Uniting the many and the few: Reconciling the Kuramoto and HKB models of biological coordination

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Prolegomenon: *As the Organizers of this conference so deeply intuit, nonlinear oscillations, neural and otherwise, are crucial to an integrative understanding of human nature. Evidence comes from the ubiquitous cyclicity of living things at all scales, essential to multiple biological functions, including the sensory, motor, cognitive, emotional and social functions of human brains. Over 40 years ago, my colleagues and I, following A.S. Iberall's "Homeokinetics" (e.g. Soodak & Iberall, 1978) pursued the idea that biological control and regulation is governed by ensembles of loosely coupled limit cycle oscillators whose stability is modulated both chemically and electrically. The nonlinear oscillator was identified as an elementary unit of action. When coupled together such units form functional synergies or coordinative structures (e.g. Kelso, 2012). The contribution herein generalizes this proposal and elucidates its foundational character for understanding the lawful basis of coordination in complex, biological systems, viz. Coordination Dynamics.*

Coordination, from cells to brains to society, is a ubiquitous feature of all living things. Existing theoretical models of coordination--from bacteria to brains--focus on systems with very large numbers of elements ($N \rightarrow \infty$) or systems with just a few elements coupled together (typically $N=2$). Both approaches have proceeded largely independent of each other. Can they be reconciled, and if so, how? It turns out, as the poet Robert Frost intimated, the secret to their unification sits in the middle. Recent joint experimental, theoretical and computational modeling of intermediate sized ensembles proves to be the key to reconciling large- and small-scale theories of coordination (Zhang, Beetle, Kelso & Tognoli, 2019). Results indicate that observed phenomena such as disorder-order transitions, multistability, metastability and order-to-order phase transitions figure prominently across all scales of observation, attesting to the importance of multi-scale, multi-level approaches. By focusing on the in between, it has proved possible to marry two well-known models of large- and small-scale coordination: one based on statistical mechanics (Kuramoto) and the other on nonlinear dynamics (extended HKB). Models of the many and the few, previously quite unconnected, are thereby united in a single formulation. The research has led to novel topological methods to handle high dimensional dynamics and has implications for the design of (bio-rhythm inspired) computers.

References

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