

Week 5 – part 5 : Stochastic spike firing in integrate-and-fire models



- ✓ 5.1 Variability of spike trains
 - experiments
- ✓ 5.2 Sources of Variability?
 - Is variability equal to noise?
- ✓ 5.3 Three definitions of Rate code
 - Poisson Model
- ✓ 5.4 Stochastic spike arrival
 - Membrane potential fluctuations
- 5.5. Stochastic spike firing**
 - subthreshold and superthreshold

Welcome to this final lecture of week five. We'll put things together now. We will consider fluctuations of spike timing and fluctuations of membrane potential in a simple neuron model-- in the leaky integrate-and-fire model.

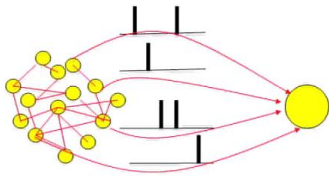
Notes

Summary



0m 04s

Neuronal Dynamics – review: Fluctuations of potential



Passive membrane

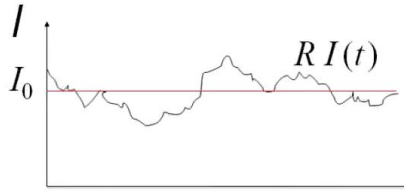
$$\tau \frac{d}{dt} u = -(u - u_{\text{rest}}) + RI(t)$$



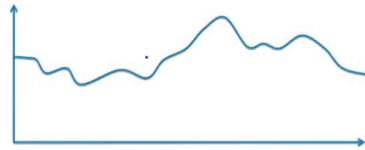
→ Fluctuating potential



Fluctuating input current



$$I^{\text{syn}}(t) = I_0 + I^{\text{fluct}}(t)$$



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So we have seen, for a passive membrane, described by this kind of differential equation, driven by a fluctuating current, that we can calculate the fluctuating membrane potential.

Notes

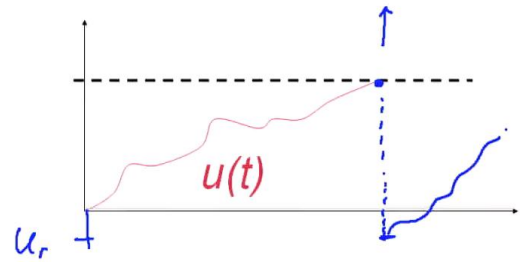
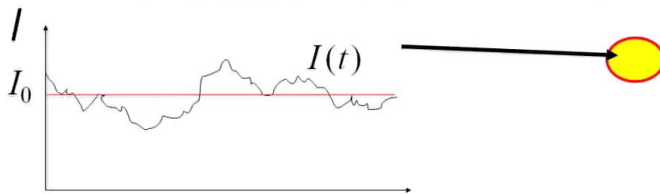
Summary



0m 21s

Neuronal Dynamics – 5.5. Stochastic leaky integrate-and-fire

effective noise current



LIF

$$\tau \frac{d}{dt} u = -(u - u_{rest}) + RI(t)$$

$$I(t) = [I_o + I_{noise}]$$

threshold : IF $u(t) = \mathcal{S}$ THEN $u(t + \Delta) = u_r$

noisy input/
diffusive noise/
stochastic spike
arrival

The main difference to the case of our leaky integrate-and-fire model is that this linear differential equation is combined with a threshold and reset process. If the membrane potential hits the threshold, then a spike is emitted. The spike is a formal event. We take note of the spike. And then we reset the membrane potential to some reset value. And this value here would be u_r . Now, the fluctuating input current continues. And so we would have another rise towards the threshold.

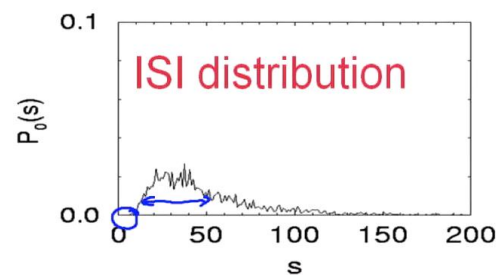
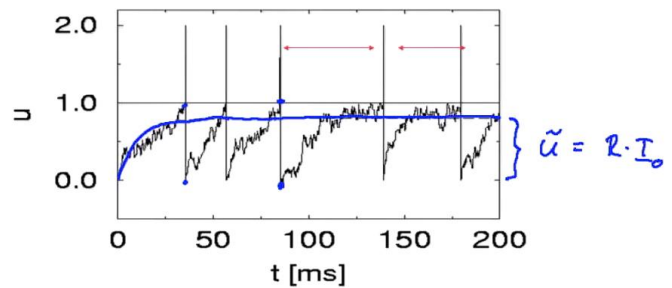
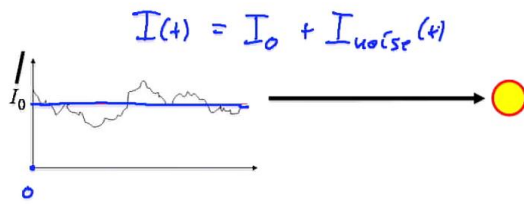
Notes

Summary



0m 37s

stochastic spike arrival in I&F – interspike intervals



So this is the simulation of this situation. It's leaky integrate-and-fire model. If the membrane potential hits the threshold, we reset, in that case, to the equilibrium potential u_r equals 0. Now, we discussed at the beginning of this week the notion of interspike intervals. In such a model, interspike intervals are irregular. And we can build up a distribution of interspike intervals. And what you see is that there's a broad distribution of interspike intervals. Moreover, there are no intervals below, say, two or three milliseconds. And the reason is that once the membrane potential has been reset, it takes some time until the membrane potential is again close to the threshold. Now, what I plotted here with the dashed line is what you would get with a current that's just the mean current. The current is switched on at 0, and then it has a constant value I_0 . If I use this constant value, my neuron, which is then noise-free, would show a membrane potential that exponentially approaches a final value, which is $\tilde{u}$ equals r times I_0 . The total current has this constant part plus a noise part. The noise part is the time dependent part. Without the noisy contribution, this neuron would never spike.

Notes

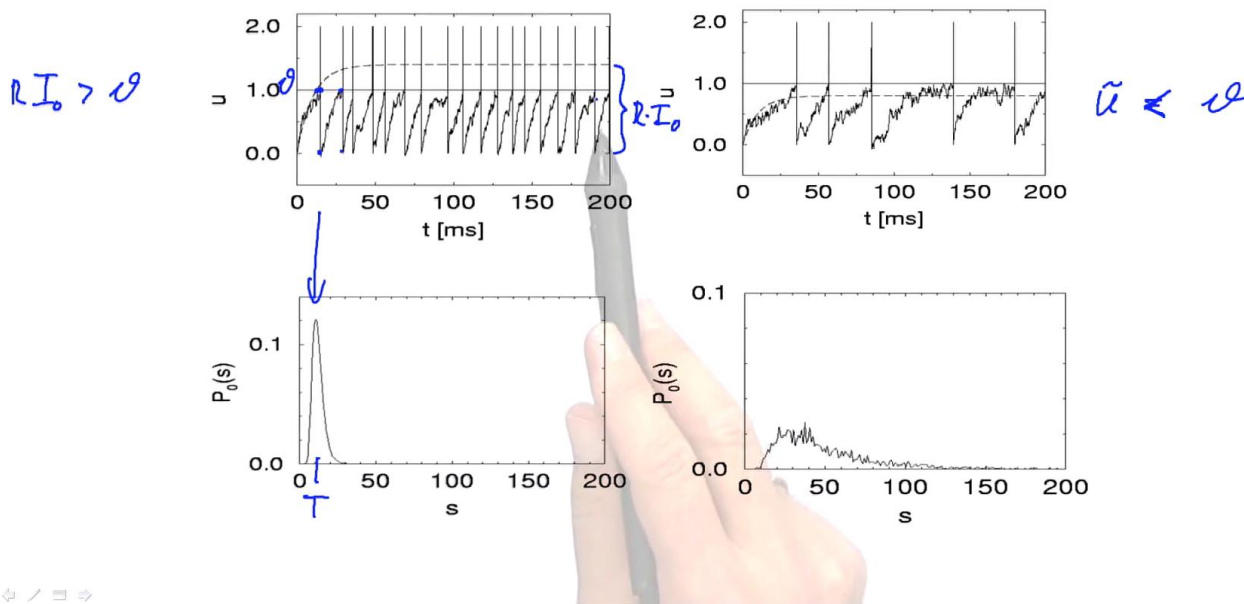
Summary



1m 27s

LIF with Diffusive noise (stochastic spike arrival)

Superthreshold vs. Subthreshold regime



The membrane potential would remain subthreshold. Subthreshold means that this u tilde is smaller than θ , and θ is this value here. It's the threshold for reset. Now, that's the situation which I just discussed. My mean value for a noise-free neuron in the absence of a threshold-- this value is really smaller than θ . And In this case, I get a broad interspike interval distribution. Now, here, my current is stronger. The mean current, without the fluctuation, itself is enough to reach the threshold. So without a threshold, the mean value would be above the threshold θ . That's indicated by the dashed line. But because there's a threshold, of course, I have a spike, I reset, I have another spike, I reset. So in this case, the threshold would be reached even in the absence of the [? fluctuating ?] contribution to the current. And for this superthreshold regime, the interval distribution is sharply peaked. And if the noise level is low, then the peak would sit exactly at the interspike interval, T , which you would find for noise-free stimulation. To say it differently, in this superthreshold regime, the neuron would fire in any case. In the absence of noise, it would fire regularly.

Notes

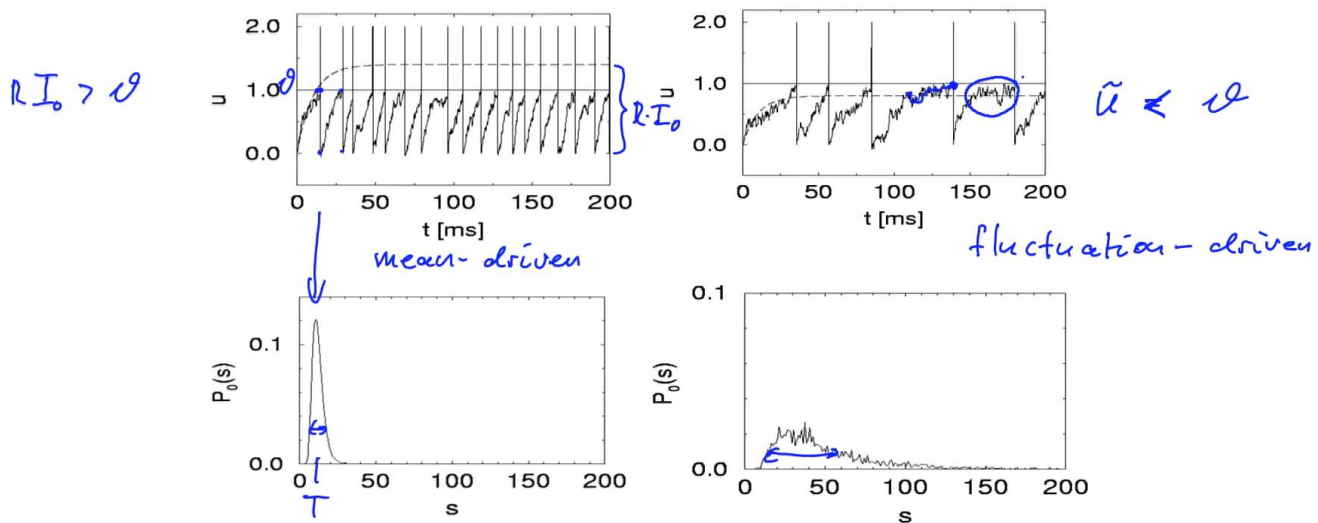
Summary



3m 38s

LIF with Diffusive noise (stochastic spike arrival)

Superthreshold vs. Subthreshold regime



The noise adds a little bit of jitter so that we have a strongly peaking interspike interval distribution. But this interval distribution is narrow. On the other hand, in the subthreshold regime, the interspike interval distribution is much much, much broader. Without the noise term, there would be no spike at all. So it's these tiny fluctuations make that eventually, from time to time, the membrane potential hits the threshold. That's spike firing is driven by the fluctuations. We call this the fluctuation driven regime. On this side here, it's driven by the mean input. The mean input alone would make the neuron fire. Interestingly, if we zoom in on this subthreshold regime, it looks very similar to the in vivo data of subthreshold membrane potential fluctuations.

Notes

Summary

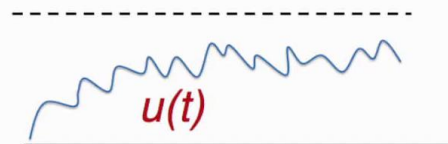


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Neuronal Dynamics – 5.5. Stochastic leaky integrate-and-fire



noisy input/ diffusive noise/
stochastic spike arrival



subthreshold regime:

- firing driven by fluctuations
- broad ISI distribution
- *in vivo* like

To summarize, a leaky integrate-and-fire model driven by a time dependent input current where the input current has a mean and a fluctuating part, also called a noisy input part-- such an integrate-and-fire model can be driven in two different regimes. It can be in the superthreshold regime. In this case, the mean input is enough to fire the neuron, and the neuron executes more or less regular firing. It's nearly periodic with a small jitter. The more interesting regime is the subthreshold regime, because it's in this regime that you see subthreshold membrane potential fluctuations. Spikes are rare events. They are driven by the fluctuations of the membrane potential. In the absence of these fluctuations, the neuron would never fire. Thus, we have identified the subthreshold regime as a particularly interesting regime in relation to *in vivo* data.

Notes

Summary



7m 19s