Interspike interval variability of cortical sensory neurons

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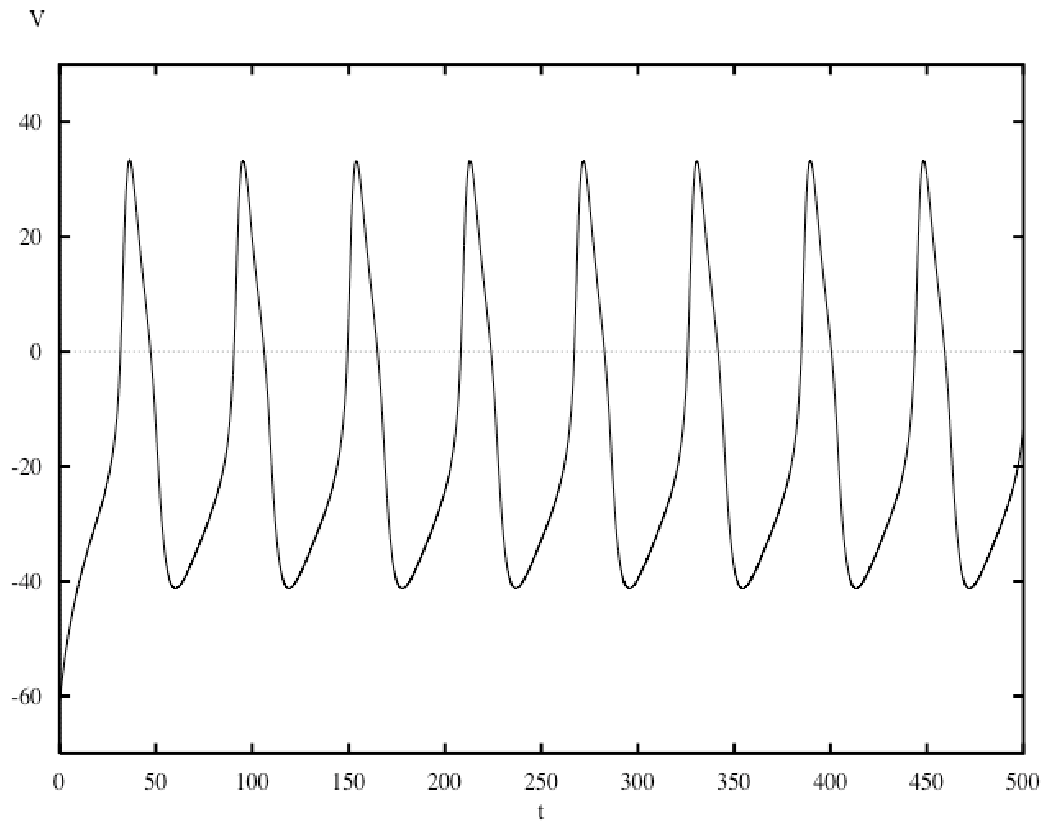
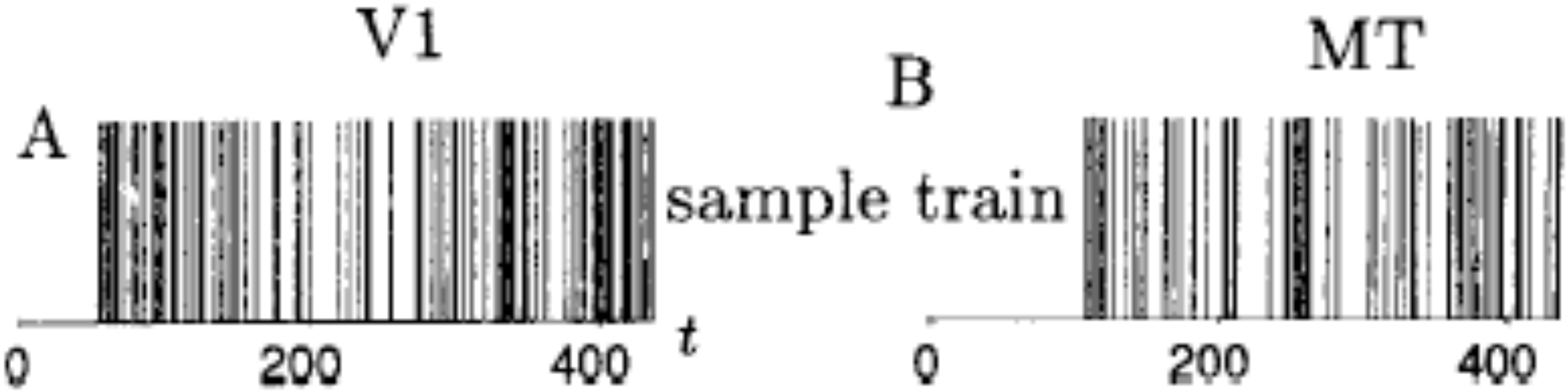
Applying depolarizing current (of high enough amplitude) to a neuron in vitro produces a train of APs with regular interspike intervals. We can simulate this:



(ML model, type I excitability; applied current I=60μA/cm^2)

In vivo, cortical sensory neurons (e.g. in primary visual cortex, area MT, etc) produce AP trains with irregular interspike intervals in response to visual stimulus:



(From Softky&Koch, sample *irregular* trains of APs fired by neurons in the primary visual cortex and the area MT)

Measures of variability* are close to those of a random process.

(* e.g. coefficient of variation Cv, calculated as [std deviation of the mean interspike interval] / [mean interspike interval])

The same stimulus produces a different spike train each time; only the mean interspike interval is approximately the same

- This is not surprising: in vivo, input to a neuron is probably very noisy, even with the same visual stimulus used.

- However: Some neurons display low interspike interval variability (e.g. retinal ganglion cells, in response to high contrast visual stimulation; see Reich et al).

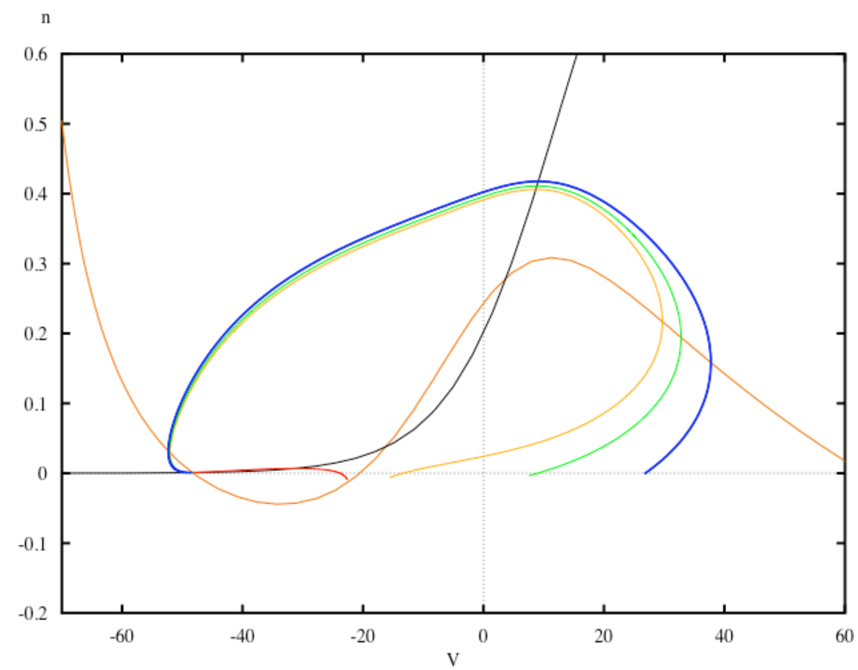
- Possibly different membrane dynamics underlie the two types of response?

- Gutkin & Ermentrout:
- Type I neurons in excitable mode produce highly irregular spike trains in response to noisy stimulation;
- Type I neurons in oscillating mode produces moderately irregular spike trains;
- Type II neurons always produce regular spike trains.

Type I neuron: excitable mode

All above-threshold inputs produce voltage spikes of about the same height, but initial movement away from the threshold is slow => timing of spikes varies significantly with input size.

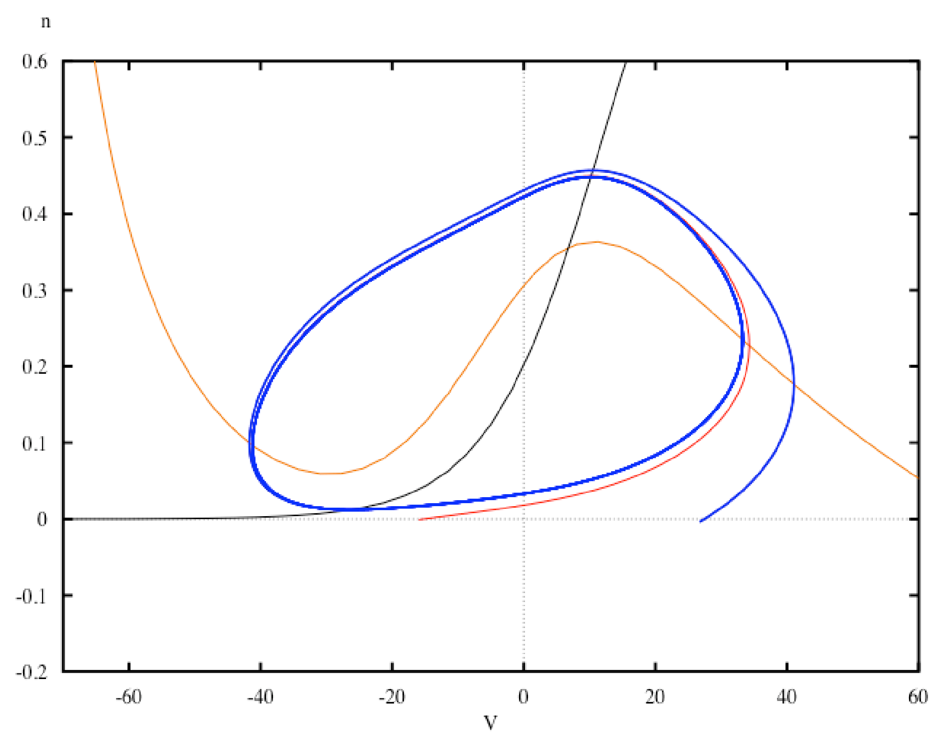
With noisy input, each instance of input of different size results in different spike delay
=> Interstimulus intervals vary.



Type I neuron: oscillating mode

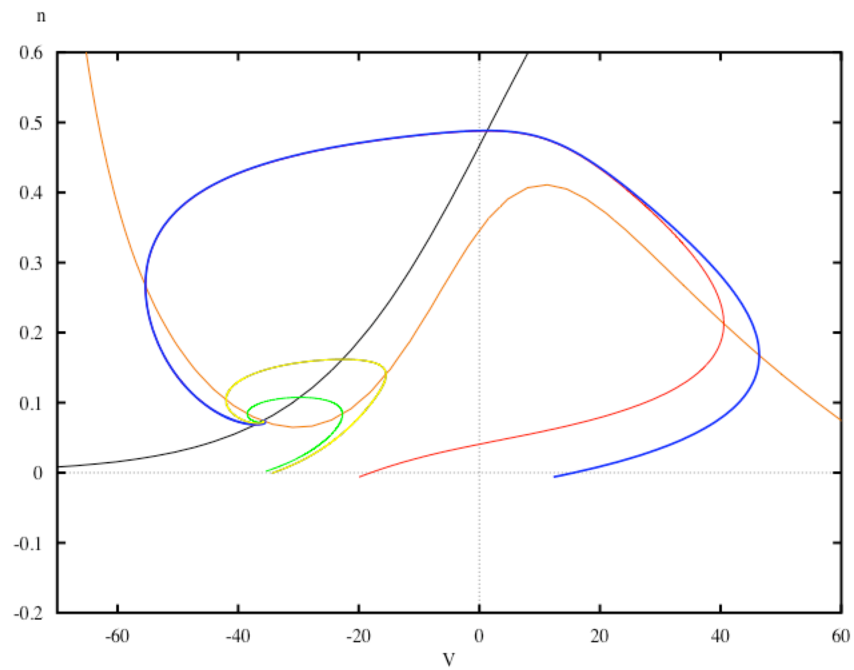
System after bifurcation (saddle-node on invariant circle)

Impact of the input is dominated by that of intrinsic oscillations, which determine the interstimulus interval (thus low variability)



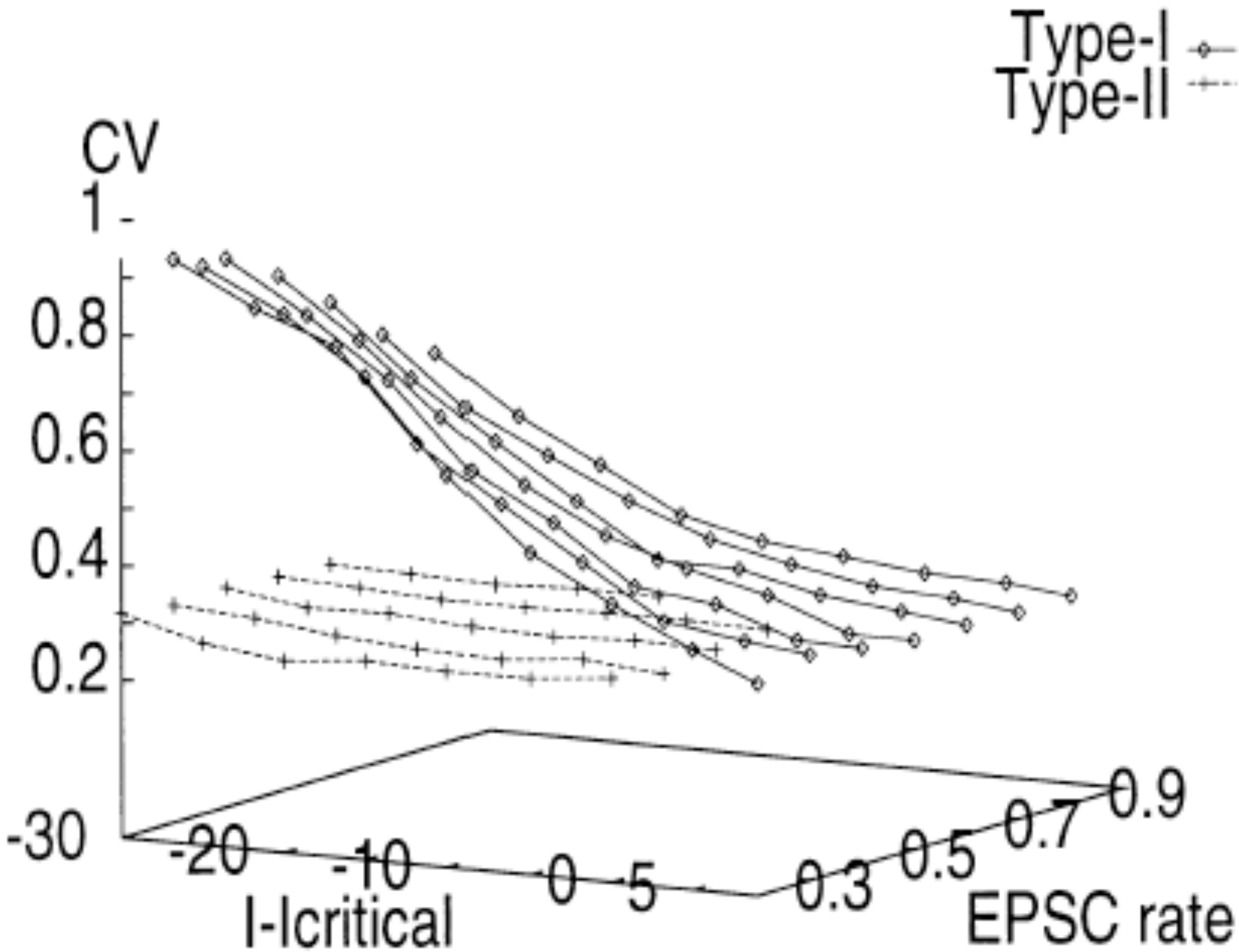
Type II neuron

- Oscillations appear with >0 frequency (subcritical Andronov-Hopf bifurcation);
- Timing of spikes is relatively insensitive to input size, thus low variability of the interstimulus interval.



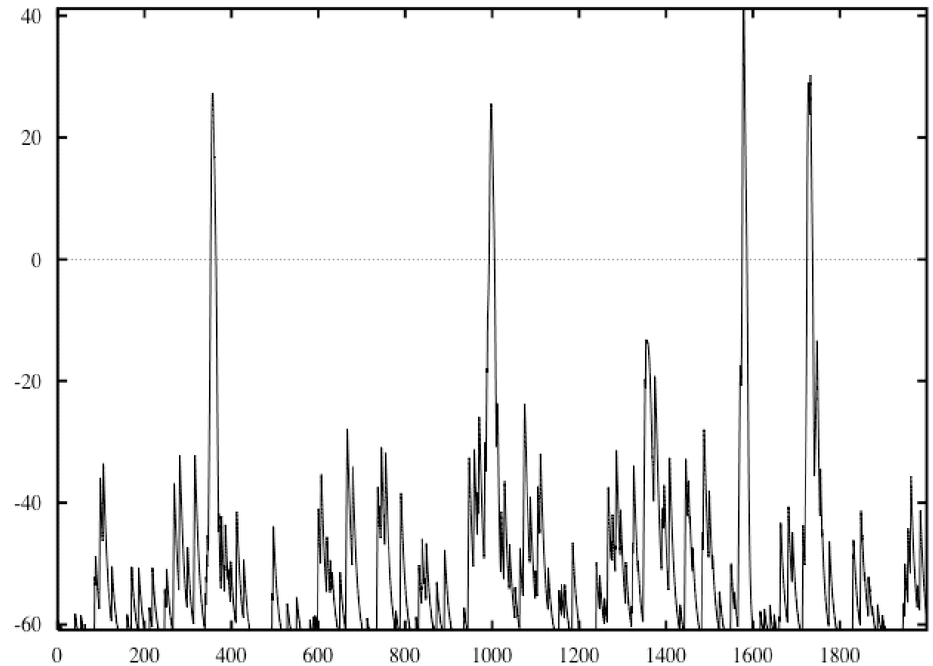
Basically:

- If spikes are triggered by noisy input, then output is noisy;
- If spikes are largely controlled by intrinsic oscillations, then noisy input still results in regular output.

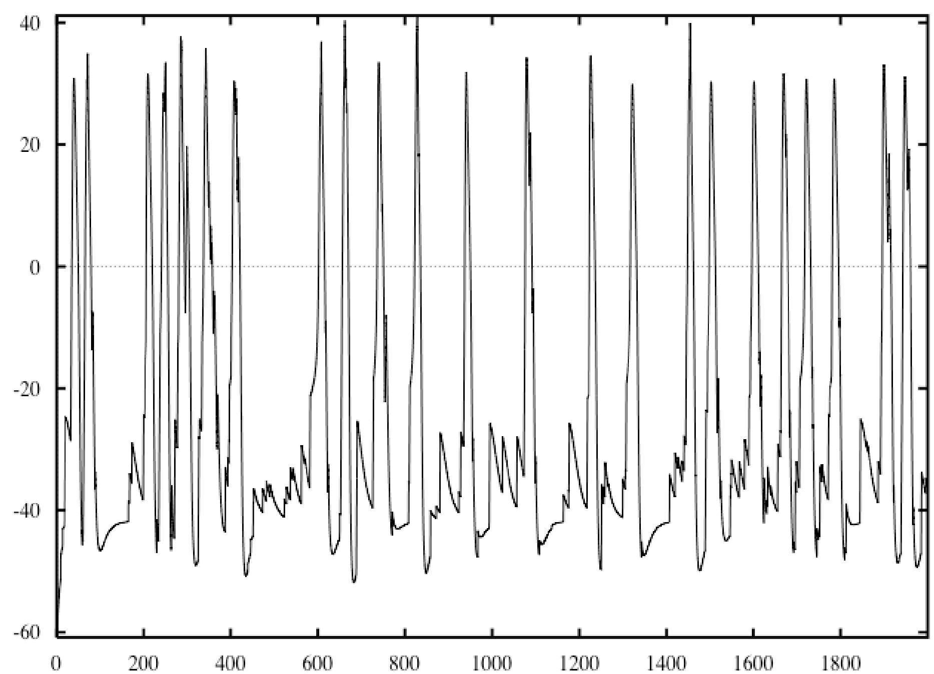


From Gutkin&Ermemntrout(1998)

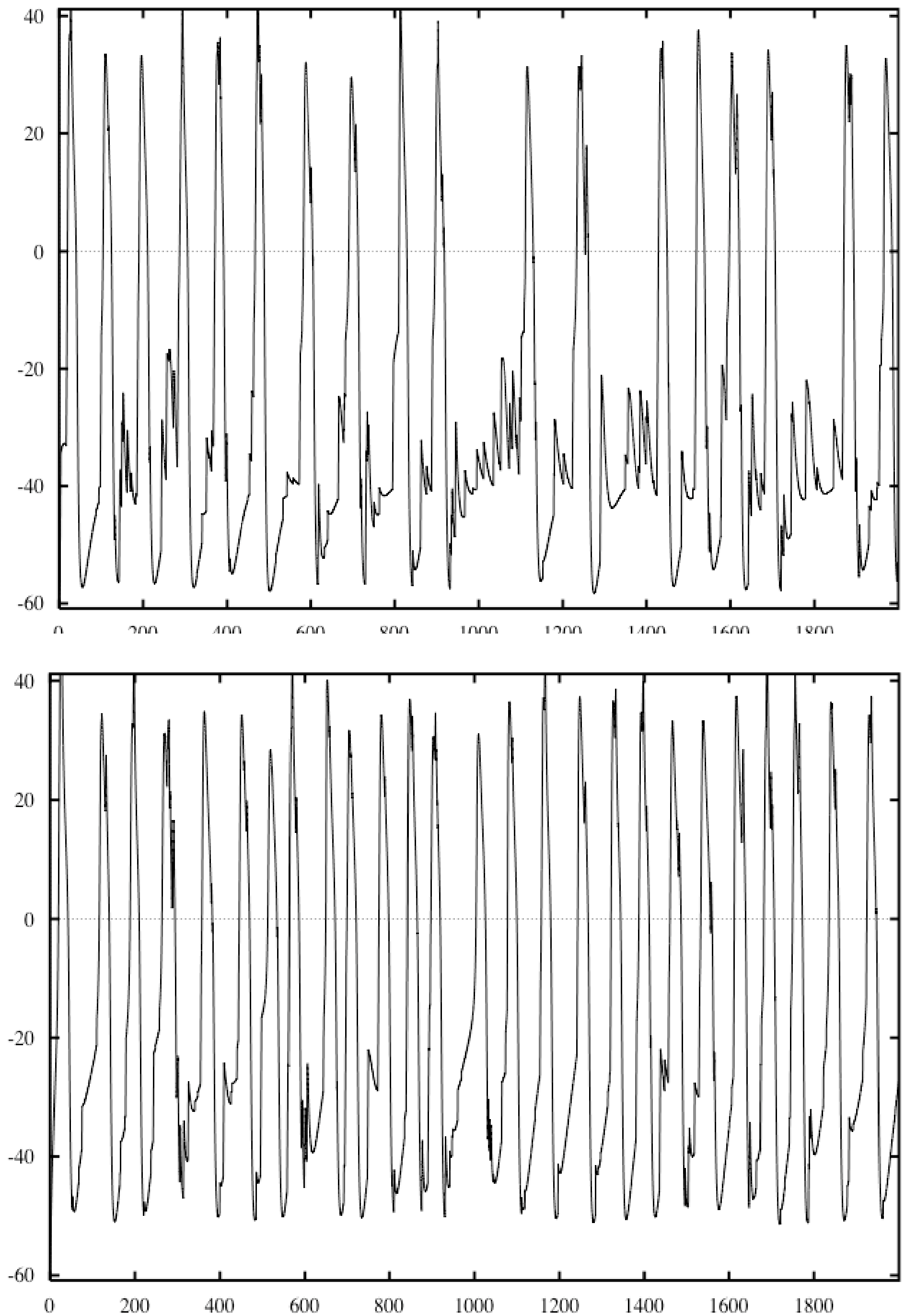
Type I, excitable mode: noisy excitatory / inhibitory input results in variable interspike interval



Type I, oscilatory mode: noisy excitatory / inhibitory input results in more stable interspike interval



Type II, both excitable and oscilatory mode: noisy excitatory / inhibitory input results in very stable interspike interval



A possibly more interesting question: Does the variability encode any information or is it really just noise?

- H1: only average interspike interval encodes information(mean input rate is encoded as mean output rate); individual intervals are simply noise;

- H2: the exact fine temporal structure of the AP train does carry information.

References

- Gutkin, B.S. & Ermentrout, G.B. (1998). Dynamics of membrane excitability determine interspike interval variability: A link between spike generation mechanisms and cortical spike train statistics. *Neural Computation,* 10: 1047-1065.

- Reich, D.S., Victor, J.D., Knight, B.W., Ozaki, T., Kaplan, E. (1997). Response variability and timing of neuronal spike times in vivo. *Journal of Neurophysiology*. 77(5): 2836-2841.

- Softky, W.R. & Koch, C. (1993). The highly irregular firing of cortical cells is inconsistent with temporal integration of random EPSPs. *The Journal of Neuroscience,* 13(1): 334-350.