Interplay of synchronization modes and synaptic plasticity in a system of class I neurons

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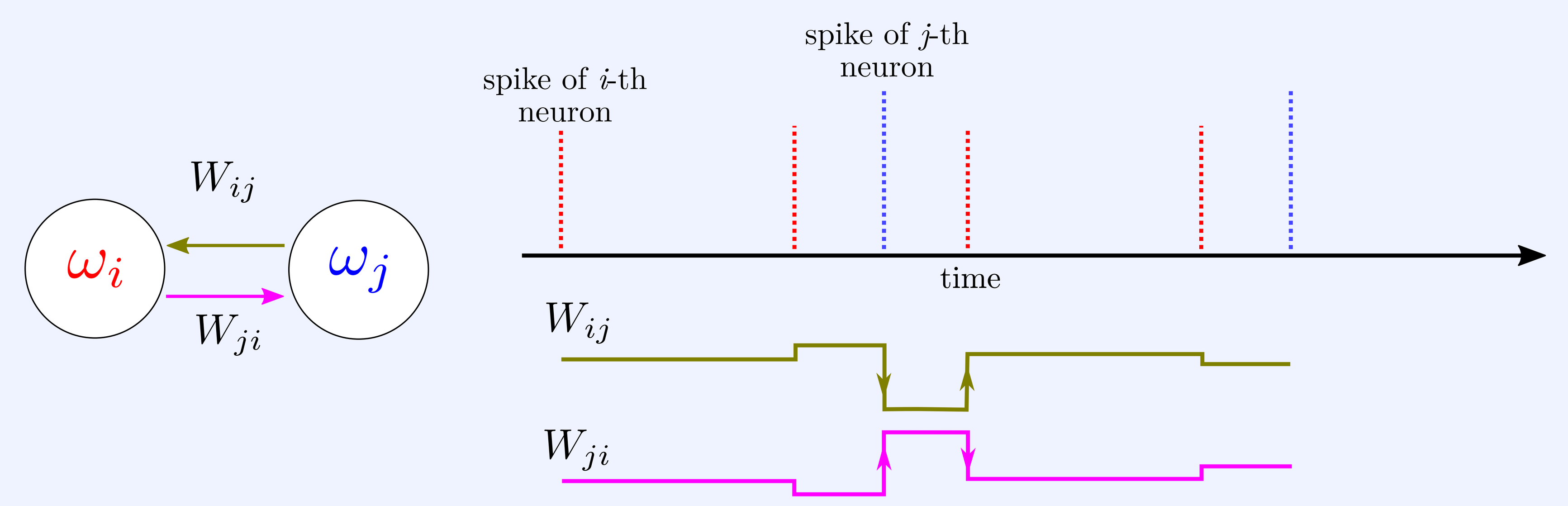
Introduction

Synchronization among neurons relies on a feedback loop between individual neuron dynamics, network structure, and the strength of coupling between neurons. We investigate this interaction by using pulse-coupled class I neurons, whose synaptic weights are governed by spike-timing-dependent plasticity (STDP) rule.

We choose class I neuronal models due their ability to generate action potentials with arbitrarily low frequency, depending on the strength of the applied current. Such models are natural candidates for analyzing the effects of plasticity in neural systems with widely varying frequencies. In this work we use three models: quadratic integrate and fire (QIF), Wang-Buzsáki (WB) and Morris-Lecar (ML).

STDP is a phenomenon in which the precise timing of spikes affects the sign and magnitude of changes in synaptic strength. It depends on interspike time interval between i-th and j-th neurons. The smaller interspike interval is, the larger impact on coupling strength W_{ij} it has.

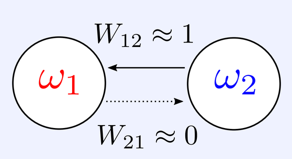
Example of synaptic strength evolution:



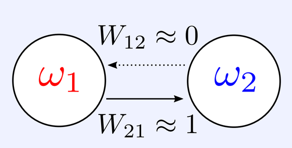
Analysis of two neurons

For two coupled neurons three different network asymptotic modes have been found.

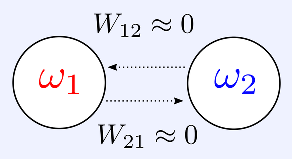
Mode (i): the link between neurons become unidirectional so that the slower neuron enslaves the faster neuron ($\omega_1 > \omega_2$);



Mode (ii): unidirectional link from faster to slower neuron emerges;



Mode (iii): both neurons become disconnected and desynchronized.



The effect of STDP on neuronal synchronization can be demonstrated through the change of the Arnolds tongue (AT). The analytical expression of AT for all class I neurons can be found near resonances. For QIF neurons AT can be found in general case. In the next column you see AT for different neuron models. Blue dotted lines represent AT of the static network, yellow dashed lines - with enabled STDP rule, red lines - analytical AT's approximation. Blue areas represent numerically estimated AT.

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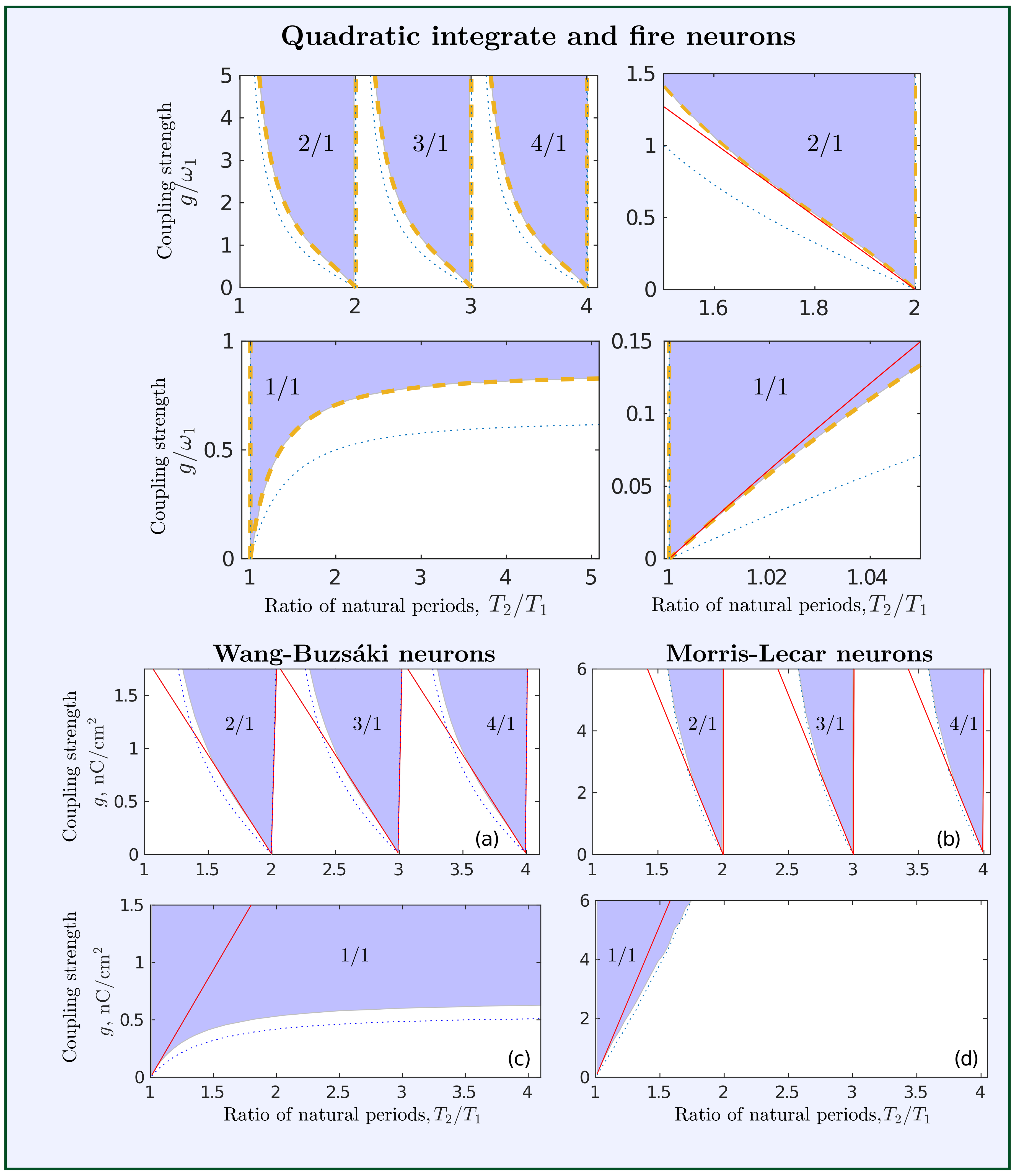

Network

Due to existence of mode (i), slow neurons in large plastic networks can become pacemakers. Bellow you can see conectivity matrix plot, at random initial conditions and after long run. Three clusters are formed. The stem plot shows that the largest cluster oscillate with period of 21st neuron, which is the fastest in the slower neurons group (21-25). From the coresponding network graph we see, that all three modes from two neurons case can be detected in larger networks.