Firefly flash synchronization

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1. Introduction

Fireflies are bioluminescent insects that emit precisely timed flashes of light through an enzyme reaction. The flashes are thought to serve as mating communication signals. When fireflies form a group they synchronize their flashes so that the entire group pulses on and off as a collective unit, a spectacular sight in nature. This sketch presents a simple model of flash synchronization.

2. Synchronization model

What is presented here is a simplified version of the models found in literature [Buck and Buck 1976; Strogatz and Stewart 1993]. The model is easy to describe and also easy to program in a variety of languages and animation packages such as Java, StarLogo and Maya. Each firefly is assumed to build up its excitation level (say, chemical concentration) until a threshold is reached, at which point it emits a flash and resets its excitation level to zero. This can be illustrated using a classic 'sawtooth' curve (Figure 1). In isolation from neighboring fireflies, this would yield precisely timed flashes.

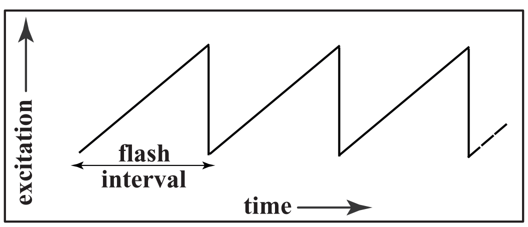

Figure 1. The buildup and flash cycle for a single firefly.

In a group, each firefly slightly modifies its flashing pattern to eventually be in flash synchrony with all its neighbors. One way this can be achieved is through phase advancement. Figure 2 shows how this works.

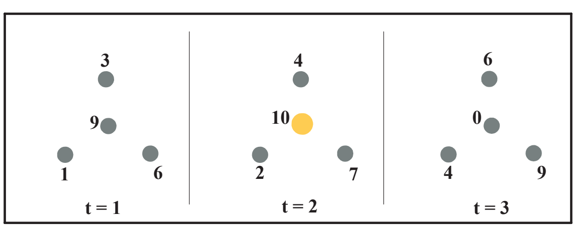

Figure 2. A flash (at t=2) from the middle firefly resets its excitation to 0 and also causes its three neighbors adjust their own excitation thresholds by skipping a unit each (at t=3).

Assume that the each fly has a flashing threshold of 10 units. Left to its own, each fly 'counts' up from 0, increments its excitation by 1 unit in each time step, flashes when it reaches its threshold, resets level to 0, then starts again. But upon seeing a neighbor flash it advances its excitation quicker, by 2 units instead of 1 (this is shown in the third panel of Figure 2, at t=3). This eventually leads to all flies in a group flashing in unison, each having adjusted its phase in small increments to achieve synchrony (Figure 3). The phases of all the flies are said to have become 'entrained'.

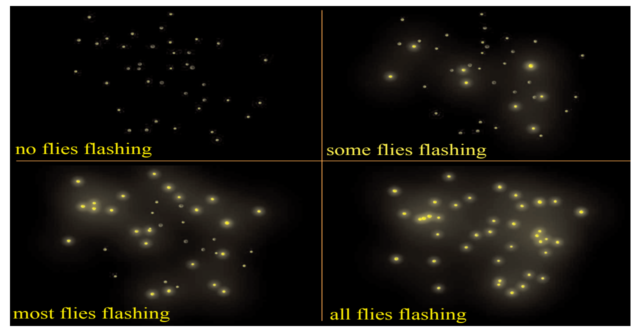

Fig. 3. Progressive stages of flash synchrony - frames taken from an animation sequence of the model implementation.

The synchronization is not instantaneous for at least a couple of reasons. The flashing is the result of a chemical reaction, and the chemicals need time to build up concentration. Further delay is from the flies' nervous systems as they process the stimulus of seeing neighbors flash.

3. Model variations

The phase advancement model presented above assumes that each fly is capable of sensing flashes from neighbors regardless of their proximity. A refinement therefore is to introduce the notion of a 'flash radius' which limits the extent to which each fly can sense flashes. A fly will adjust its threshold only if it sees flashes from neighbors that are within its flash radius. Making this adjustment to the simulation shows clusters of fireflies flashing in synchrony within their own cluster but not with other clusters situated beyond the flash radii. Further, if flies from two clusters already in their own synchrony approach each other to form a bigger cluster, that leads to all the flies breaking their existing synchrony to match flashes with all members in the bigger group.

Other variations to explore are having a few 'aging' flies with longer excitations (which would slow down the time required to obtain synchrony) and introducing 'metronomes' with non-varying flash intervals to which all others would synchronize. The presence of metronomes leads to 'wave synchrony' where the synchronization spreads outward from the metronomes in 'ripples'.

4. Conclusion

The synchronization model presented here might be useful in CG to simulate not just firefly flashing but also other collective visual oscillatory phenomena such as clapping of hands, dancing etc.

5. References

BUCK, J. AND BUCK, E. 1976. Synchronous fireflies. *Scientific American*, *5*, 74-85.

STROGATZ, S. H. AND STEWART, I. 1993. Coupled oscillators and biological synchronization. *Scientific American*, *12*, 68-75.

 The definitive version was published in SIGGRAPH 2003 Sketches & Applications, https://doi.org/10.1145/965400.965421.