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Modeling and Analysis of Synchronous Behavior in Biological Systems

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How can individuals in a group all act in unison, without any leader or orchestrator that guides them? An audience all clapping their hands in sync—who initiated that? Many systems in nature operate in such a way. We propose to study multiple systems—all readily observable—such as Southeast Asian firefly swarms and groups of fiddler crabs. In both systems, the individuals are predominantly immobile while synchronizing, making their behavior more trackable and tractable (as we can directly relate them to established models of coupled oscillators). We quantify synchrony via the "order parameter" for firefly swarms over time, and observe perhaps an unexpected outcome: meta oscillations of the order on an intermediate timescale (i.e., much slower than the flashing period) (Fig. 1).

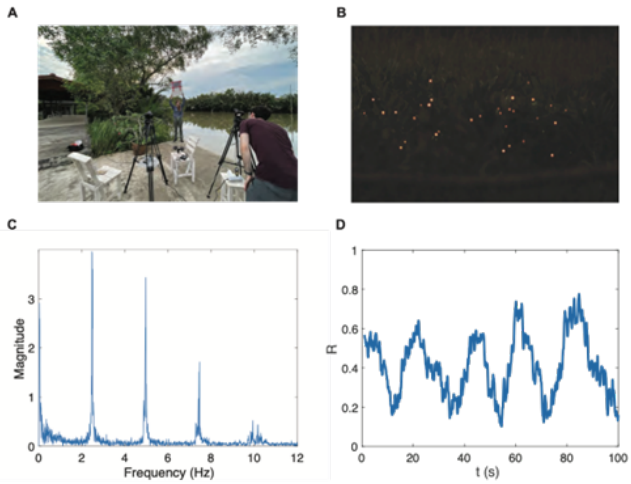

Figure 1. Data acquisition and analysis. (A) Team calibrating dual-camera setup. (B) Snapshot from a video of firefly swarm. (C) Frequency spectrum from flash times. (D) Order parameter over time.

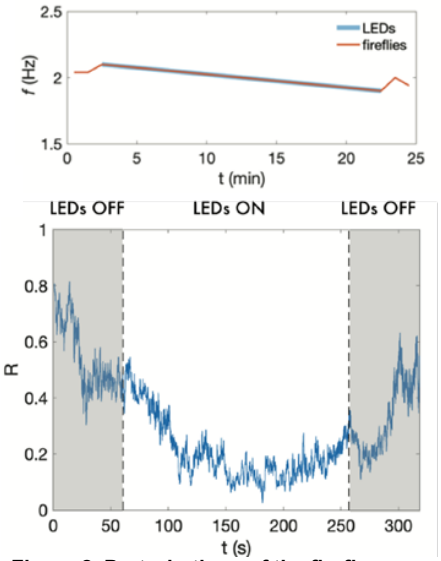

Figure 2. Perturbations of the firefly swarms. (Top) Entrainment experiment. (Bottom) Experiment to break down swarm sync.

Our plan is to use data to develop and test new models for biological sync, then to go beyond observation and perform model-informed field experiments. To that end, we are developing "synthetic fireflies" that can be embedded within natural swarms and interact with them. Fig. 2 shows preliminary results of two different open-loop experiments.

Firefly populations are declining (as are many other insects), so it's urgent to study them now—both for the sake of raising awareness to this natural wonder, but also as a means of conserving it. In addition, as we strive for a general understanding (that goes beyond the specifics of each system) we hope to uncover common principles of synchronization across scales, leading to a new focus in the mathematical study of coupled oscillators.

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