Synchronization of distant cortical areas through thalamic relay

Leonardo L. Gollo[1] , Javier Iglesias[2] and Alessandro E. P. Villa[2] , Claudio Mirasso[1]

1 IFISC (CSIC-UIB) Palma de Mallorca – Spain.
2 NeuroHeuristic Research Group, UJF, Grenoble – France.
Information Systems Department ISI, UNIL, Lausanne – Switzerland.

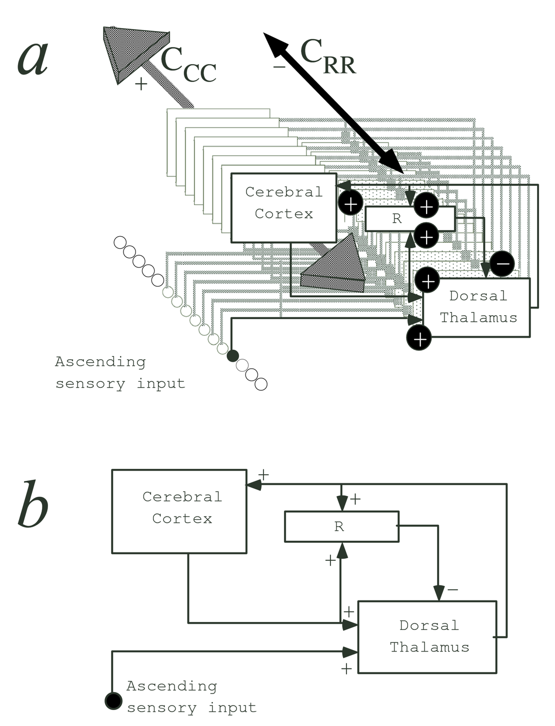
leonardo@ifisc.uib-csic.es

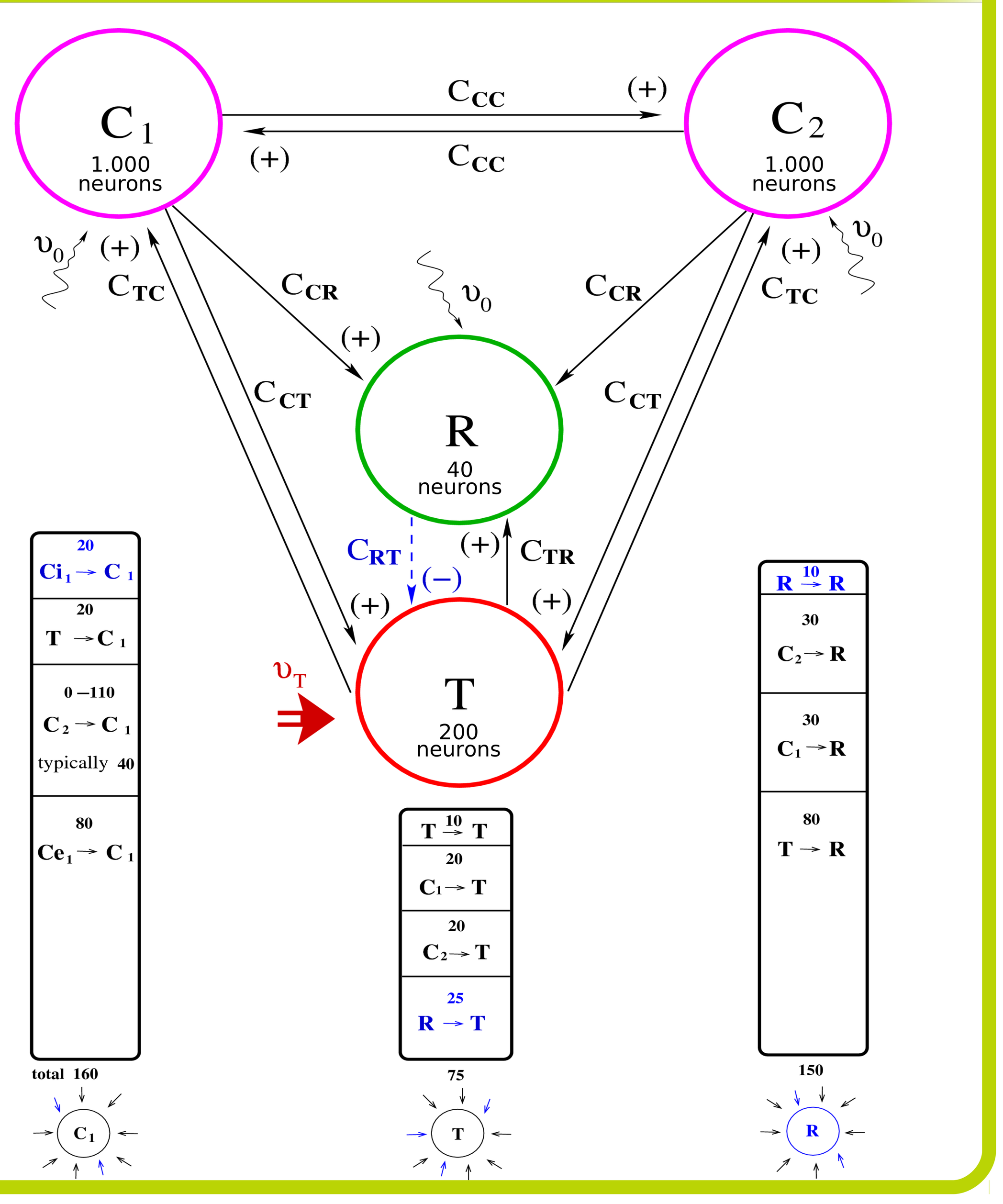
Abstract

Binding of features and information which are processed at different cortical areas is generally supposed to be achieved by synchrony despite the non-negligible delays between the cortical areas. We study the dynamics and synchronization properties of a simplified model of the thalamocortical circuit where different cortical areas are interconnected with a certain delay, that is longer than the internal time scale of the neurons. We find that the thalamus could serve as a central subcortical area that is able to generate zero-lag synchrony between distant cortical areas by means of dynamical relaying (Vicente et al., 2008). Our results show that the model circuit is able to generate fast oscillations in frequency ranges like beta and gamma bands triggered by an external input to the thalamus formed by independent Poisson trains. We propose a control mechanism to turn “On” and “Off” the synchronization between cortical areas as a function of the relative rate of the external input fed into dorsal and ventral thalamic neuronal populations. The current results emphasize the hypothesis that the thalamus could control the dynamics of the thalamocortical functional networks enabling two separated cortical areas to be either synchronized (at zero-lag) or unsynchronized. This control may happen at a fast time scale, in agreement with experimental data, and without any need of plasticity or adaptation mechanisms which typically require longer time scales.

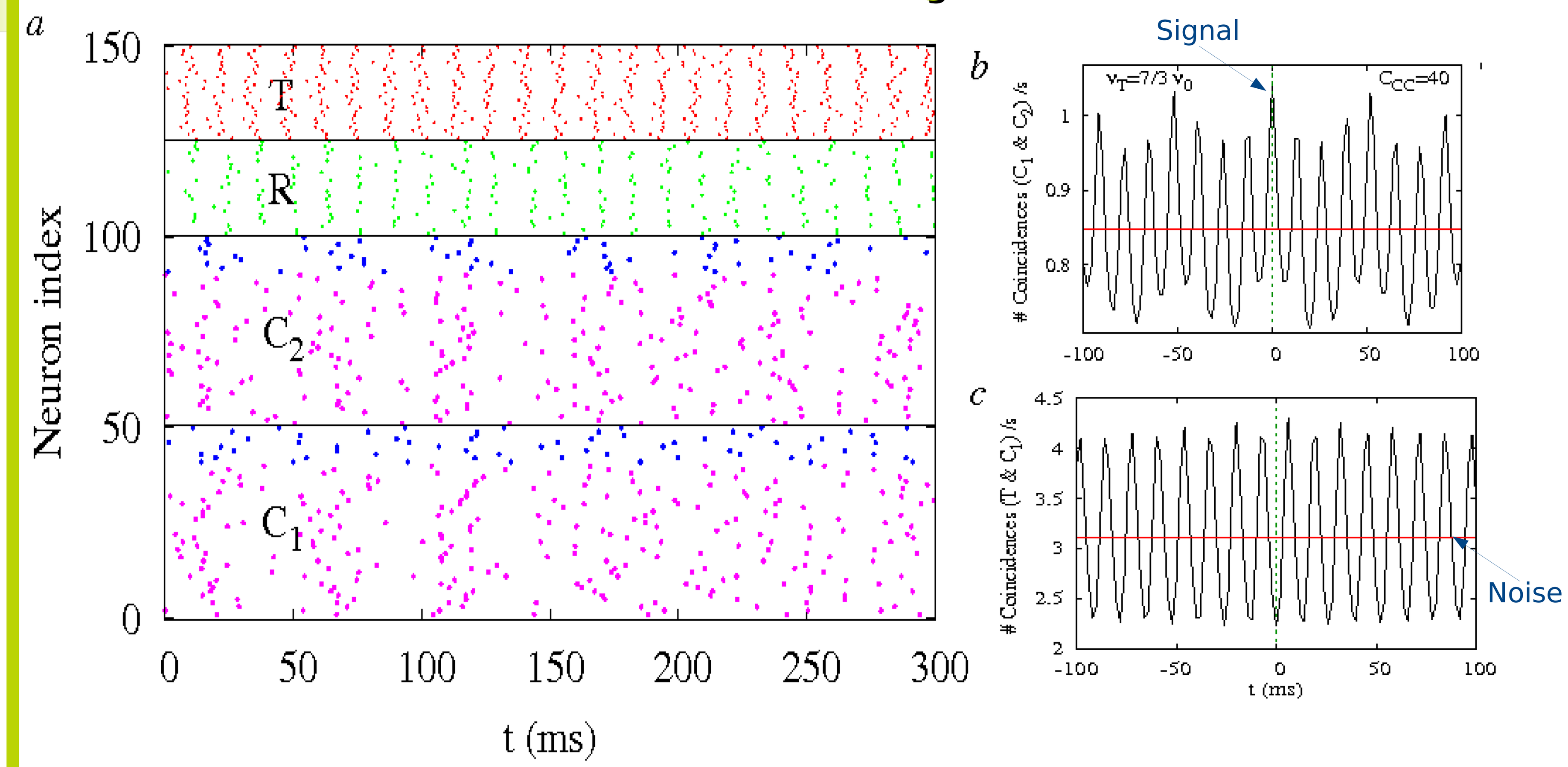
Thalamocortical circuit

Schematic thalamocortical modular organization and our simplified model circuit of Integrate and Fire spiking neurons driven by 450 external neighbors modeled as a Poisson process with rate ν_0 =10 Hz.





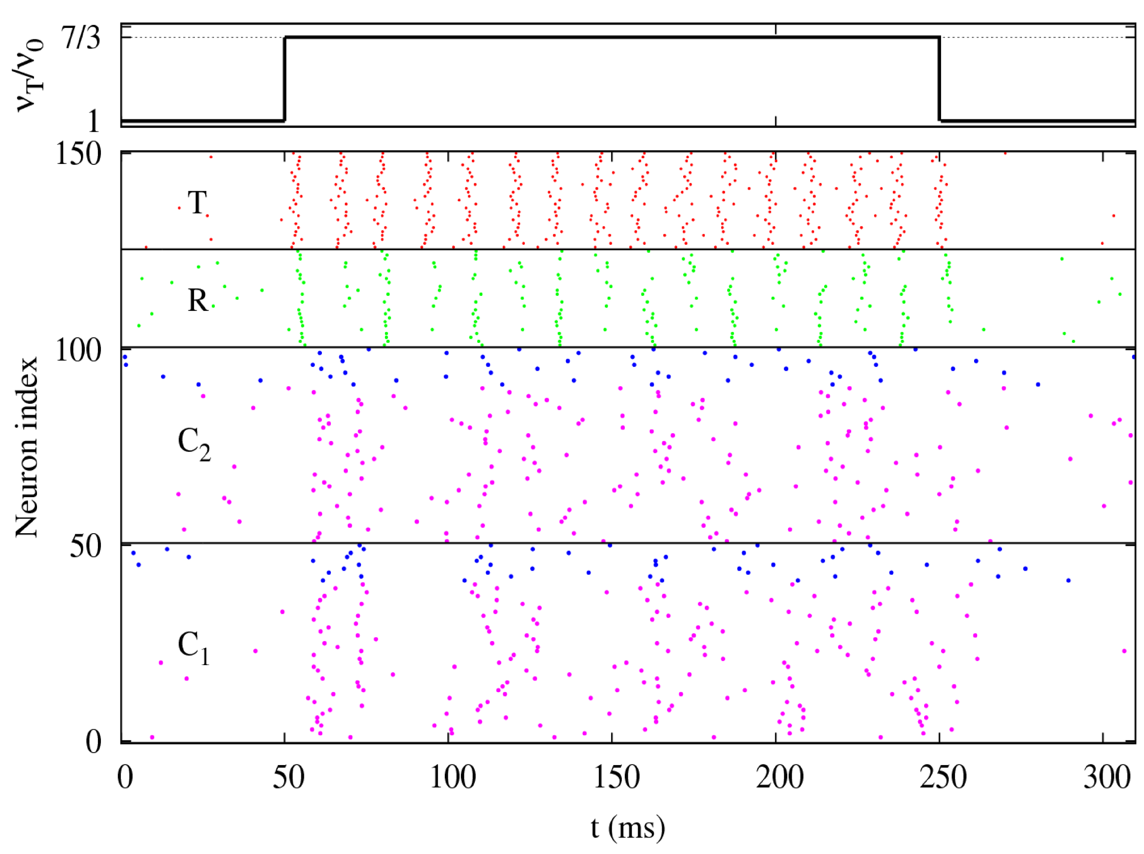
Thalamocortical dynamics



a) Raster plot of 150 random neurons (50 from each cortical population and 25 from R and T) displays zero-lag cortical synchrony and skipping cycles.

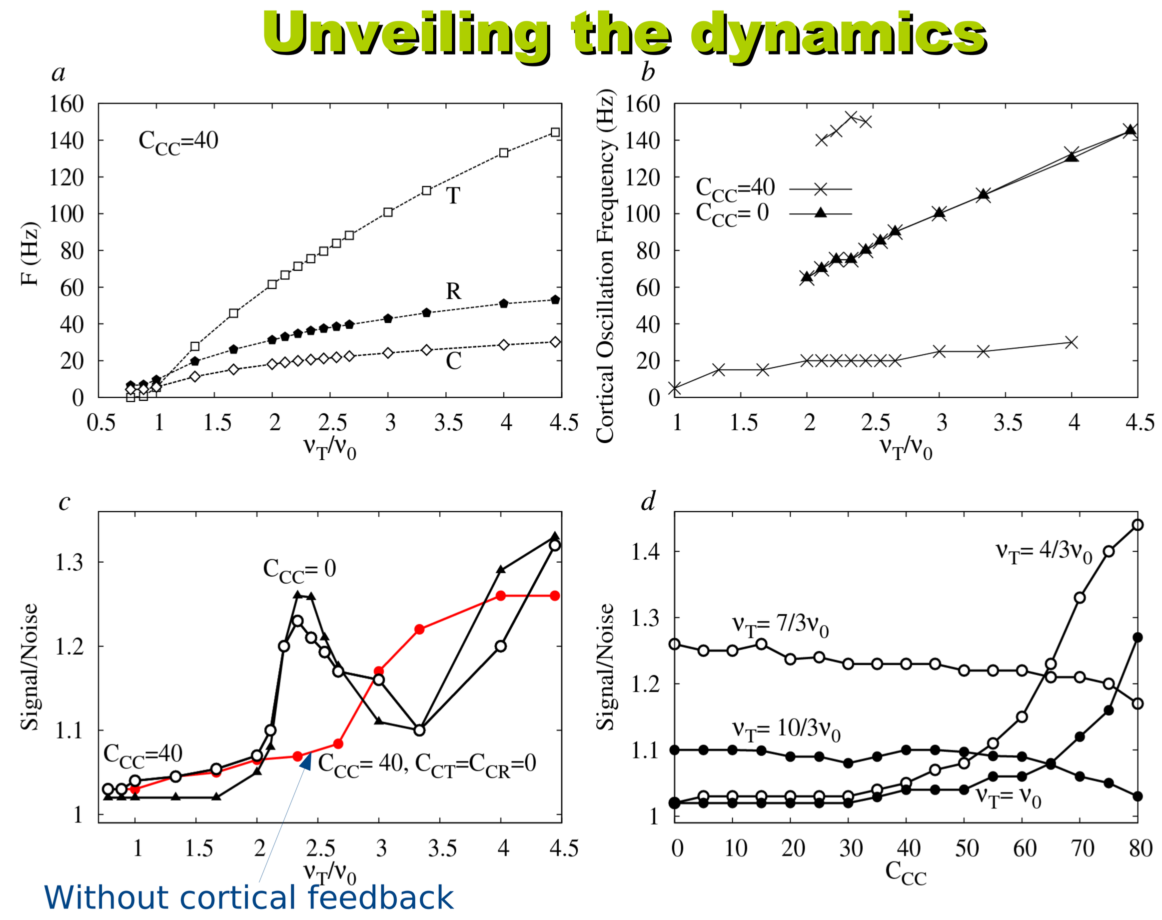
Cross-correlograms of 100 trials of 3.000 random neuron pairs of different populations show multiple cortical oscillatory frequency, zero-lag cortical synchrony (b) and out of phase correlation between T and C (c).

On-Off synchrony control



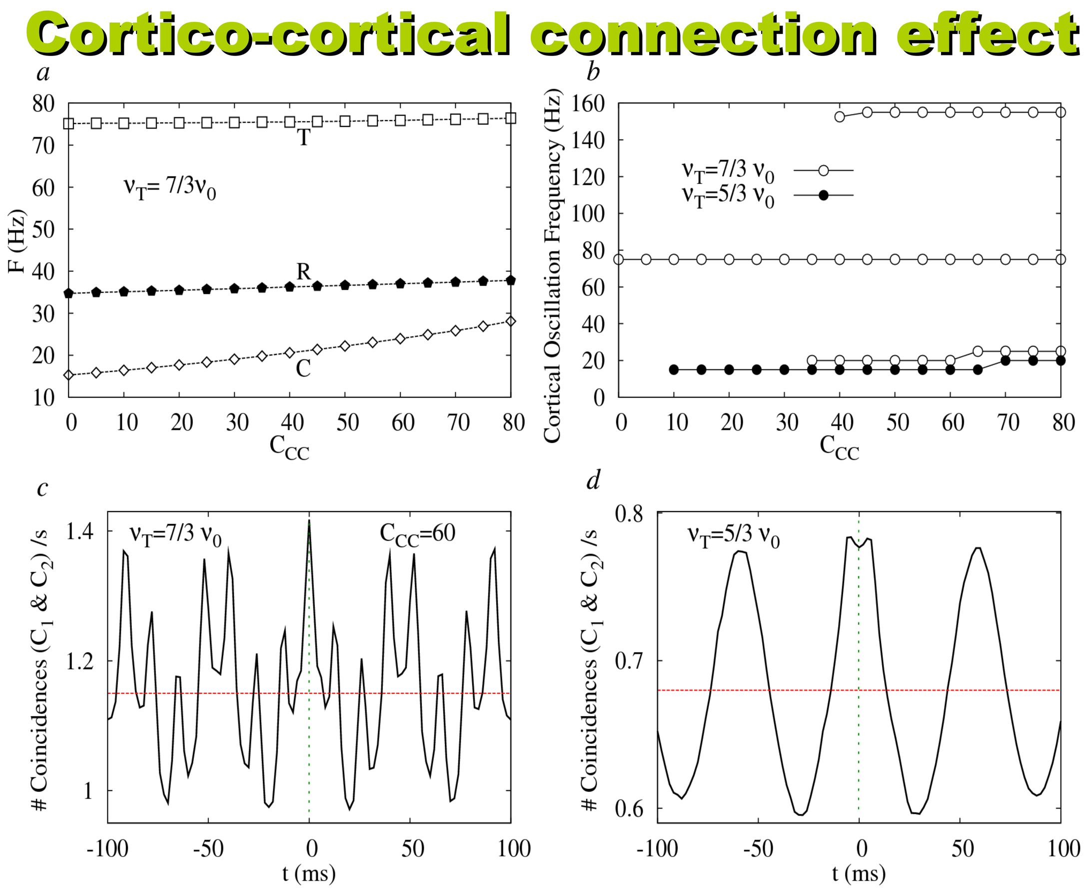
Cortico-cortical synchrony controlled by external driving innervated into the thalamic populations.

Unveiling the dynamics



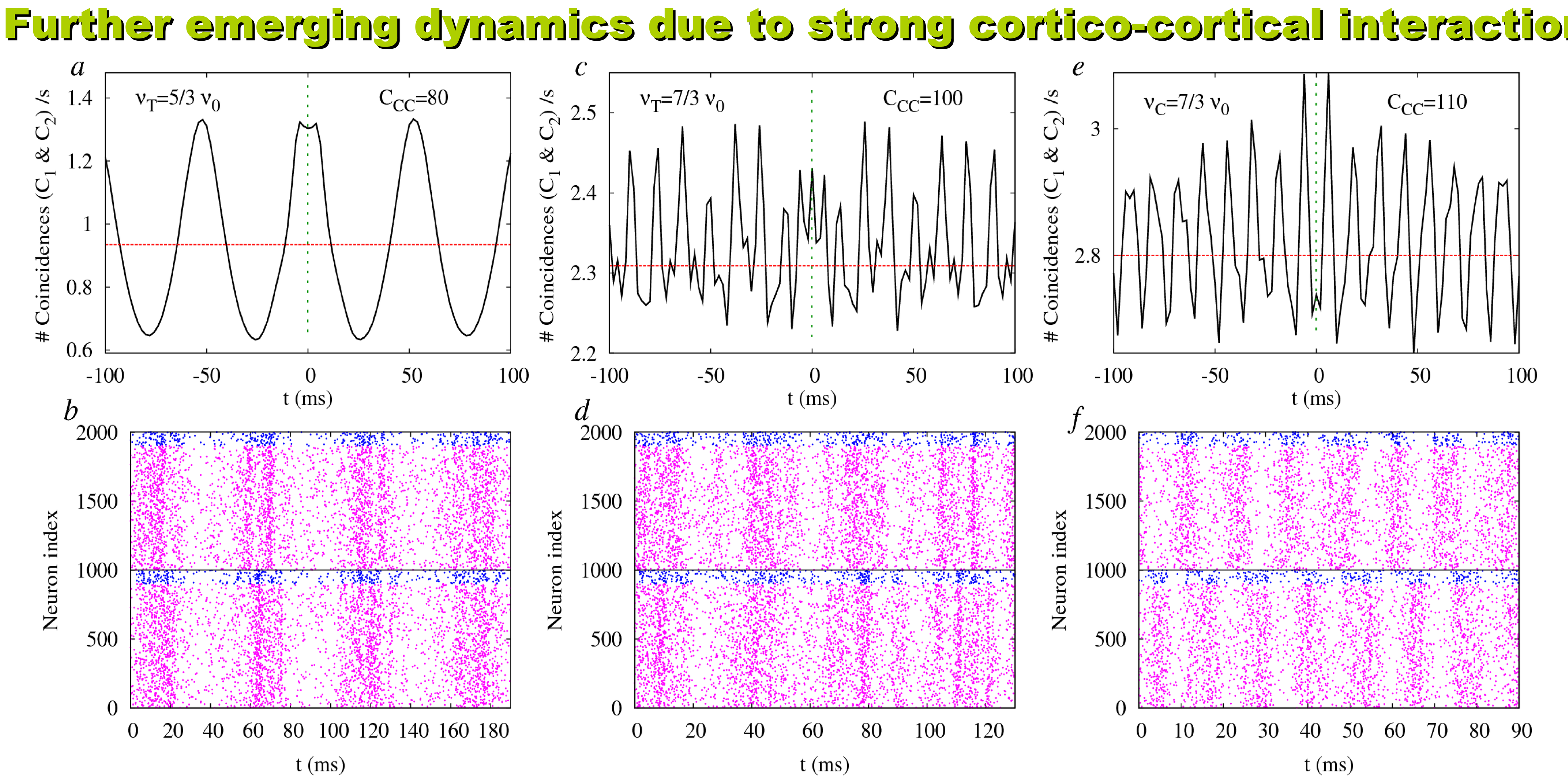
Mean firing rate, multiple oscillatory frequency and Signal/Noise can be quantified from highly fluctuating systems by averaging over trials.

Cortico-cortical connection effect



Results are robust against cortico-cortical connectivity.

Further emerging dynamics due to strong cortico-cortical interaction



Master-slave (a,b); zero-lag and leader-laggard competition (c,d); out-of-phase cortical oscillation (e,f) can appear in the thalamocortical system with large cortico-cortical connections .

Conclusions

Supported by extensive numerical simulations of a spiking neuron model of the thalamocortical circuit we suggest that:

>The thalamus cold be a central subcortical area capable of facilitating zero-lag synchrony of distant cortical areas via the phenomenon of dynamical relaying;

> the thalamus itself is able to generate fast oscillations due to the thalamic intrinsic properties, even under the presence of an uncorrelated input;

> more importantly, the thalamus could control the dynamics of the thalamocortical functional networks, in a way that it enables two separated cortical areas to synchronize (at zero-lag) or desynchronize their dynamical states.

References

> Vicente, R., Gollo, L. L., Mirasso, C. R., Fischer, I., Pipa, G., 2008. Dynamical relaying can yield zero time lag neuronal synchrony despite long conduction delays. Proc. Natl. Acad. Sci. 105, 7157–17162.

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