Exploring Neural Synchrony in Multi-Agent Systems: A Computational Study

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ABSTRACT. Understanding synchronisation in complex systems is vital for disciplines ranging from neuroscience and ecology to engineering and social dynamics. This paper presents a computational study of phase-coupled oscillators interacting on dynamically evolving networks. Inspired by the classic Kuramoto model, we extend the analysis to incorporate noise, time-varying connectivity, and adaptive coupling strengths. Our approach allows us to systematically explore the conditions under which synchrony emerges, degrades, and recovers.
We simulate systems of up to 1000 agents under various initial distributions, coupling regimes, and network topologies including small-world, scale-free, and lattice structures. Results demonstrate that synchrony is highly sensitive to coupling strength and network topology, but also resilient to moderate levels of stochastic perturbation. In particular, synchronisation is observed to emerge faster in densely connected and small-world networks, while sparse or modular networks require adaptive feedback mechanisms to maintain global phase coherence.
We also investigate the effect of delayed coupling and show that phase lag can induce metastable synchrony—periods of partial alignment that precede abrupt synchronisation breakdown. Through noise injection experiments, we quantify robustness and demonstrate that phase correction mechanisms based on local coherence gradients significantly enhance synchrony preservation.
Our findings have implications for modelling collective dynamics in natural systems such as circadian rhythms, neural oscillations, and social consensus formation, as well as engineered applications including sensor fusion, robotic swarms, and power grid stability. We conclude by outlining a roadmap for translating these insights into decentralised control algorithms for real-world networks with partial observability and agent-level constraints.
This work serves as a foundational benchmark for understanding synchronisation in evolving, noisy systems and provides a flexible modelling framework for extending to hybrid continuous-discrete dynamics, hierarchical coordination, or bio-inspired swarm intelligence.

KEYWORDS: neural synchrony, multi-agent systems, computational neuroscience, noise, coordination

1 INTRODUCTION

Synchrony among distributed units—whether in brains, swarms, or sensor networks—has intrigued scientists for decades. We aim to explore this phenomenon computationally using a simplified model where agents act as coupled oscillators under noise.

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