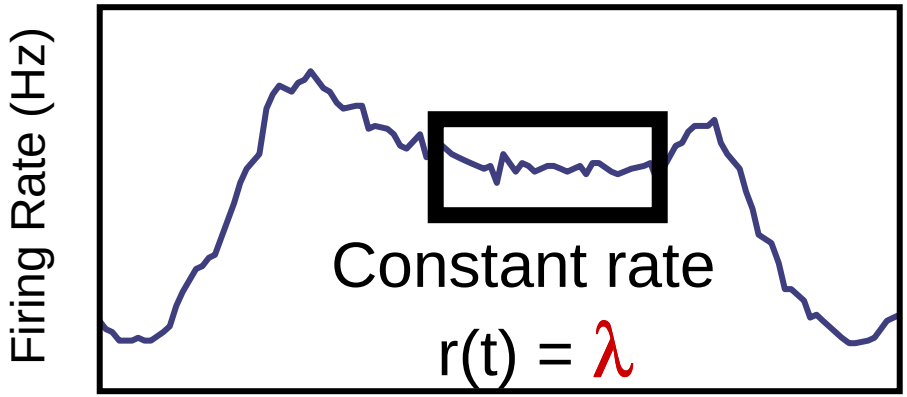

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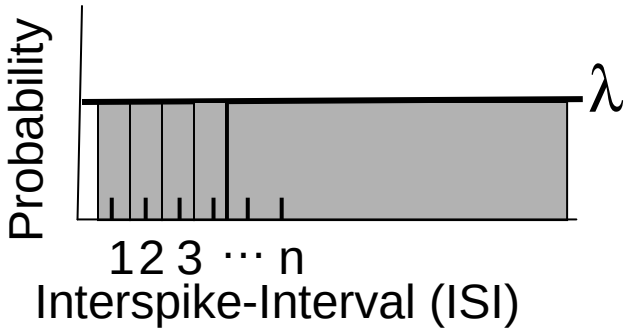

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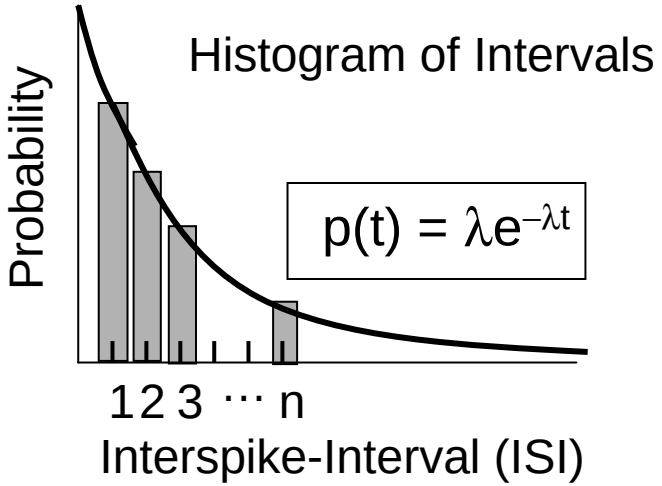

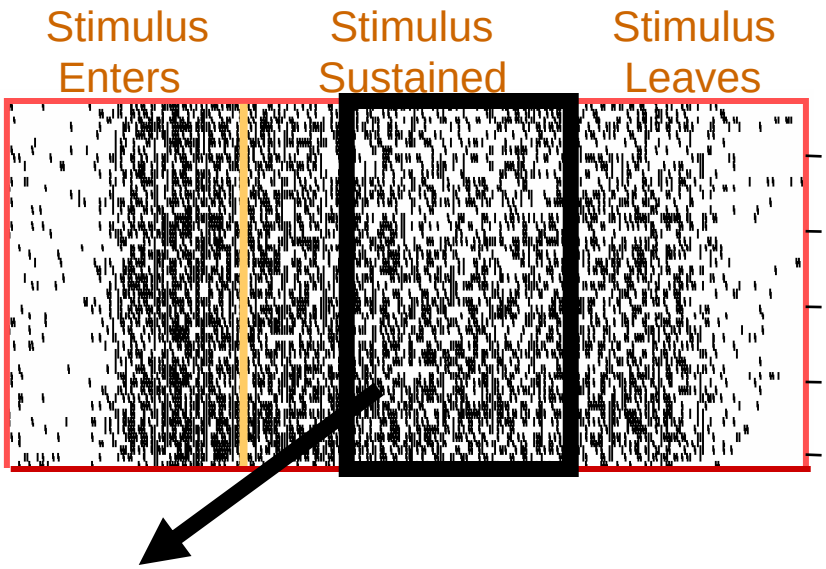

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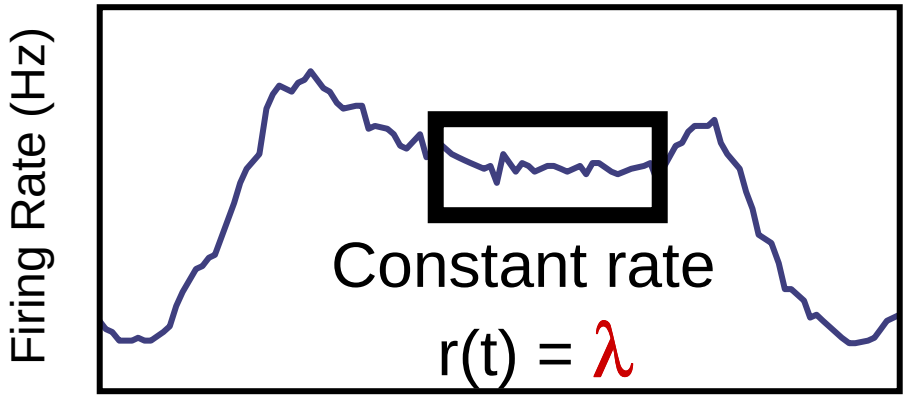

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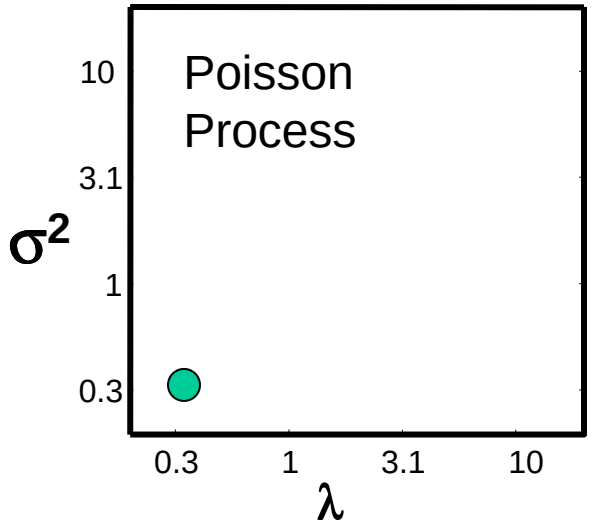
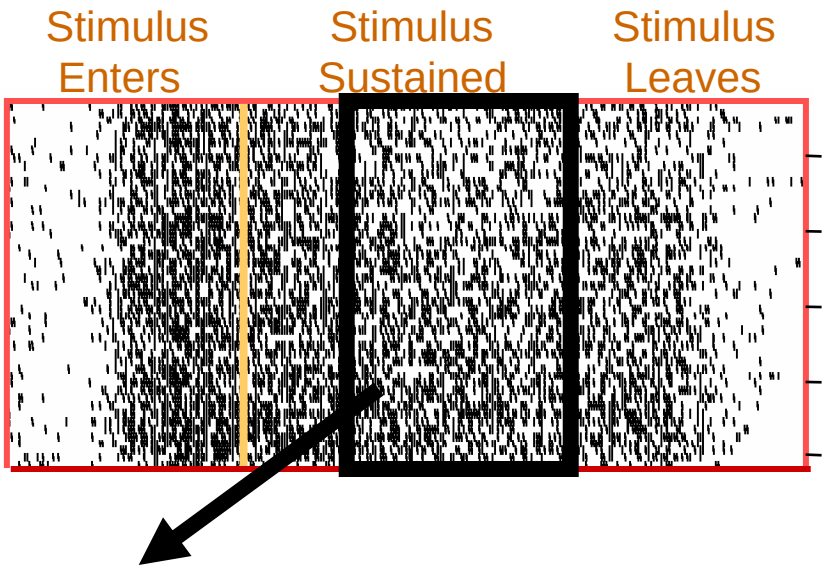
$$\sigma^2 = \lambda$$





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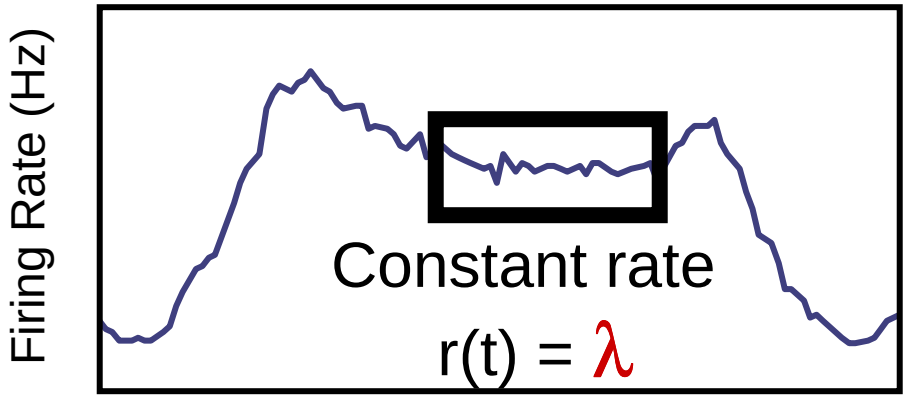

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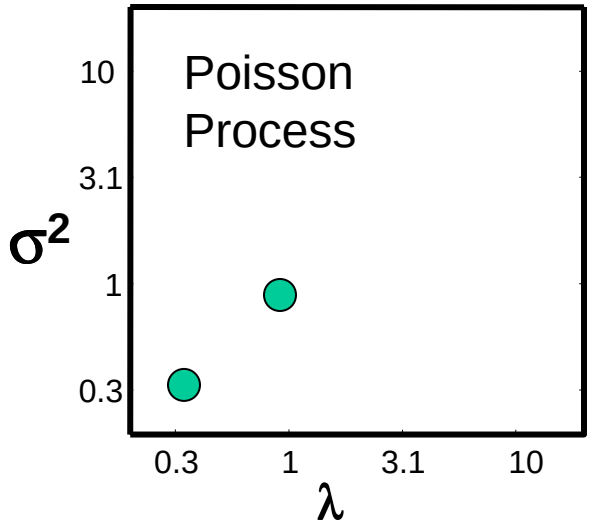

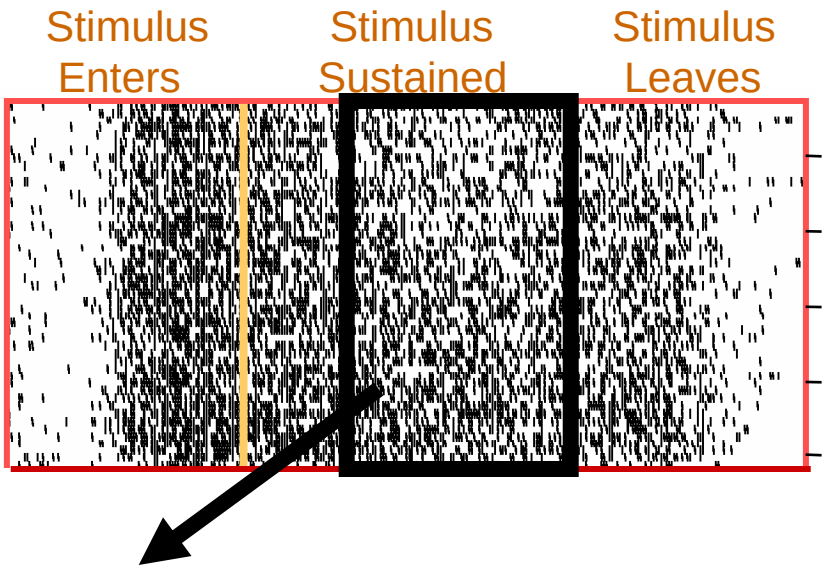

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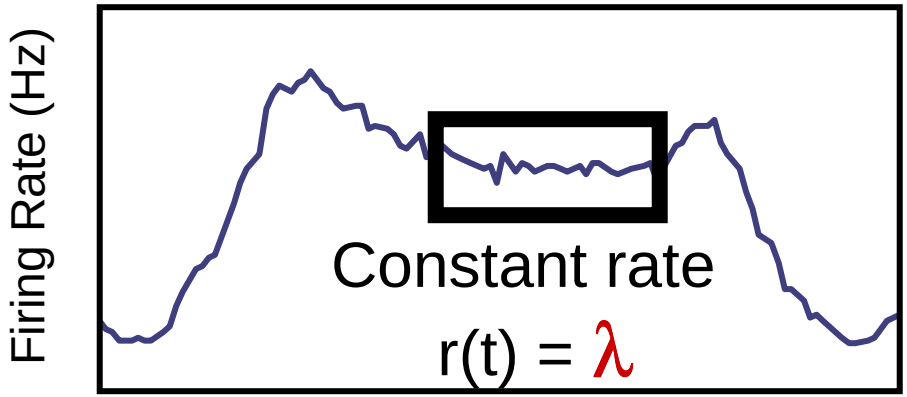

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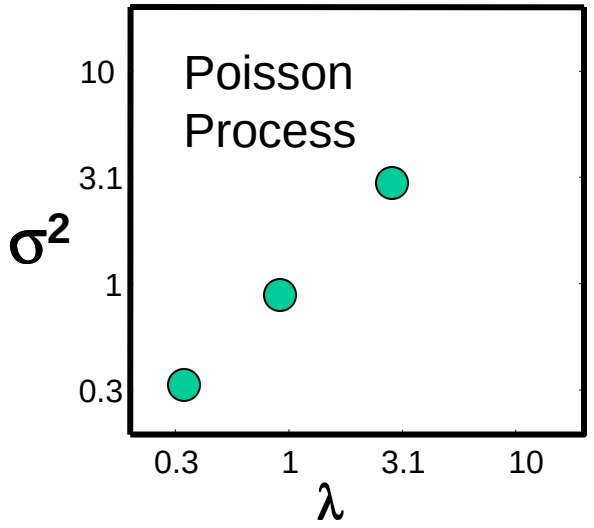

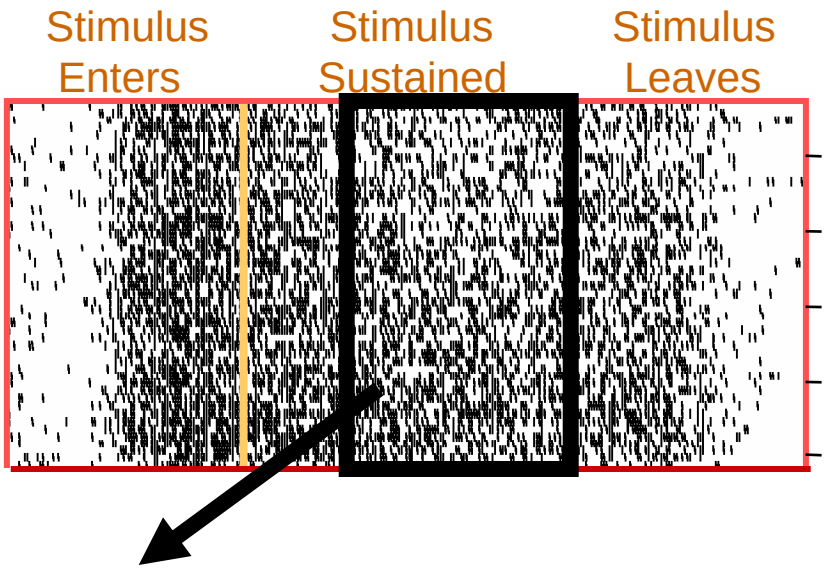

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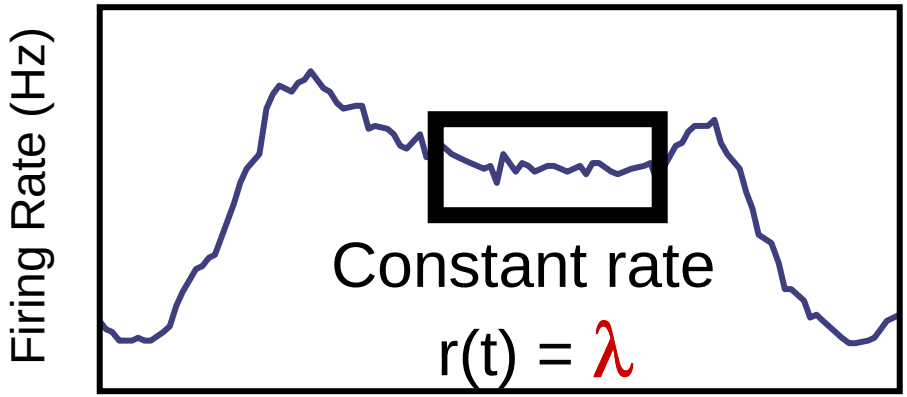

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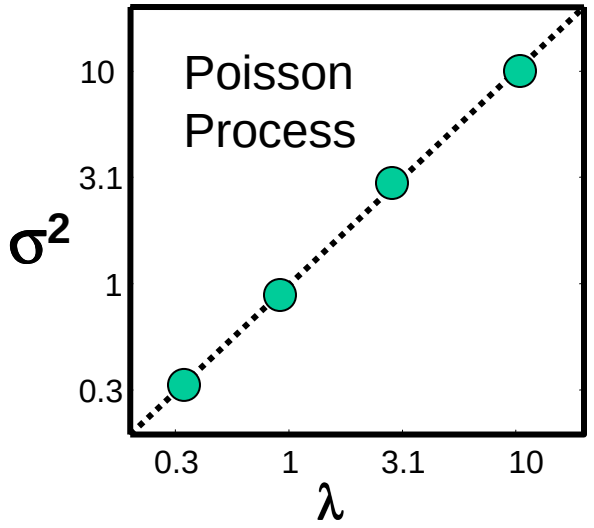

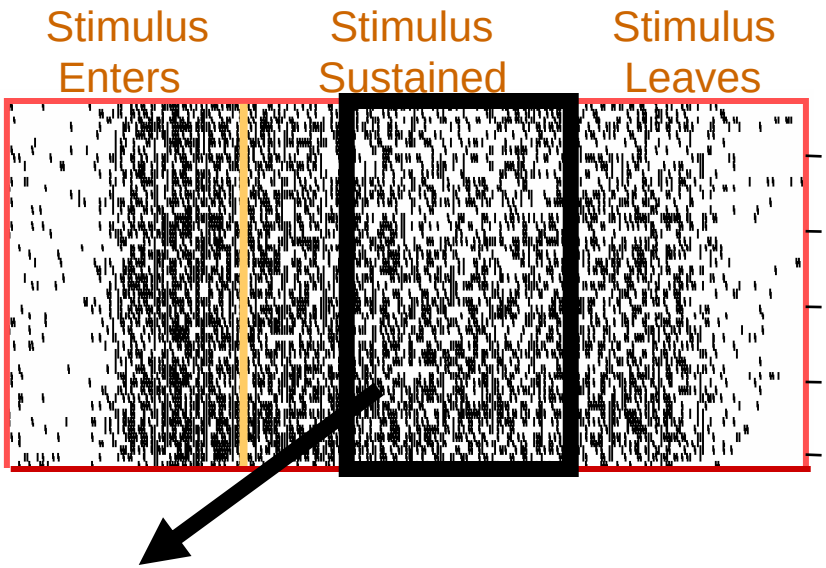

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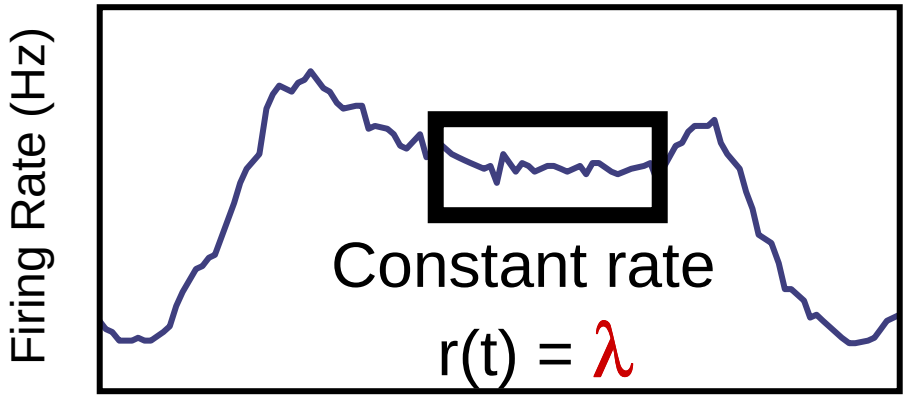

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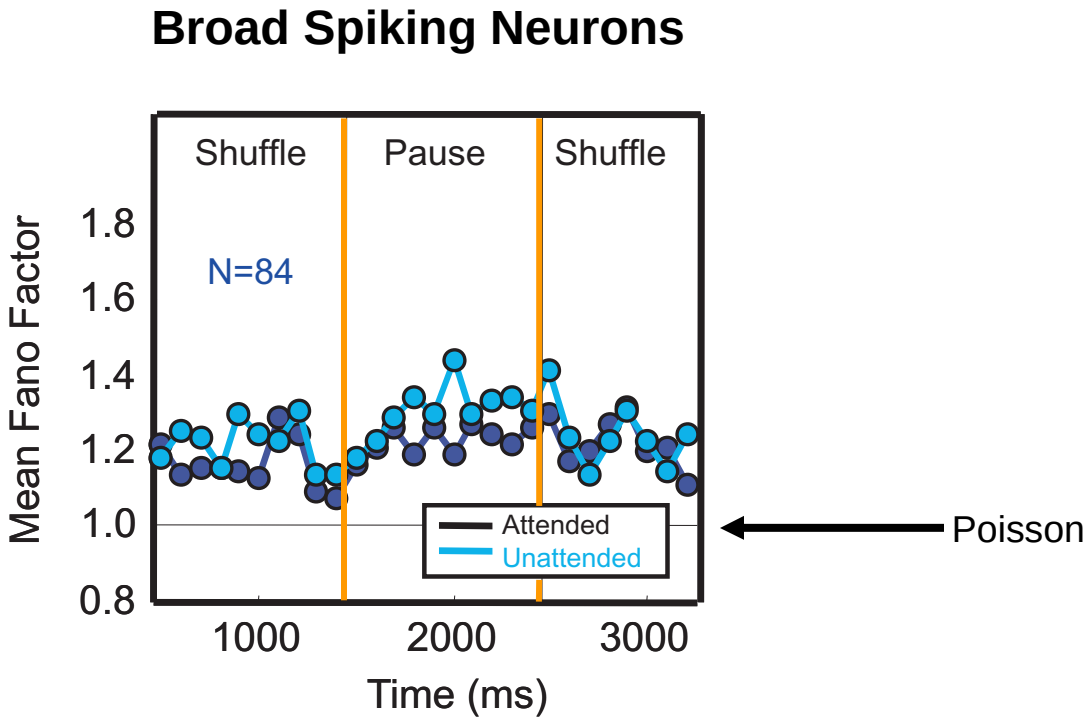
Poisson Approximation has been found to be a relatively good description of neuronal responses:

(Softky & Koch, 1993)
(Shadlen & Newsome, 1998)
(McAdams & Maunsell, 1999)

Question 1: Do narrow and broad spiking neurons behave like Poisson processes?

Question 2: Can attention be described as scaling the rate of a Poisson process?

Attention-dependent modulation of response variability



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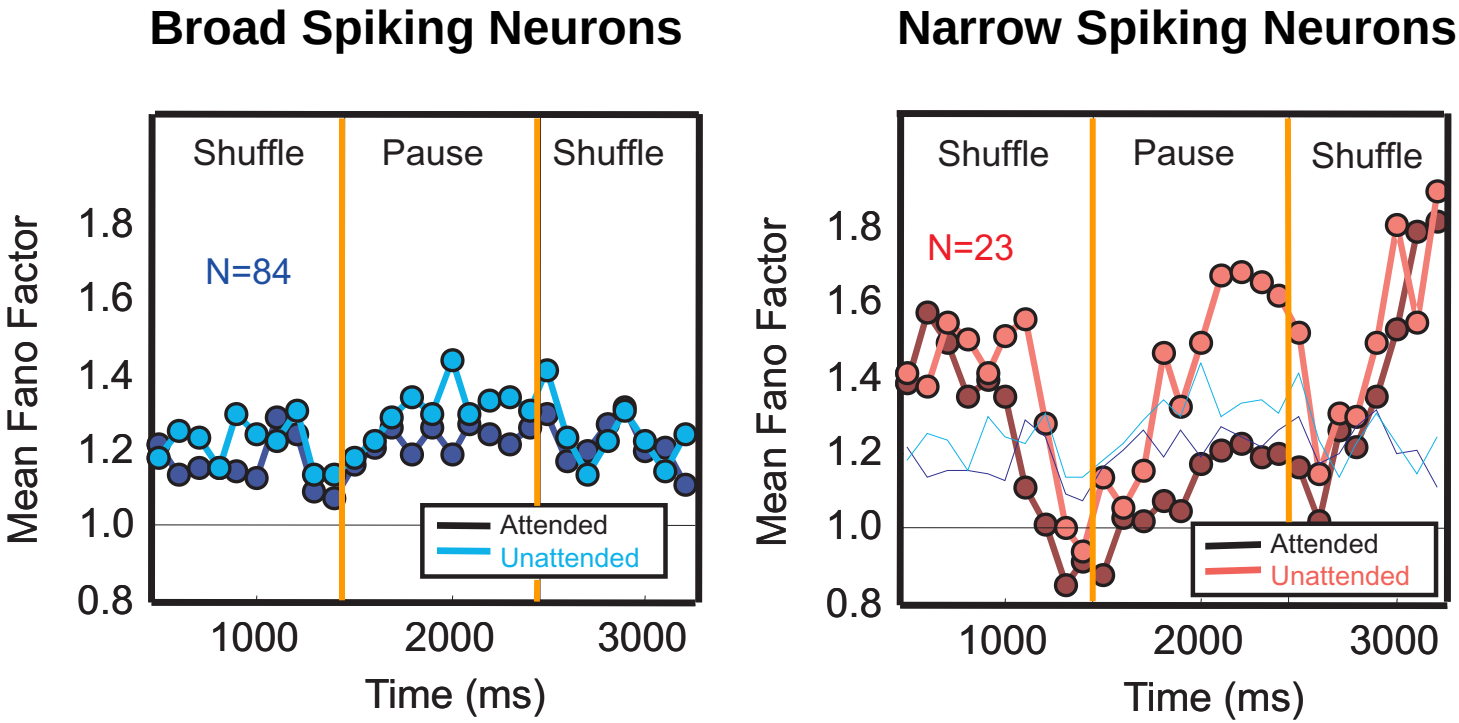
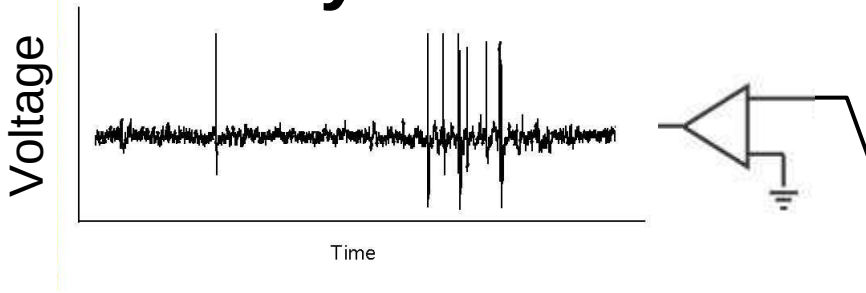
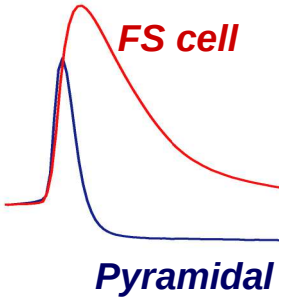
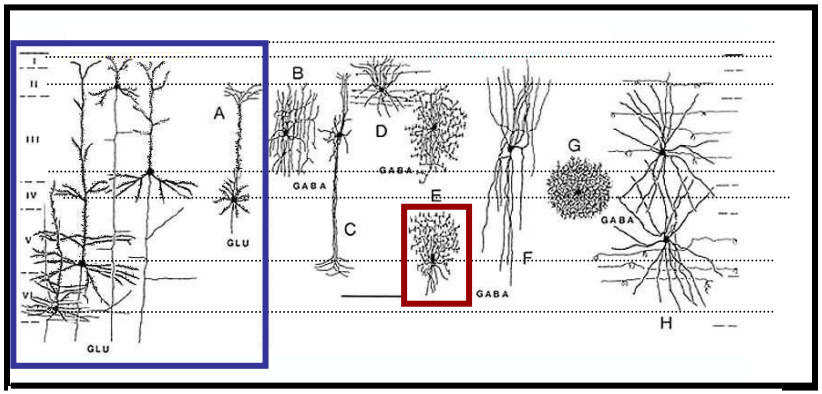
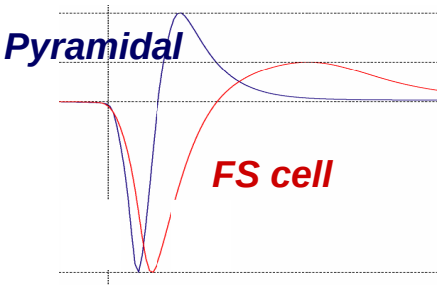


Summary/Conclusions









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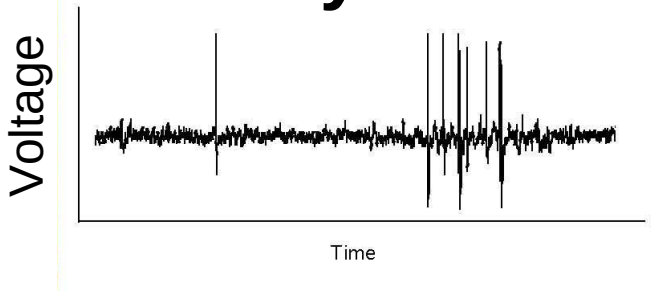

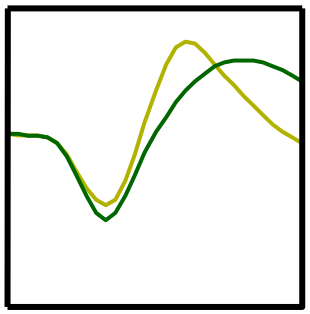

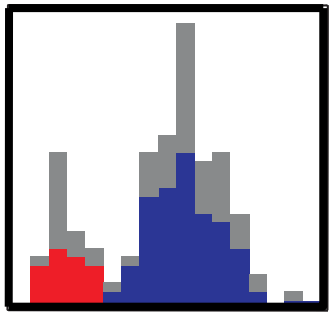

Broad Spiking Neurons
Largely Pyramidal
Attention causes increases and decreases in response
Attention reduces Fano Factor

Narrow Spiking Neurons
Largely Inhibitory Interneurons
Attention increases response
Attention strongly reduces Fano Factor