Collective Behavior & Synchronization

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What is collective behavior?

Examples of Collective Behavior

- Swarming
  - Flocks of birds
  - Schools of fish

- Crowd response
  - Fads
  - Rumors

Examples

Starlings

https://www.youtube.com/watch?v=eakKfY5aHmY

Start at 0:45

Watch ~ 30 seconds

Fish

https://www.youtube.com/watch?v=U9T0O1AOv0c

Start at 2:10

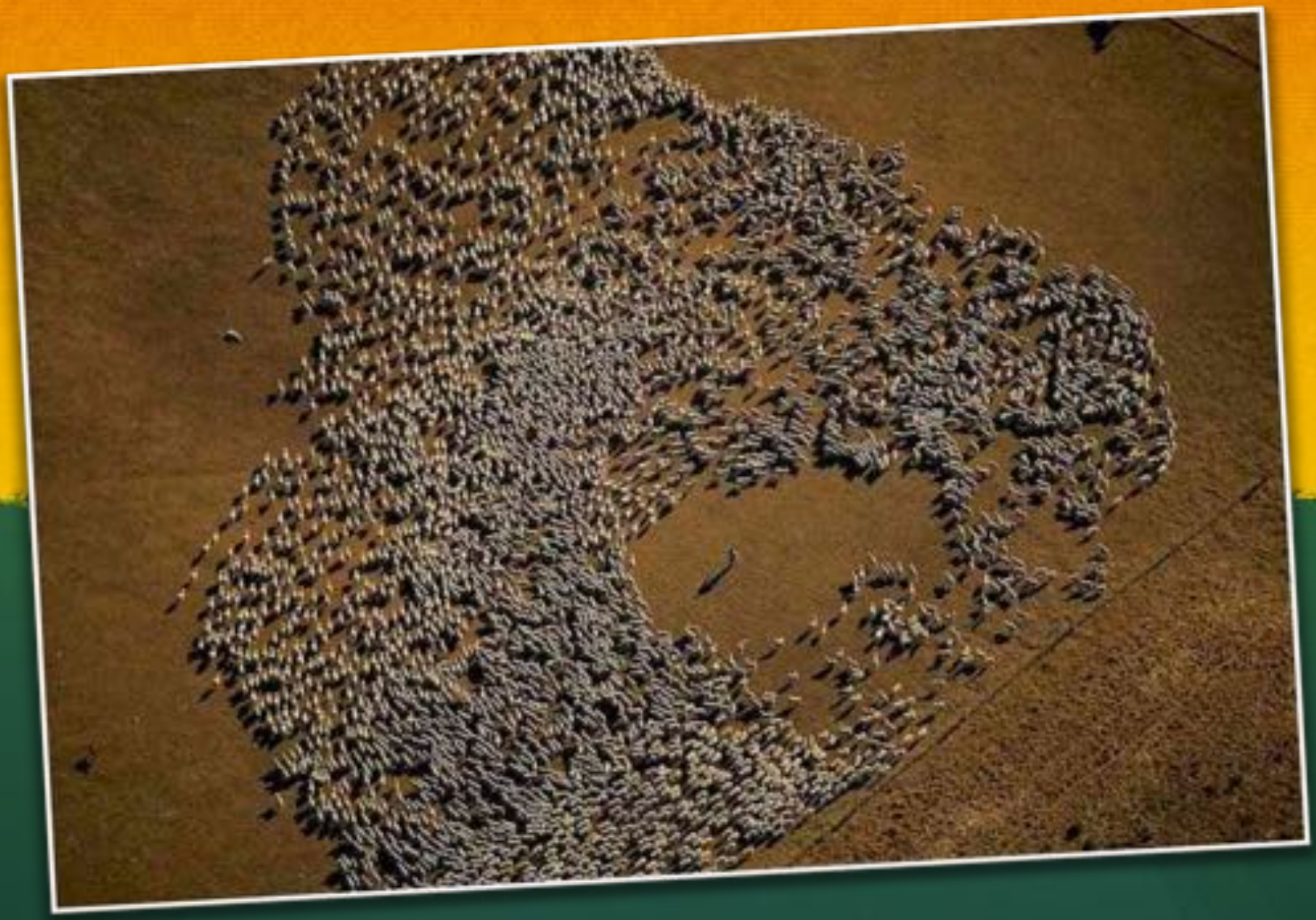
Watch ~ 30 seconds

Defining collective behavior

Collective behavior refers to relatively *spontaneous* and relatively *unstructured* behavior by large numbers of individuals acting with or being influenced by other individuals.

Reaction to intrusion

How does the group respond?



Fish avoiding a predator

https://www.youtube.com/watch?v=mgg6HhKRwY0

Start at 0:38

Watch ~ 10 seconds

Can we produce collective behaviors?

Let's try!

What happens?

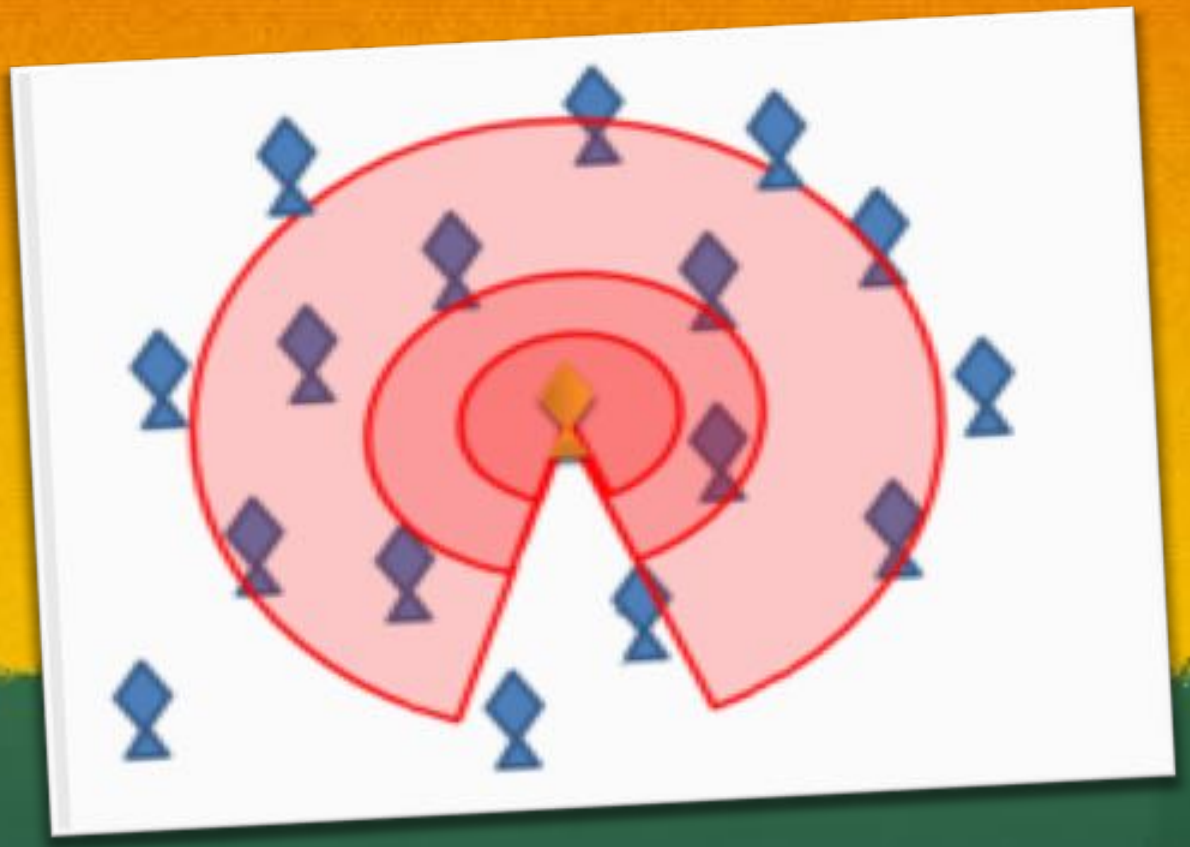
1. Pick one person in the room (Don't tell who it is!). We'll call them Person A.
2. Pick a different person in the room (Don't tell who it is!). We'll call them Person B.
3. When I say go, make sure that *you always stay between Person A and Person B*.

Now, what happens?

1. Pick one person in the room (Don't tell who it is!). We'll call them Person A.
2. Pick a different person in the room (Don't tell who it is!). We'll call them Person B.
3. When I say go, make sure that *you keep Person A between yourself and Person B*.

Simple rules lead to complex behavior

- Attraction of individuals at long distance
- Repulsion of individuals at short distance
- Must head in a similar direction to where you were going



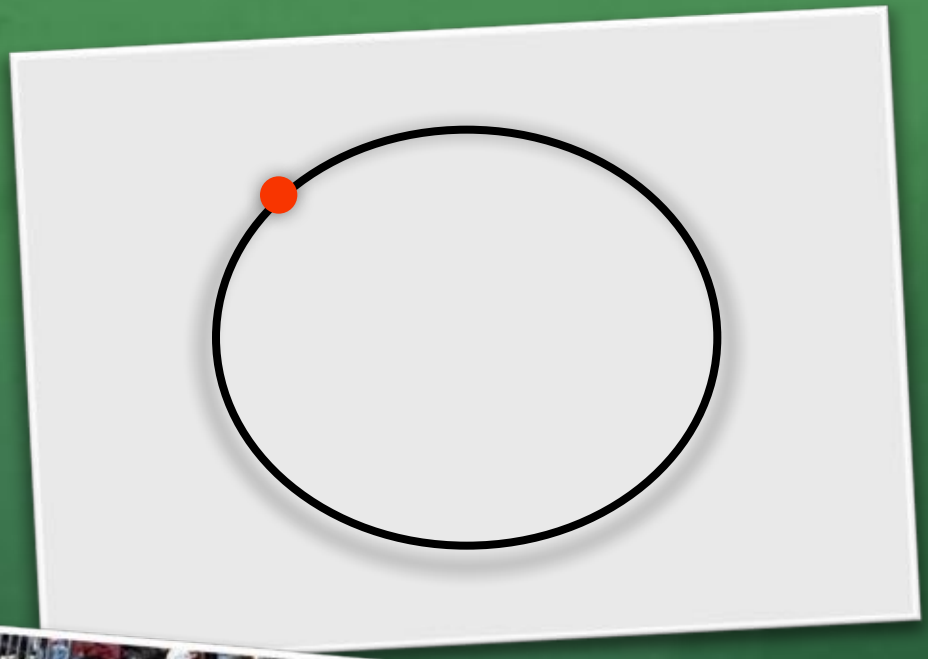
How one fish acts

What about dynamic behavior?

Oscillations in time

Let's simplify

Think of runners on a track



Interaction of runners

- Want to run in a group with friends
- Want to run far away from others

How individuals move

$$\text{Change in position on the track} = \text{Preferred running speed} + \frac{1}{N}\,\text{Sum}\Big\{\underbrace{\big(\text{How much one wants to run with others}\big)}_{K} \times \big(\text{Where everyone else is}\big)\Big\}$$

Interaction of runners

- Want to run in a group with friends

  $K > 0$

- Want to run far away from others

  $K < 0$

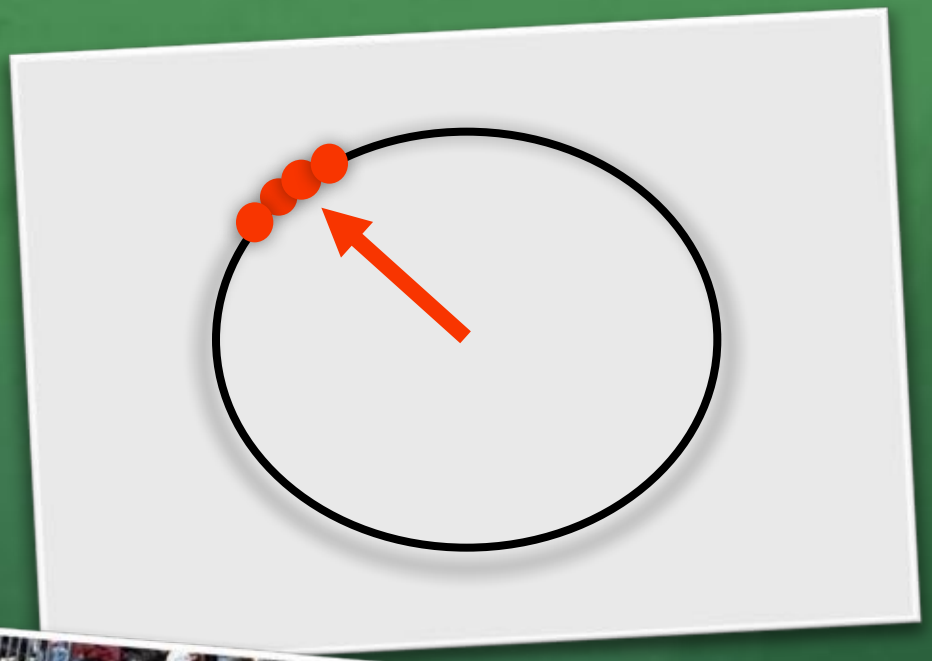
Where are most runners?

Idea of an average

- Sum all the numbers
- Divide by how many numbers there are

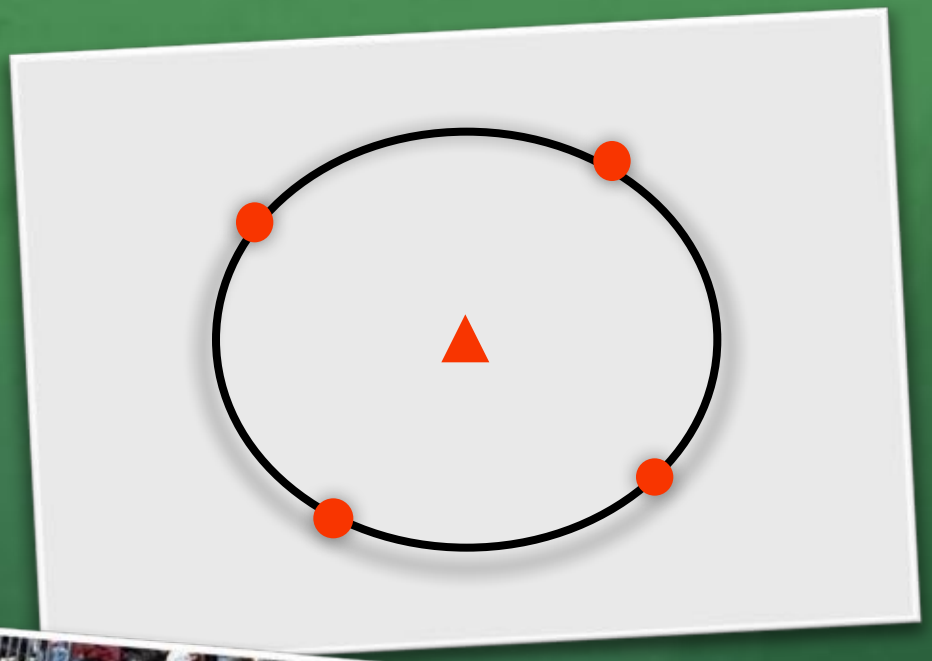
- Example
  - Everyone pick 0 or 1

Where are most runners?



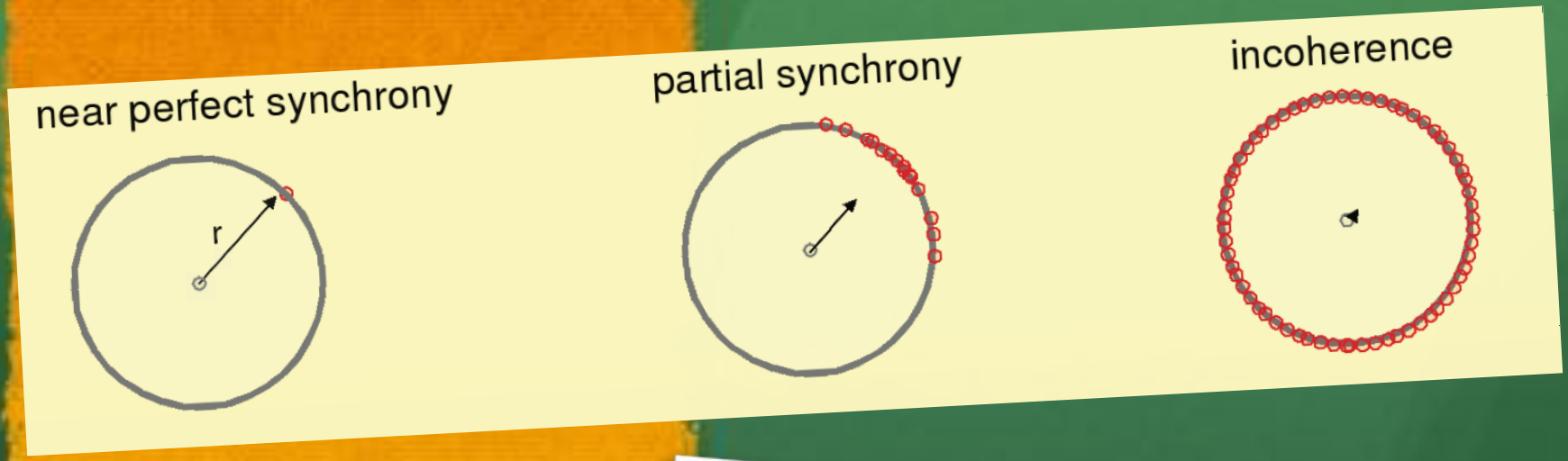
Where are most runners?

Where are most runners?

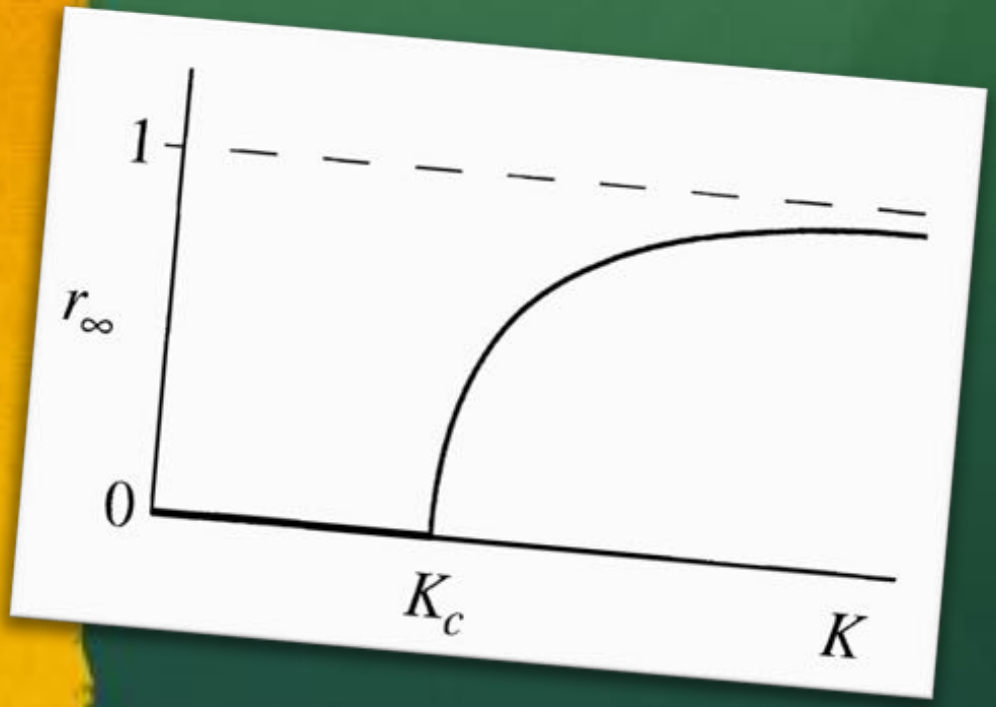


What happens as K increases?

Synchronization!



r = length of arrow

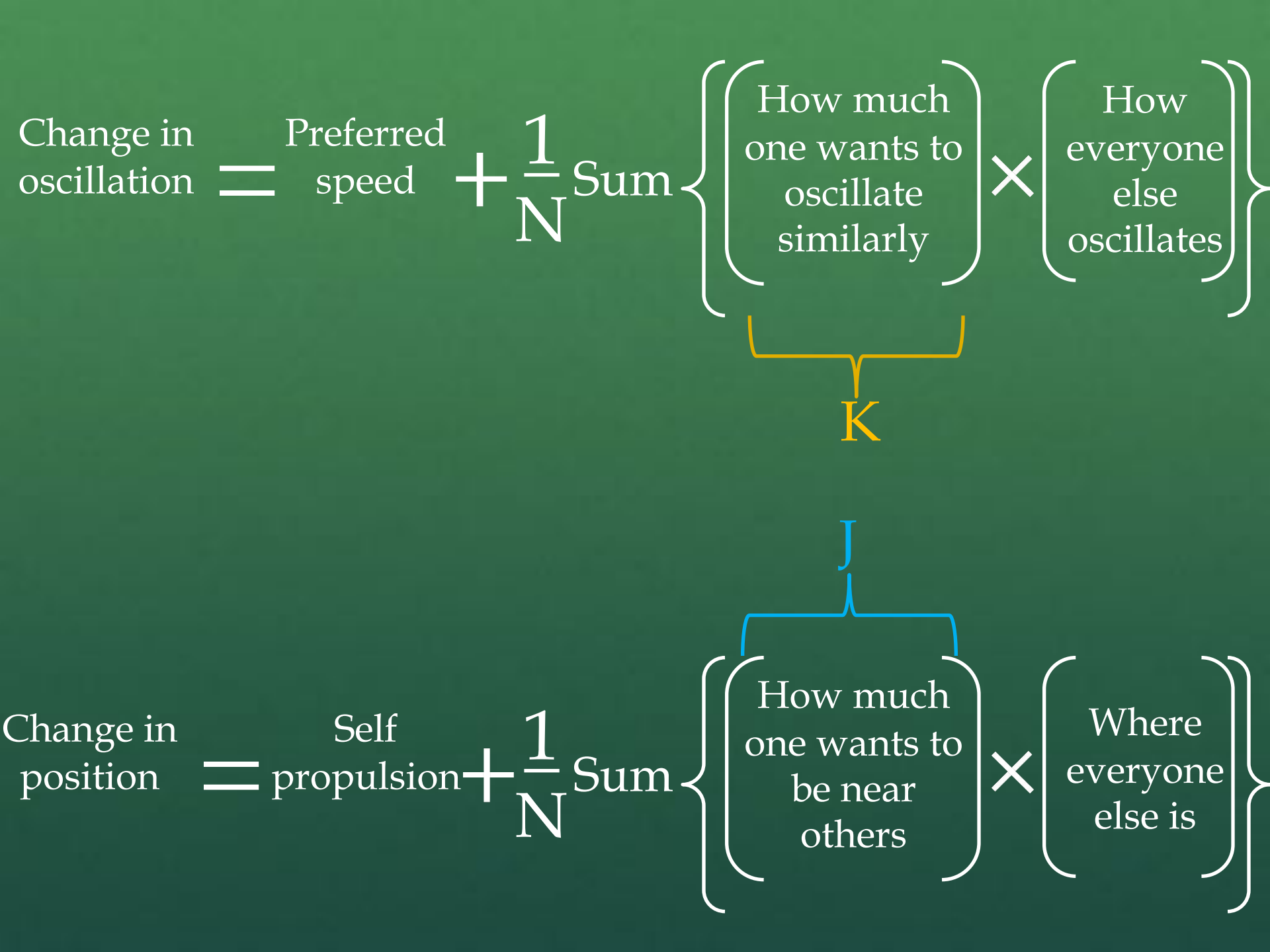


Bring swarms and oscillators together

Swarmalators!

Definitions

- Each individual is an oscillator
- Color of the individual tells where in the oscillation the individual is
  - Red = lighting up
  - Blue = dark
- Simple rules of behavior
  - K = attraction of stage of oscillation
  - J = attraction of position


Change in oscillation
=
Preferred speed
+
1/N
Sum
How much one wants to oscillate similarly
×
How everyone else oscillates
K
J
Change in position
=
Self propulsion
+
1/N
Sum
How much one wants to be near others
×
Where everyone else is

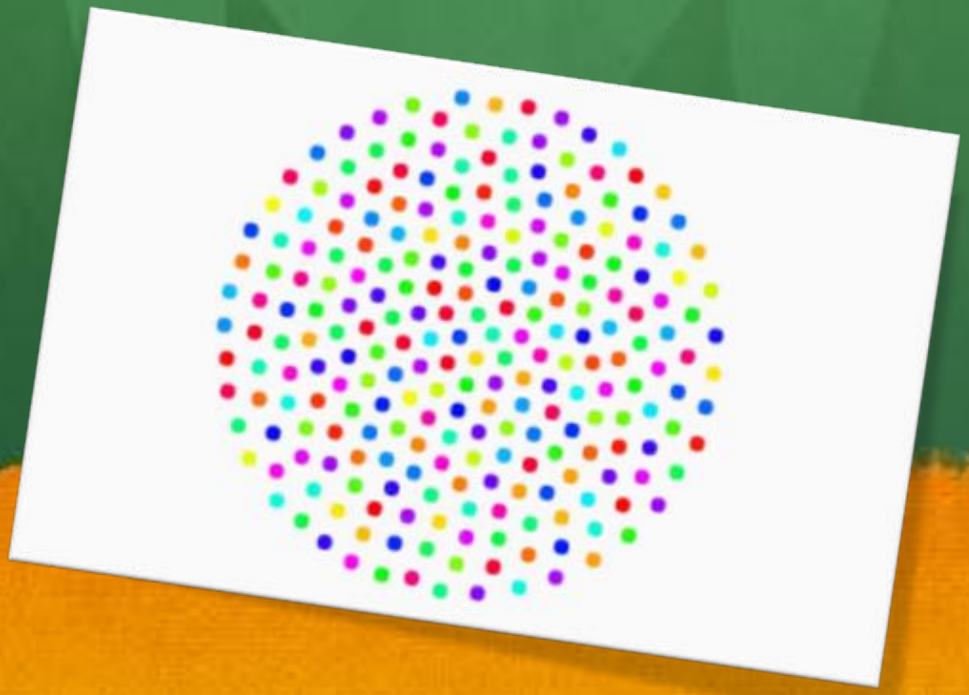
What happens as we change J and K?

Static states

Synchronization

J = 0.1

K = 1



No synchronization

J = 0.1

K = -1

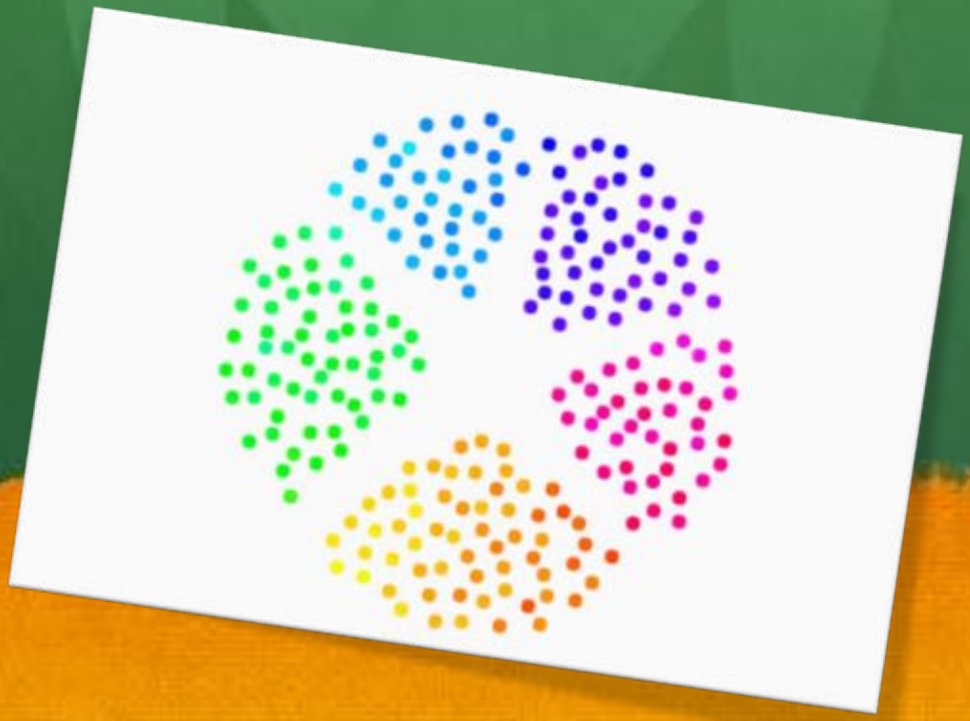
Static wave

J = 1

K = 0

What happens as we change J and K?

Mobile states



Splintered wave

J = 1

K = -0.1

Active wave

J = 1

K = -0.75

THANK YOU!

More about Swarmalators

- https://www.nature.com/articles/s41467-017-01190-3.pdf
- http://usediscretion.blogspot.com/2017/01/the-swarmalator.html#21977057672306319l4
- https://mikesmathpage.wordpress.com/2017/11/19/having-kids-play-with-swarmalators/


Kevin O'Keeffe


Hyunsuk Hong


Steven Strogatz

References

Spinner picture: https://news.playhaven.com/lists/before-there-were-fidget-spinners-there-were-the-other-crazy-toy-fads

Fish model: https://en.wikipedia.org/wiki/Swarm_behaviour

Runners on track: https://dakotapress.photoshelter.com/image/I0000YEg14Dhv7Ec

Diver with fish: https://johnwhye.com/2015/10/24/scuba-diving/

Firefly: https://houstonarboretum.org/2016/05/fireflies/

Flocks of birds: https://www.howitworksdaily.com/why-do-birds-flock-together/

Sheep: flatrock.org.nz (cached google search: herd of sheep overhead)