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Predicting n:1 locking in pulse coupled two-neuron networks using phase resetting theory

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Background

Harmonic locking has been observed between breathing and heart beat rhythms, in hippocampal slices between interneurons firing at gamma and pyramidal neurons firing at beta frequencies with missed gamma beats and in model networks between theta and gamma rhythms. Existence and stability criteria for harmonic locking modes were derived for two reciprocally pulse coupled oscillators based on their first and second order phase resetting curves (PRCs). These methods were then tested using two reciprocally inhibitory Wang and Buzsaki model neurons.

Methods

PRCs were generated in an open loop configuration and applied to the analysis of the circuit under the assumption that after each perturbation the trajectory returns near its limit cycle and that the synaptic inputs received in the closed loop circuit remain similar to those used to generate the PRCs [1]. Figure 1A shows how an assumed firing pattern can be used to produce a map, which can then be linearized for a stability analysis. The dots indicate a variable number of spikes in the faster neuron 1. The periodicity criteria in this case are ts1 [n] = tr2 [n], ts21 [n] = tr11 [n], ts22 [n] = tr12 [n] with the intervals defined as shown in the figure. The periodicity criteria can be rewritten in

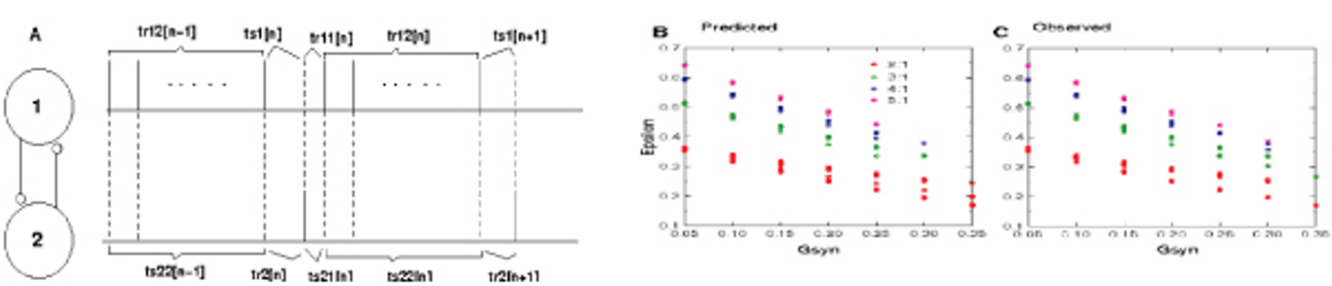

Figure 1
A) A schematic of an n:1 locking is shown. **B-C)** Comparison of predicted and observed modes of harmonic locking. Here, ε represents the difference in applied current which produces a difference in the intrinsic frequency of the two neurons and *Gsyn* is the synaptic conductance strength.

terms of the relevant phases φ_{ij} which denote the phase of the *ith* neuron when it receives *jth* input from the other neuron. If one then assumes the phase at which the slower neuron receives the *Nth* input in its cycle, the periodicity criteria can be used to calculate the value of the phase. If the calculated value matches the assumed value, then a mode is predicted to exist. These modes can be determined graphically as the zeros of the function defined as the difference between the assumed and calculated values. A stability analysis of the linearized map provides a single eigenvalue for the map, provided the second order resetting of all but the last input in a cycle is disregarded.

Results

Previously, Ermentrout [2] derived existence and stability criteria for *n*:*m* locking assuming weak coupling using averaging theory. The methods presented here do not require the coupling to be weak and are easier to implement and apply to real neurons since only the PRCs are required. Both methods agree in the weak coupling regime (not shown), but the new method shows good agreement with the observed modes from the simulated network even in strong coupling regimes (Figure 1BC).

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References

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