CRITICALITY and NETWORK STRUCTURE drive emergent oscillations in a stochastic WHOLE-BRAIN MODEL

Brain Criticality Meeting 2022

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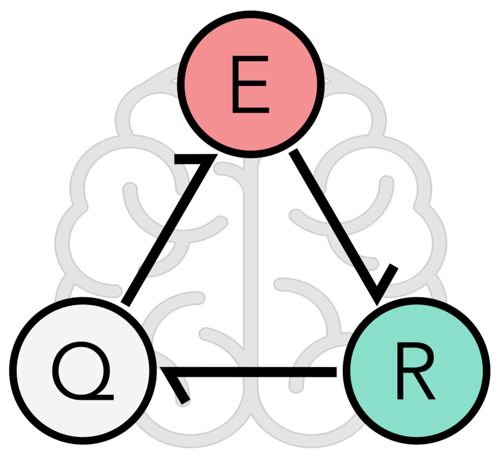
J. Phys. Complex. 3 025010 (2022)

Dynamical systems at their **CRITICAL POINT** are able to generate complex emergent patterns out of simple microscopical rules. In turn, their temporal evolution is also shaped and constrained by the underlying **NETWORK STRUCTURE**.

- What can we say about these combined effects in **WHOLE-BRAIN MODELS**?
- What is their role in driving **EMERGENT COLLECTIVE BEHAVIORS**?

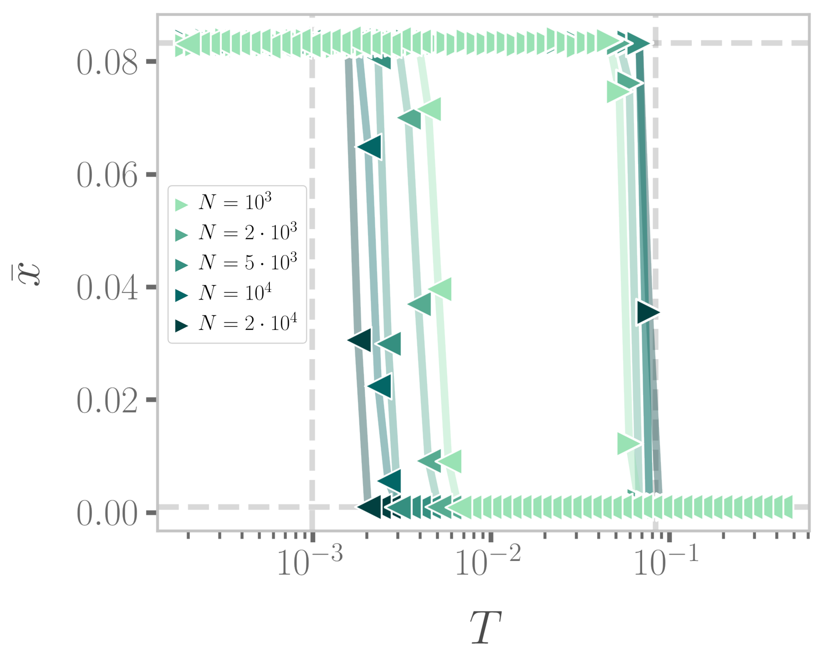
A STOCHASTIC WHOLE-BRAIN MODEL

- We study a three-state model - QUIESCENT, EXCITED or REFRACTORY - used by Haimovici et al. (PRL, 2013) to match resting state networks when tuned to a percolation-like critical point. However, not much was known about its dynamics!



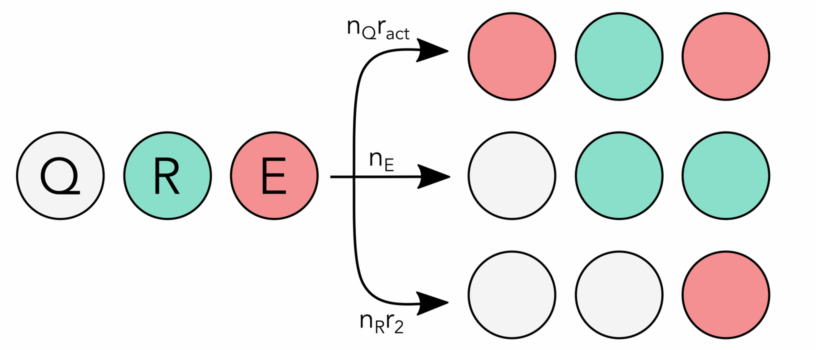
$$\mathrm{Q} \to \mathrm{E} \quad \text{if } \sum_j W_{ij} n_j^{(\mathrm{E})} > T \text{ or with prob. } r_1$$
$$\mathrm{E} \to \mathrm{R} \quad \text{with prob. } 1$$
$$\mathrm{R} \to \mathrm{Q} \quad \text{with prob. } r_2$$

- We derive the exact **MEAN-FIELD APPROXIMATION** from the microscopic dynamics and study its behavior as we change the control parameter T, the input threshold for exciting a node.

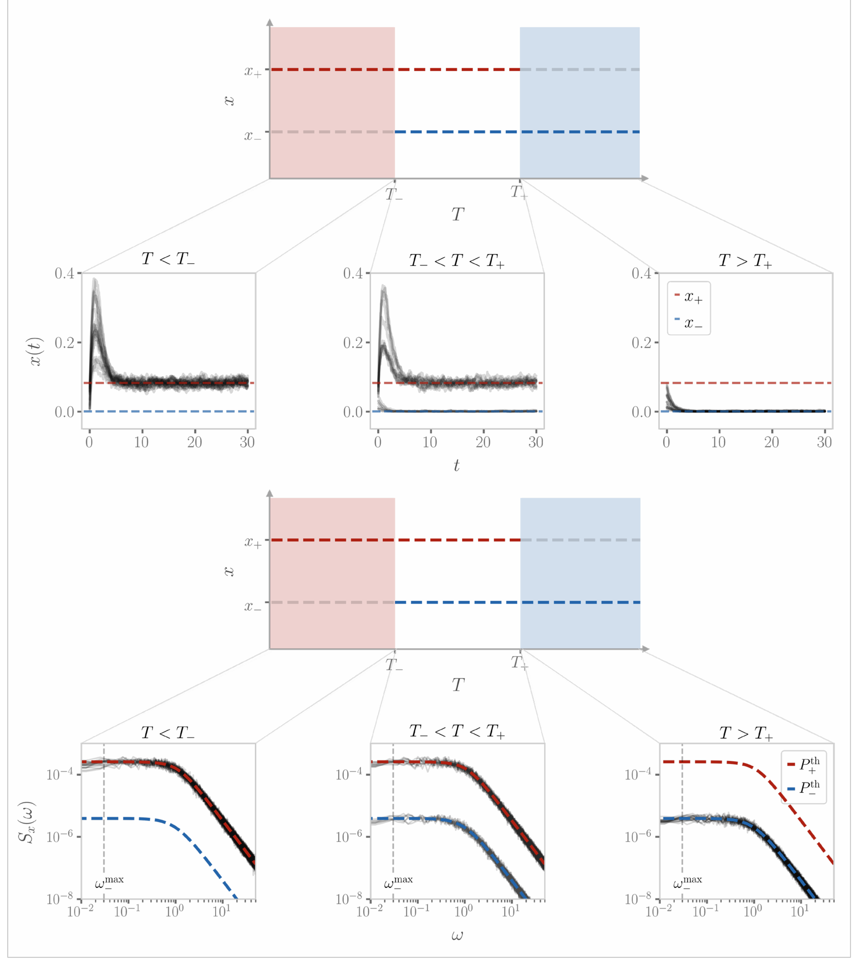


We find no critical transition, but a **BISTABLE REGION** with hysteresis cycles between a high-activity and a low-activity fixed points.

MEAN-FIELD APPROXIMATION

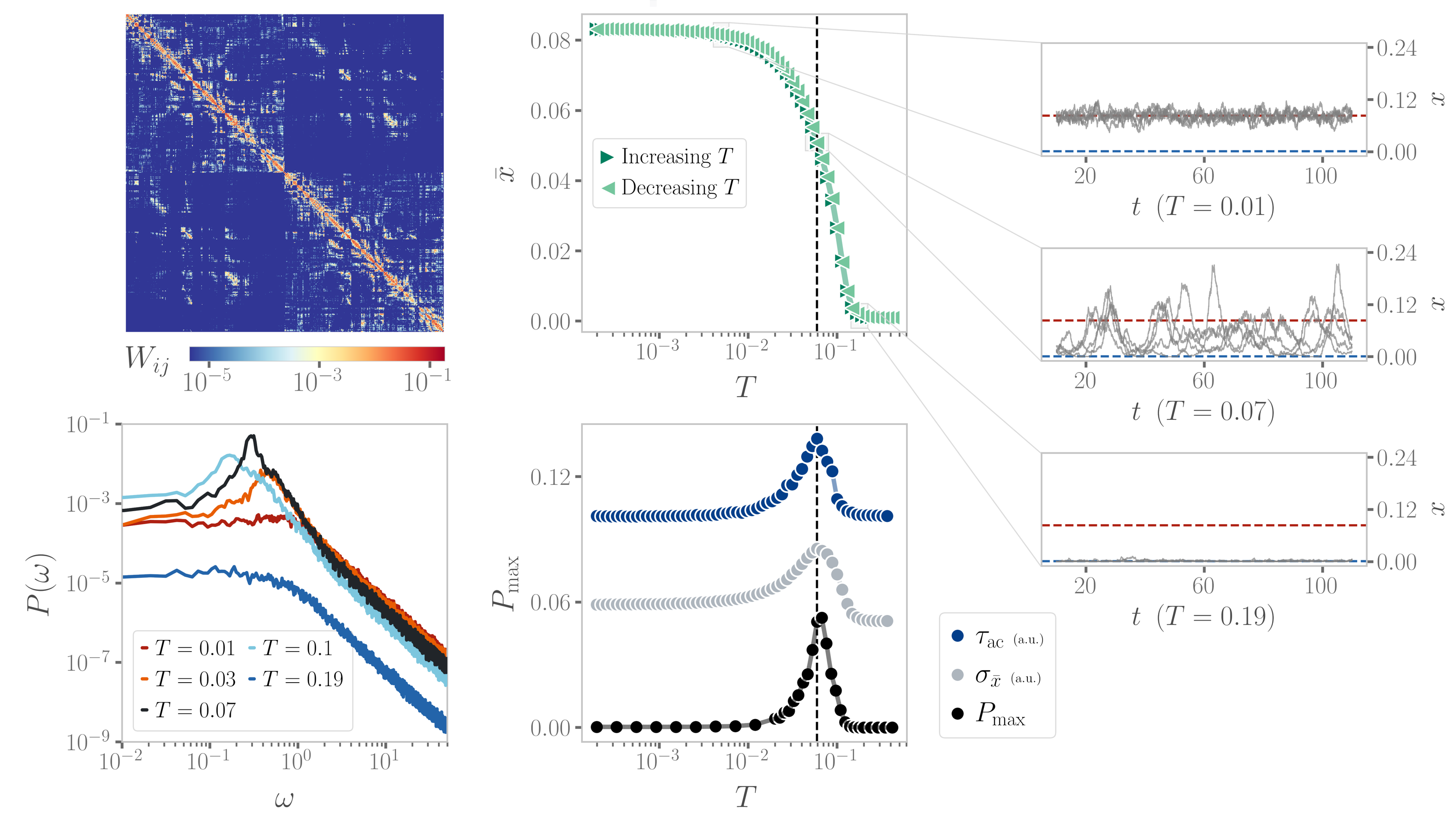


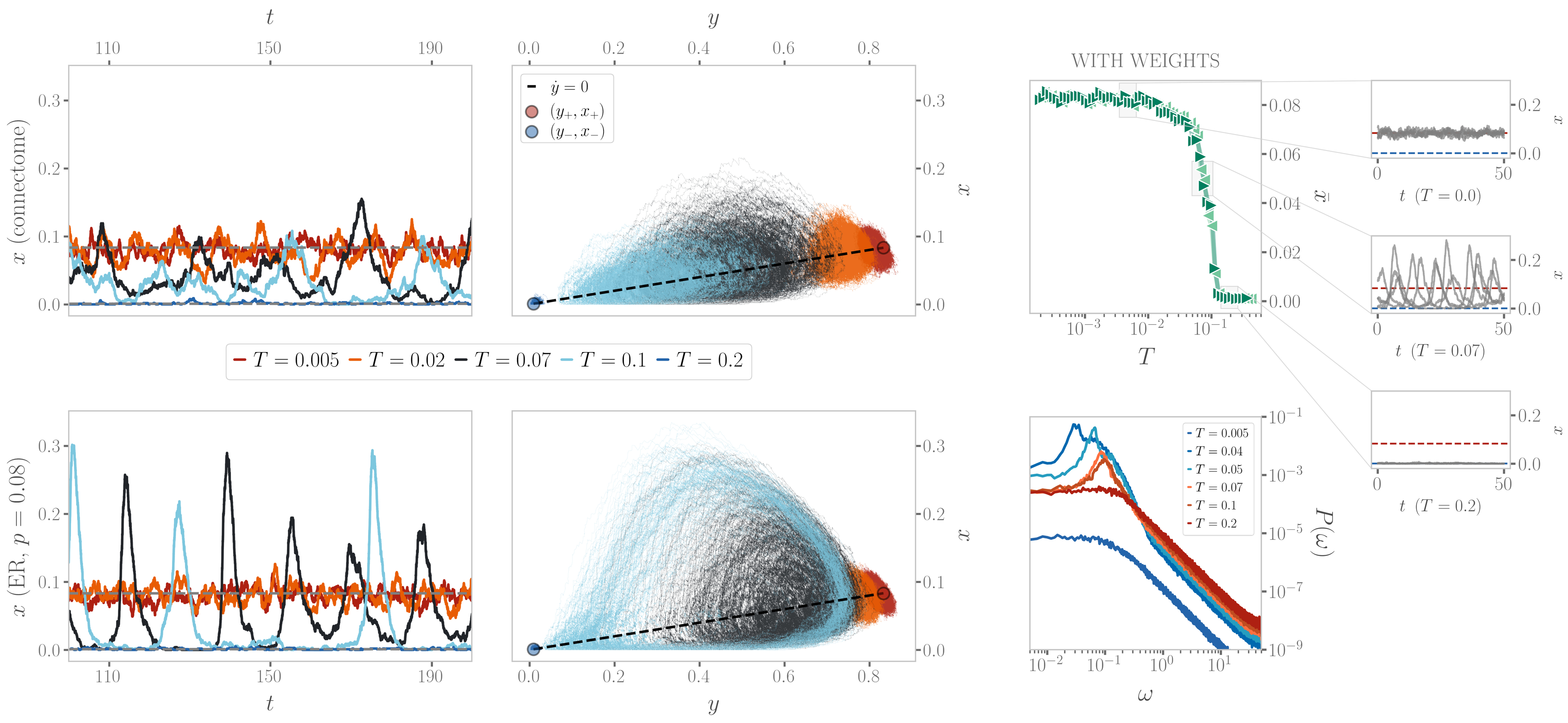
$$x = \frac{n_E}{N} \qquad y = \frac{n_R}{N} \qquad \begin{pmatrix} \dot{x} \\ \dot{y} \end{pmatrix} = \begin{pmatrix} A_1(x,y) \\ A_2(x,y) \end{pmatrix}$$
$$A_1(x,y) = (1-x-y)[r_1 + (1-r_1)\Theta(x-T)] - x$$
$$A_2(x,y) = x - r_2 y$$



CRITICALITY VS NETWORK STRUCTURE

- We embed the model in an **EMPIRICAL HUMAN CONNECTOME** and find that the complex network structure smooths the hysteresis cycles.
- At intermediate values of the threshold, the **AUTOCORRELATION TIME** and the VARIANCE OF THE ACTIVITY peaks, suggesting the presence of a **CRITICAL-LIKE TRANSITION**.
At the same threshold value, the **POWER-SPECTRUM** peaks due to the emergence of collective oscillations localized in subregions of the network.





- We find that both **NETWORK SPARSITY** and **WEIGHT HETEROGENEITY** are fundamental in smoothing the mean-field bistable region.
- However, sparsity and weights alone generate network-wide oscillations between the mean-field fixed point. **HIGHER-ORDER STRUCTURES** of the connectome are responsible for a smooth change of the dynamical fixed point and the emergence of local **COLLECTIVE OSCILLATIONS**.

In whole-brain models the underlying **NETWORK STRUCTURE** plays a crucial role and shapes the nature of dynamical transitions. In complex networks, a **CRITICAL-LIKE TRANSITION** appears and generates **COMPLEX EMERGENT BEHAVIORS**.

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