University at Buffalo The State University of New York

Department of Physics
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"*Deriving a unified view of Visual Attention in Area V4*"

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Complacency Can Be Fatal

In Africa, every morning a gazelle wakes up it knows it must run *faster* than the *fastest* lion or it will be *killed.*

Every morning the lion wakes up and it knows that he must outrun the *slowest* gazelle or it will *starve* to death.

It doesn't matter whether you are a lion or a gazelle, when the sun comes up, you'd better start *running.*

--African proverb

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The question

How is visual information represented, transmitted, processed and turned into actions?

Spatial attention

Searching for a localized change

O'Regan et al., Nature, 1999

Spatial attention

Searching for a **localized** change

Spatial attention

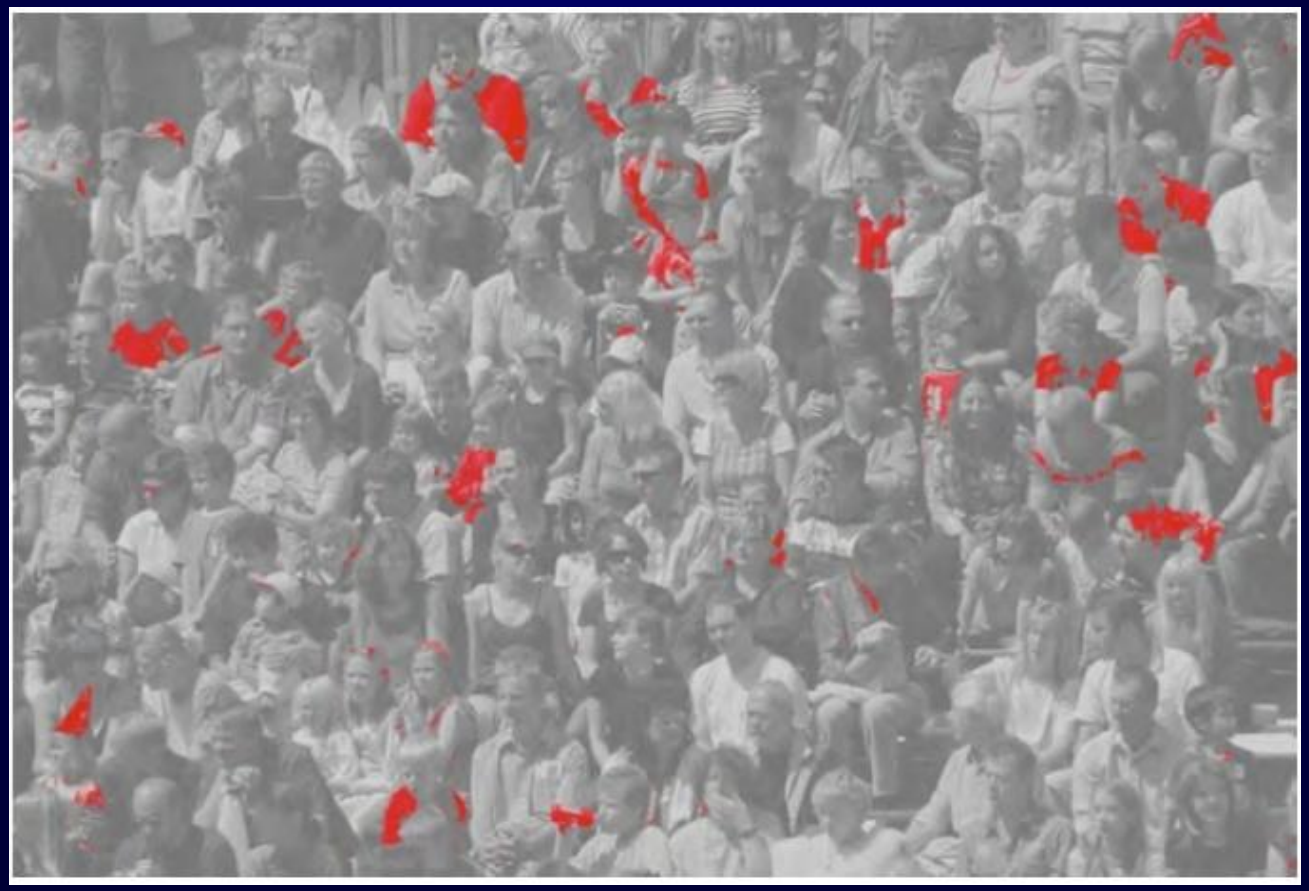
Searching for **localized** change

O'Regan et al., Nature, 1999

Feature attention

Searching for a person with a red shirt

Feature attention



Searching for a person with a red shirt

The problem

Visual scenes have enormous spatial and temporal information that are transduced into spike trains. Psychophysics indicates that only a small portion is consciously **accessible**.

You can not ‘see’ everything at the same time – one has to focus **attention** on particular aspects.

How does the brain do it?

How is information encoded, processed, and decoded in the brain?

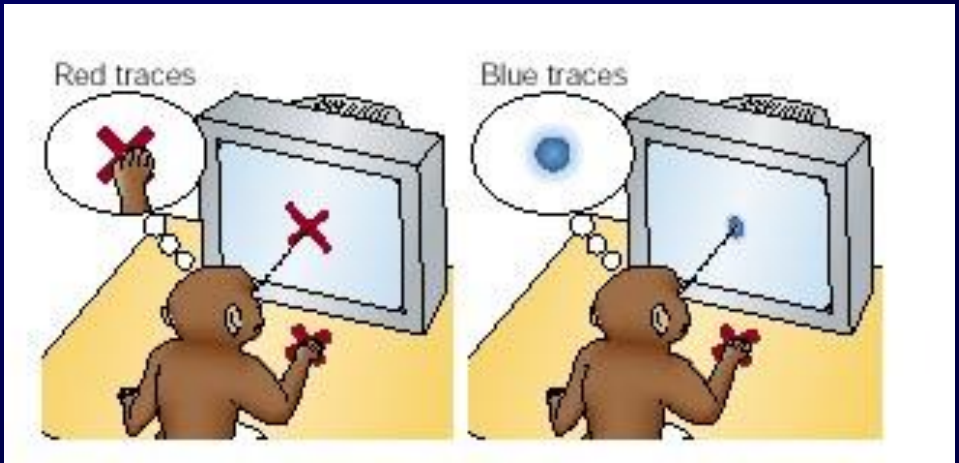
Selective Attention

- Perception and awareness are necessarily selective (cell phone while driving)

- Behavioral goals determine states of perceptual selectivity, which in turn can modulate sensory input via cortical feedback

- Attention is the set of cognitive and neuro-physiological mechanisms that implement the selection of relevant perceptual input and the rejection of what's irrelevant

Example of a task

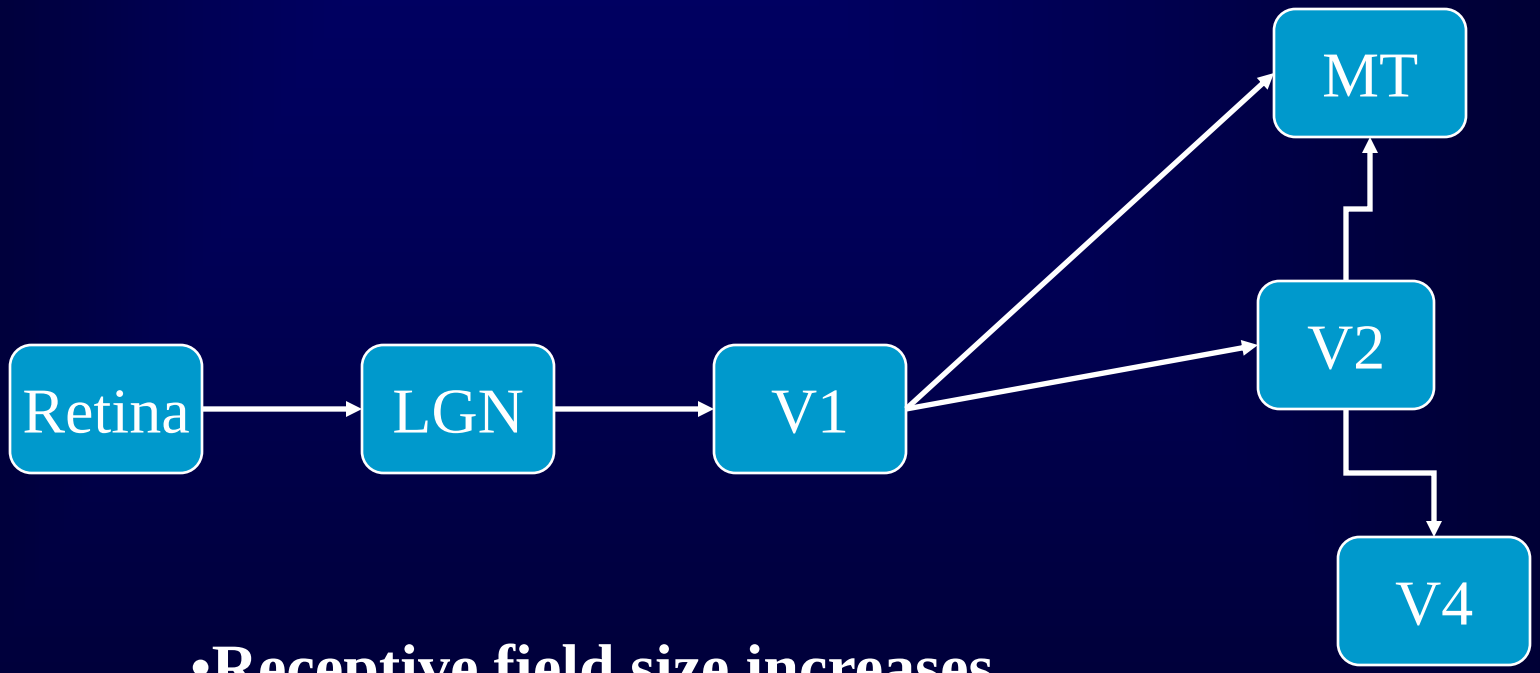


Same tactile and visual stimuli on each trial

- **focus on tactile stimulus for reward on some trials**
- **focus on visual stimulus for reward on other trials**

Record from several neurons in a brain area sensitive to visual stimuli

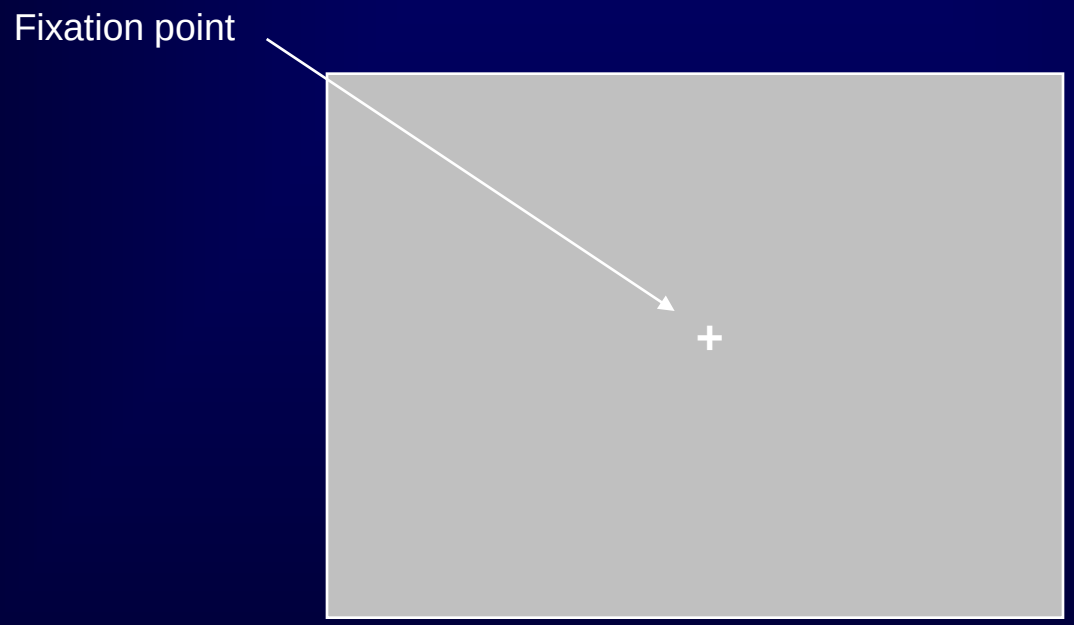
Macaque visual pathway



- **Receptive field size increases**
- **Coherence increases**
- **Signals get segregated (motion, color,…)**
- **Signals have to be combined into percepts**

Attentional task in behaving monkeys

- Typical task (fixed stimuli)



- Extracellular recordings: spikes and LFP

Attentional task in behaving monkeys

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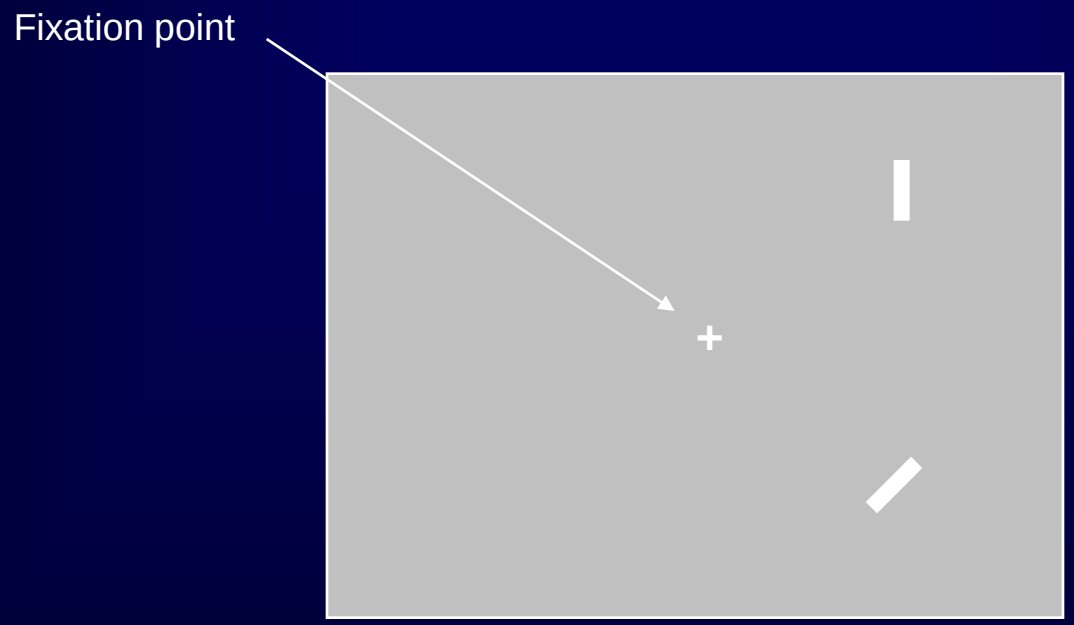

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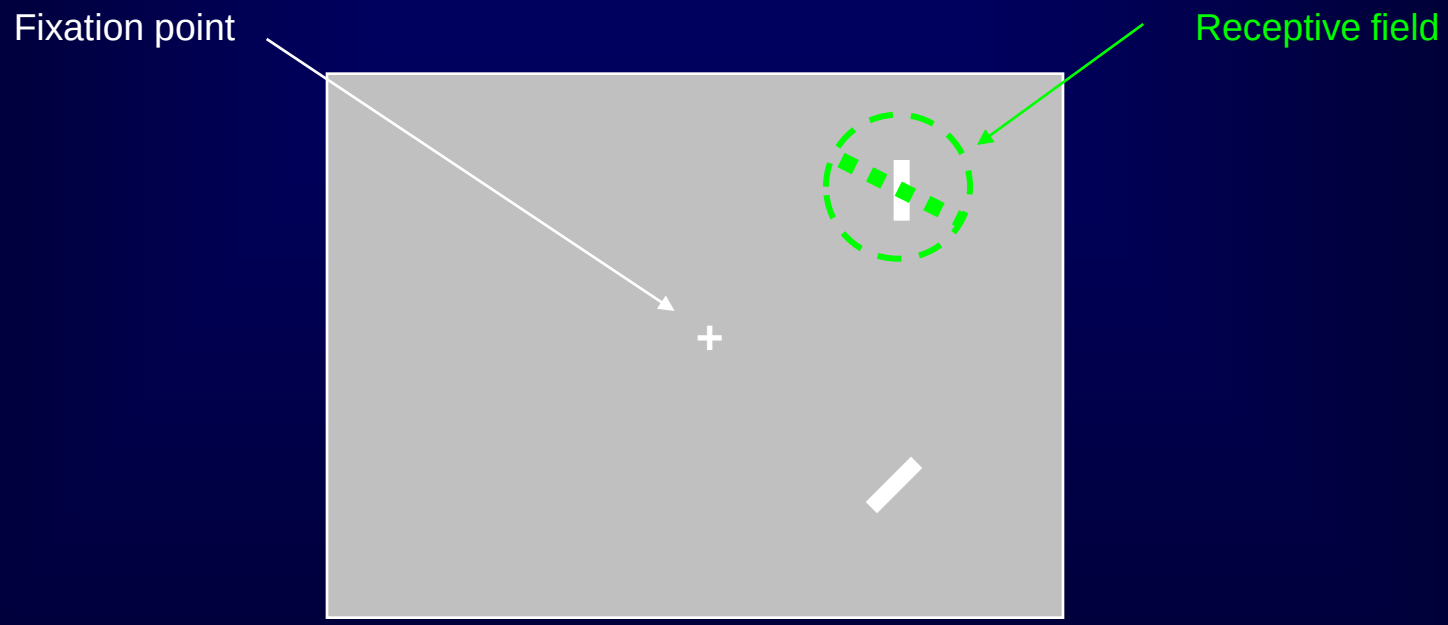

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Attentional task in behaving monkeys

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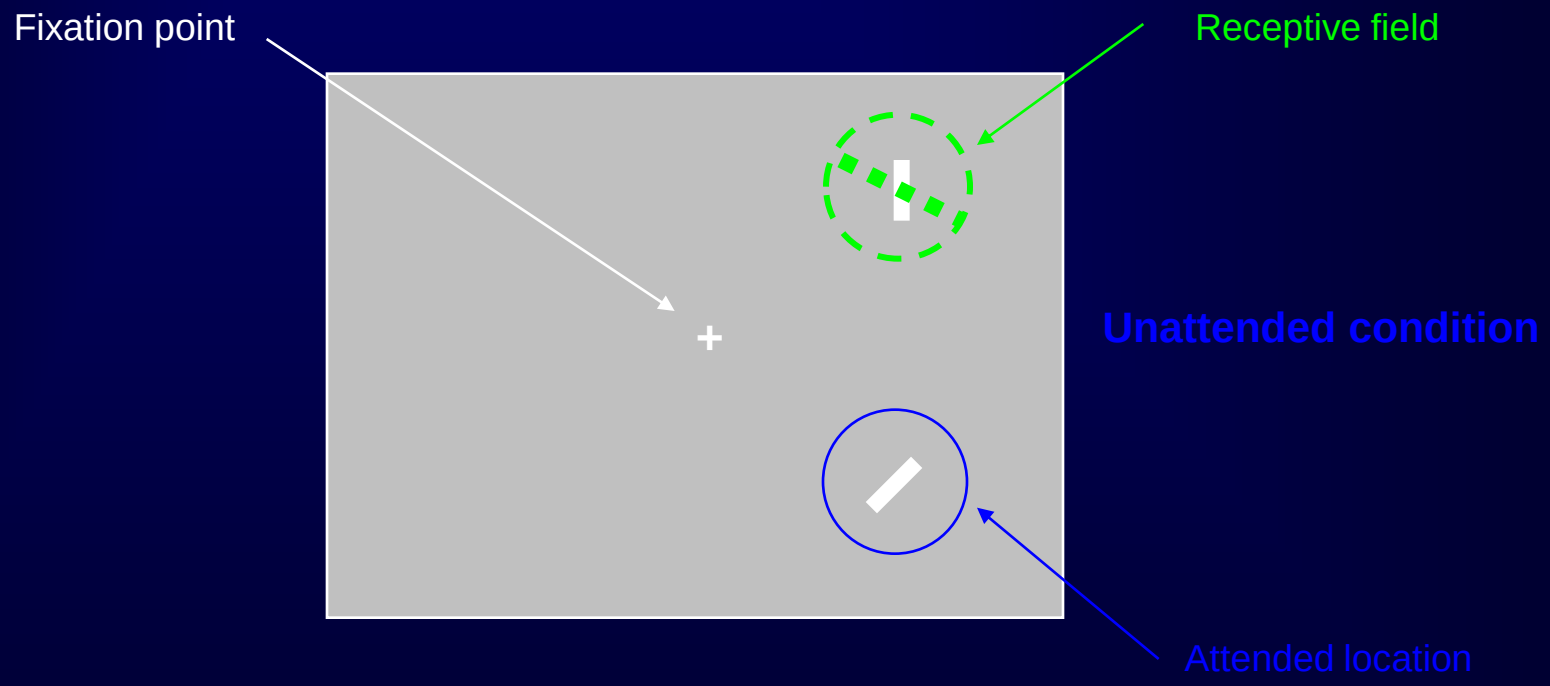
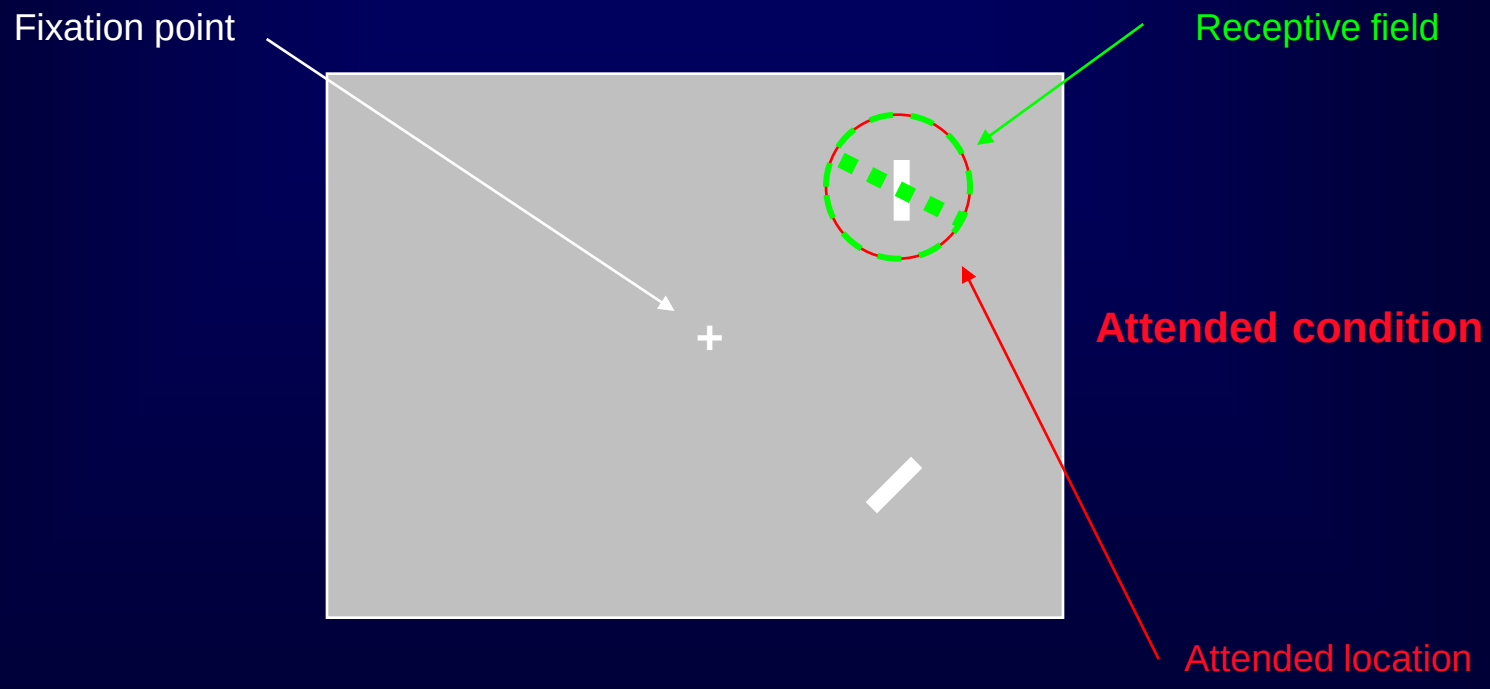


• Extracellular recordings: spikes and LFP

Attentional task in behaving monkeys

• Typical task (fixed stimuli)

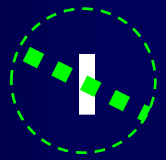


• Extracellular recordings: spikes and LFP

Attention and orientation selectivity

- Attention increases the neuron's firing rate

Receptive field

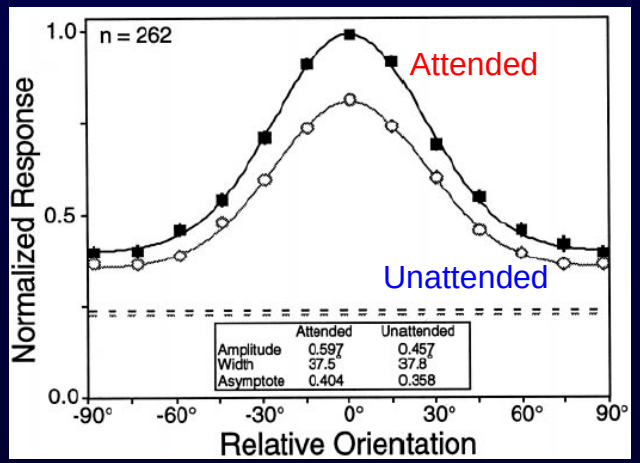


r

r

- Multiplicative gain modulation of tuning curves

r_{Att}/r_{Unatt}



McAdams and Maunsell, J Neurosci, 1999

Attention and orientation selectivity

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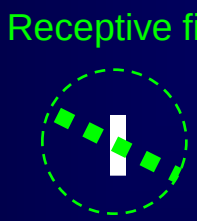
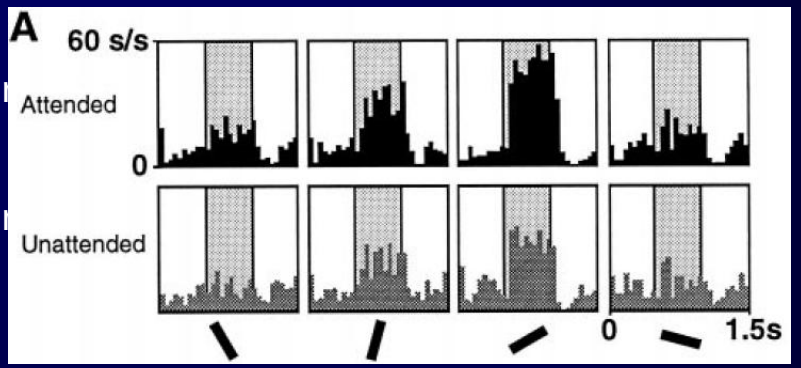
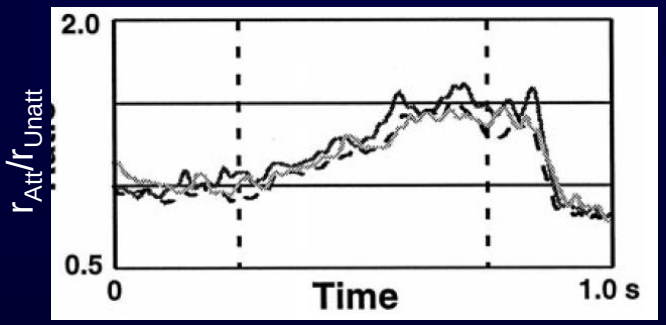
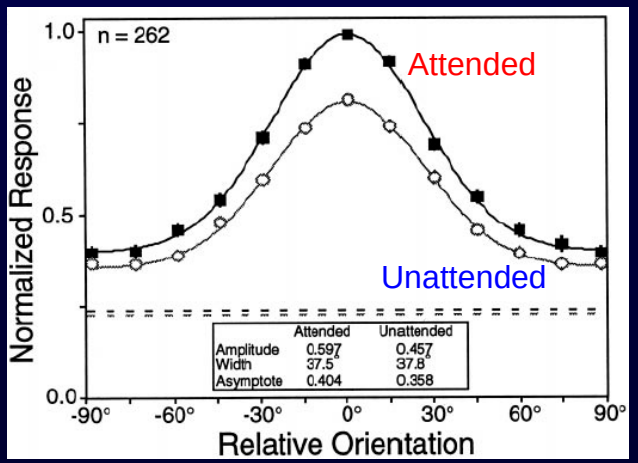




- Multiplicative gain modulation of tuning curves

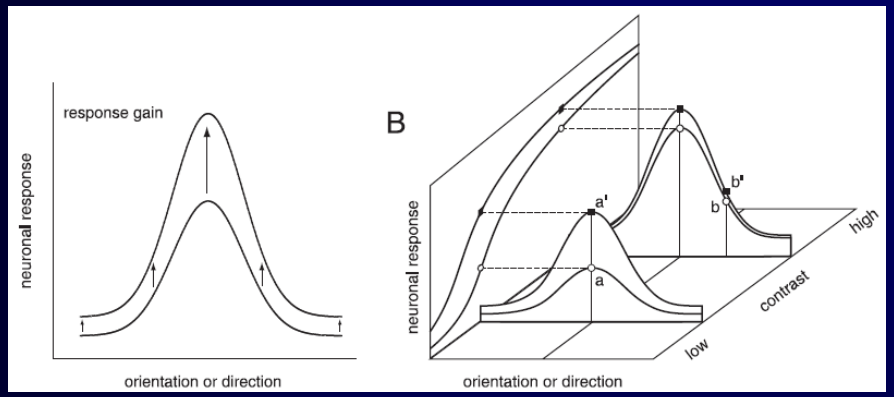


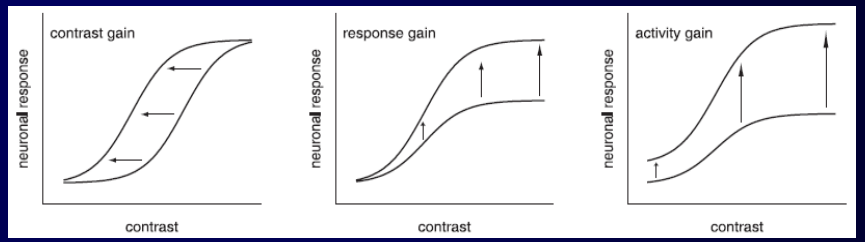


McAdams and Maunsell, J Neurosci, 1999

Attention and stimulus contrast

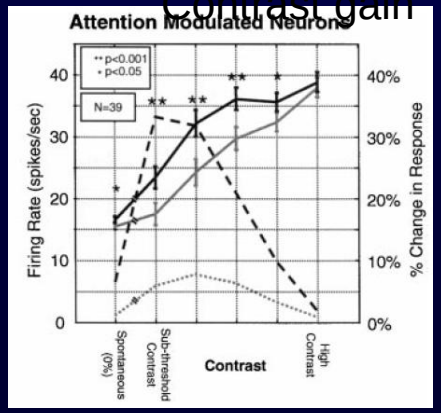
- **Contrast response function (CRF) modulation**



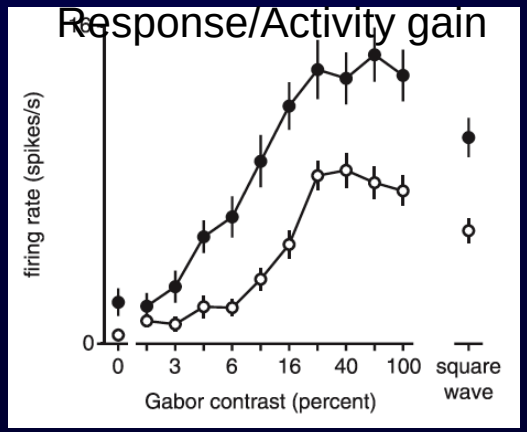


- **Observation of different CRF modulation types**

Contrast gain



Response/Activity gain

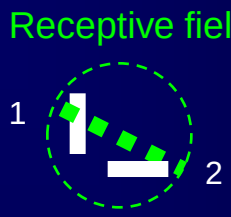


Reynolds et al, Neuron, 2000

Williford and Maunsell , J Neurophysiol, 2006

Attention for 2 stimuli

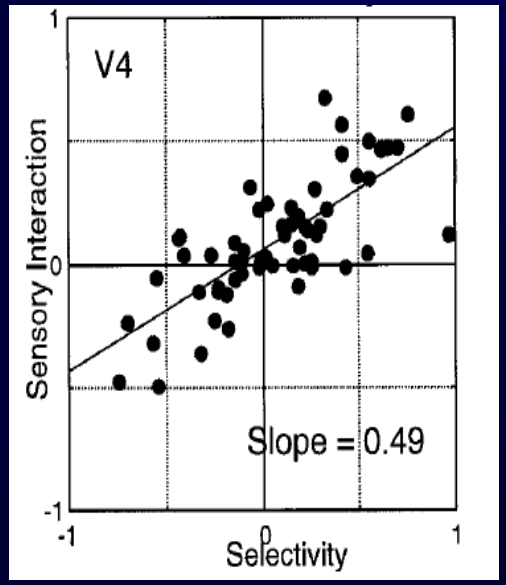
2 stimuli in the same receptive field



$$\text{Slope} = \frac{f_{12} - f_1}{f_2 - f_1}$$

No attention

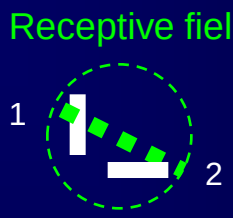
Competition



Reynolds et al, J Neurosci, 1999

Attention for 2 stimuli

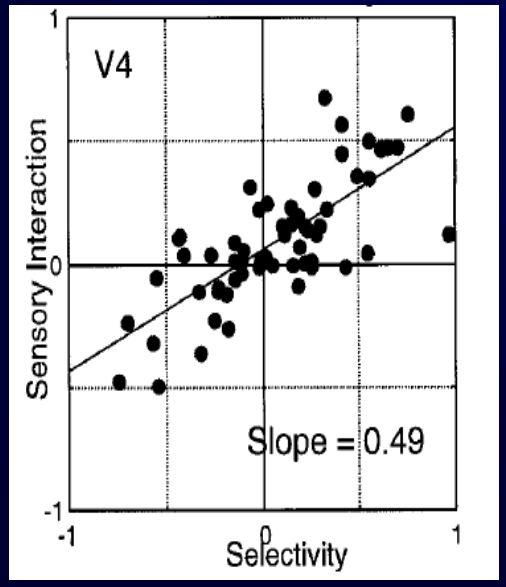
2 stimuli in the same receptive field



$$\text{Slope} = \frac{f_{1+2} - f_1}{f_2 - f_1}$$

No attention

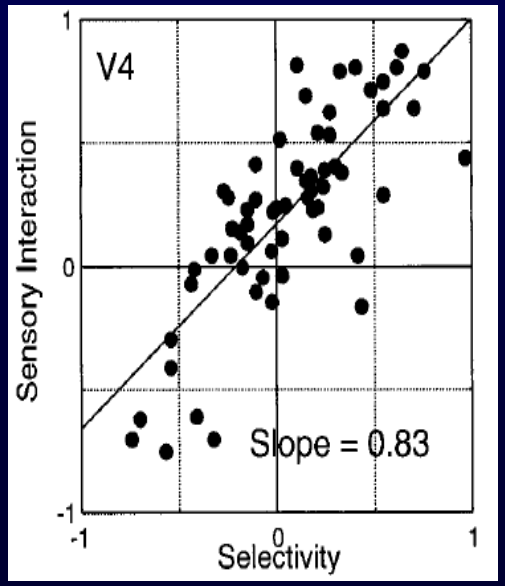
Competition



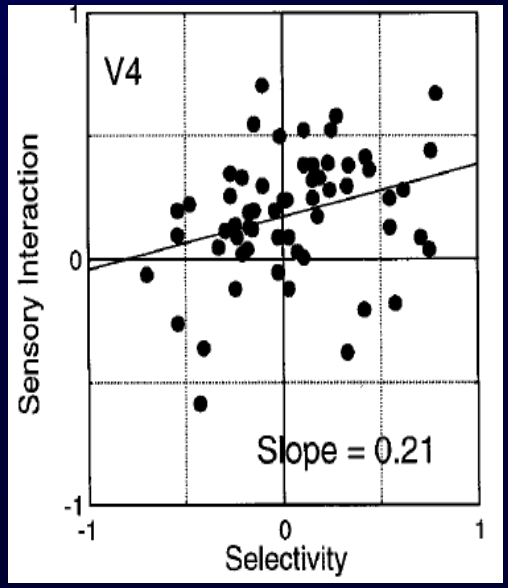
Attention

Biased competition

Stronger stimulus attended



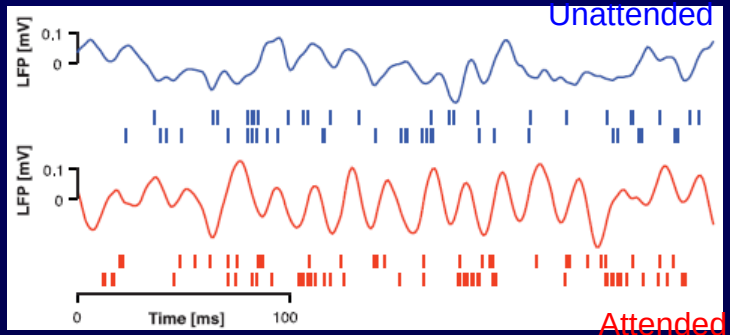
Weaker stimulus attended



Reynolds et al, J Neurosci, 1999

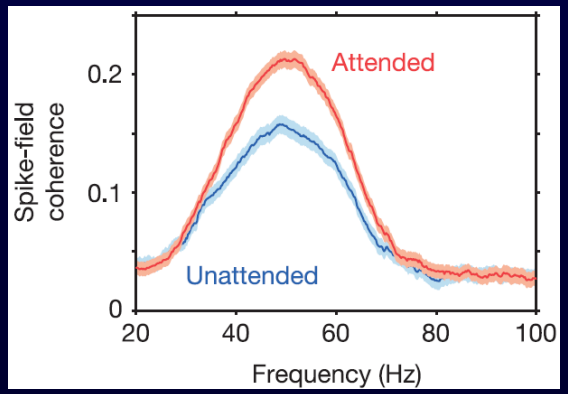
Attention and network oscillation

- LFP oscillation enhancement in the gamma frequency range



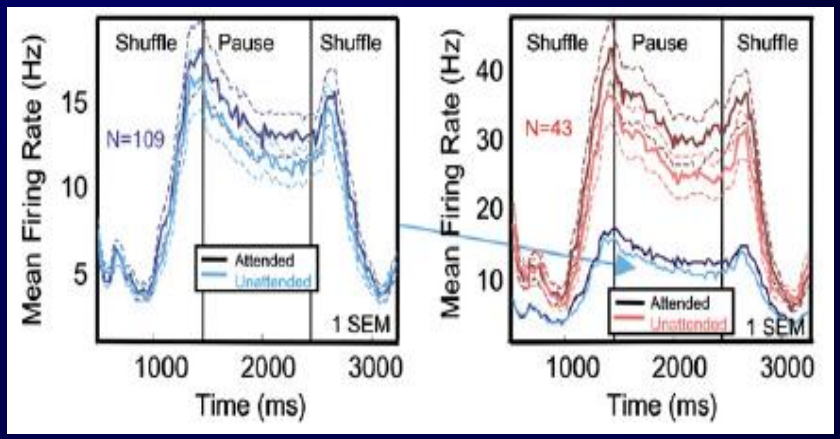
Fries et al, Science, 2001

- Firing phase-locking enhancement in the gamma frequency range



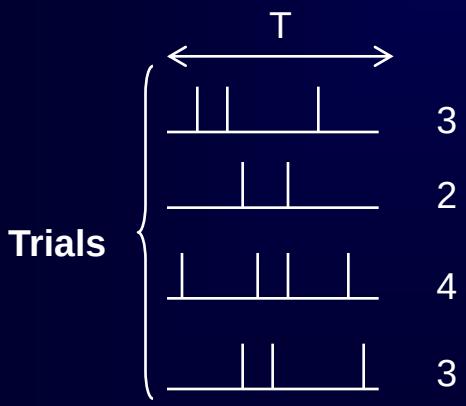
Womelsdorf et al, Nature, 2006

More details on neural activity



Mitchell et al., Neuron, 2007

More details on neural activity



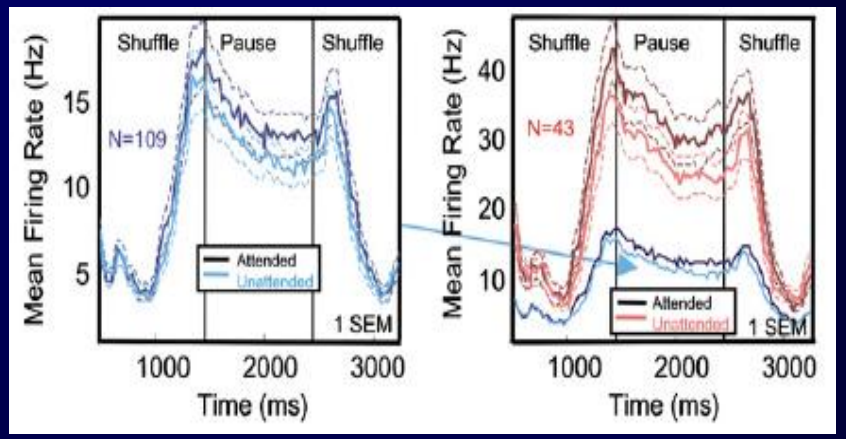
Mean count: m

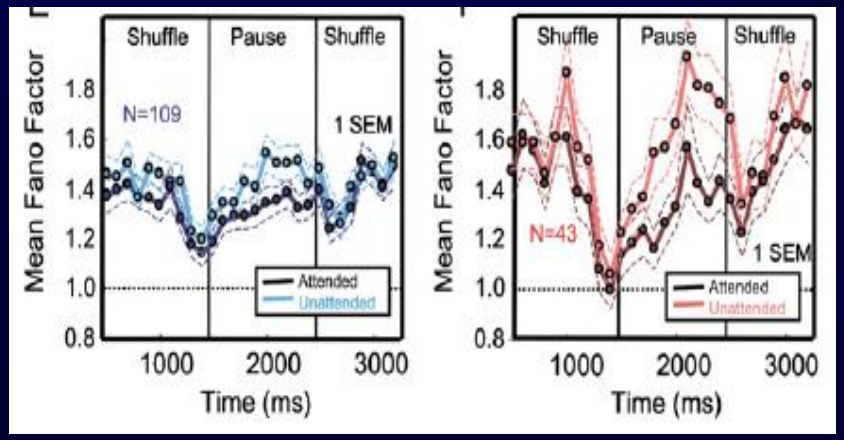
Count variance: v

Fano factor:

FF = v/m

Pyramidal neuron **Interneuron**





Mitchell et al., Neuron, 2007

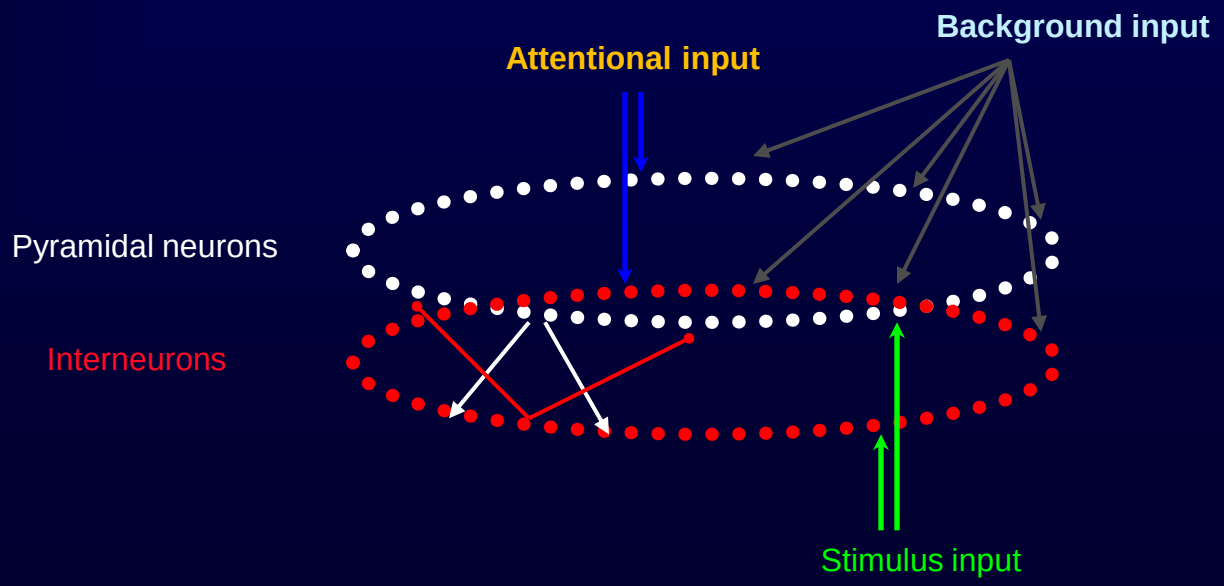
Questions

- Can the diversity of attentional modulations be explained in a unified way?
- What is the nature of the attentional input to V4?
- What mechanisms in the V4 network are responsible for the neural activity modulations?

Neural network model of V4

- Space and orientation dimensions: one dimensional approximation

- Local random connectivity
- Local stimulus input (from V2)
- Global background input (from other areas)
- Attentional input (feedback)



Neural network model of V4

- **Neurons: conductance-based models**
  - **Pyramidal neuron: from (*Traub and Miles, 1991*)**
  - **Interneuron (*Wang and Buzsaki, 1996*)**

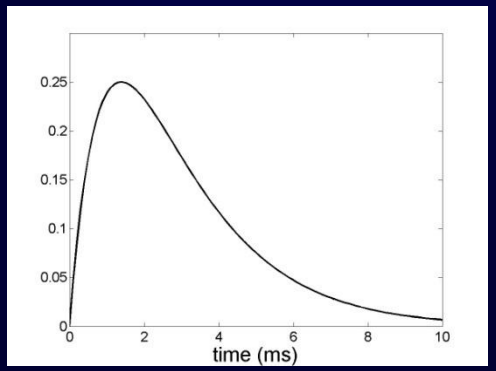
$$C dV/dt = -I_{Na} - I_K - I_L + I_{syn}$$

- Synapses:
  - Current

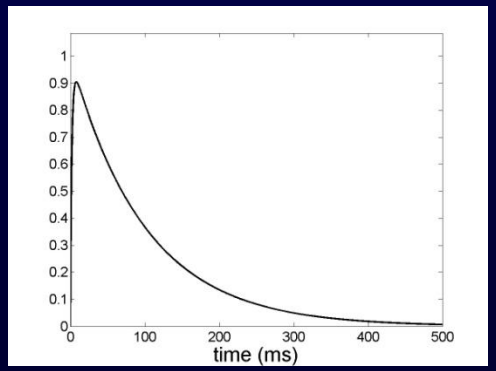
$$I_{syn} = -g_E(t)(V-V_E) - g_I(t)(V-V_I), \quad g_X(t) = \gamma_X \Sigma_{spikes}\, s(t-t_{spike})$$

  - Conductance input (for one spike)

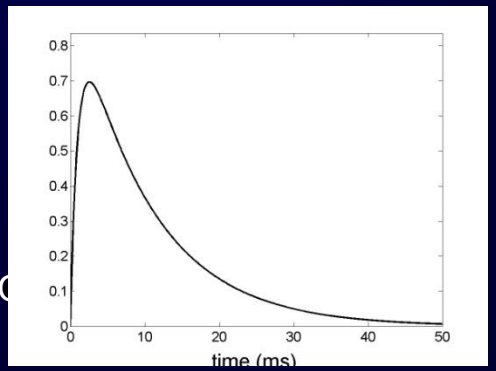
- AMPA



NMDA



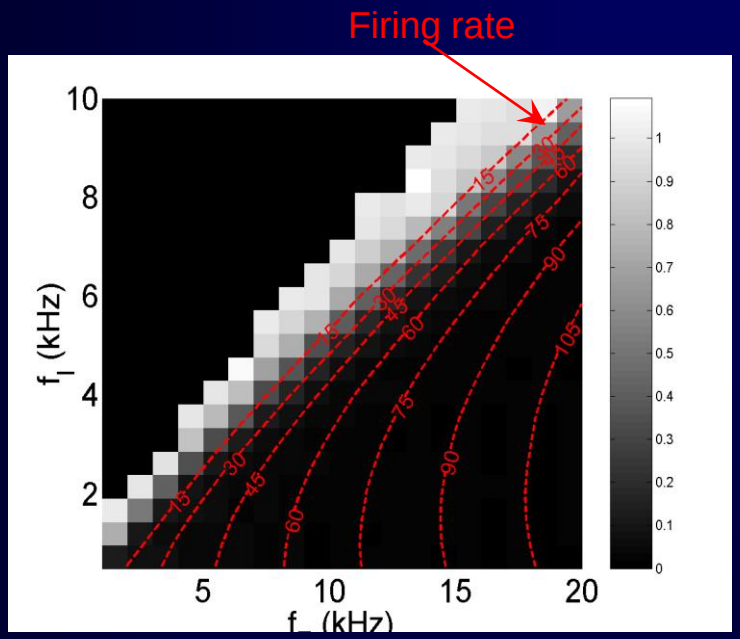
$GABA_A$



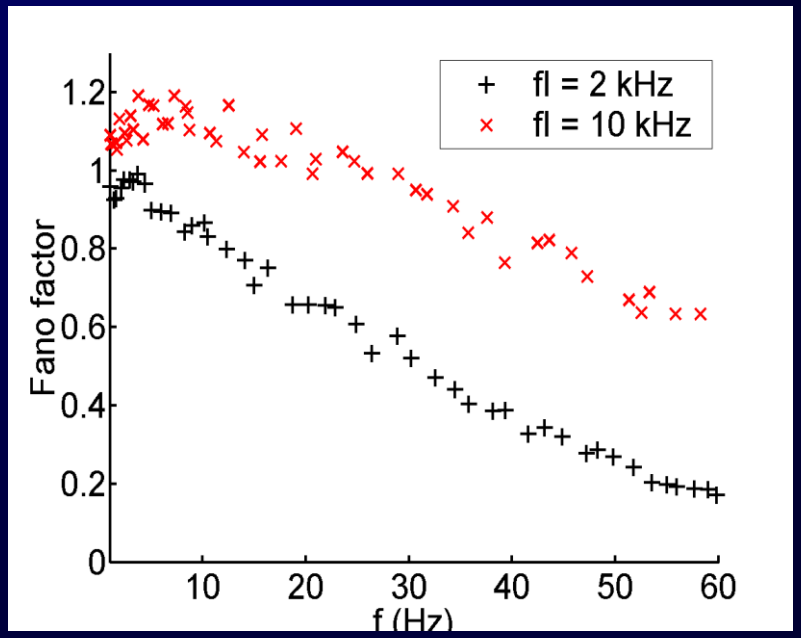
High variability at high firing rates?

Single neuron response to excitatory and inhibitory Poisson spike train inputs

Pyramidal neuron



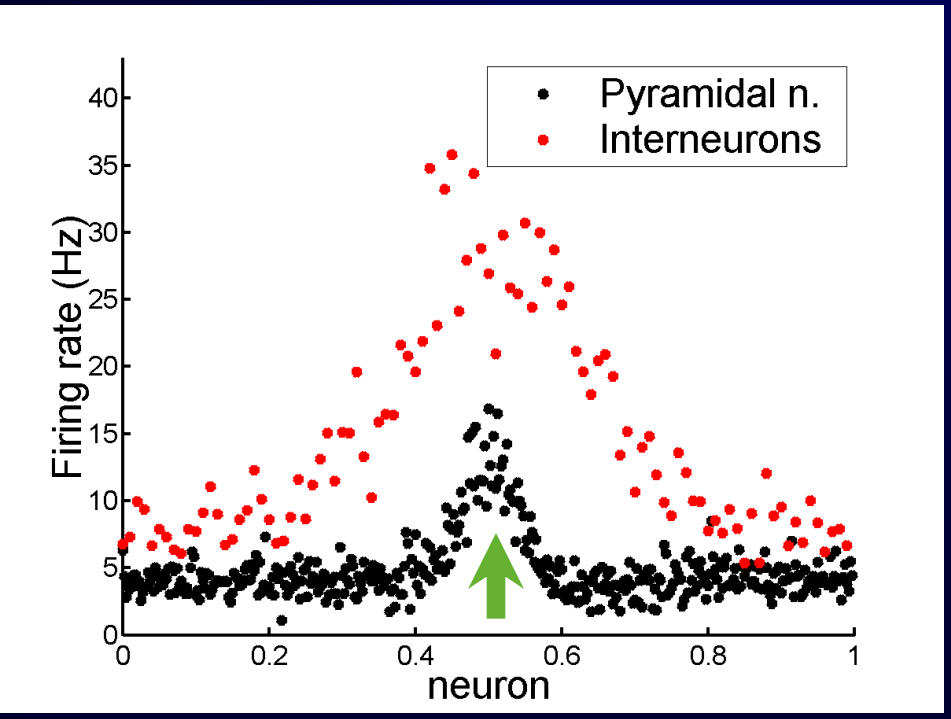
Fano factor

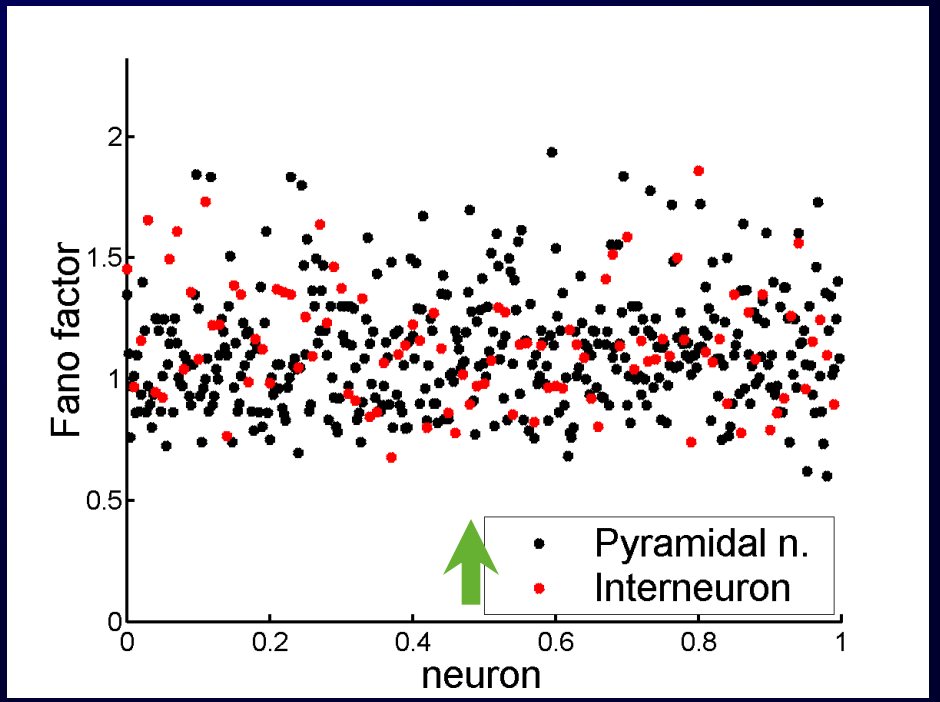


- **Need of high input rates and excitatory-inhibitory input balance (*Shu et al, Nature, 2003; Haider at al, J Neurophysiol, 2006*).**

Response to 1 stimulus

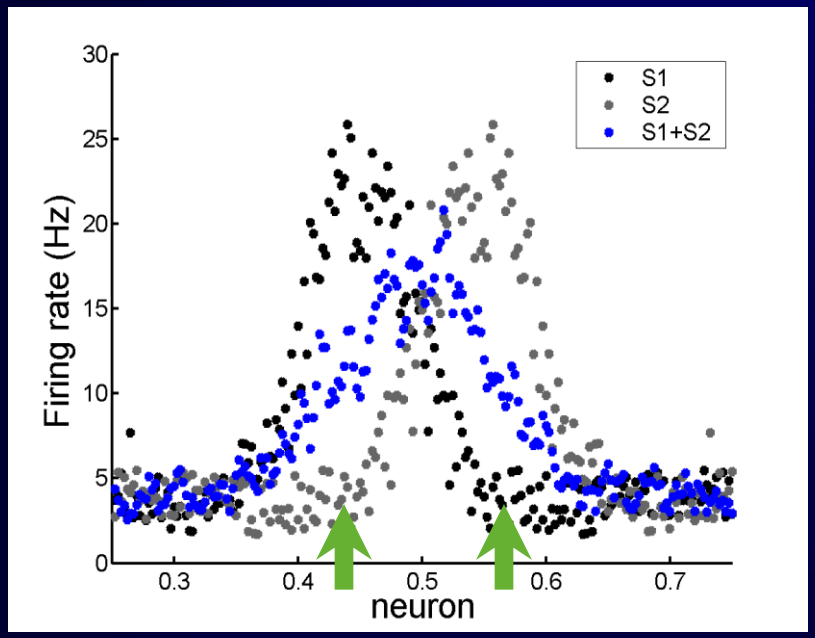
Network activity

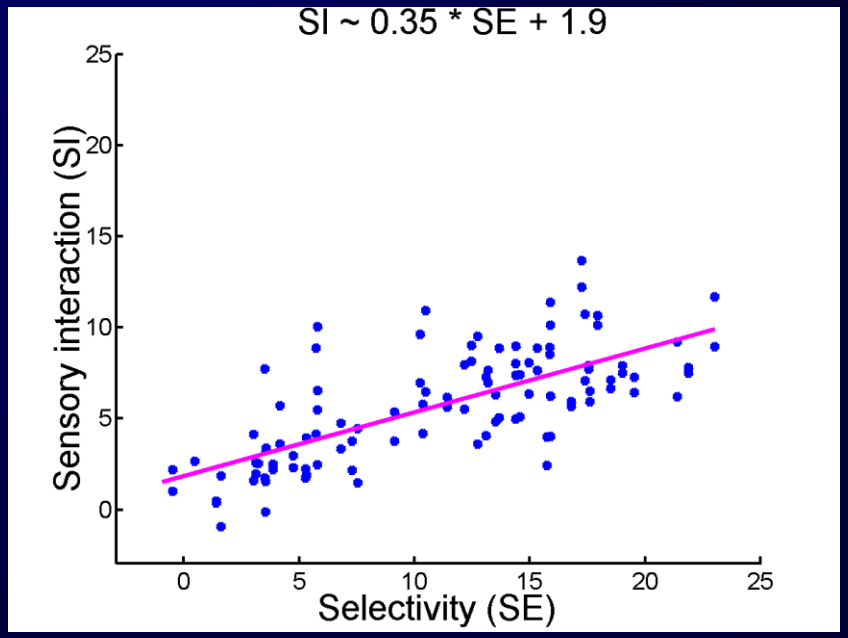




Response to 2 stimuli

Network activity





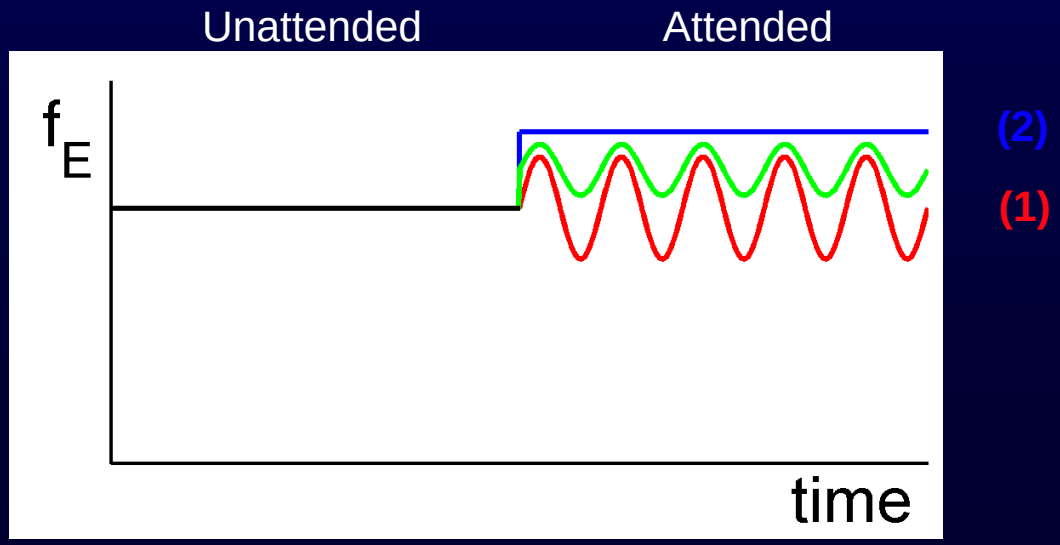
- Our network model implements stimulus competition.

V2 exhibits stimulus competition (*Reynolds et al, J Neurosci, 1999*)

Attentional input

Characteristics:

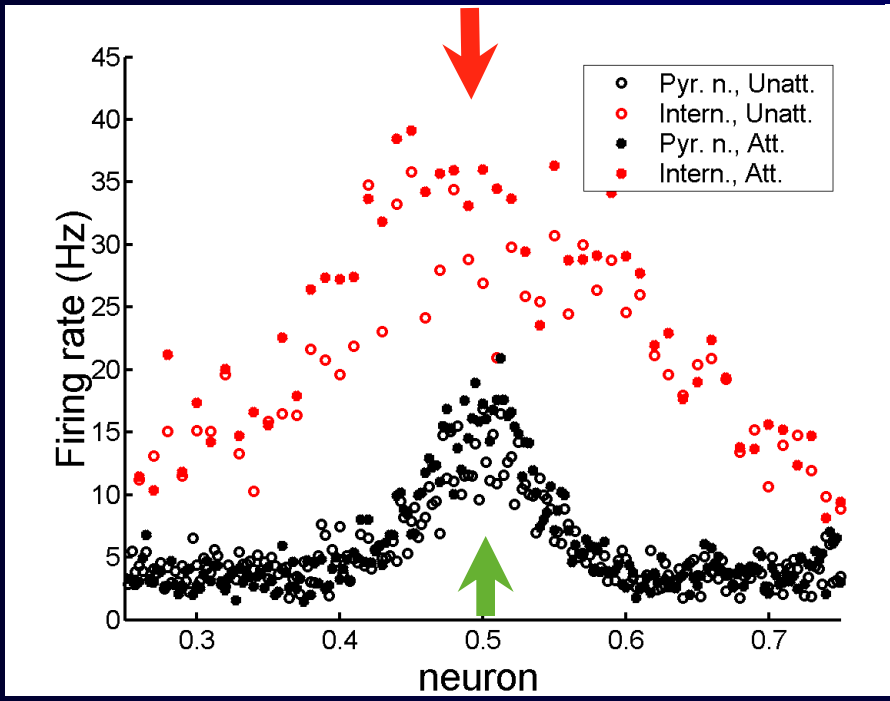
1. **Excitatory (feedbak connections)**
2. **Spatially: localized (*Moore and Armstrong, Nature, 2003*)**
3. **Temporally: (1) oscillating in the gamma frequency range (30-80 Hz) (*Gotts et al, SfN 2006*) and/or (2) increase of the mean input**

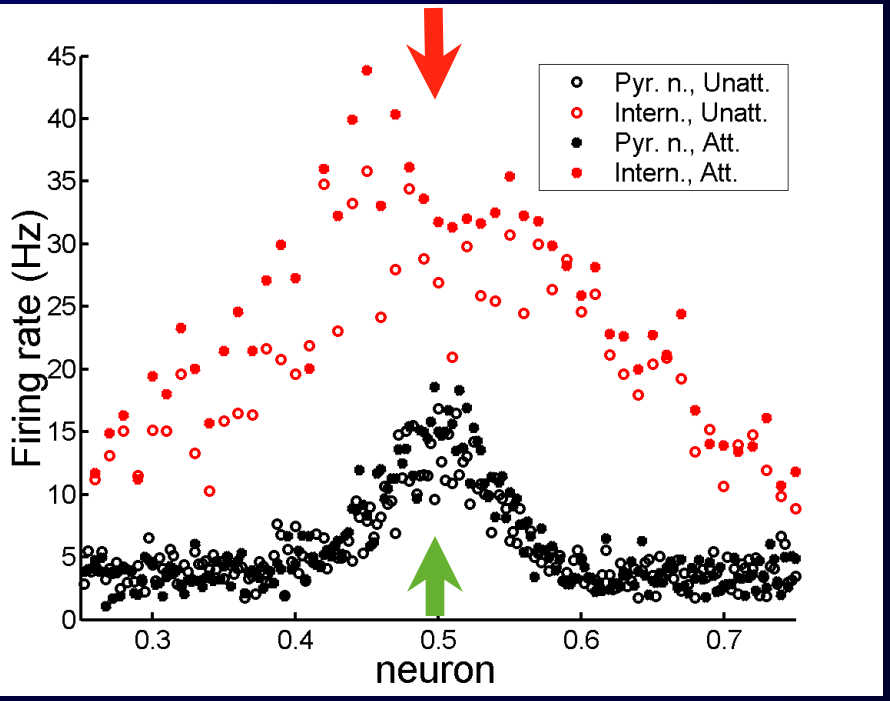


Attention with 1 stimulus

(1) Gamma oscillation

(2) Increase of the mean

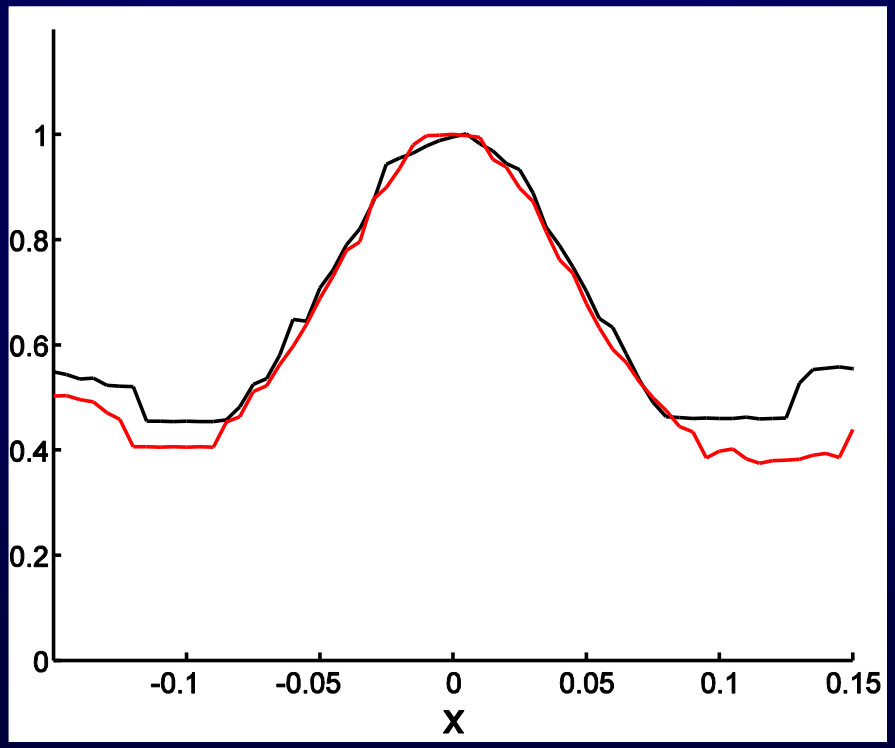




- Firing rate enhancement around the attended location.
- Non-unicity of the attentional input. Biologically plausible: origin-dependent, task-dependent.

Tuning curve modulation

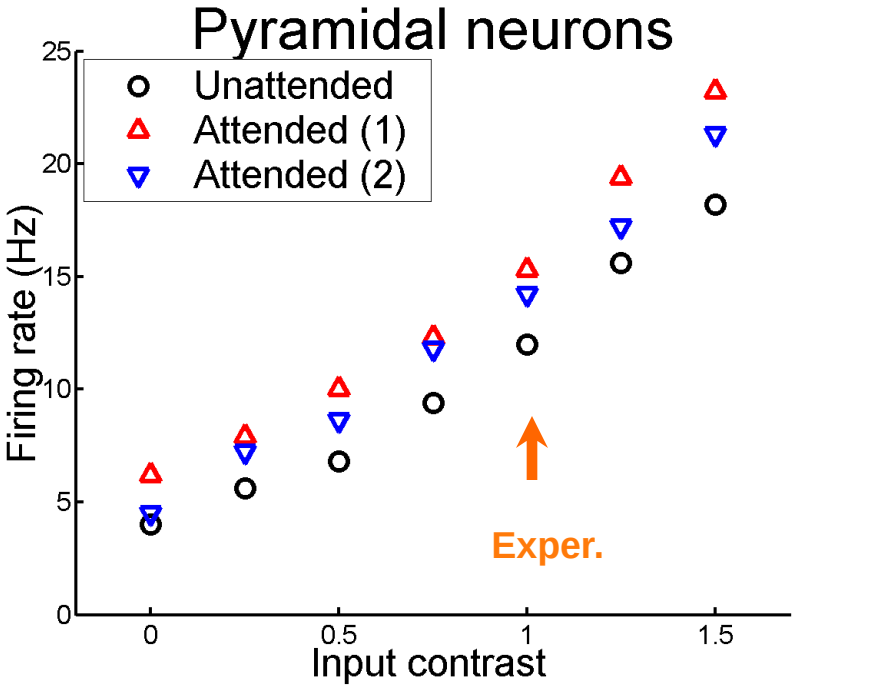
Normalized tuning curve

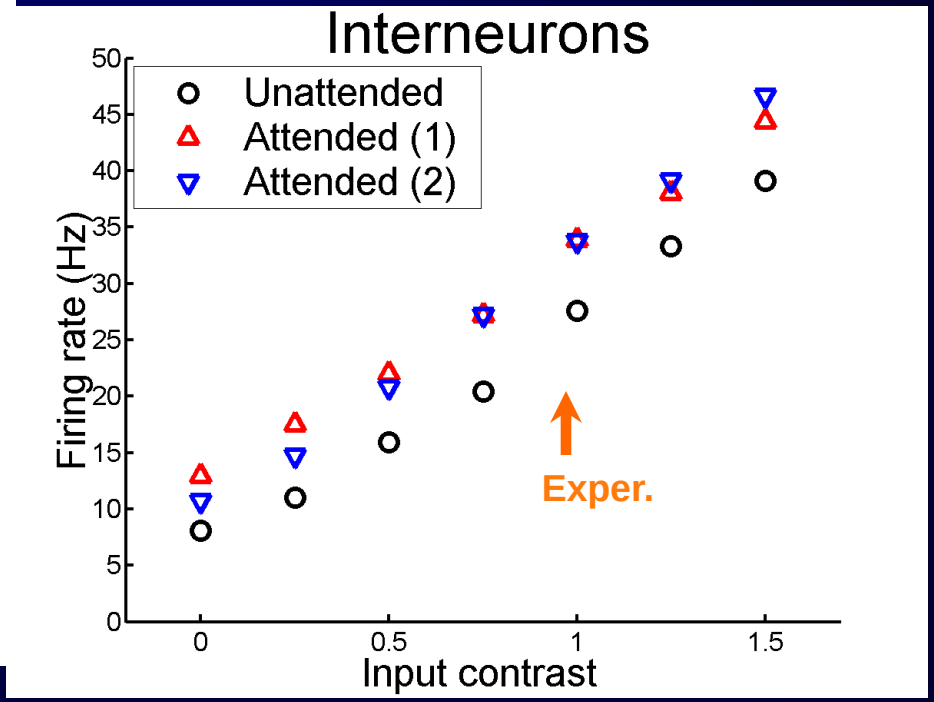


Stimulus location - preferred location

- Multiplicative gain modulation of tuning curves

Attention and the CRF

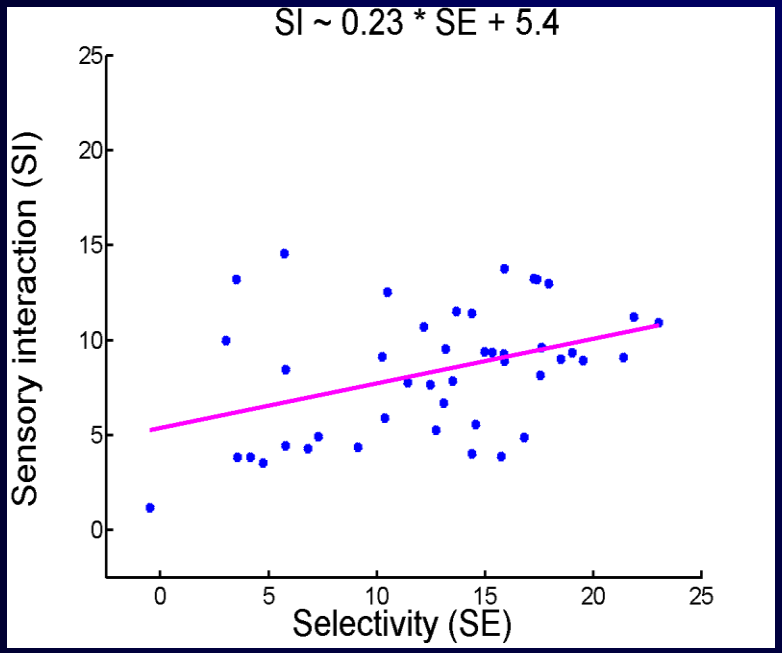




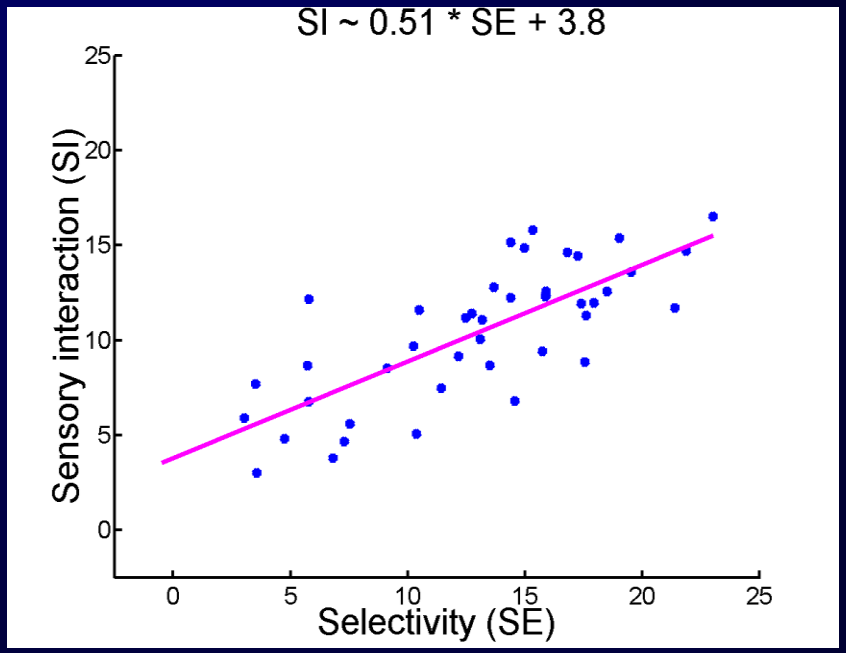
- the purely oscillatory input induces generally a stronger modulation, this is not the case when the firing rate approaches the frequency of the gamma range oscillation (50 Hz here. The CRF modulation depends on the attentional input type and on the neuronal type.

Attention with 2 stimuli

Weaker stimulus attended

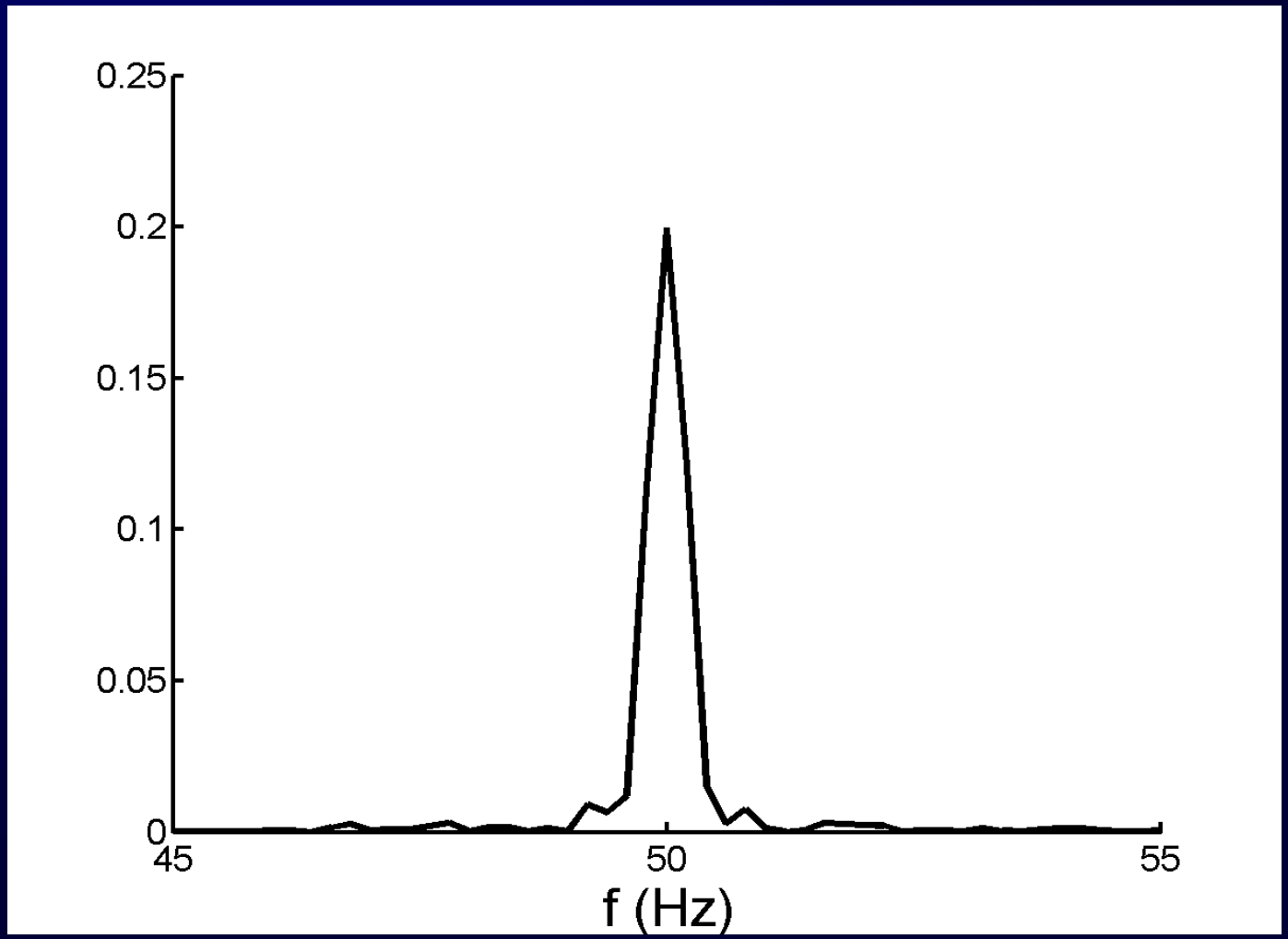


Stronger stimulus attended



- The attentional signal enhances activity around the attended location.
- Lateral inhibition decreases it in the surround.
- The network model implements biased competition.

Network oscillation



- Local network oscillation (around the attended location) in the gamma frequency range

Conclusions

- The V4 network model reproduces and explains, in a unified and quantitative way, the V4 neural activity in response to stimuli and when paying attention.
- High response variability for high input rates and balanced inputs.
- Non-unicity of the attentional input (prediction). This facilitates a unique type of attentional modulation when the attentional input may originate from different brain areas or vary with the behavioral task and its difficulty.
- The CRF modulation depends on the attentional input and on the neuronal type. Explains the modulation diversity found experimentally.

Remaining questions

- What are the roles of the V4 modulations on information processing?
- With the present unified model we can now ask quantitative questions at the cognitive level

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The end…..

- Thank you for your attention!!!!!
- any questions?