Synchronized Flashing in Fireflies

Biology

- Fireflies are beetles
  - > 2000 species world wide
  - Males rove around looking for sedentary female
    - Mating is the goal
  - Elaborate flashing used to guide courtship
    - Morse code
  - In groups, flashing becomes highly synchronized
    - Only by males though …

Synchronization

- No apparent leader or conductor
  - Firefly swarms can change dynamically
- No global communication
- Synchronization is emergent
- Takes time to achieve complete synchronization
- 1000’s of insects can be involved
- In 1930’s effect was denied to exist
  - Could not explain it, so it didn’t occur!
  - Suggested that it had reproductive benefit

Explanations

- Craig (1917)
  - “It’s accidental”
  - “It’s the observer blinking his eyes!”
- Wheeler (1917)
  - “A fine sense of [individual] rhythm”
- 1865
  - “Puffs of wind cause synchronous flashing”
- Repetitive external stimuli could not explain phenomenon

Explanations

- Blair (1915)
  - Each firefly requires period of recharging after flash
  - Every other firefly stimulated to flash when they see a flash
- Critique
  - Fireflies can’t see very far
  - What happens when the leader leaves?
  - Flash propagation is 55-80ms, flash is 30ms, so can’t be done

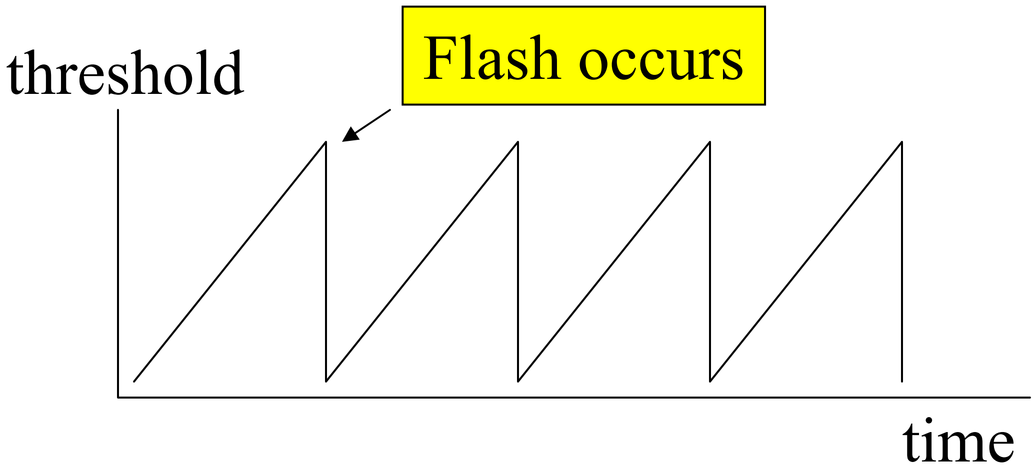
Actual Explanation

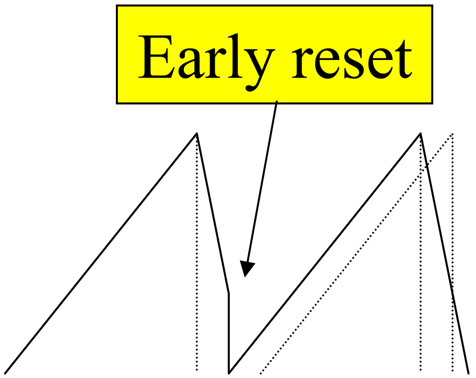
- Fireflies had neural timing mechanism
  - An oscillator
- Oscillator frequency is stimulated or inhibited by flashing light

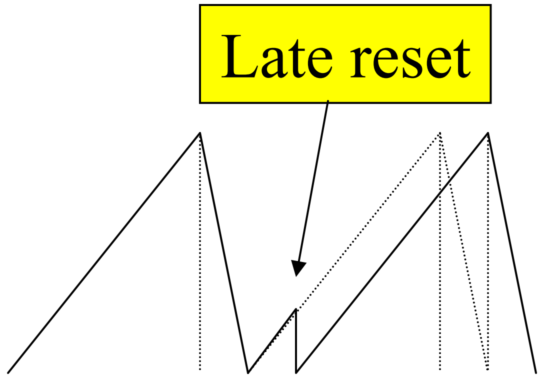
Experiments

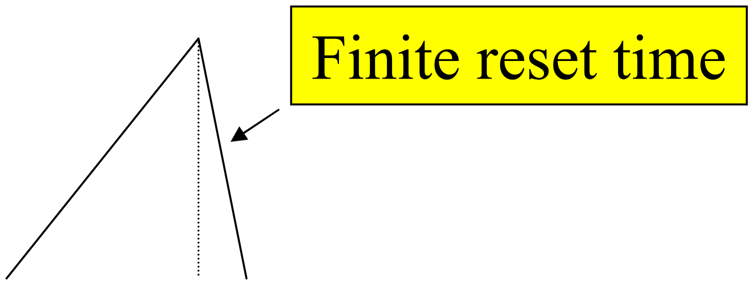
- Buck (1981)
  - Free range flash cycle: 965 ms ± 90 ms
  - Injected 40 ms random flashes every 10 sec
  - 21 pulses applied
- Results
  - Synchronous: no effect
  - After (110-840 ms): next flash delayed ~1 sec
  - Before (>840 ms): next flash early ~800 ms
  - Several cycles of normal flashing between test flashes

Model

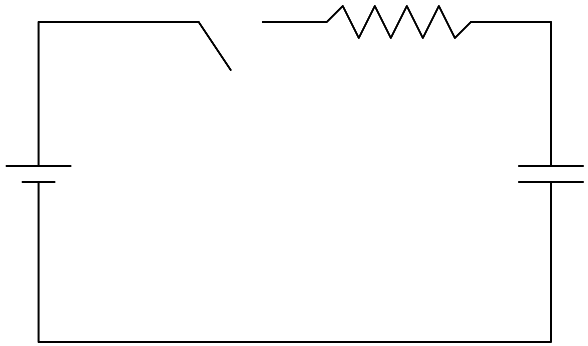

threshold
Flash occurs
time


Early reset

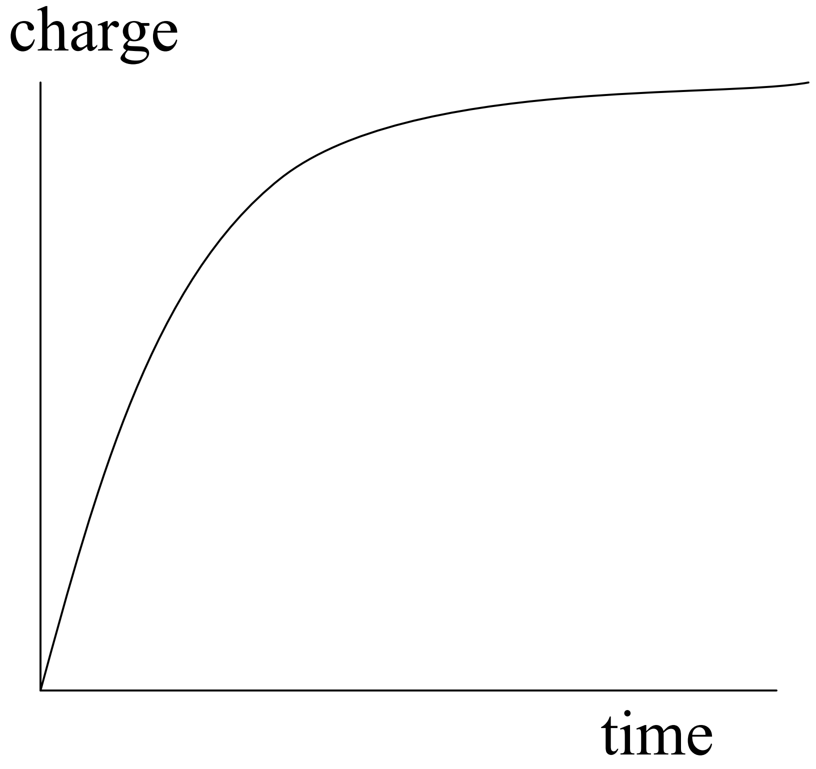

Late reset


Finite reset time

Physical Model



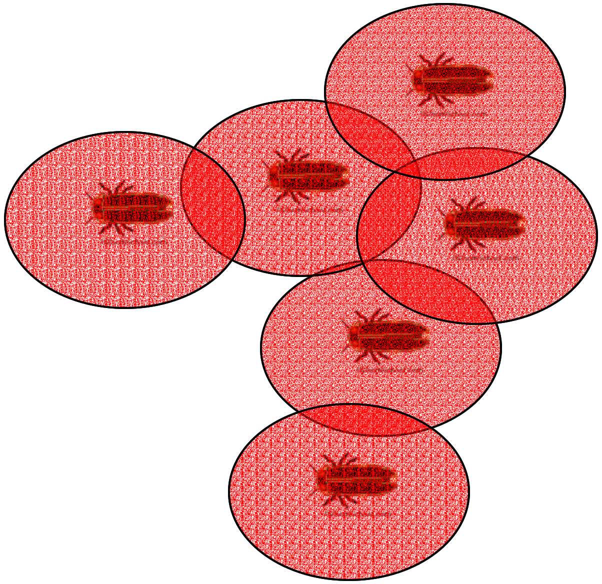
Oscillator modelled as
a circuit: resistor in series
with a capacitor



Comments

- Reset takes finite time (discharge)
- When flash detected reset is immediate
- Result is subsequent flash will occur later or earlier depending upon flash timing
- With random movement result is “global” synchronization
  - Firefly acts as intrinsic oscillator
  - Flashes at characteristic frequency
  - Coupling via perception of neighbors flashing

Coupling

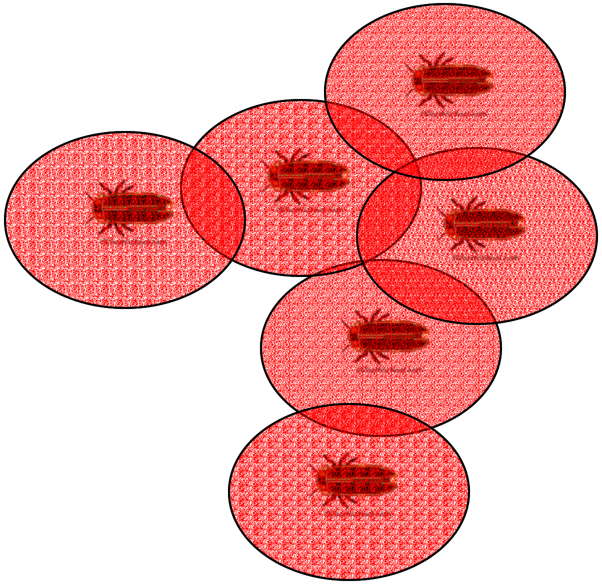


Limited horizon for sensing of light

Movement (a random walk) causes changes to occur in flashing

Run the demo …

More Complex Though …



Feedback from neighbours means that synchronization can take a while …

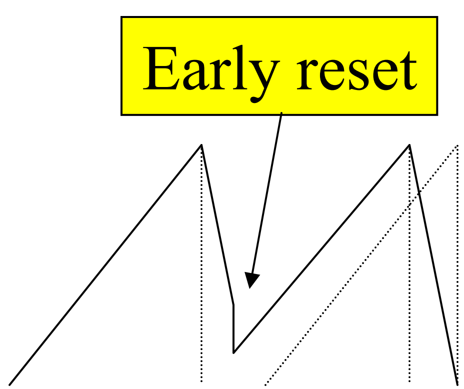
Run the demo …

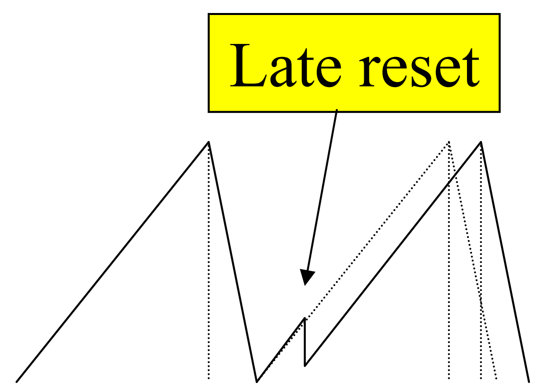
Comments

- Minolli and Strogatz analysed behavior:
  - Identical oscillators
  - Oscillators sensitive to light throughout cycle
  - Excitation is concave downwards (not linear)
- Results
  - Synchronization under almost all conditions
  - However, model isn't real

Enhancements

- Some species require several cycles to synchronize (e.g. Luciola pupilla)
  - Threshold only changes partially
  - Can only change within limits





Humans do it too!

- Finger tapping
  - Close eyes and tap fingers
  - Synchronization will be rapid!
  - Tapping will synchronize at ~2-3 taps per sec.

Other examples

- Fidler crab: synchronized craw waving
- Honey bees: synchronized respiration
- Ants, synchronized:
  - Activity cycles [Franks and Bryant, 1970]
  - Alarm drumming [Hölldobler and Wilson, 1990]
- Termites: synchronized chewing
- Herring gulls: synchronized breeding

References

- Strogatz, S.H., and Stewart, I., Coupled Oscillators and Biological Synchronization. *Scientific American* pp. 68-75. (December, 1993)
- Buck, J. and Buck, E., Synchronous Fireflies. *Scientific American* pp. 74-85. (May, 1976)

Applications and Sites

- Action at a distance
- The FireFly Files site
- http://iris.biosci.ohio-state.edu/projects/Ffiles/