

Intrinsic and circuit resonance properties in map-based model neurons

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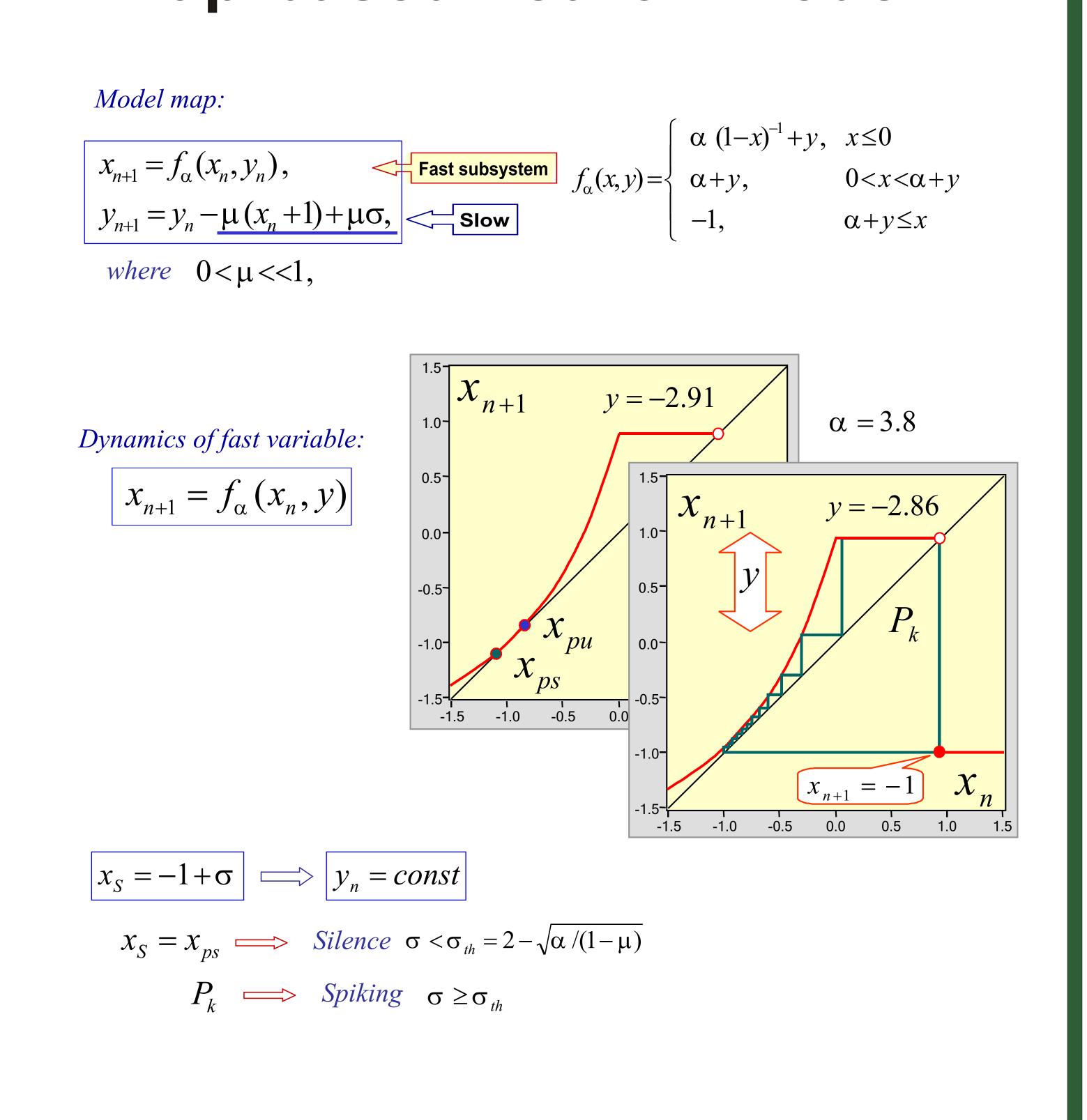
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1. Introduction

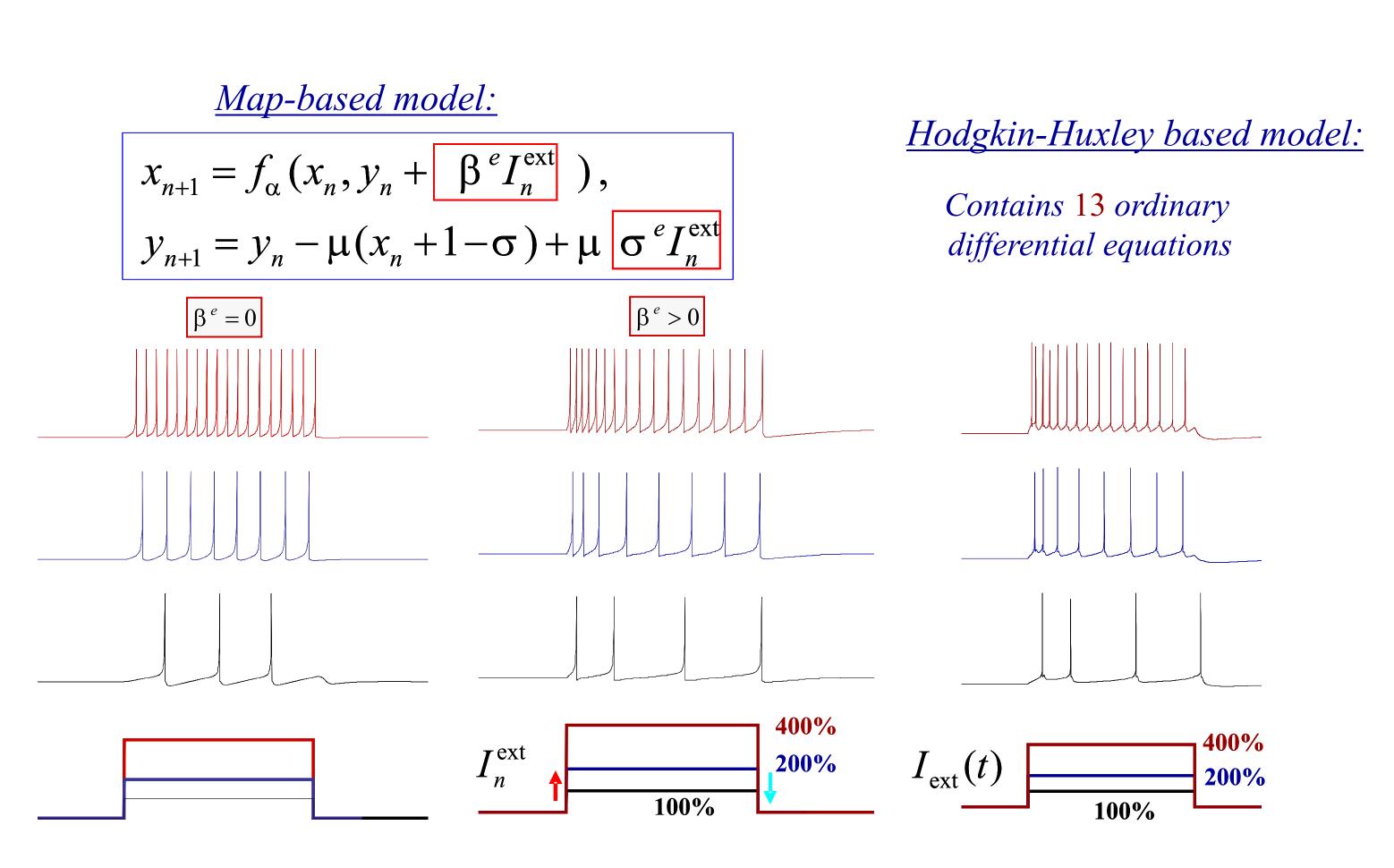
Intrinsic neuronal properties and synaptic interactions control the responses of networks of thousands of neurons by creating spatio-temporal patterns of activities that are used for sensory processing, memory formation and other cognitive tasks. The modeling of such systems requires single neuron models capable of displaying both realistic response properties and computational efficiency. We use difference equations (map-based models) to simulate the individual dynamics of neurons and synapses. With this approach, networks containing hundreds of thousands of neurons of different cell types can be simulated within realistic times using a conventional workstation. The dynamics of the model was tuned to fit experimental data and displayed complex intrinsic resonance properties found in vitro and in simulations with conductance-based models.

2. Map-based neuron model



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2. Models of fast-spiking (FS) and regular spiking (RS) cells



3. Cellular resonance

Each cell in the network received a Poisson distributed train of spikes with periodically modulated mean rate of spiking: $R(f_m) = \Omega - 0.5 \Omega \sin(f_m n)$, where $\Omega = 200 \text{ Hz}$, n is time in iterations, f_m is

the frequency of modulation (0-30 Hz).

4. Spike-timing reliability

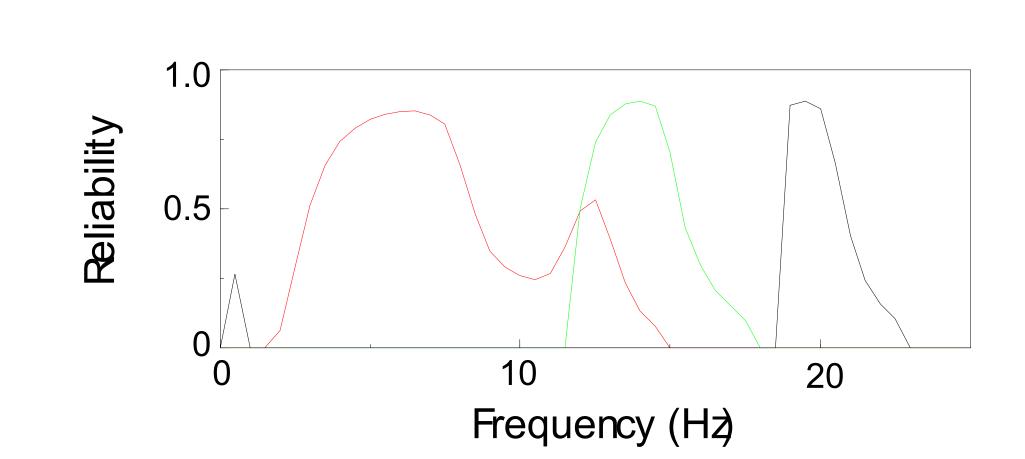
$$STR = \sum_{i=1}^{N} \sum_{\substack{k=1 \ k \neq i}}^{N} \frac{u_i u_k}{\sqrt{u_i^2 u_k^2}}$$

$$u_i = s_i(n) \otimes G(n)$$

$$G(n) = \exp\left(-\left(\frac{n}{\Delta}\right)^2\right)$$

The reliability of responses in RS (top panel) and FS (bottom panel) neurons. Different curves correspond to 3 different stimulation amplitudes ($g_{syn1} < g_{syn2} < g_{syn3}$).

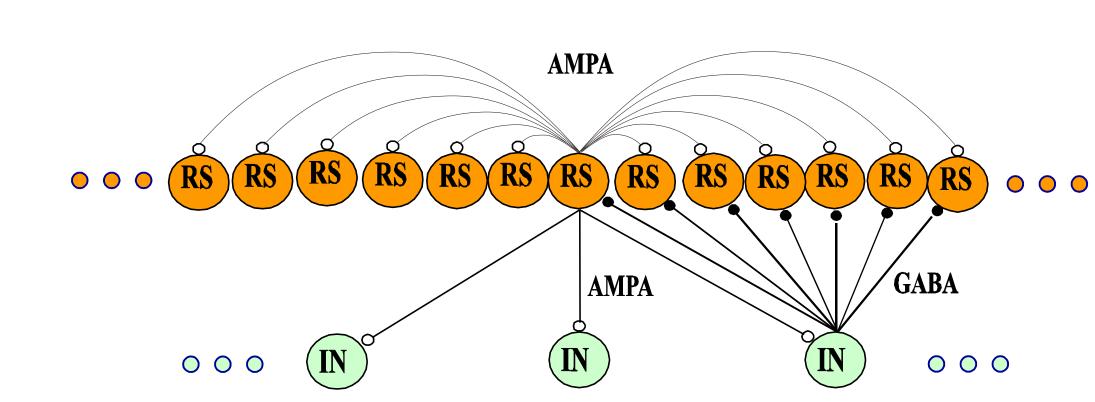
4.1 Control of STR by the model parameters



Increasing μ and σ "depolarizes" the neuron closer to its firing threshold and shifts the reliability curve to higher frequencies.

5. Network resonance

5.1 Topology of the network model



Map-based model for a synapse with depression

$$\{I_{n+1}^{syn}, d_{n+1}\} = \begin{cases} \{\gamma I_n^{syn} - g_{syn} d_n (x_n^{post} - x_{rp}), (1-\eta) d_n\}, & \text{spike}^{pre}, \\ \{\gamma_S I_n^{syn}, 1 - (1-\rho)(1-d_n)\}, & \text{otherwise.} \end{cases}$$

5.2 SRT in the network model

No inhibitory feedback

Inhibitory feedback

Frequency dependence of spike timing reliability in the network model with different strength of excitatory coupling. Left panel - the network without inhibitory IN-PY coupling. Right panel - the network with inhibitory feedback.

5.3. Effect of synaptic coupling on STR

Effect of PY-IN coupling

Effect of IN-PY coupling

Frequency dependence of STR in the network model as a function of inhibitory feedback. Left panel shows the effect of increasing excitatory (AMPA-mediated) input from pyramidal cells onto the inhibitory interneurons. Right panel displays the effect of increasing GABA-A conductance mediated by inhibitory interneurons.

6. Summary

Our study demonstrated: (1) For periodic inputs (sine waves or rate modulated Poisson distributed spike trains) map-based neurons responded with high reliability within a specific frequency range (typically 3-6 Hz). (2) In regular spiking neurons the reliability decreased to zero as the frequency of the stimuli got below some threshold level (1-2 Hz) while in interneurons the reliability remained finite. (3) A network of excitatory cells and inhibitory interneurons can enhance and fine-tune reliability of responses to external stimuli within a broader range of frequencies than in the isolated neurons.