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 $I=60\mu A/cm^2$)
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 $C_v$, 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, oscillatory mode: noisy excitatory / inhibitory input results in more stable interspike interval
Type II, both excitable and oscillatory 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.
