Unit 6

Rythms and Oscillations

Autocorrelation

Reminder:

- Is there anything in the stimulus that predicts the spike train (firing rate)?
- Can one reconstruct (predict) the stimulus from the spike train?
- Can one detect some aspects of a stimulus in a spike train?

$$\left\langle S(t)R(t+t')\right\rangle = C(t')$$

$$\left\langle S(t-t')R(t)\right\rangle = C(t')$$

⇨ Reverse correlation, spike triggered average, d' and ROC curves

New questions:

- Is there any 'regularity'/'information' in a spike train? If so, where?
- Is a spike correlated with another spike?

Autocorrelation

Autocorrelation: Theory

t_1 t_2 t_k t_N

0000000000000100000000001000000000…010000000000000…...1

Spike train x(t): $$x(t) = \sum_{k}^{N} \delta(t - t_k)$$ with μ=N/T = firing rate

Autocorrelation of x(t): $$\langle x(t)x(t+t') \rangle = Q_{xx}(t')$$ with t'→ ∞, Q_{xx} → μ^2

Autocovariance of x(t): $$\langle (x(t)-\mu)(x(t+t')-\mu) \rangle = A_{xx}(t')$$

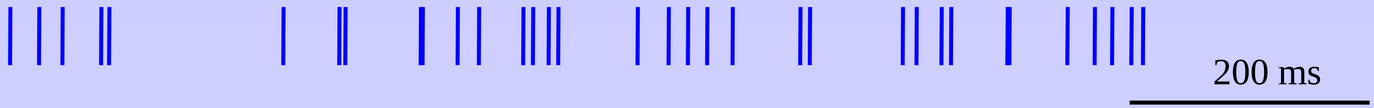
$$A_{xx}(t') = \frac{1}{T}\int_0^T (x(t)-\mu)(x(t+t')-\mu)dt$$

Time lag

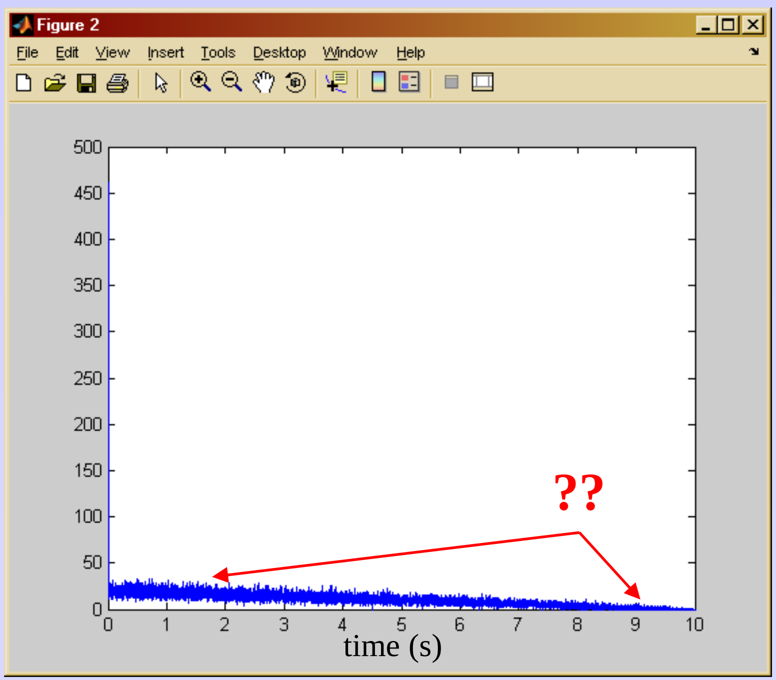
Warning: in a lot of papers, 'autocovariance' = 'autocorrelation'

Autocorrelation

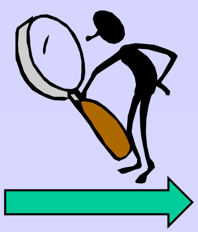
10 sec long Poisson train at 40 Hz

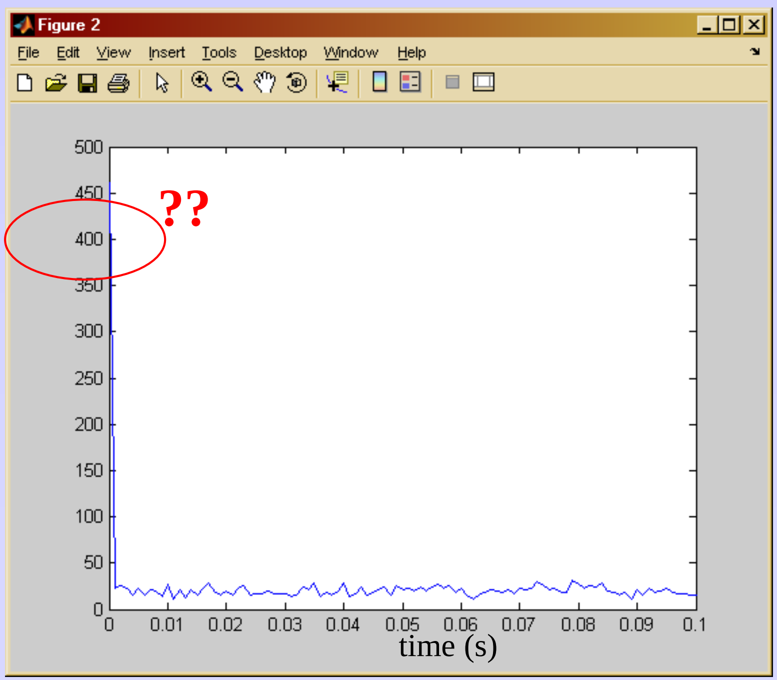


- Histogram of time differences between all spike pairs. Δt=1ms.



t_i - t_j





t_i - t_j

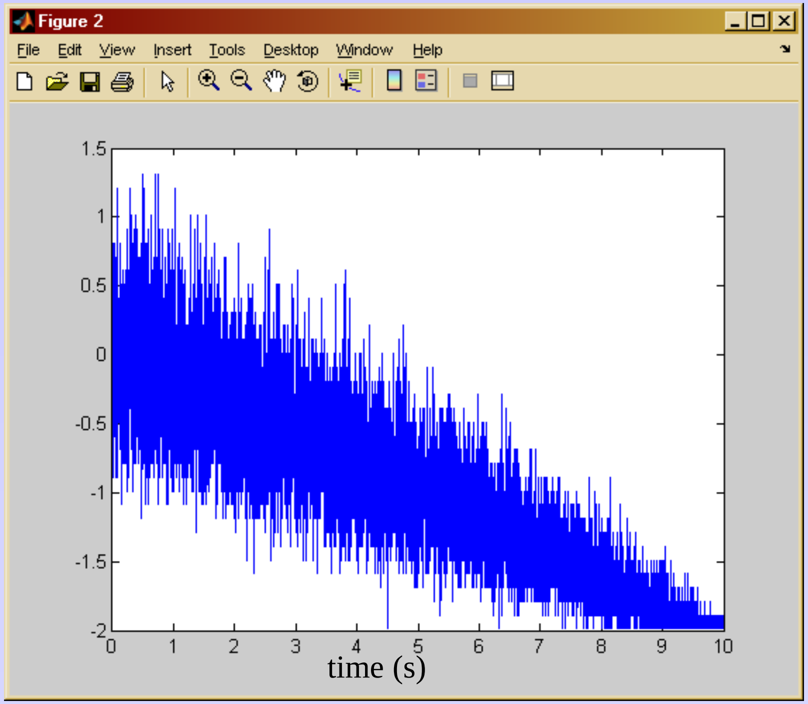
Autocorrelation

Autocorrelation: Practice

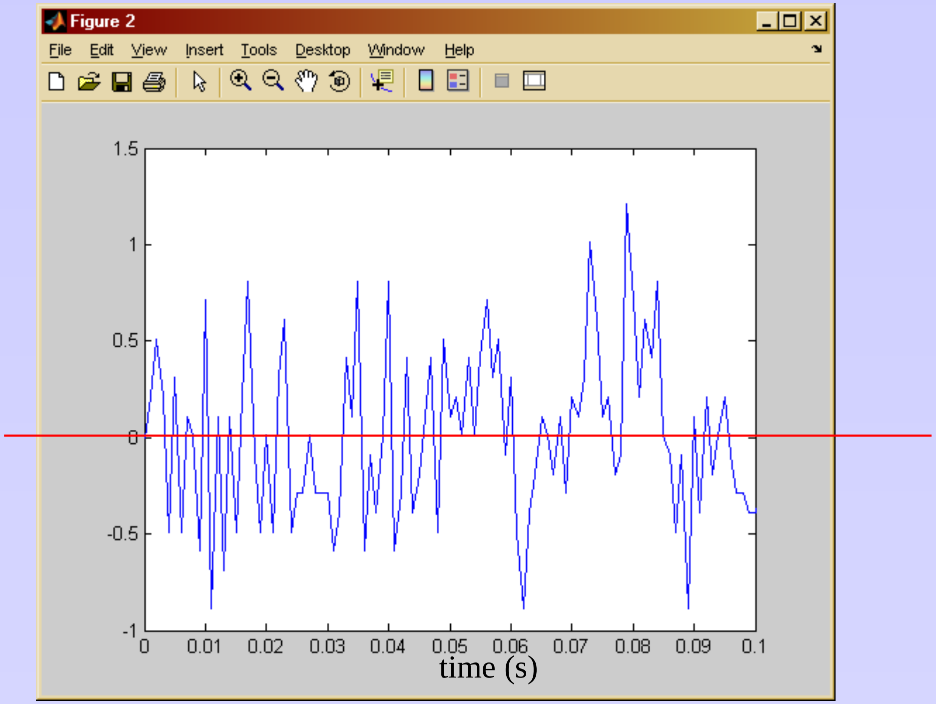
- Divide time [0 T] into bins of width Δt.
- Histogram. In bin m: number of times any 2 spikes are separated by a time interval between $(m-1/2)\Delta t$ and $(m+1/2)\Delta t$. This includes pairs of identical spikes.
- If the intervals between N^2 spikes pairs were uniformly distributed between 0 and T, we would have $N^2\Delta t/T$ pairs in each bins. Subtract this number from all bins.
- Divide all bins by T (i.e. make the histrogram count relative to spike train duration).
- For small Δt, the bin at 0 is the firing rate. This bin is typically much larger than the others, and is removed from the histogram.
- The resulting histogram H is the **autocorrelation histogram** of the spike train.
- The autocorrelation *function* is defined as $H/\Delta t$ when $\Delta t \rightarrow 0$.

Autocorrelation

- Autocorrelation



$t_i - t_j$



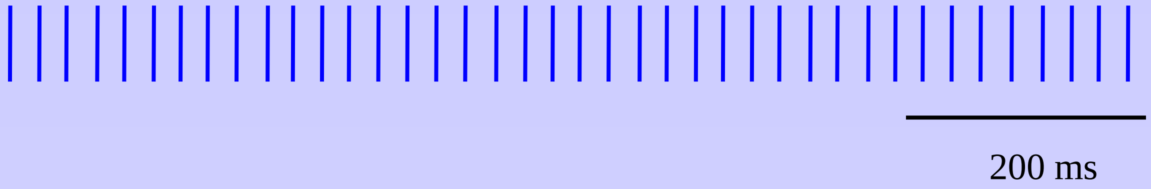
$t_i - t_j$

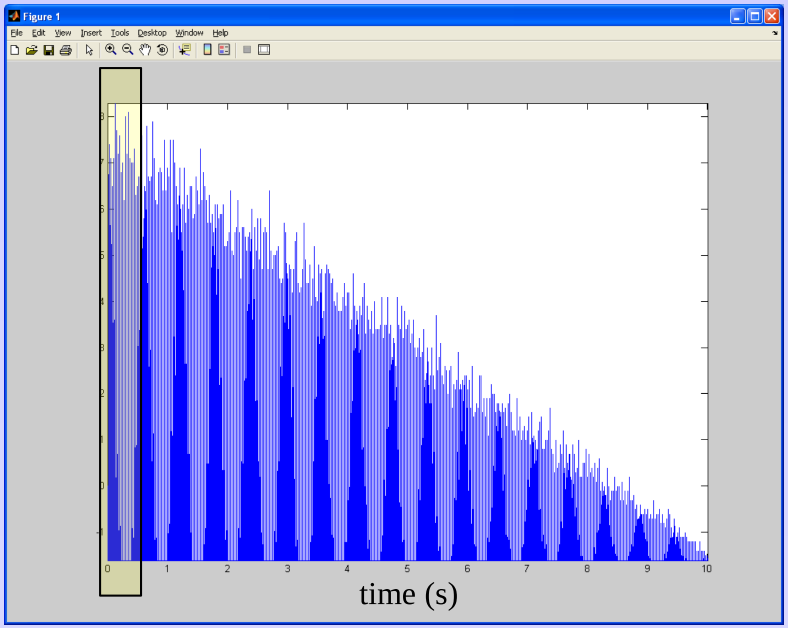
- The autocorrelation of a Poisson spike train is 0 (for all t’, except t’=0).

$$A_{pp}(t')=\mu\delta(t')$$

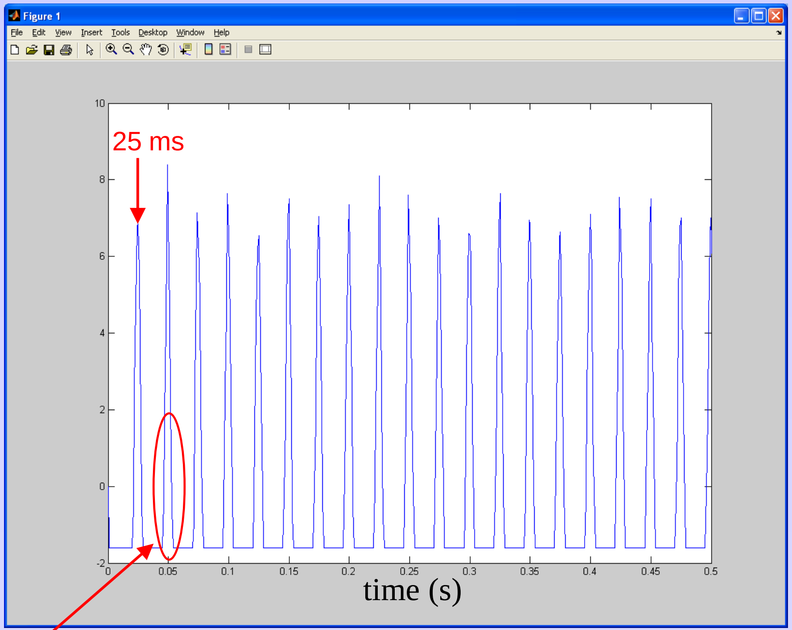
Autocorrelation

- 10 sec long 40 Hz oscillation with 2 ms jitter





$t_i - t_j$



$t_i - t_j$

??

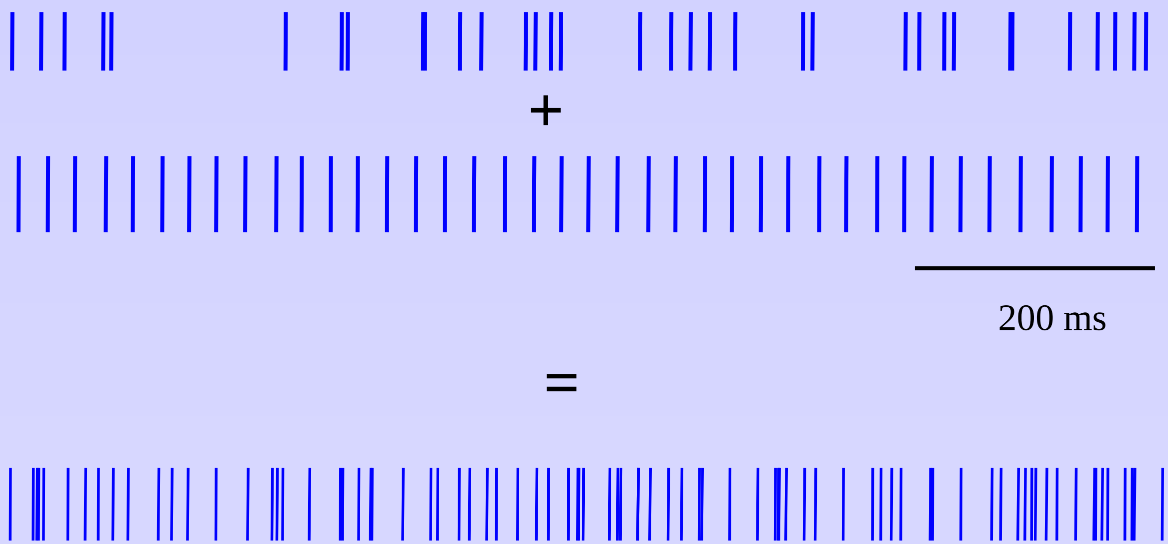
Autocorrelation

- Let’s ‘hide’ an oscillatory signal in a random spike train

10 sec long Poisson train at 40 Hz

+

10 sec long 40 Hz oscillation with 2 ms jitter



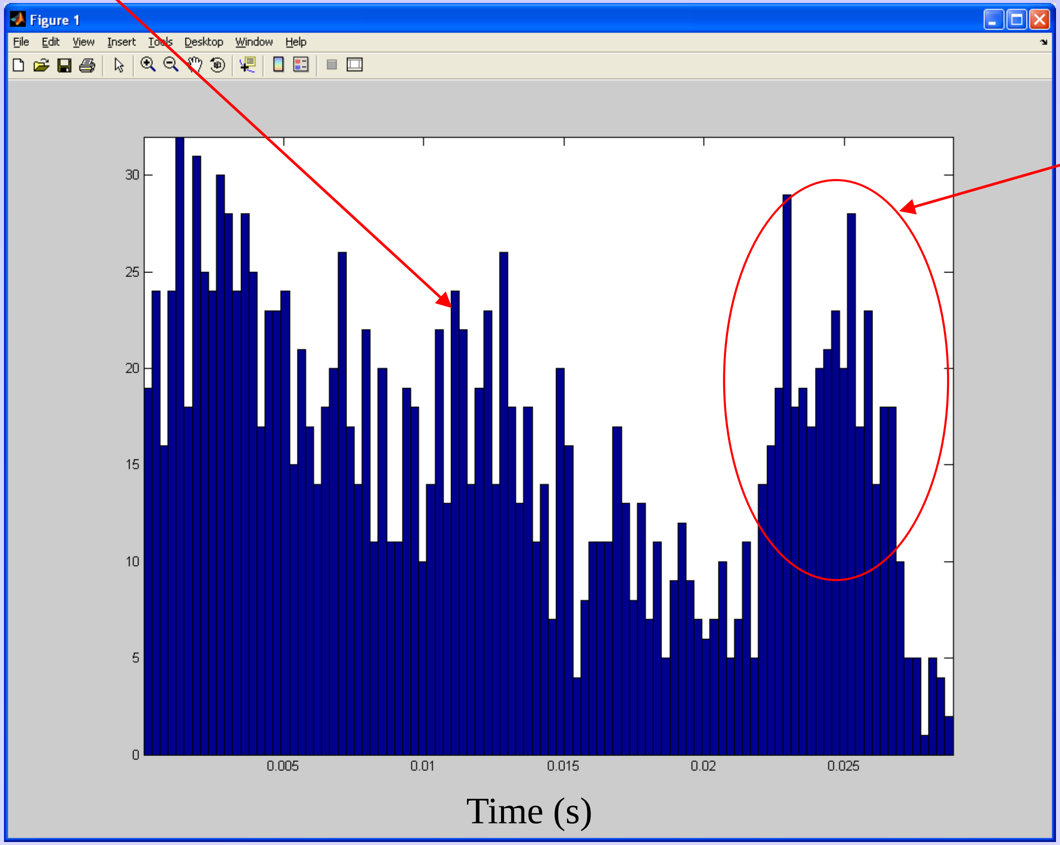
Firing rate = ~80 Hz

Autocorrelation

- Goal: Can we detect the 40Hz signal?

80 Hz → ISI =12.5 ms

Histogram of ISIs



40 Hz ?

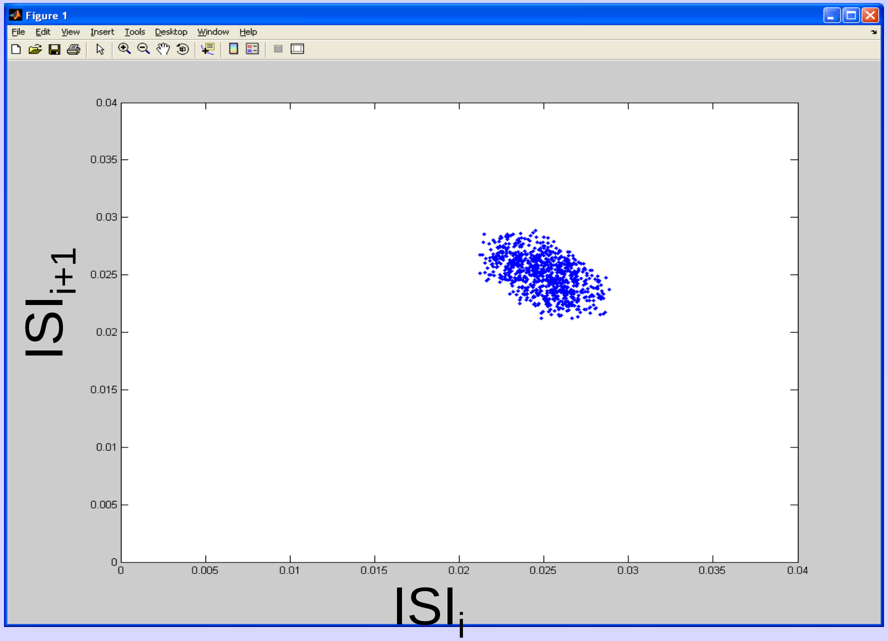
→ Not (well) using the ISIs

Autocorrelation

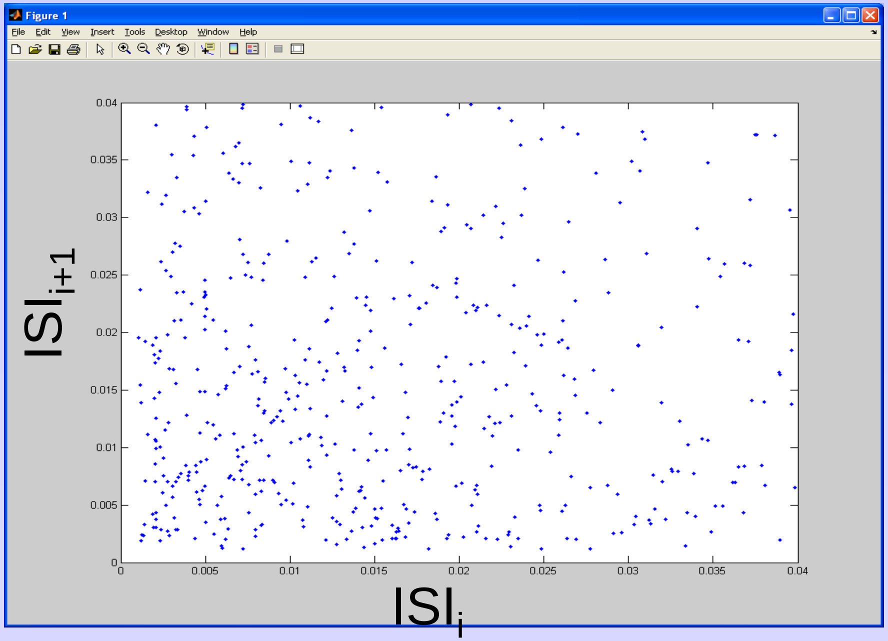
- Can we detect the 40Hz signal?

Return maps

40 Hz oscillation

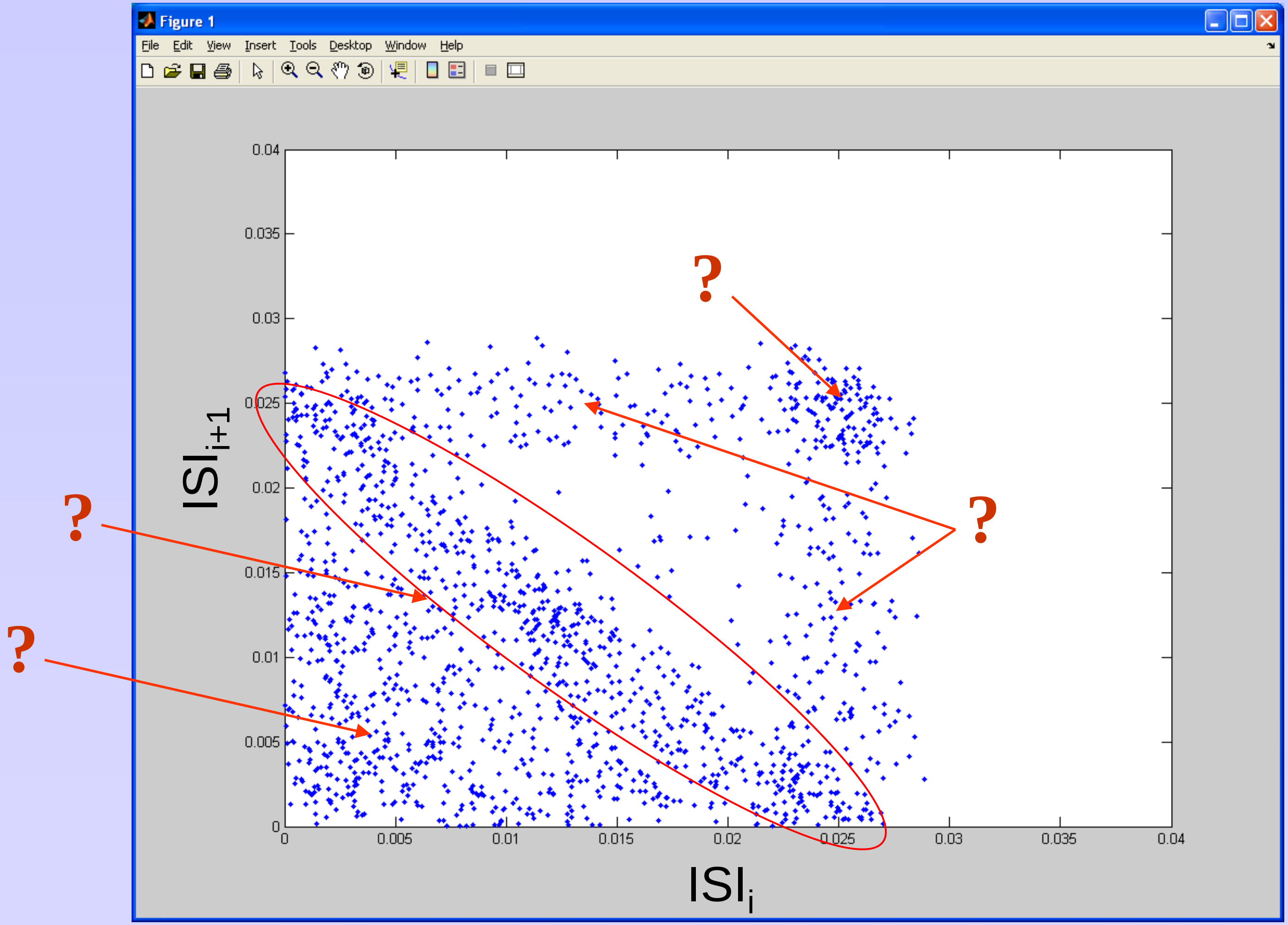


40 Hz Poisson



Autocorrelation

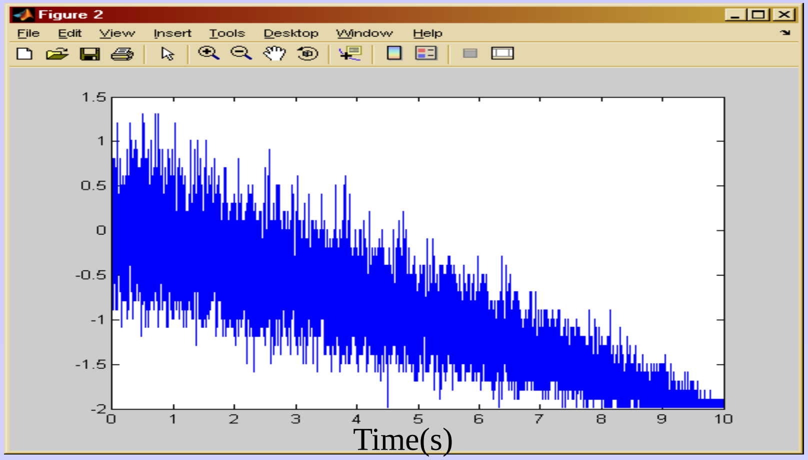
Poisson+ Oscillation: Return map



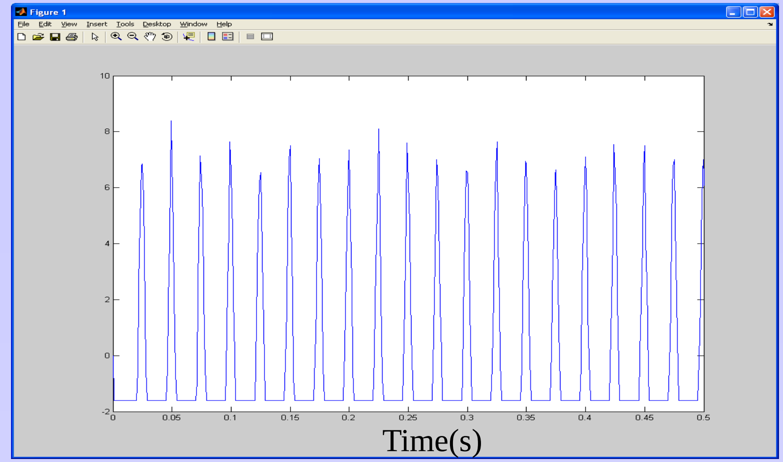
- Return maps are **not simple linear combinations** of elementary return maps

Autocorrelation

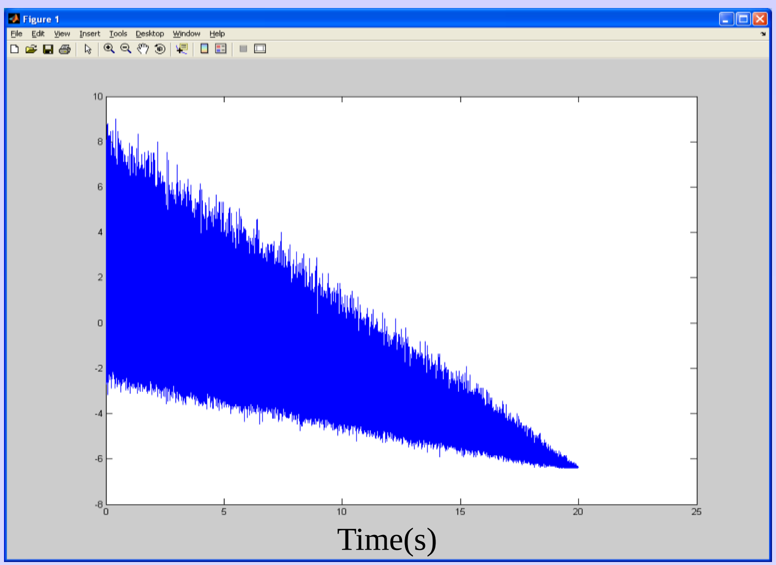
Poisson

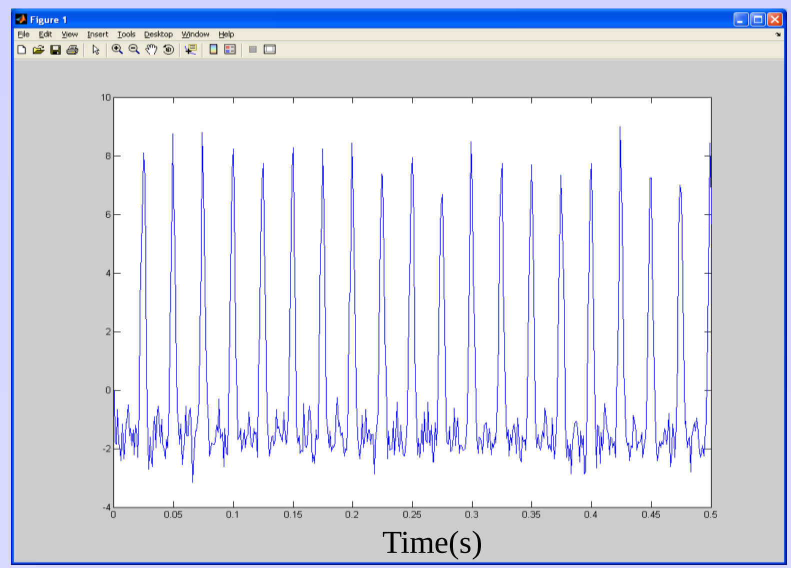


Oscillation



Poisson + Oscillation



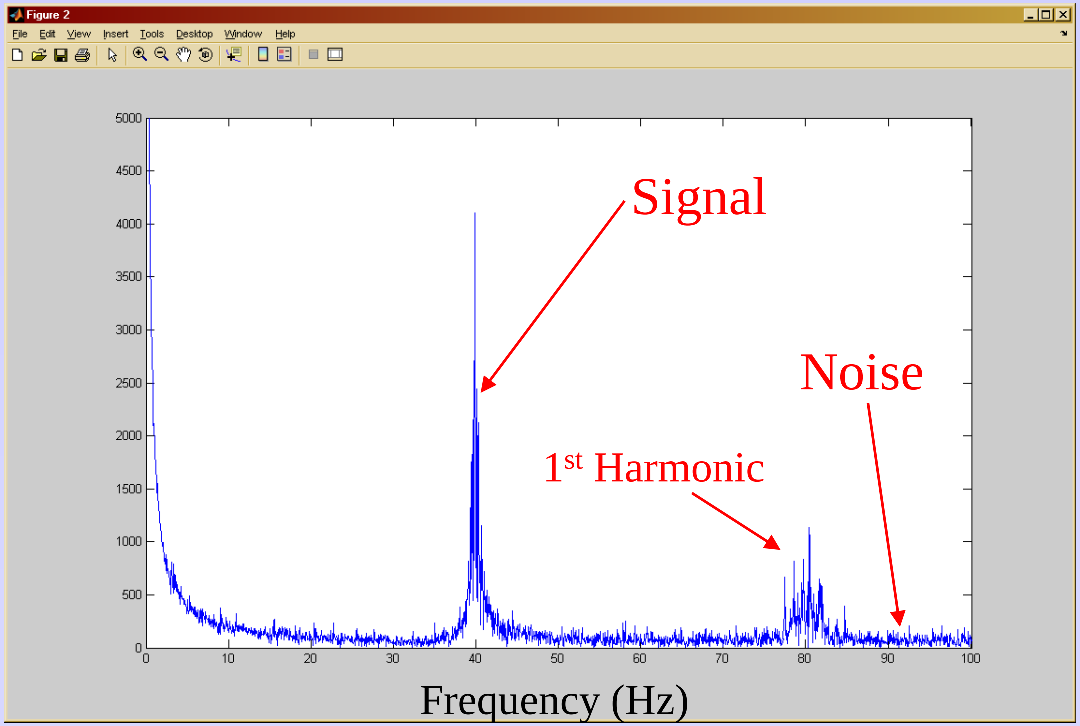


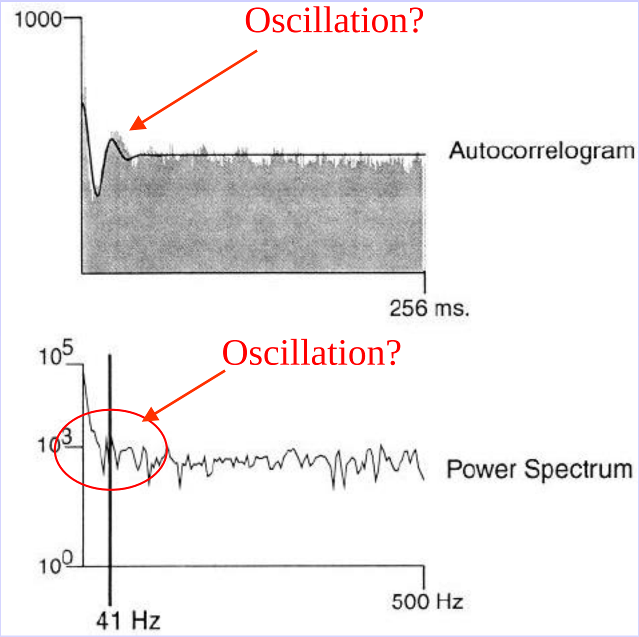
- Autocorrelations **<u>are</u>** **<u>linear</u>** combinations of elementary autocorrelations

Power Spectrum

- Because the major information gathered by the autocorrelation is about '**oscillations**' it is useful to do the analysis in **Frequency** space.
- Power spectrum = Fourier transform of the autocorrelation
- Real symmetric → real symmetric.

But in practice: use fft → complex numbers → magnitudes





Beware of 'false peaks' in the autocorrelation.

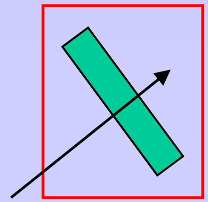
(Ghose Freeman, 1992)

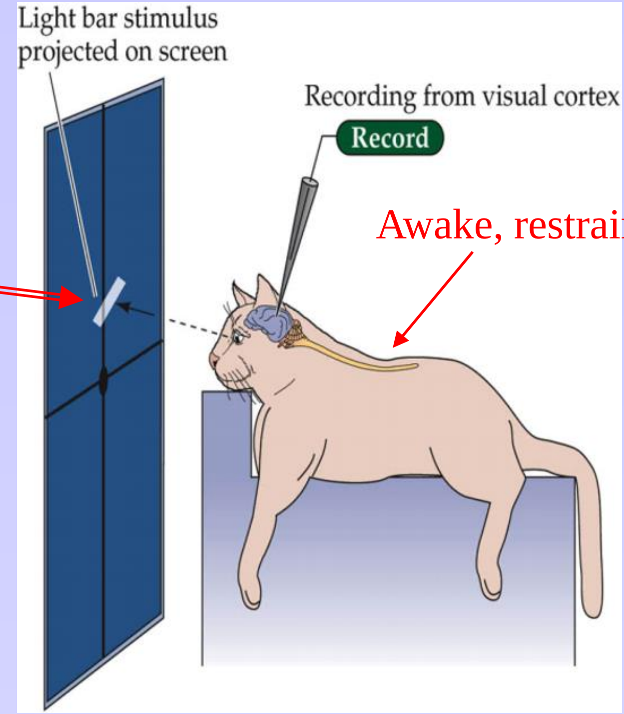
- Note: If normalize by sum(abs(fft)) → %.

Detection of Oscillatory Activity

- What does an oscillation depend on, **Part I: Stimulus dependence**

Optimal stimulus



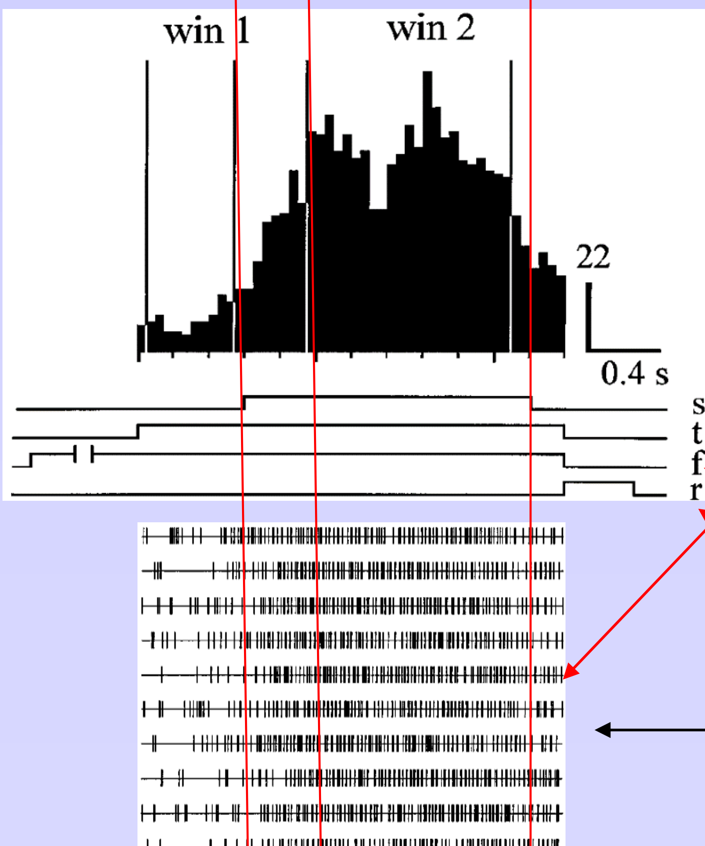


Awake, restrained

(Gray and DiPrisco 1997)

Spontaneous

Stimulus-driven



Stimulus

Data acquisition

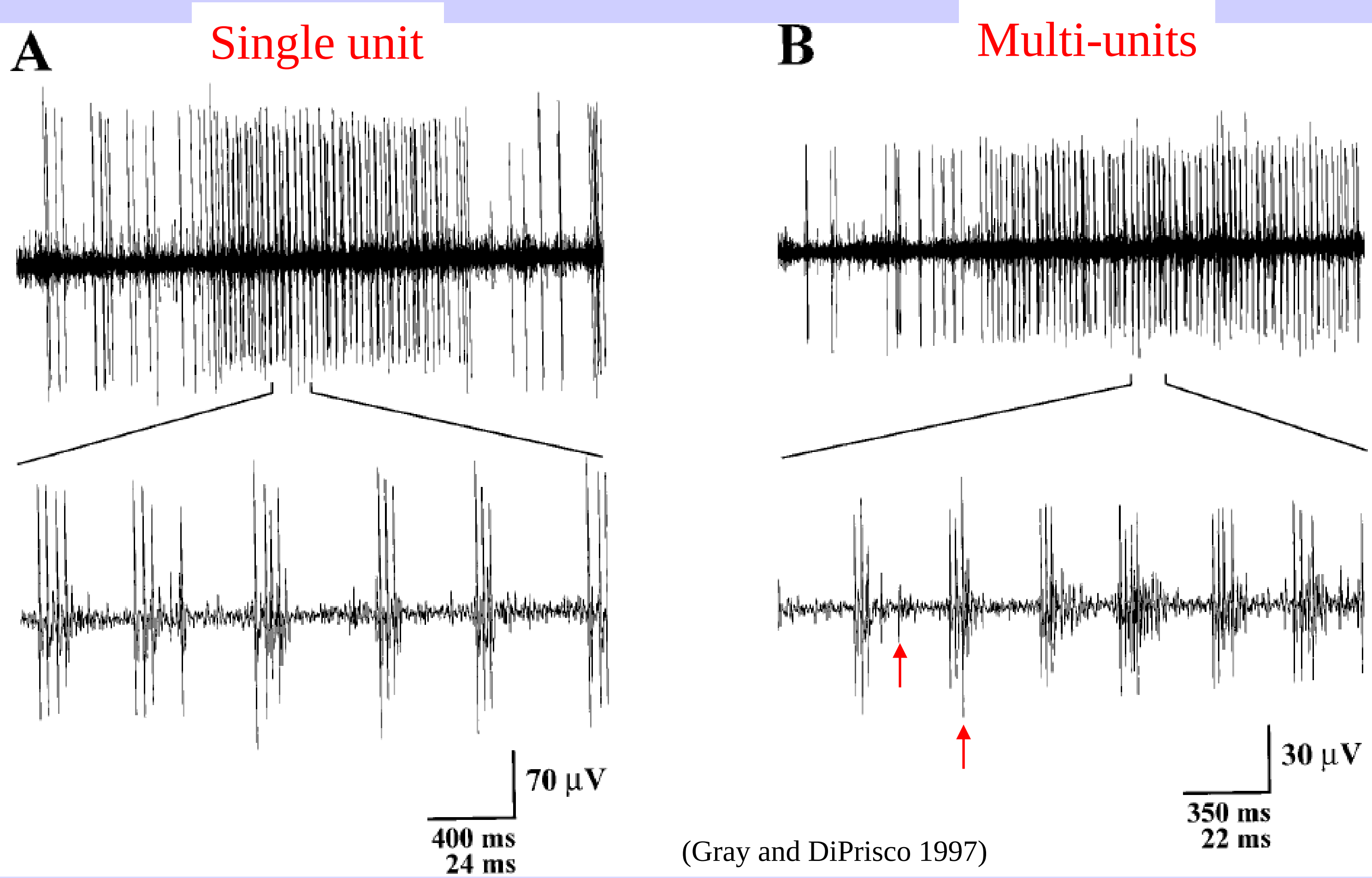
Fixation

Reward

Is there any hidden oscillatory component?

Detection of Oscillatory Activity

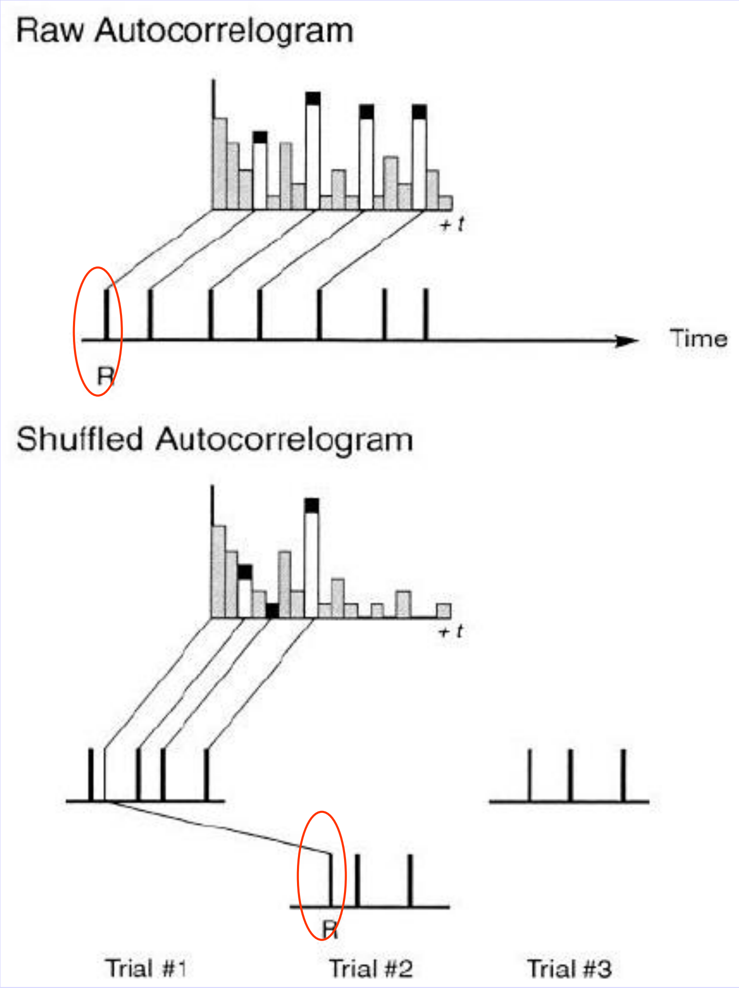
- **Note1**: Single unit VS multiunit activity
- If oscillations are seen in multi-units recordings… they are likely to be (locally) synchronous.

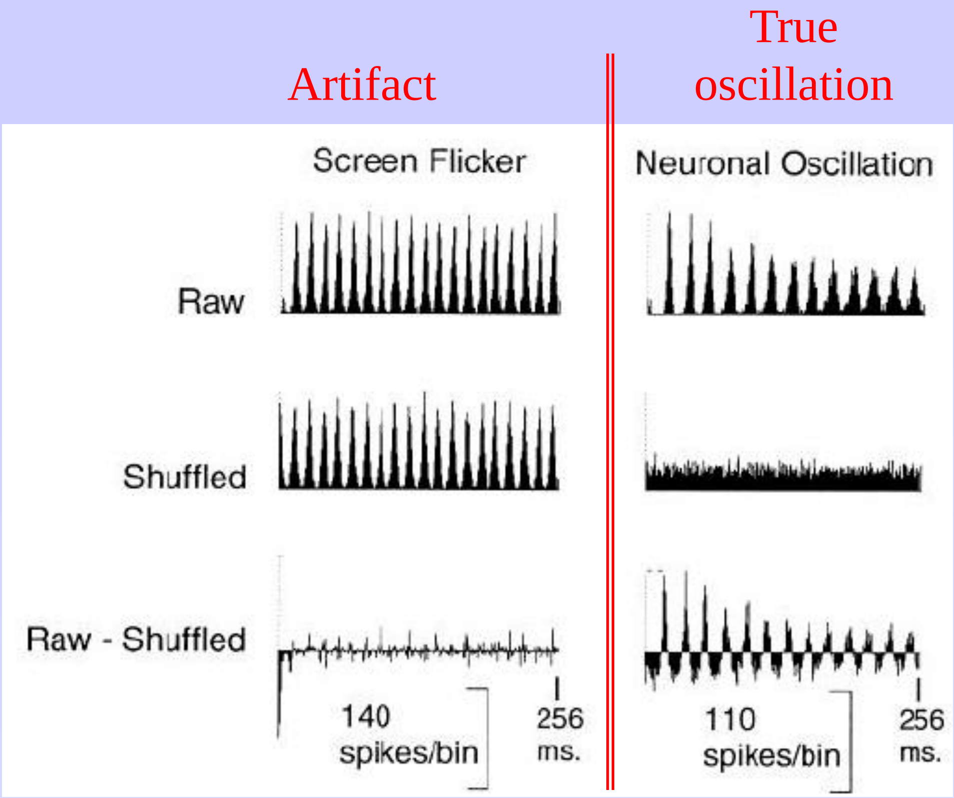


(Gray and DiPrisco 1997)

Detection of Oscillatory Activity

- **Note2**: Is an oscillation an artifact of the stimulus?
- Trial shuffling procedure





(Ghose Freeman, 1992)

Use reference spike from trial 2 to compute the autocorrelogram of trial 1

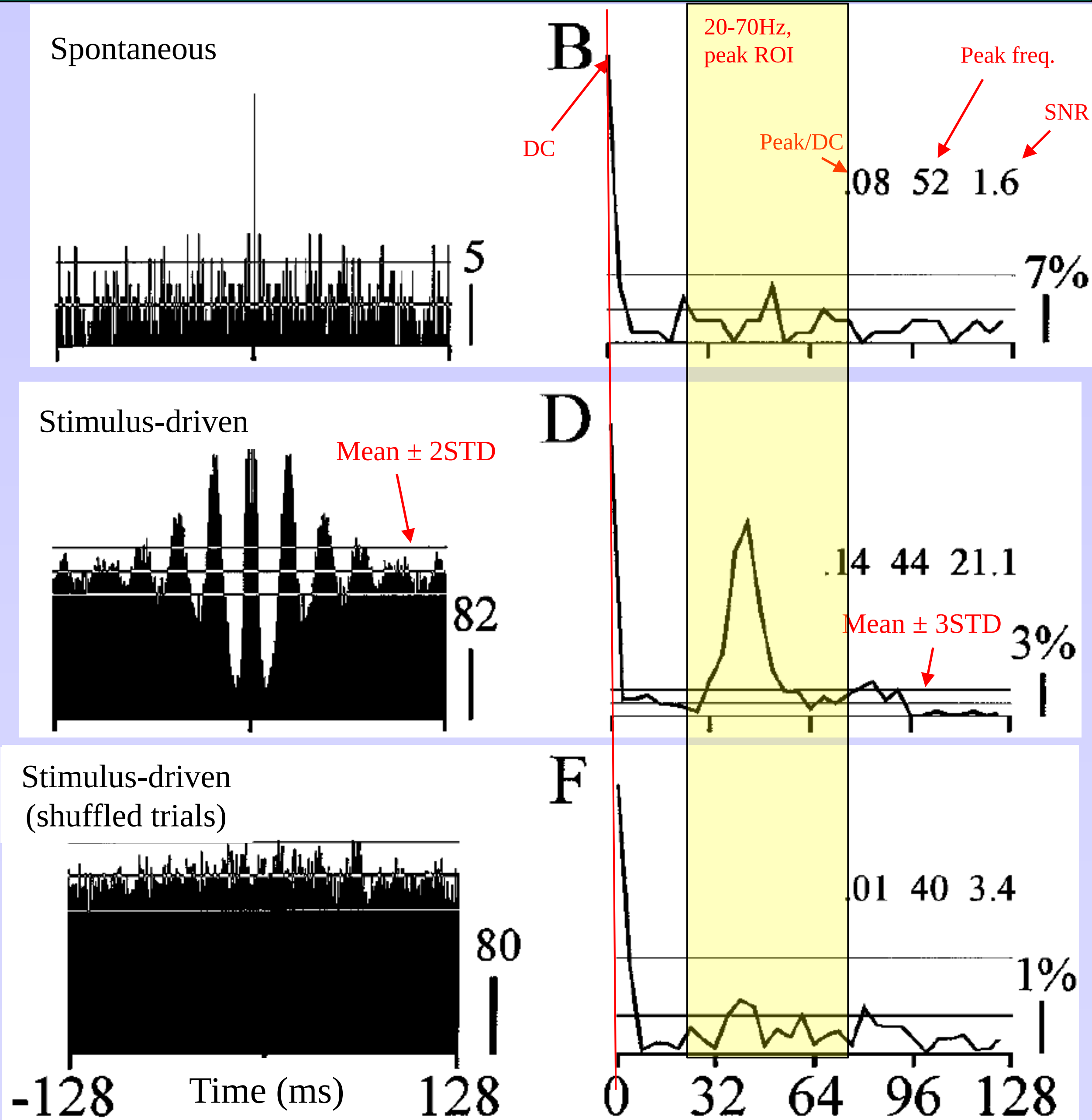
Detection of Oscillatory Activity

- Across all trials

- Quantifying oscillations: Peak frequency, Peak/DC, SNR

- Controlling for stimulus *dependence* (spontaneous activity)

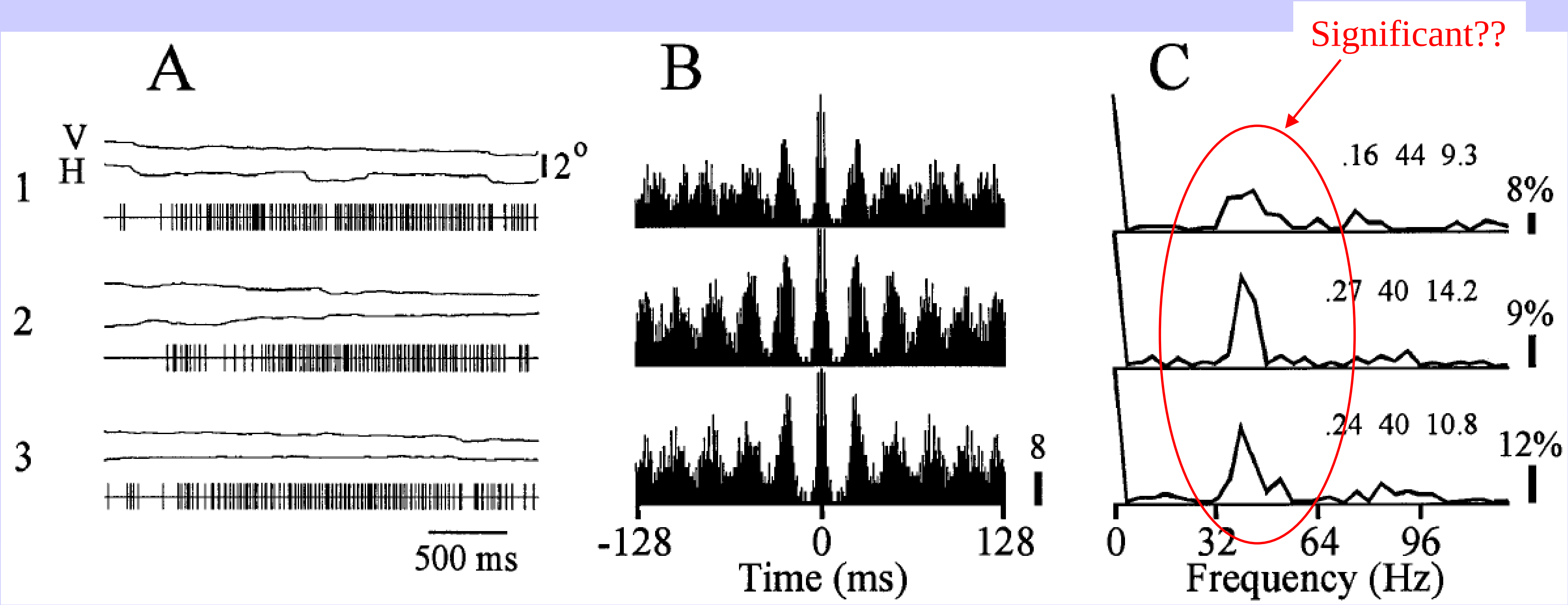
- Controlling for stimulus *artifacts* (trial shuffling)



(Gray and DiPrisco 1997)

Detection of Oscillatory Activity

- Are there oscillations in single trials ?

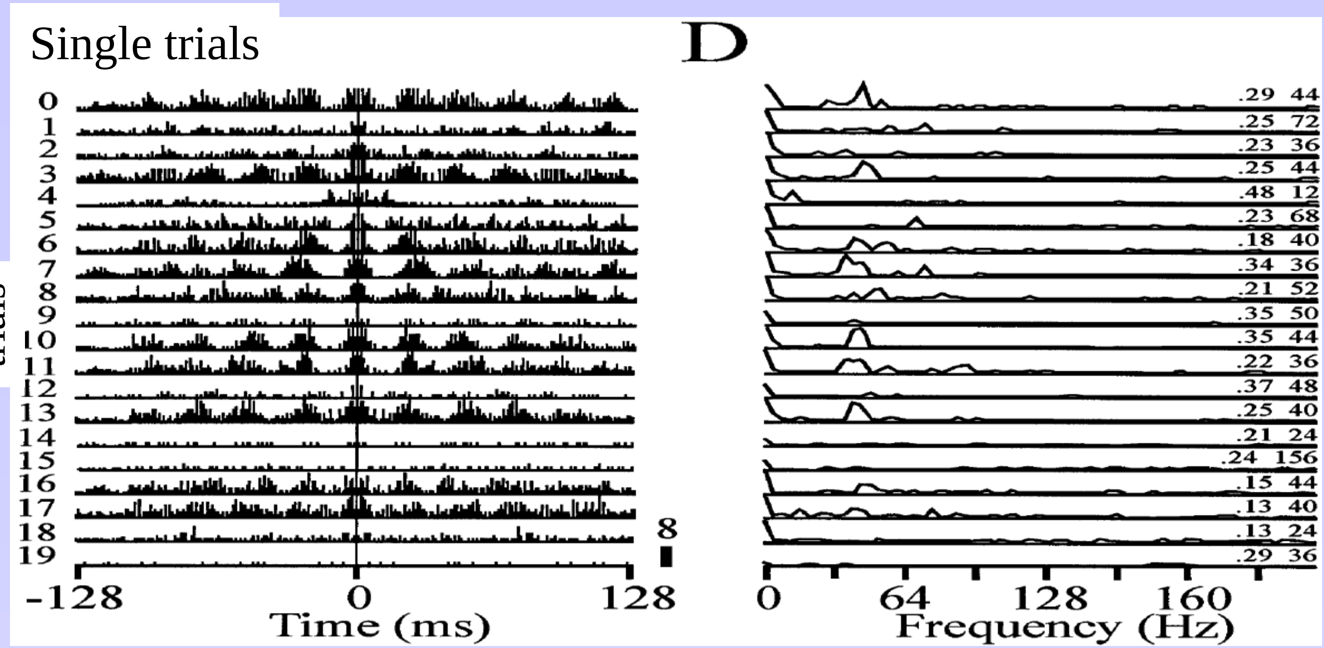


(Gray and DiPrisco 1997)

- Need for **significance criteria. E.G.**
  - CV < 0.5
  - Peak in the **P**ower**S**pectrum > mean + 3STD
  - Peak in the PS > 90% of all peaks in the shuffled PS
  - SNR > 1.5

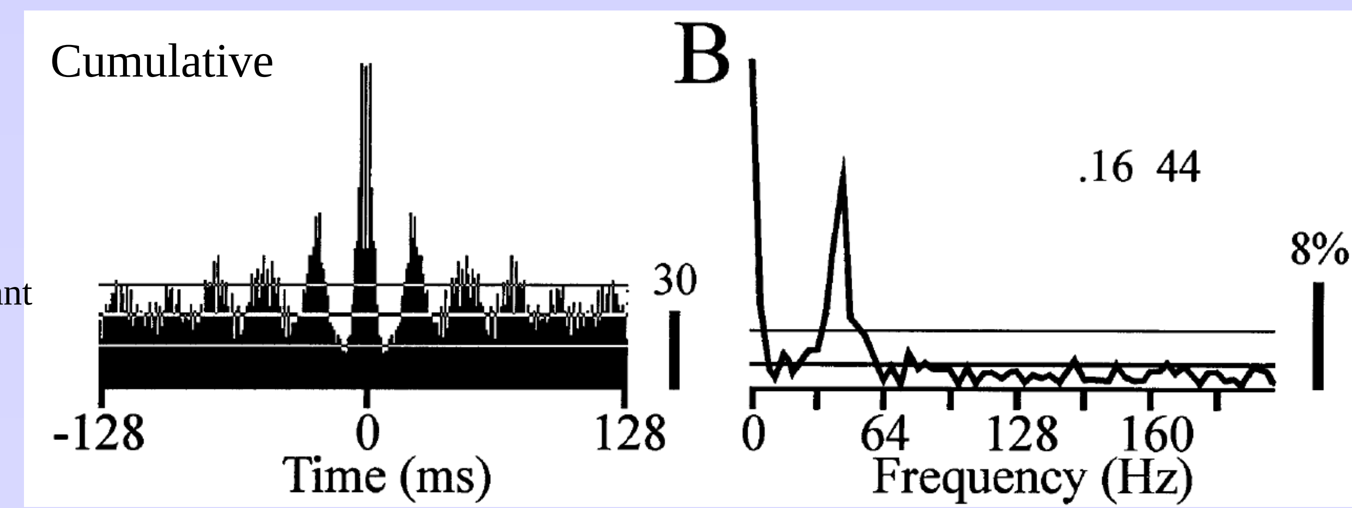
Detection of Oscillatory Activity

- Rare occurrence of oscillations, but when they occur, oscillations have the same frequency



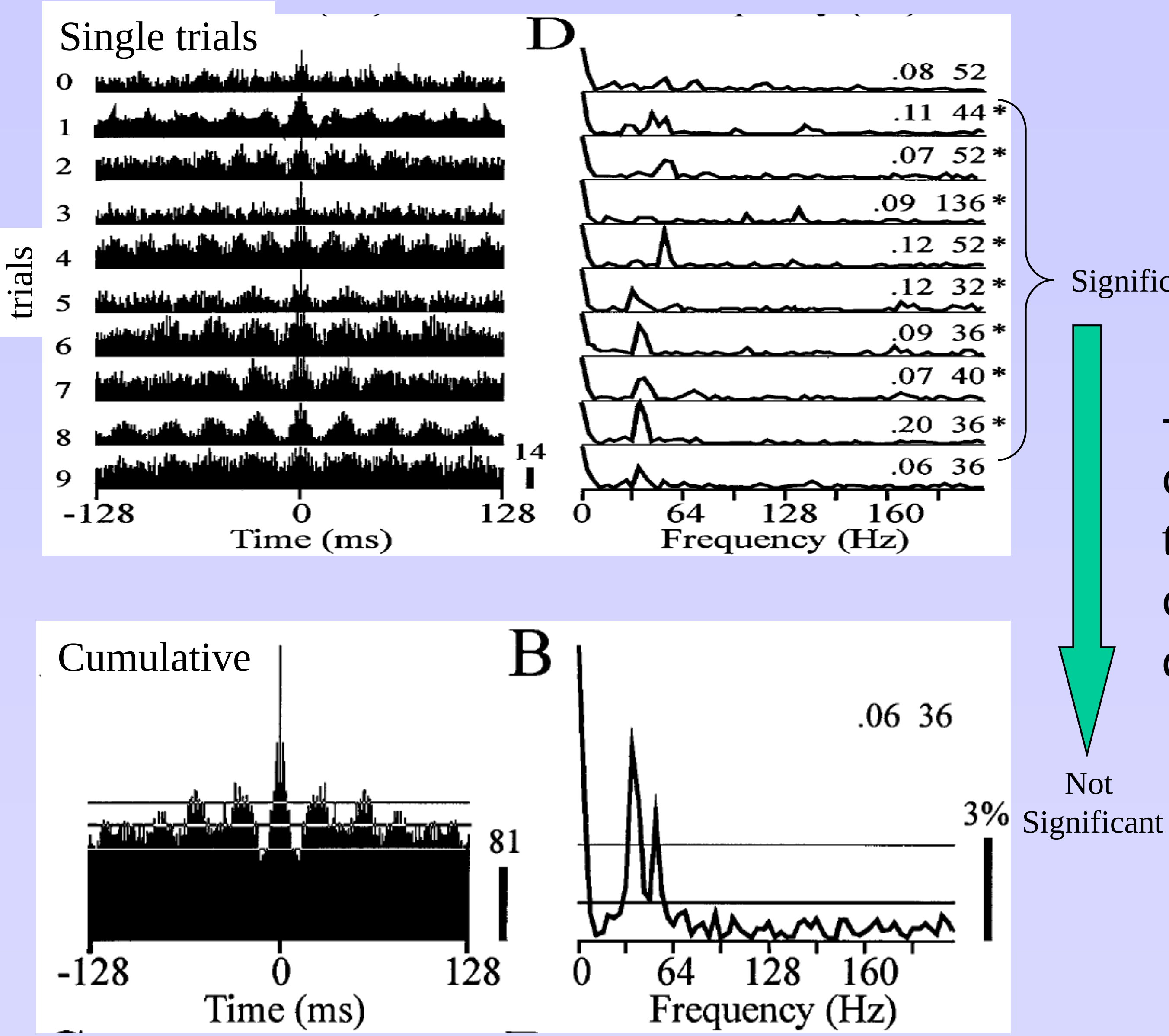
Single trials: Not significant

Cumulative: Significant



(Gray and DiPrisco 1997)

Detection of Oscillatory Activity



- high occurrence of oscillations, but when they occur, oscillations have different frequencies

(Gray and DiPrisco 1997)

Stimulus dependence of oscillations

- The ‘big debate’: Is the Oscillation ‘meaningful’?

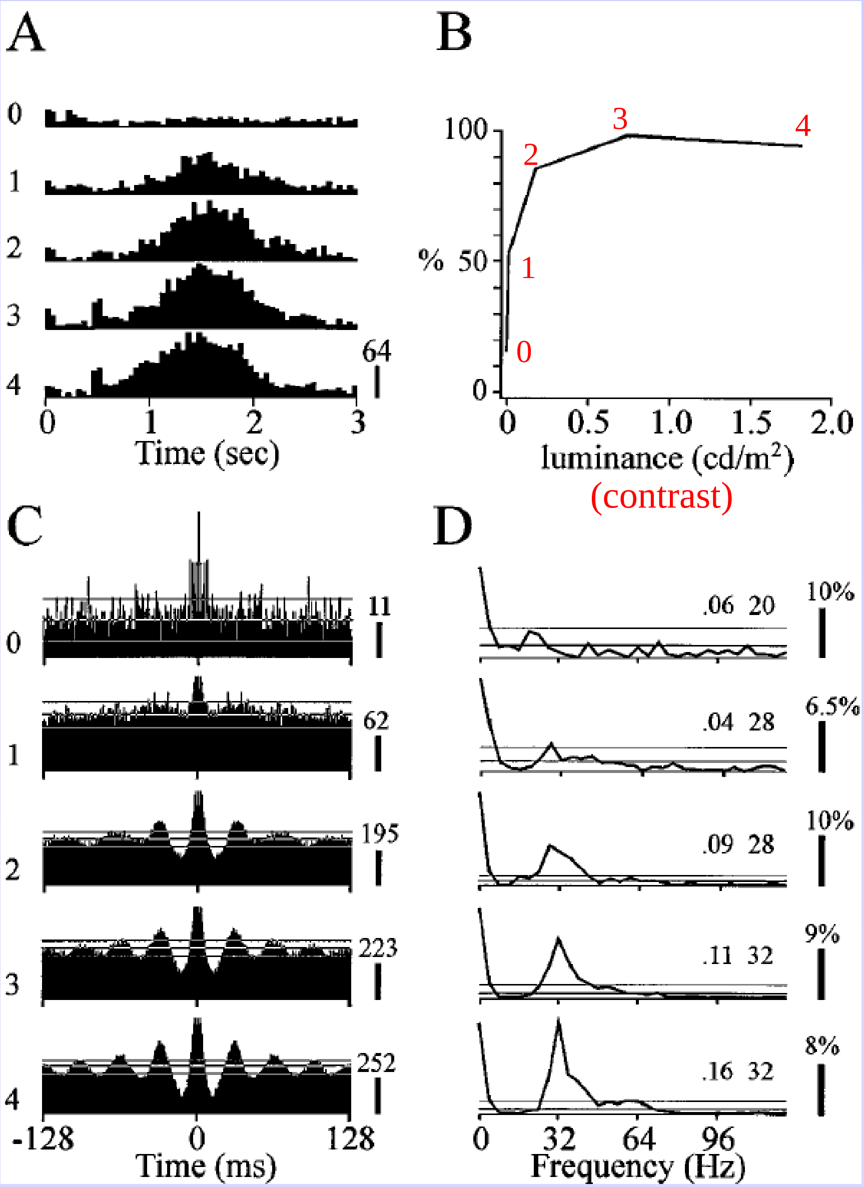
Increase in stimulus contrast

↓

Increase in firing rate, decrease in latency

↓

Increase in oscillatory Power



(Gray and DiPrisco 1997)

Stimulus dependence of oscillations

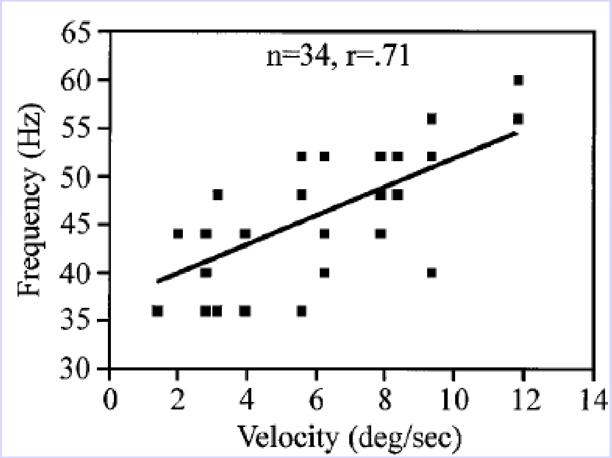
Increase in stimulus velocity

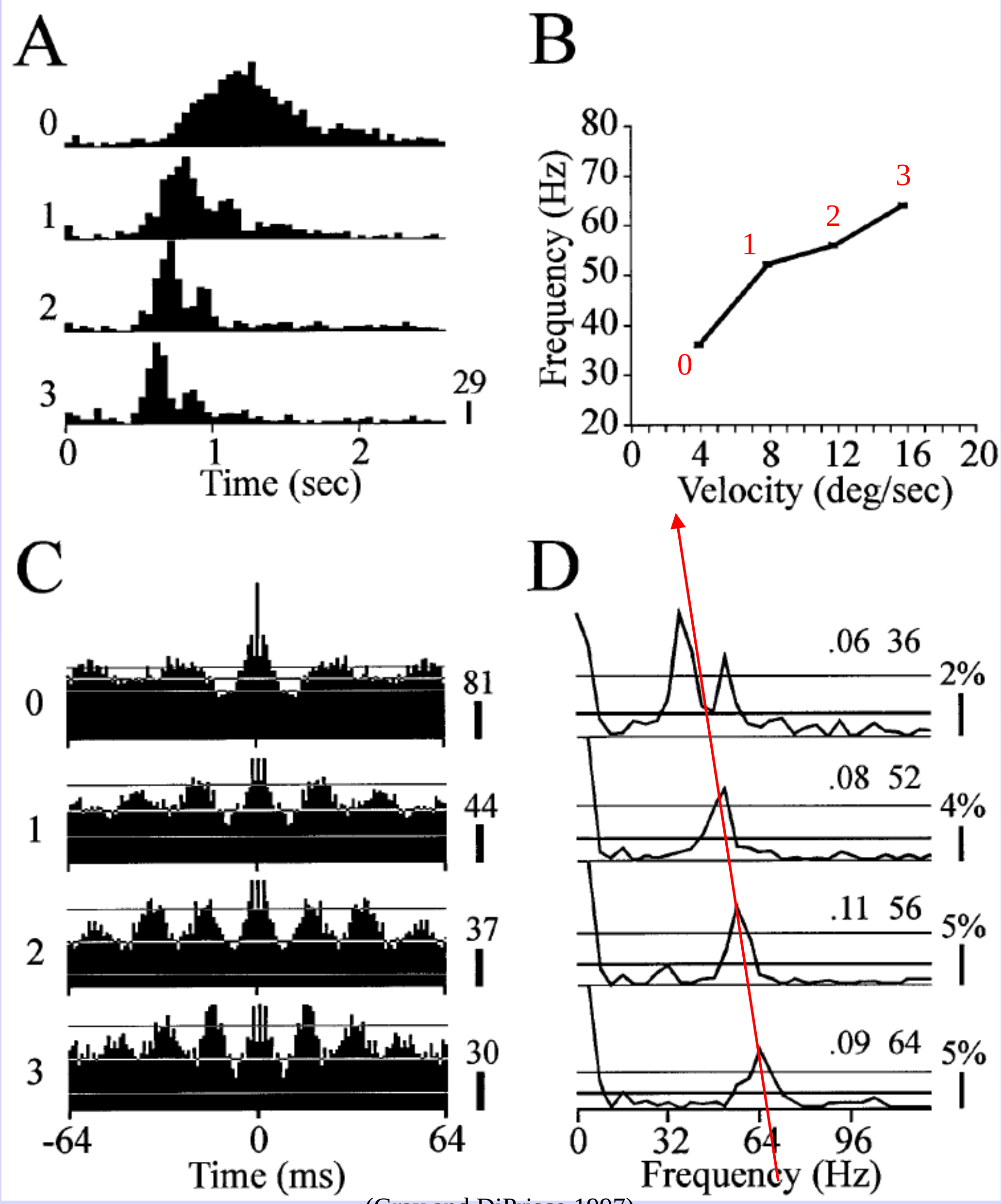
↓

Decrease in latency, decrease in firing rate, increase in *precision* (see next class)

↓

Increase in oscillation Frequency





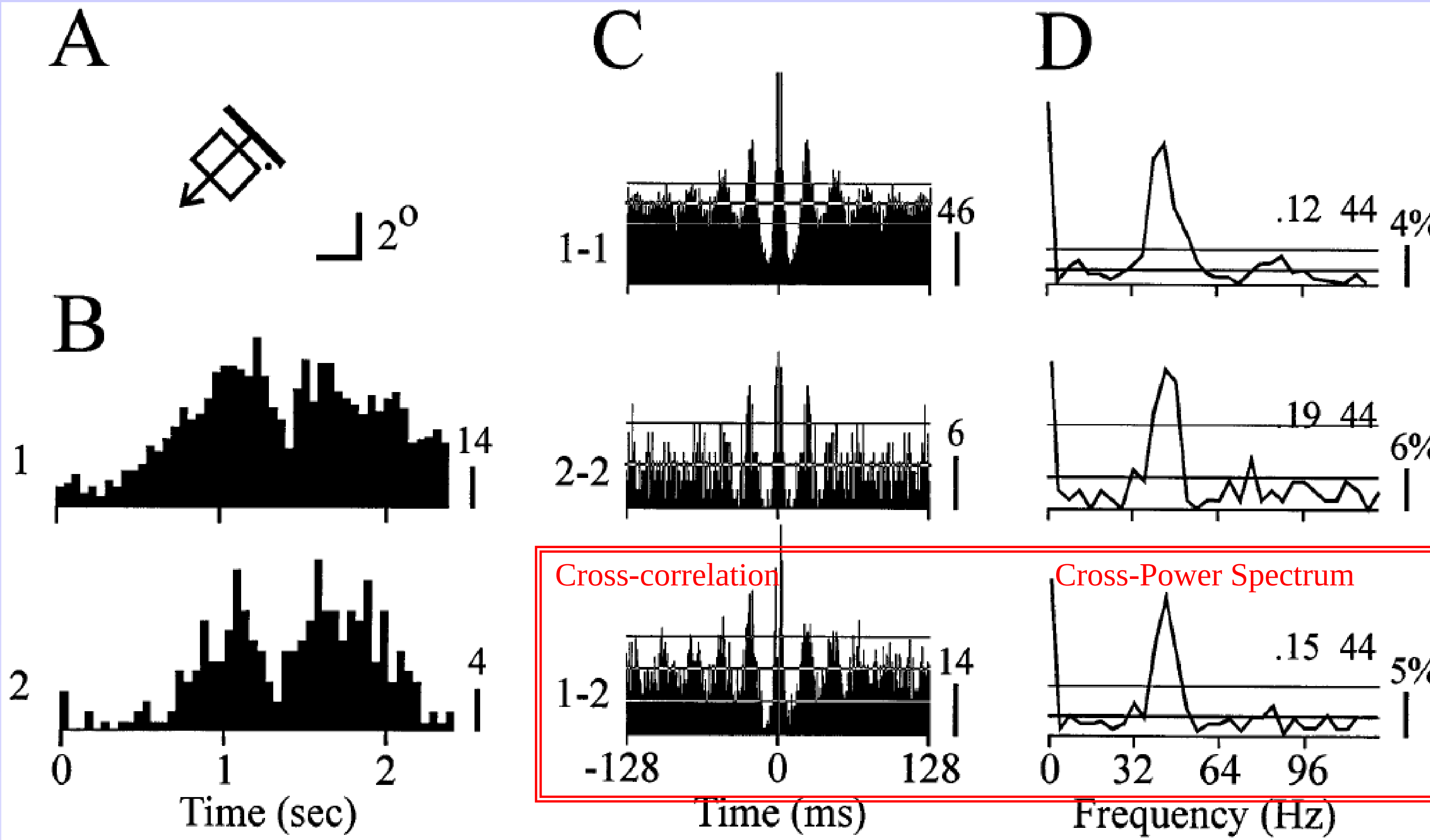
(Gray and DiPrisco 1997)

Cross-correlation (preview)

- Are oscillating cells synchronized

$t^1_i - t^2_j$

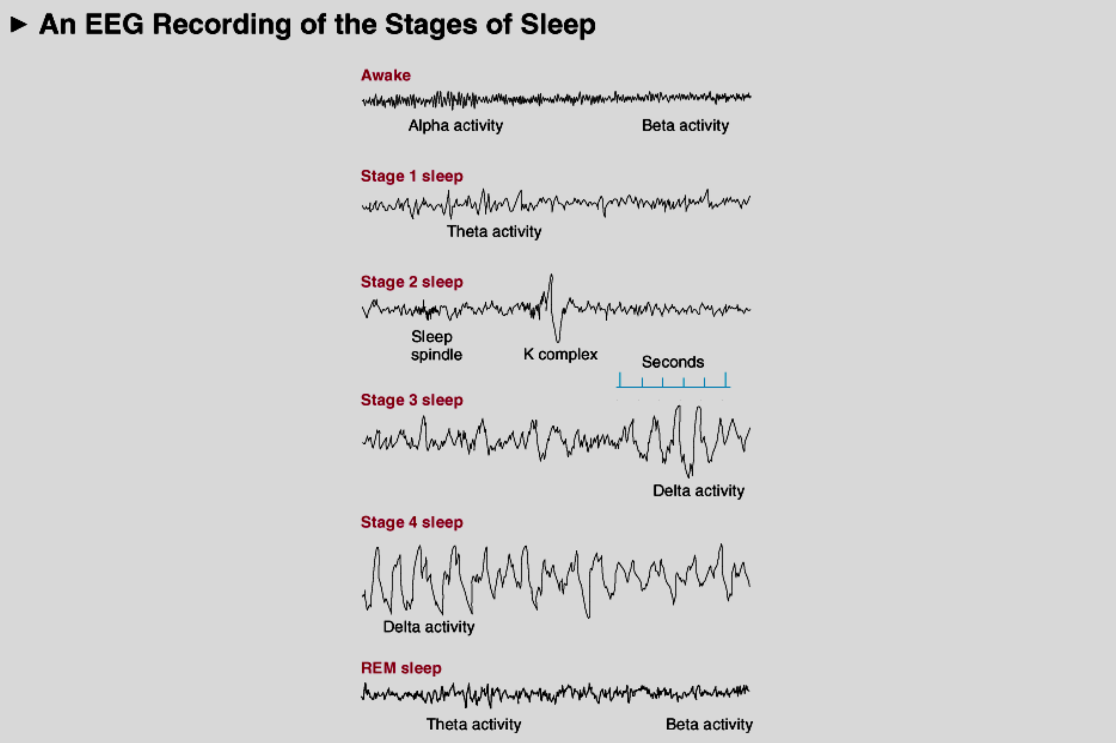
2 cells isolated from a multi-unit recording



(Gray and DiPrisco 1997)

Spectrogram

- What does an oscillation depend on, **Part II: Intrinsic mechanisms**



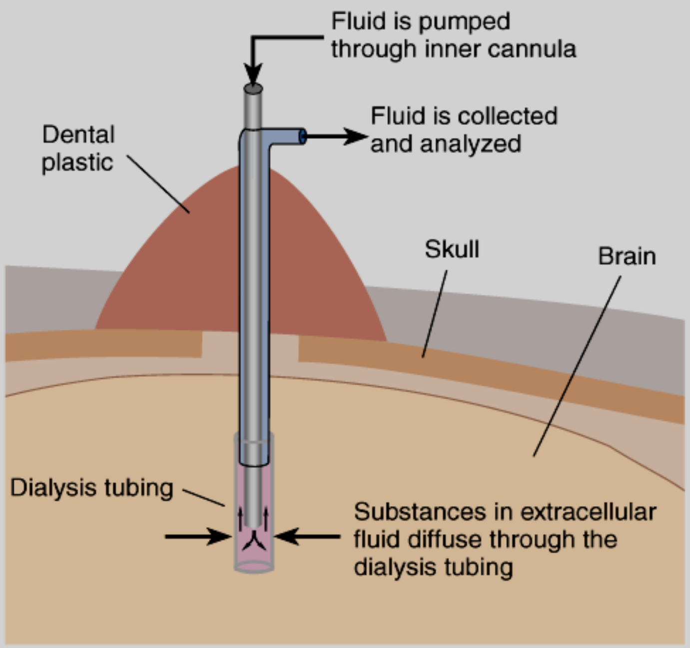
Source: From Horne, J.A. *Why We Sleep: The Functions of Sleep in Humans and Other Animals.* Oxford, England: Oxford University Press, 1988.

- In rats: Theta and Delta (and bursts of sharp waves).
  - Theta depends on network and intrinsic properties of cells. Found in REM sleep and in exploratory behaviors.
  - h-current (potassium hyperpolarization activated) present in hippocampus CA1 neurons

Spectrogram

- Role of Ih in the generation/maintenance of Theta oscillations *in vivo*?
- Method: Injection of Ih blocker in the Septum (ZD7288)

► **Microdialysis**



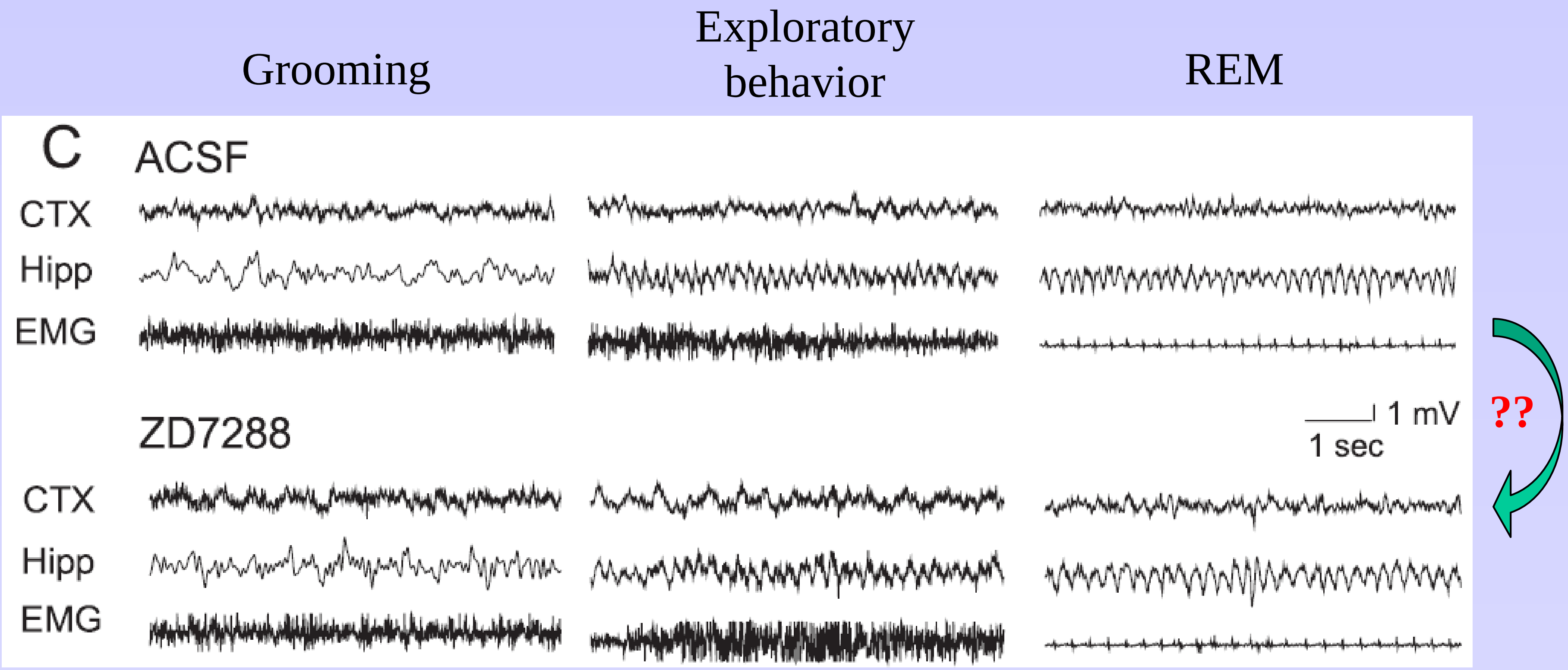
Source: Adapted from Hernandez, L., Stanley, B.G., and Hoebel, B.G. *Life Sciences*, 1986, *39*, 2629–2637.

+ EEG electrodes
  Cortex + Hippocampus
+ Stim electrodes
  nuc. Pontis oralis (starts theta)

Spectrogram

- Awake behaving condition

- Does Ih Blockade affect theta oscillations?

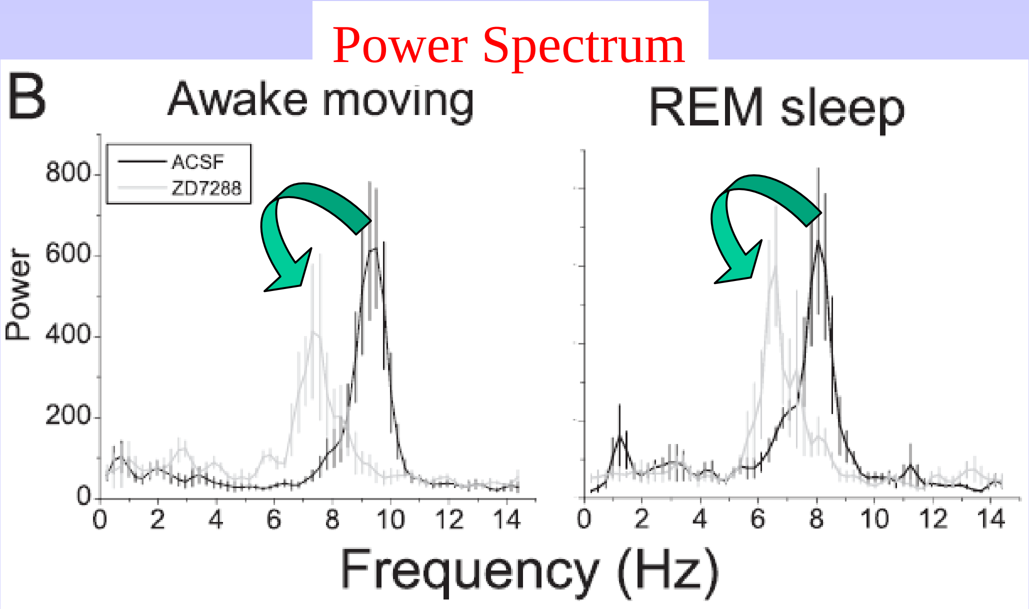


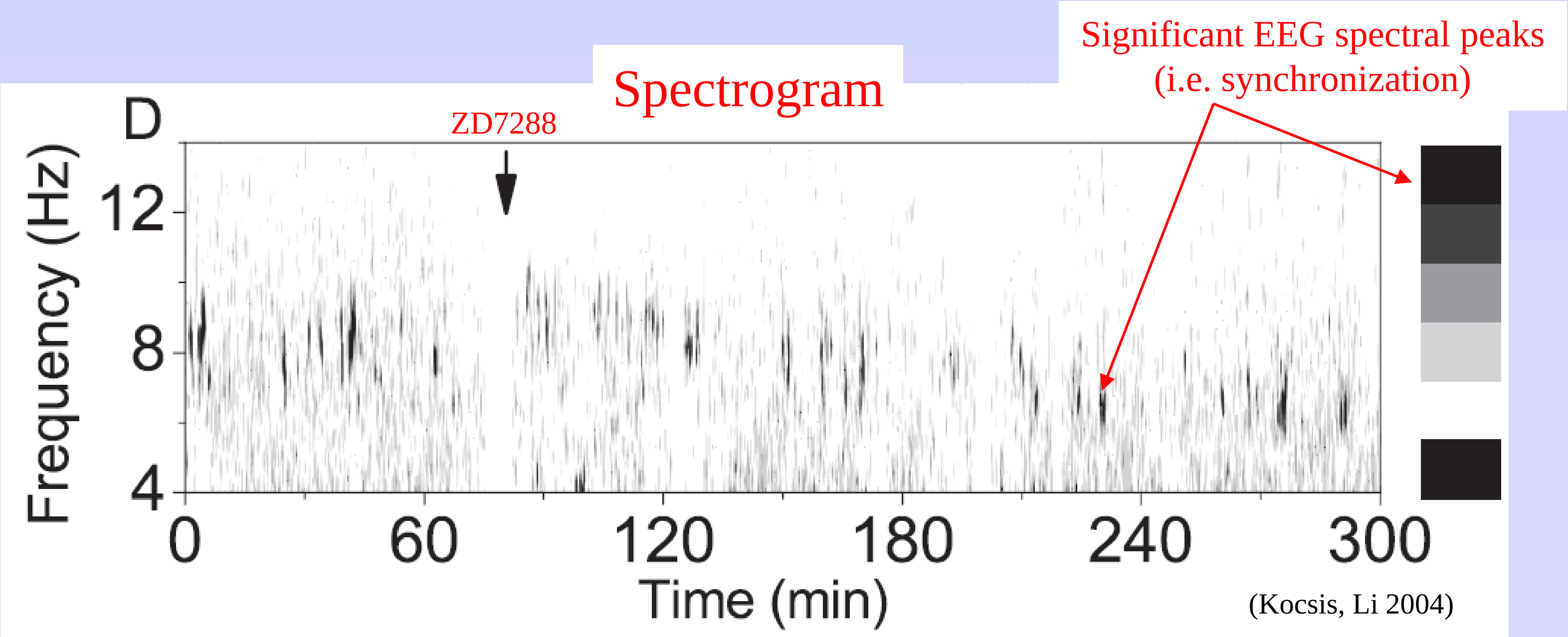
(Kocsis, Li 2004)

ZD7288 = Ih channel blocker
ACSF = Artificial CerebroSpinal Fluid

Spectrogram

Power Spectrum
Vs
Spectrogram

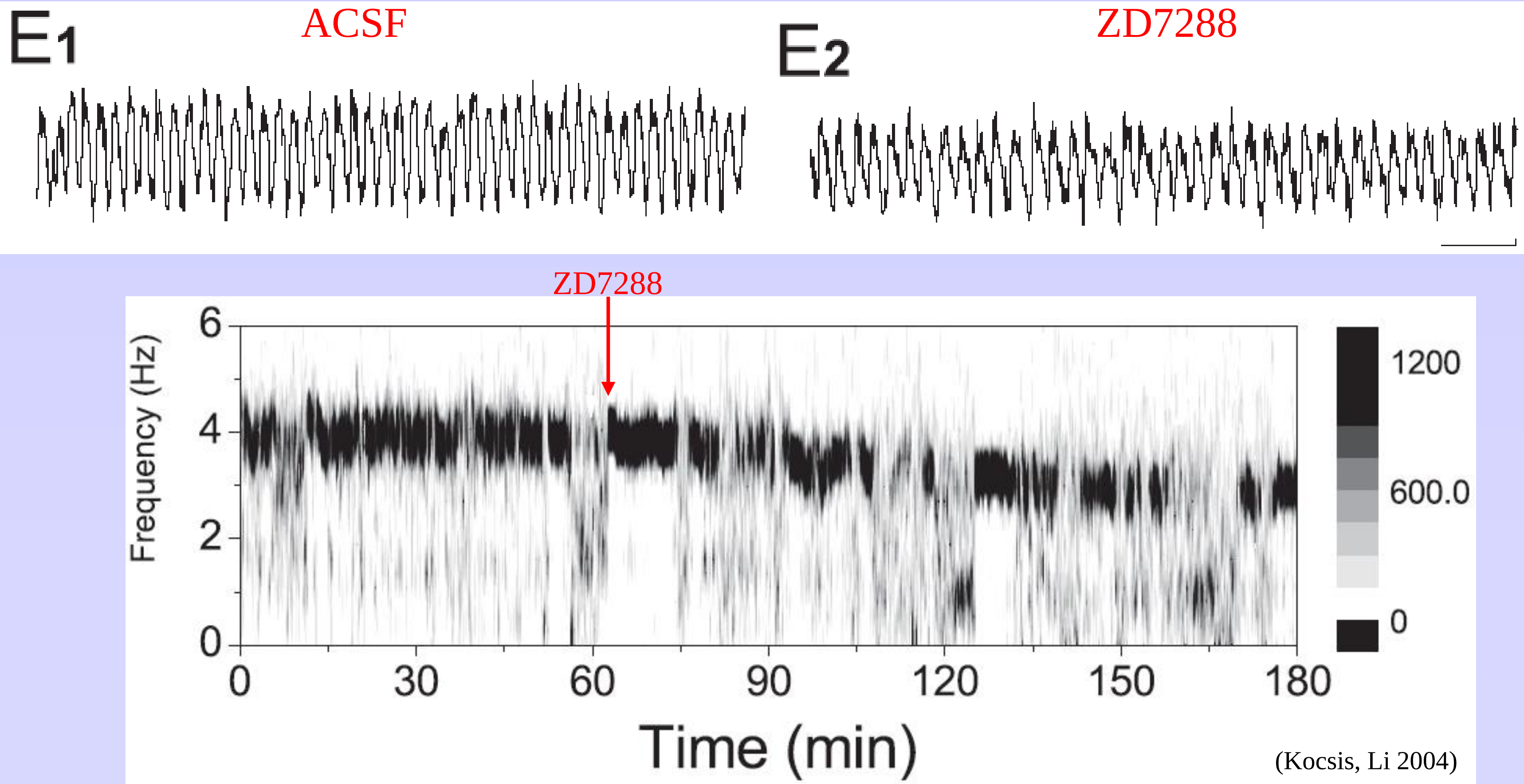




Spectrogram

- Anesthetized condition (urethane)

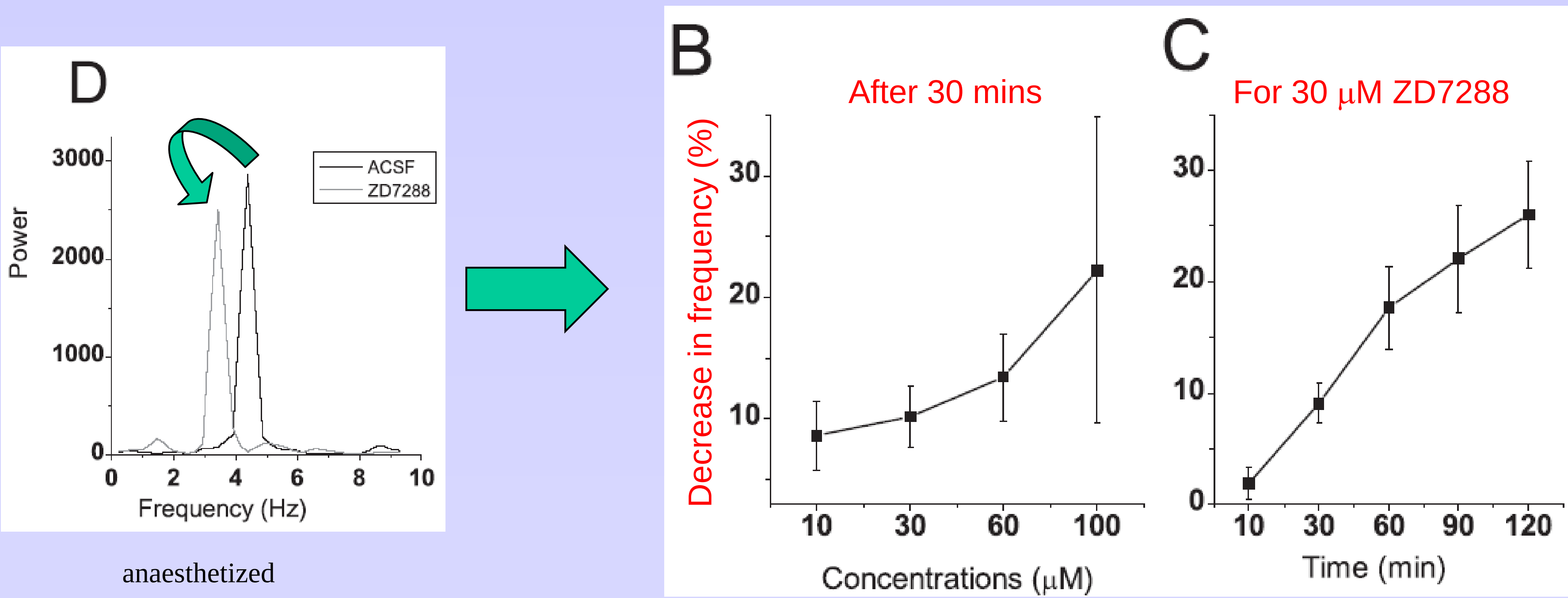
- Same phenomenon…Note frequency values.
  → Basic intrinsic mechanisms



(Kocsis, Li 2004)

Spectrogram

- Explain the mechanisms and dynamics of Ih influence on theta oscillations: Variation and dynamics of blockade

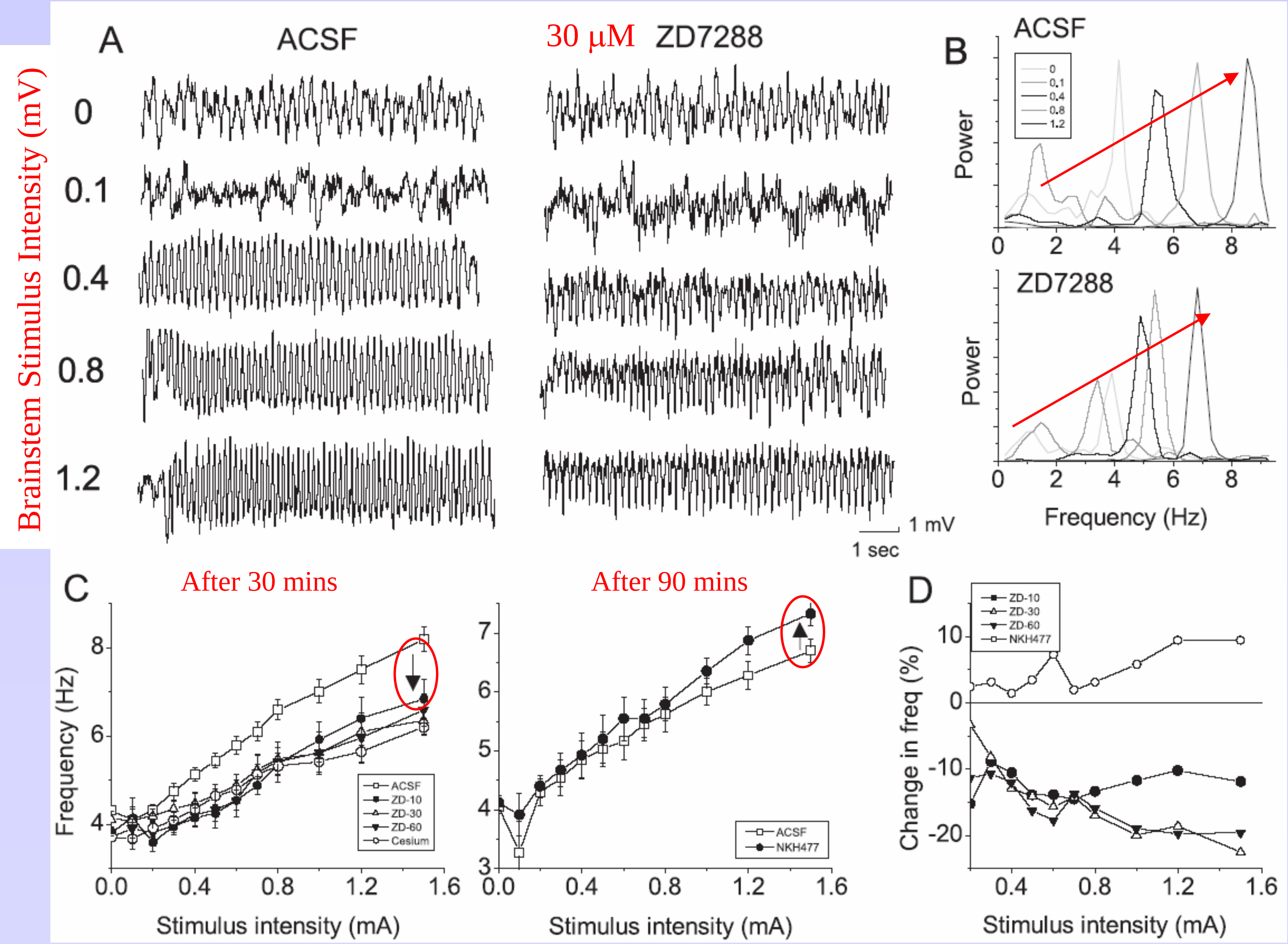


anaesthetized

(Kocsis, Li 2004)

Power Spectrum

- The case of elicited Theta oscillations



NKH477: adenylate cyclase agonist (Ih increase)