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Synchronized Memory-Dependent Intracellular Oscillations in Compartmental-Reaction Diffusion Systems

The Kuramoto model has been used in the last decades to gain insight into the behaviour of coupled discrete oscillators, as it is simple enough to be analyzed and exhibits a breadth of possible behaviours, such as synchronization, oscillation quenching, and chaos. However, the question arises how one can derive precise coupling terms between spatially localized oscillators that interact through a time-dependent diffusion field. We focus on a compartmental-reaction diffusion system with nonlinear intracellular kinetics of two species inside each small and well-separated cell with reactive boundary conditions. For the case of one-bulk diffusing species in $\mathbb{R}^2$, we derive a new memory-dependent integro-ODE system that characterizes how intracellular oscillations in the collection of cells are coupled through the PDE bulk-diffusion field. By using a fast numerical approach relying on the "sum-of-exponentials" method to derive a time-marching scheme for this nonlocal system, diffusion induced synchrony (in-phase, anti-phase, mixed-mode etc.) is examined for various spatial arrangements of cells. This theoretical modelling framework, relevant when spatially localized nonlinear oscillators are coupled through a PDE diffusion field, is distinct from the traditional Kuramoto paradigm for studying oscillator synchronization on networks or graphs. It opens up new avenues for characterizing synchronization phenomena associated with various discrete oscillatory systems in the sciences, such as quorum-sensing behaviour. (This is joint work with Michael J. Ward.)