Decision-Making Swarms

Sanza Kazadi, George Jeno, Xinyu Guan, Nick Nusgart, Andriy Sheptunov

Illinois Mathematics and Science Academy

1500 Sullivan Rd., Aurora, IL 60506

Decision-making swarms are prevalent in the world

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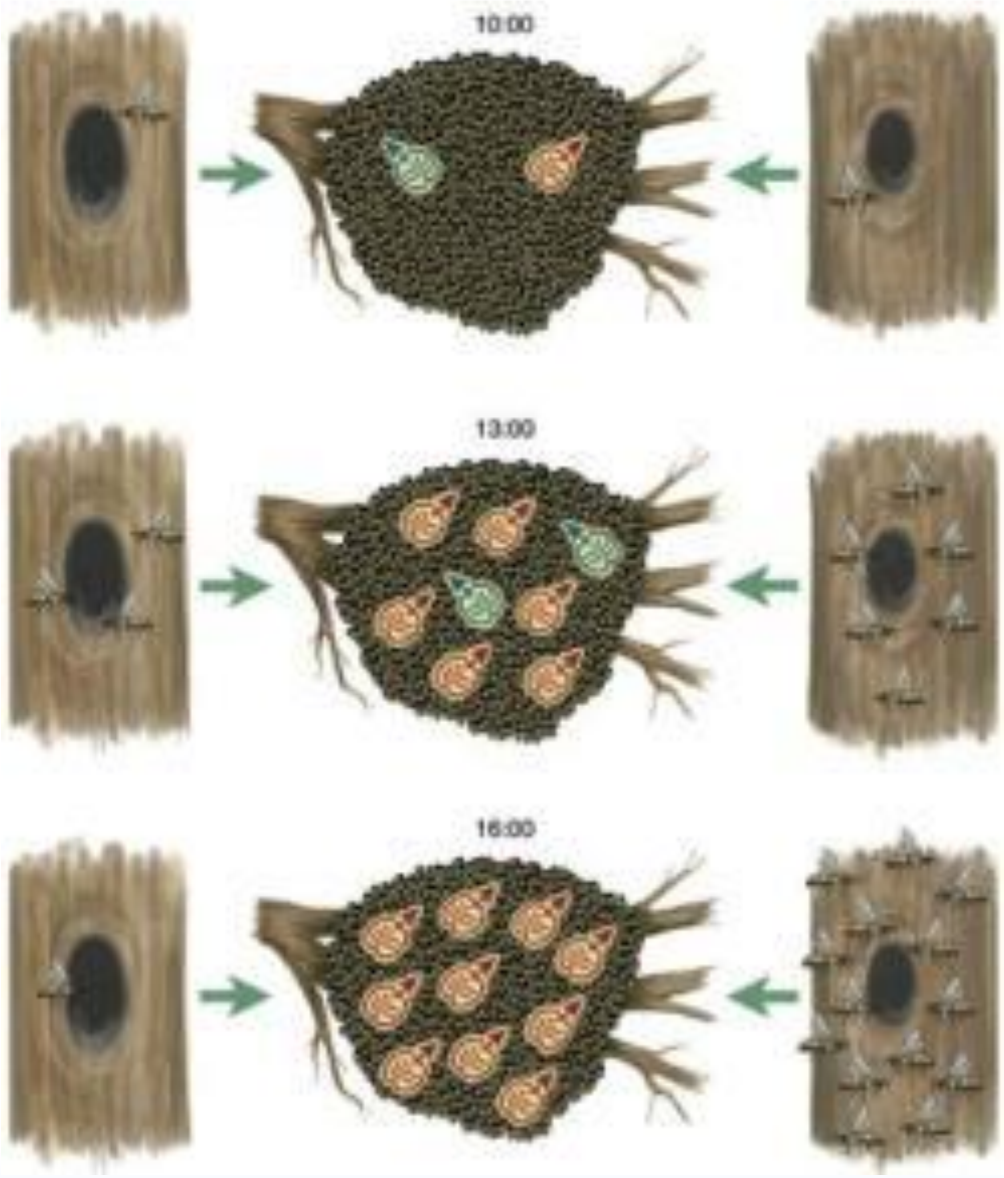


Decision-making swarms are prevalent in the world

How can we engineer swarms to make predictable, reproducible decisions?

Outline

- Swarm Definitions
- Swarm Design
- Designing Ant Swarms
- Measuring Shortest Length with Ant Swarms
- Designing Locust Swarms
- Measuring Density with Locust Swarms

An agent is an subset of a system which has autonomous control over at least one degree of freedom

A swarm is a collection of agents whose collective abilities is a proper superset of the abilities of an agent.

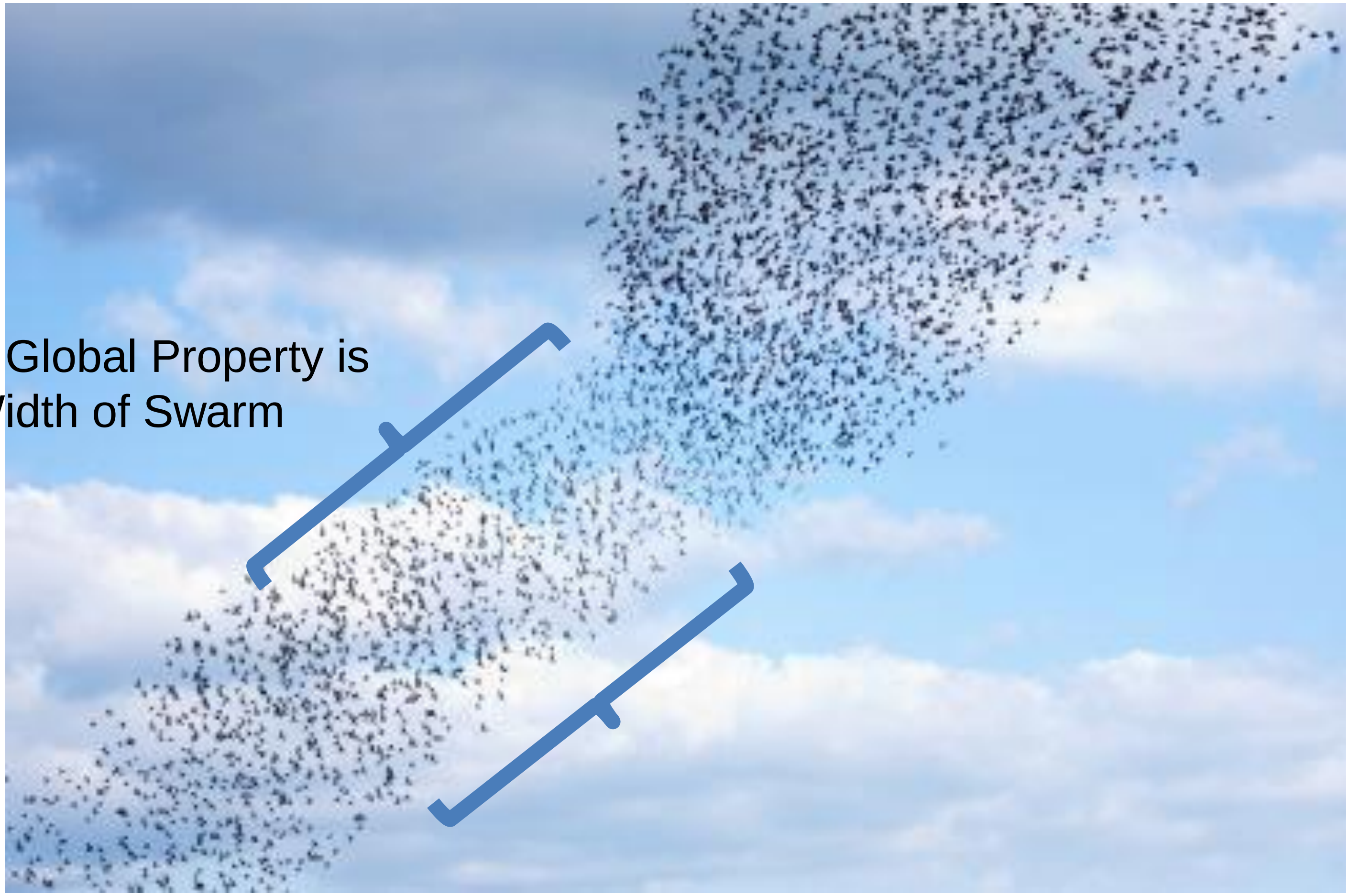
How do we mathematically analyse a swarm?

Local properties are anything the agent can directly observe or interact with.

A Local Property is
Relative Position

Global properties are well-defined, differentiable functions of the local properties.

A Global Property is
Width of Swarm



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A Global Property is
Length of Swarm

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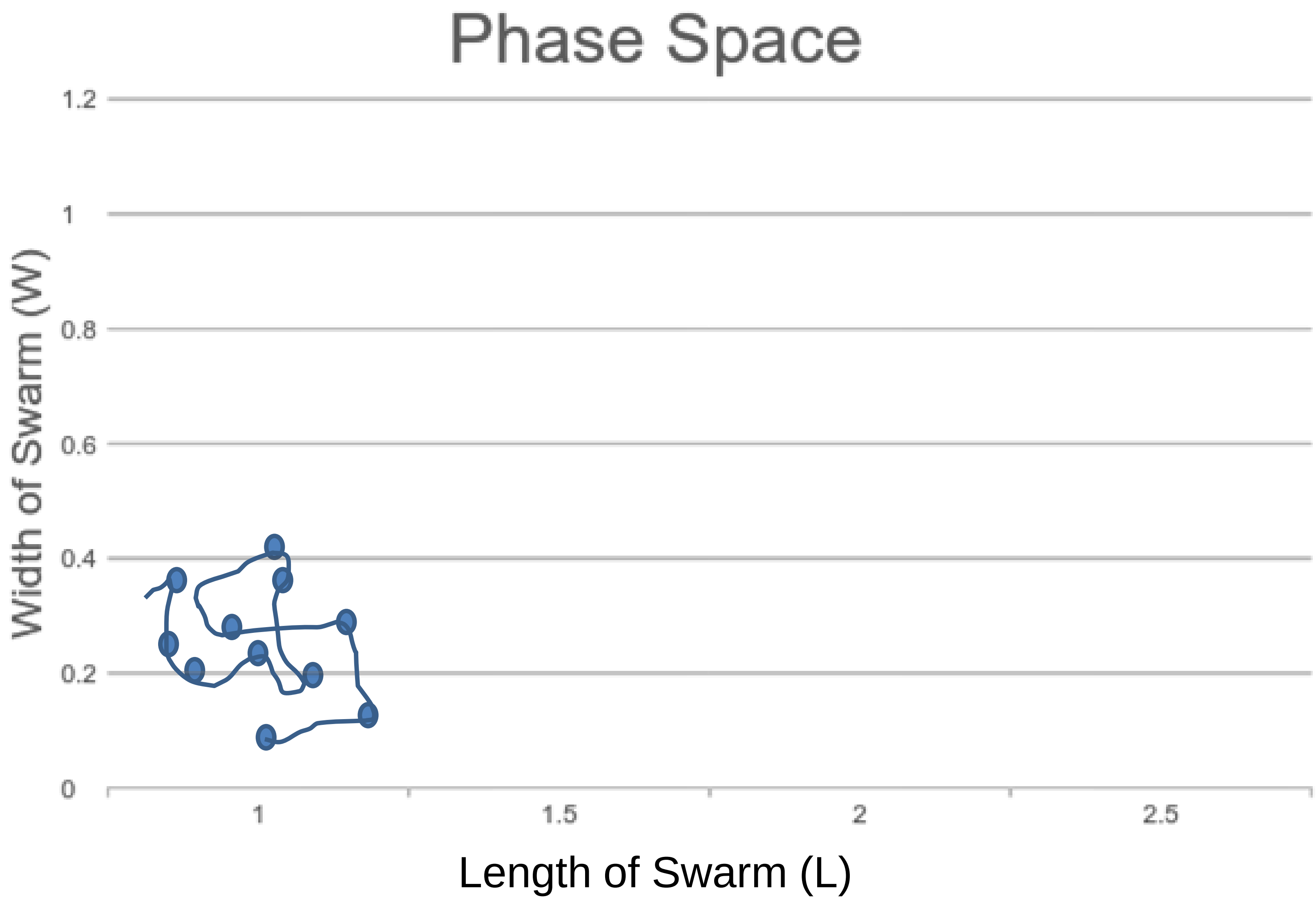
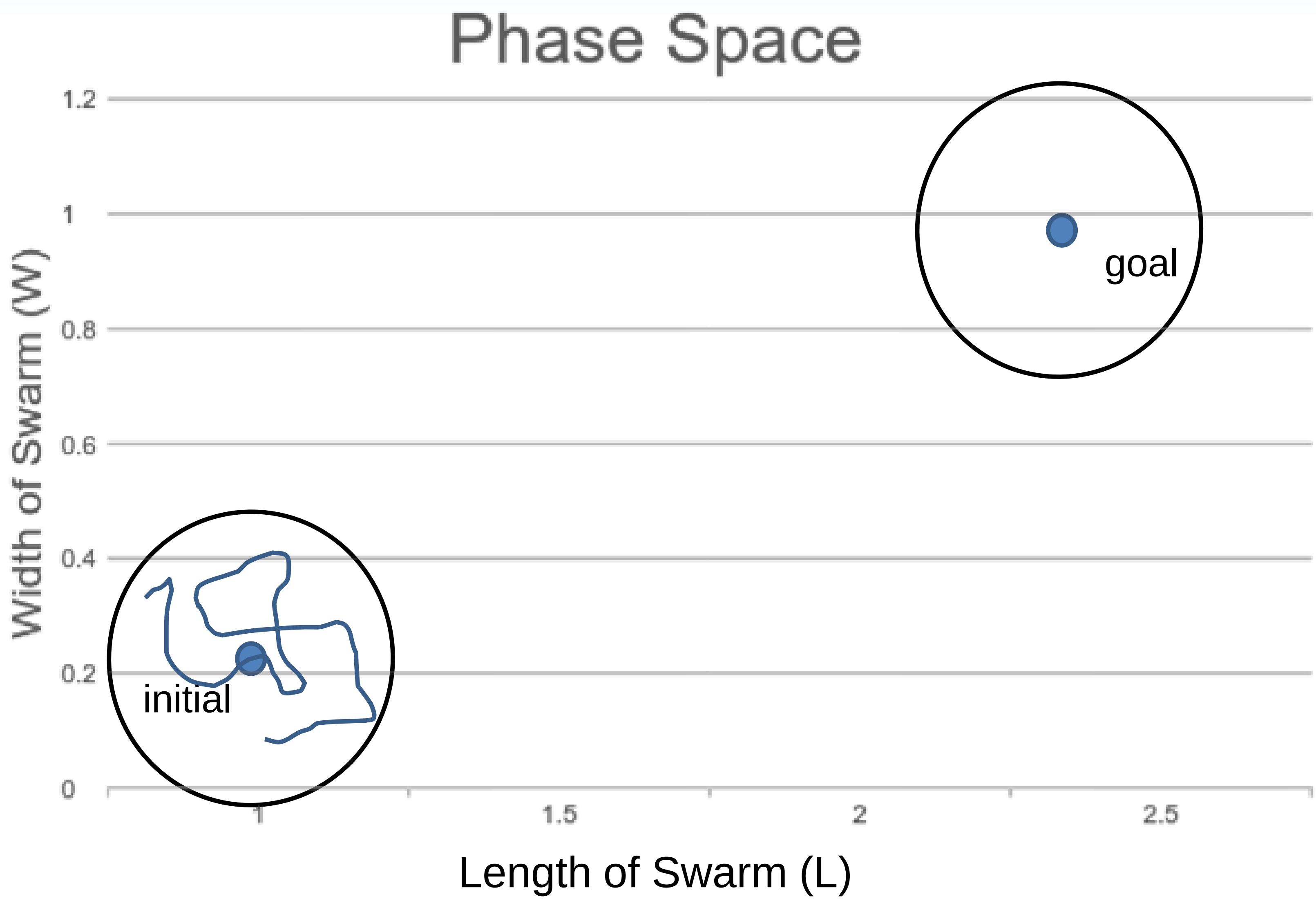
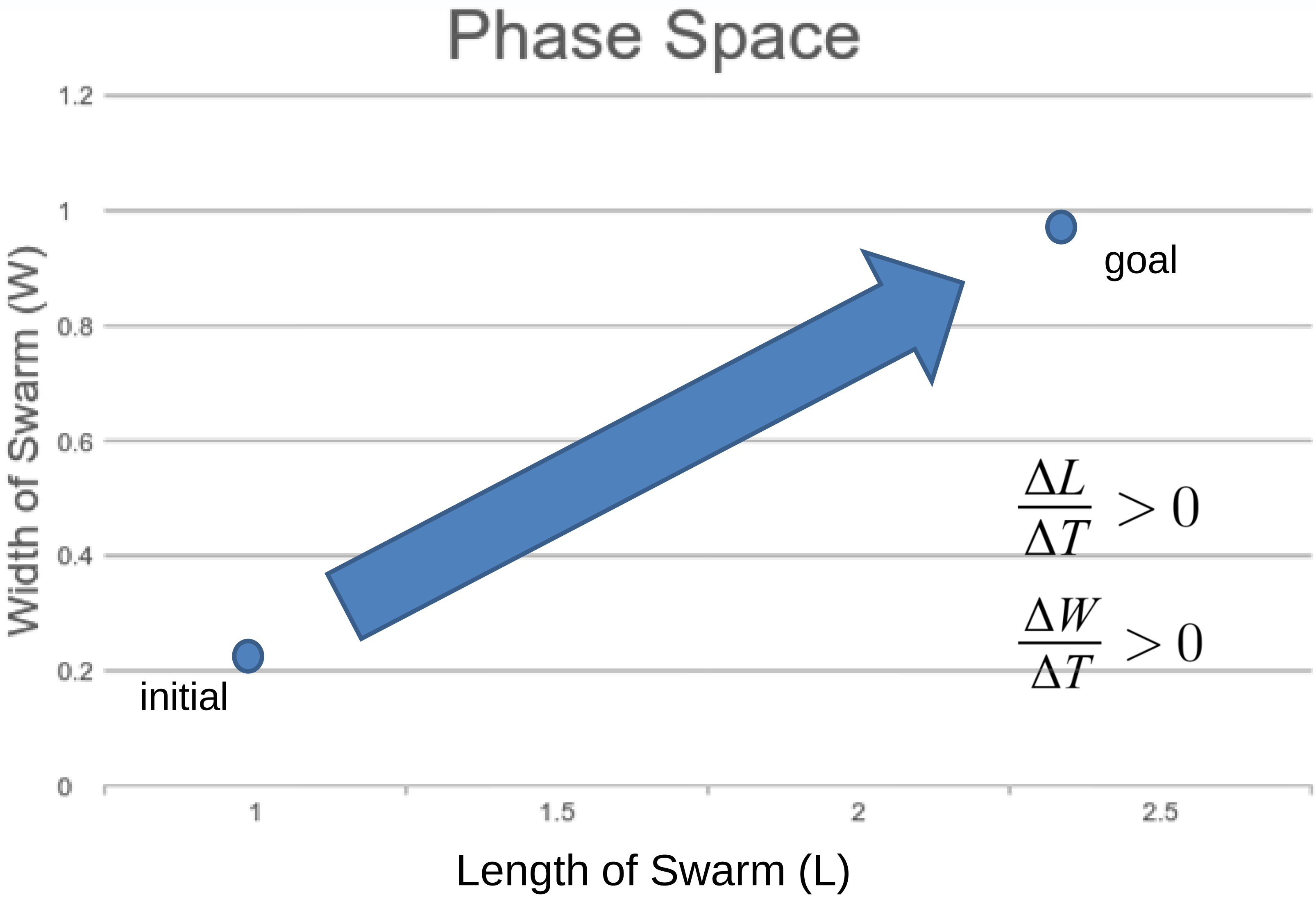
The Global Property space, or the Phase Space, can be drawn.



The Phase Space shows clearly the ways in which the swarm must change in order to reach the desired end phase.



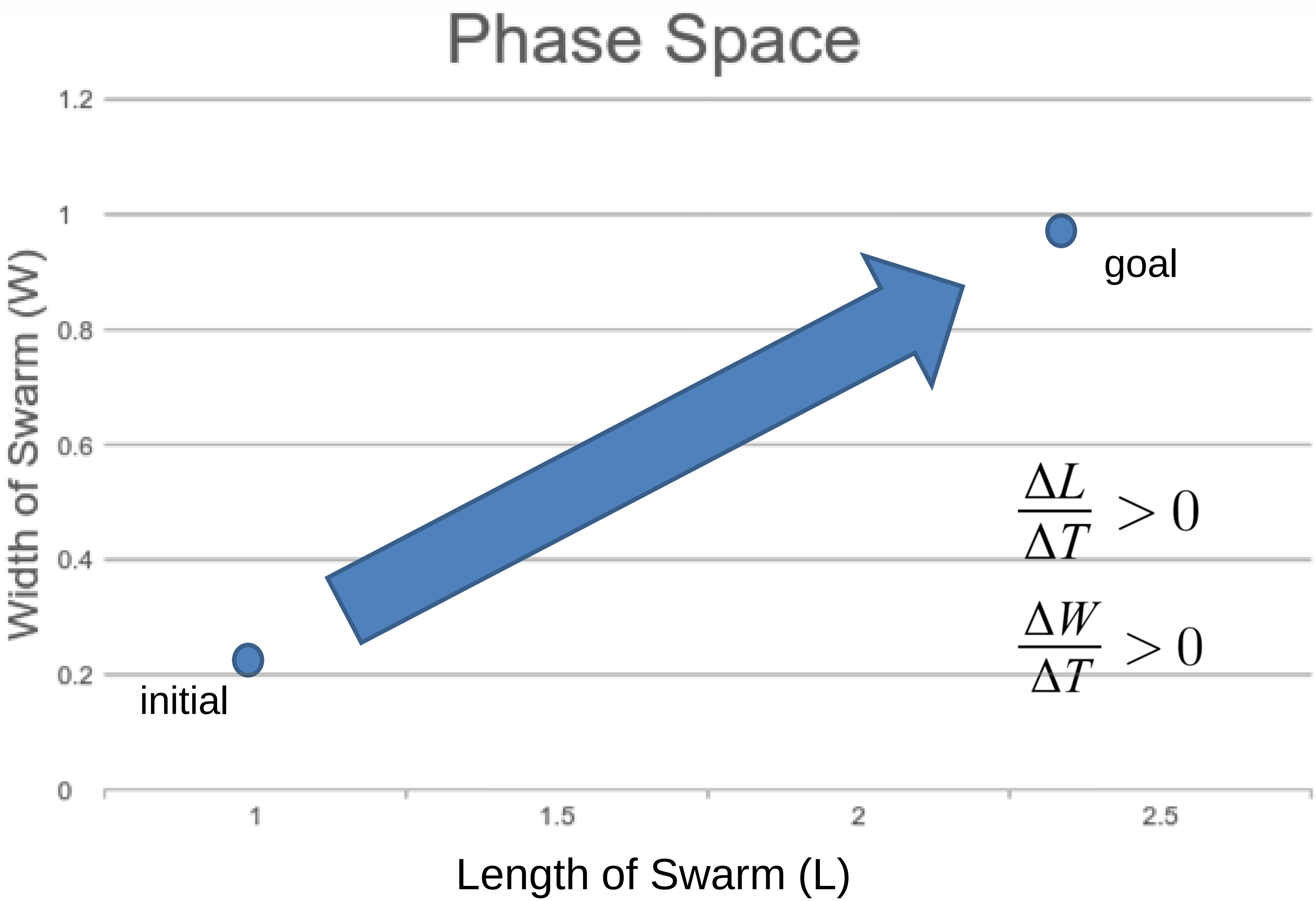
The Hamiltonian Method of Swarm Design entails looking at the phase space and determining which direction the Global Properties must change. The direction that they must go determines the swarm conditions, which must be met in order for the desired outcome to be achieved.



$$\frac{\Delta L}{\Delta T} > 0$$

$$\frac{\Delta W}{\Delta T} > 0$$

A swarm decision is a change in attractor in Phase Space.



$$\frac{\Delta L}{\Delta T} > 0$$

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How do we make the swarm flexible so it can decide to converge to a closer food source if the closer one is made available to the swarm at a much later time than the further food source?

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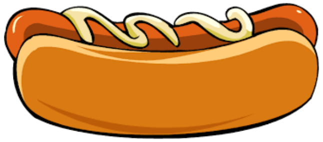

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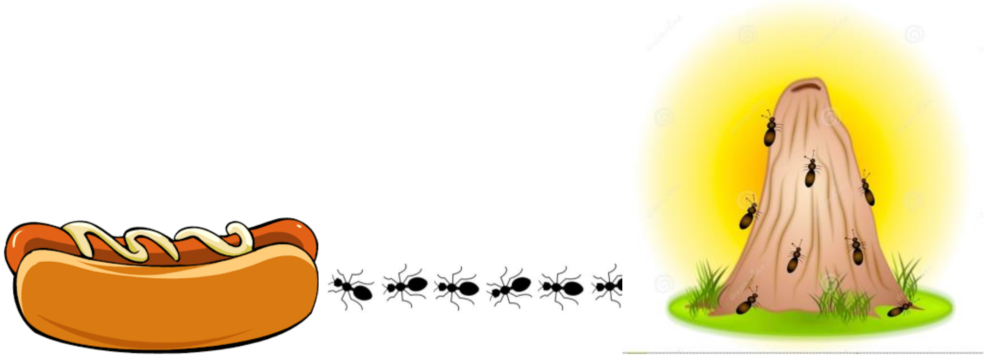

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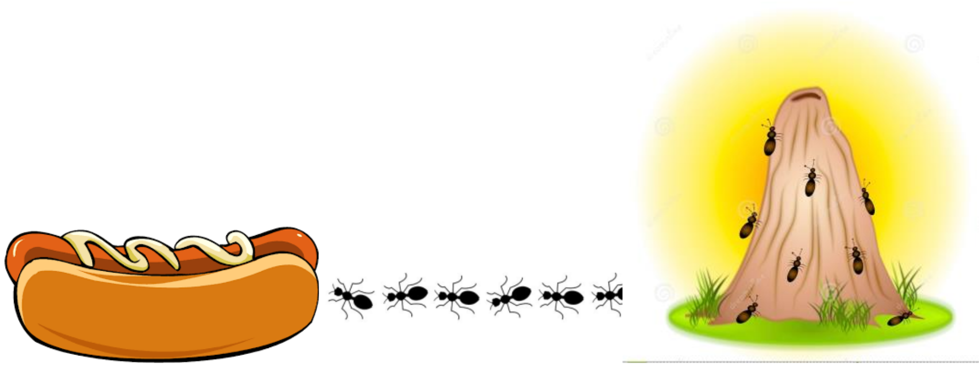

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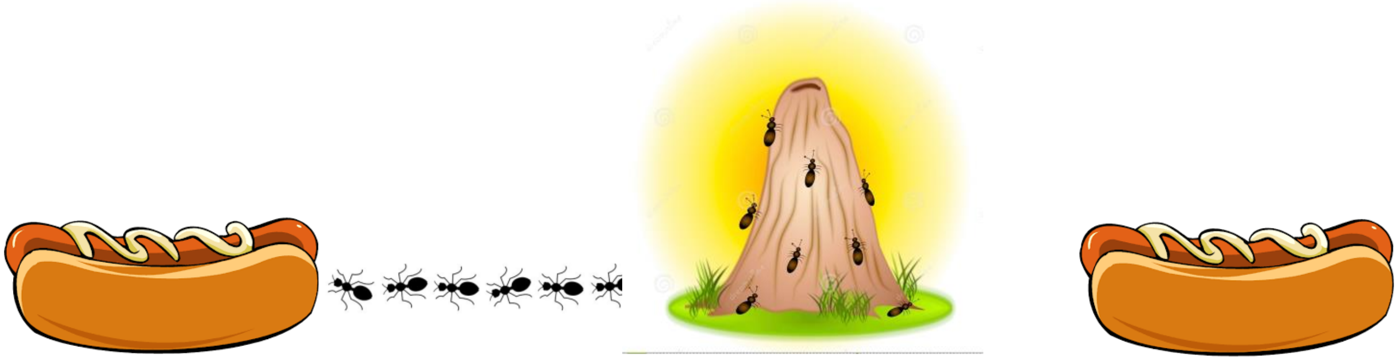

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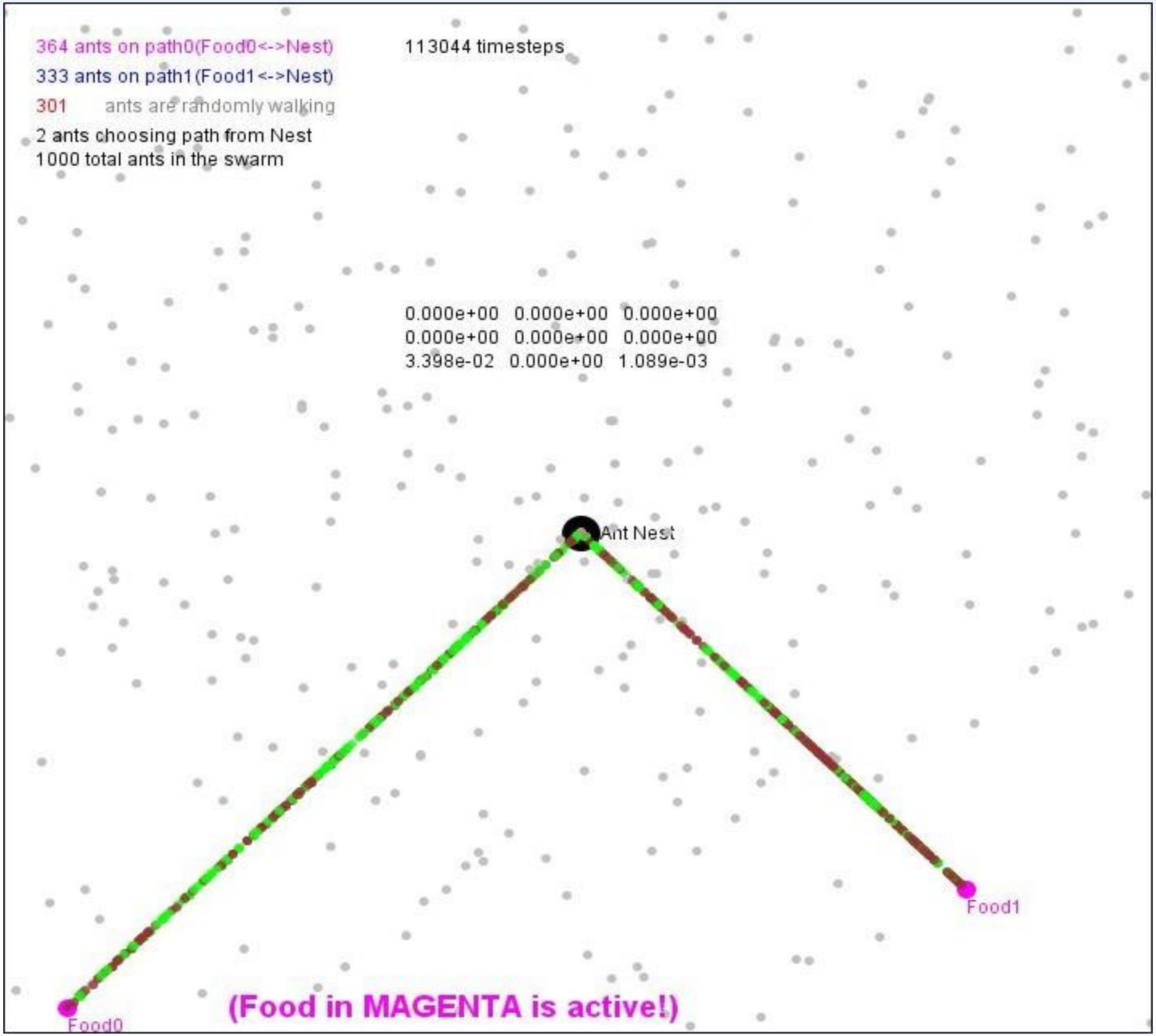
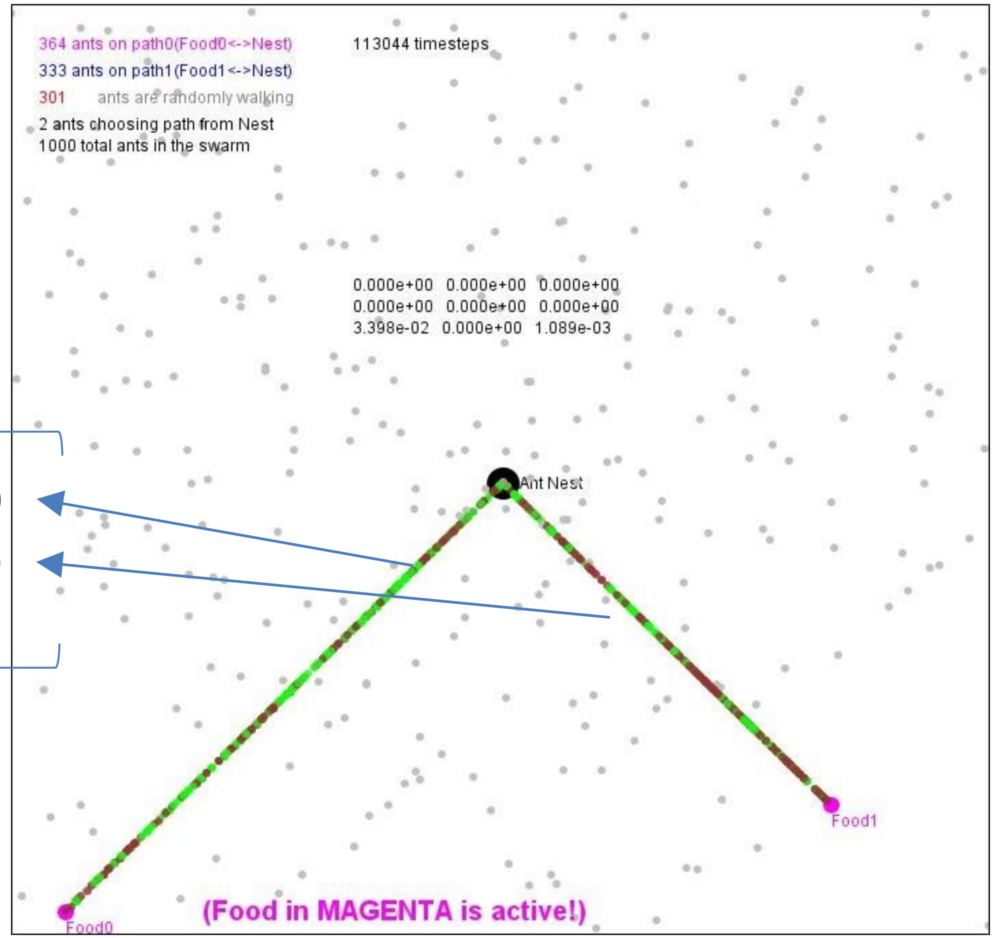


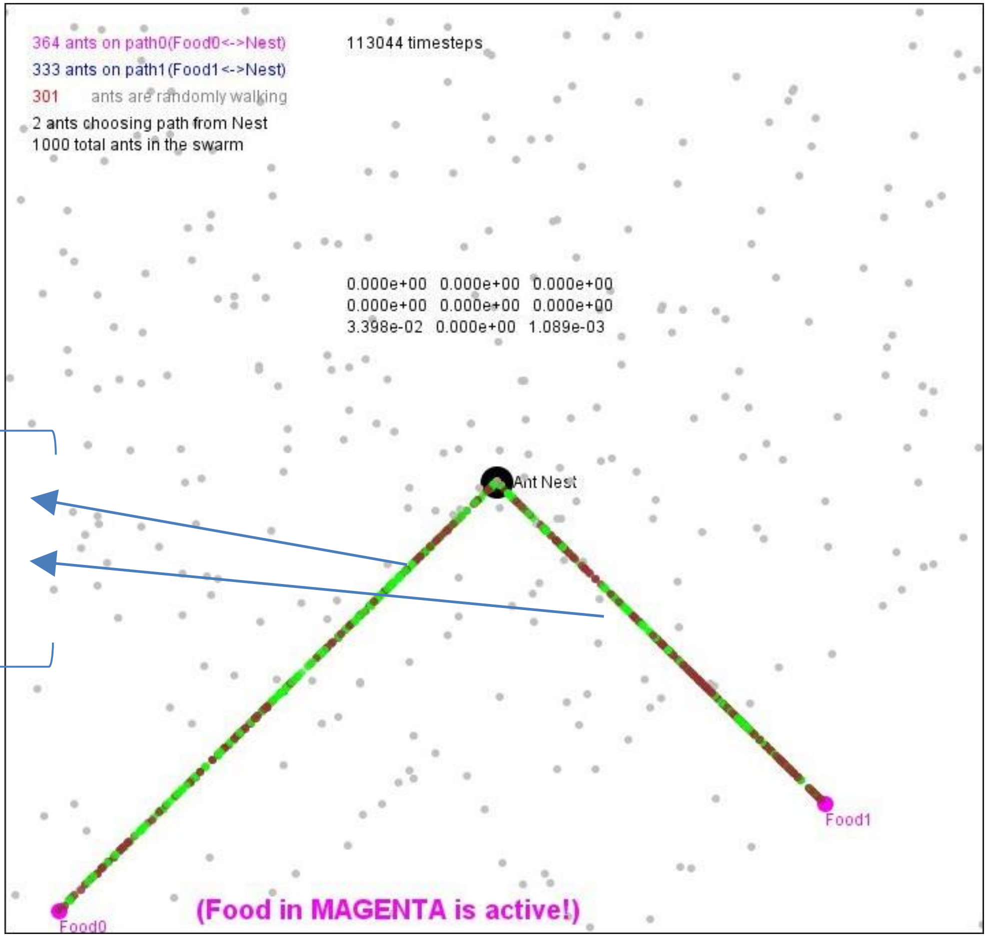
A global property is the length of the paths

$$\vec{d}_T = \begin{bmatrix} 400 \\ 300 \end{bmatrix}$$

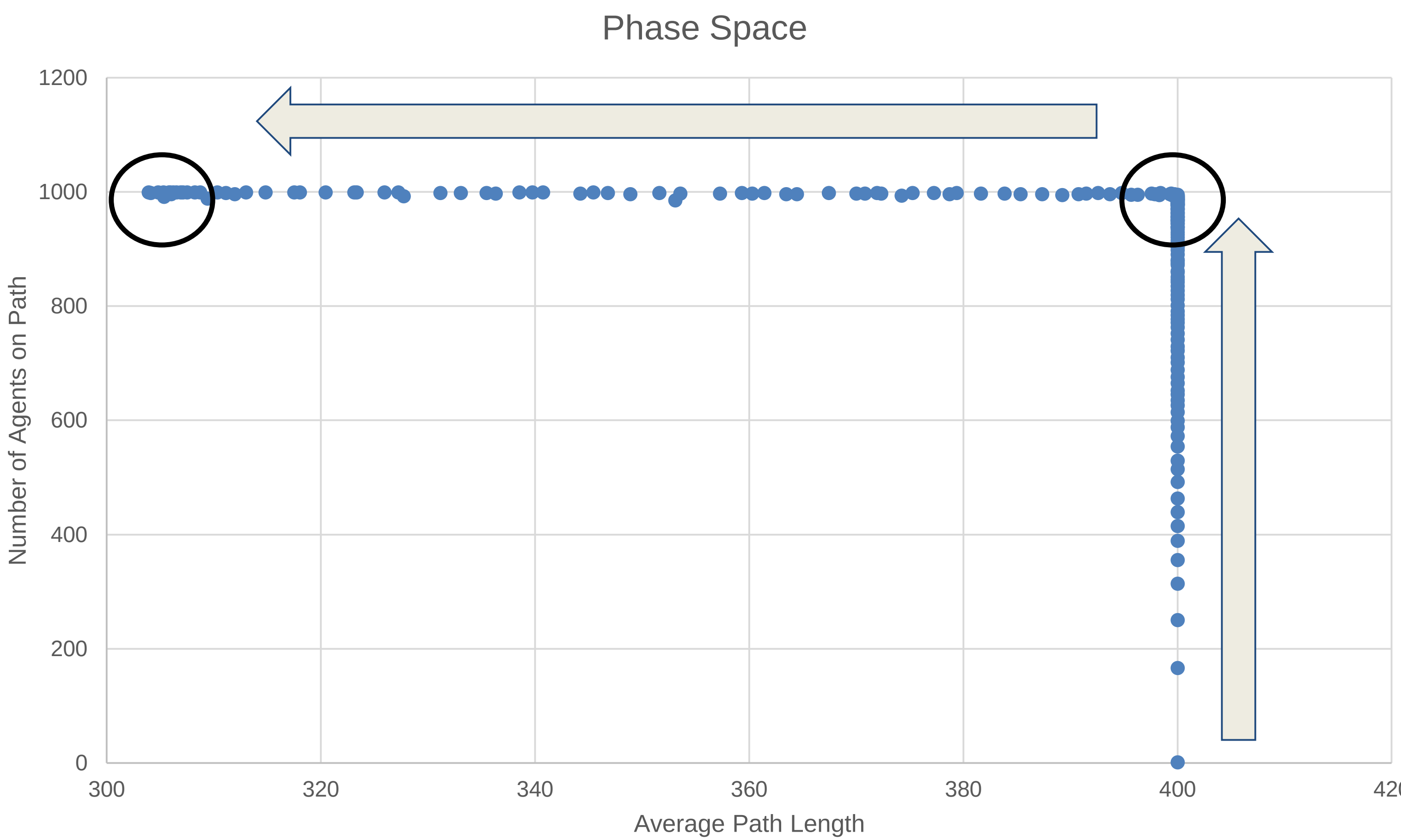


A global property is the number of ants on each path.

$$\vec{N}_T = \begin{bmatrix} 364 \\ 333 \end{bmatrix}$$



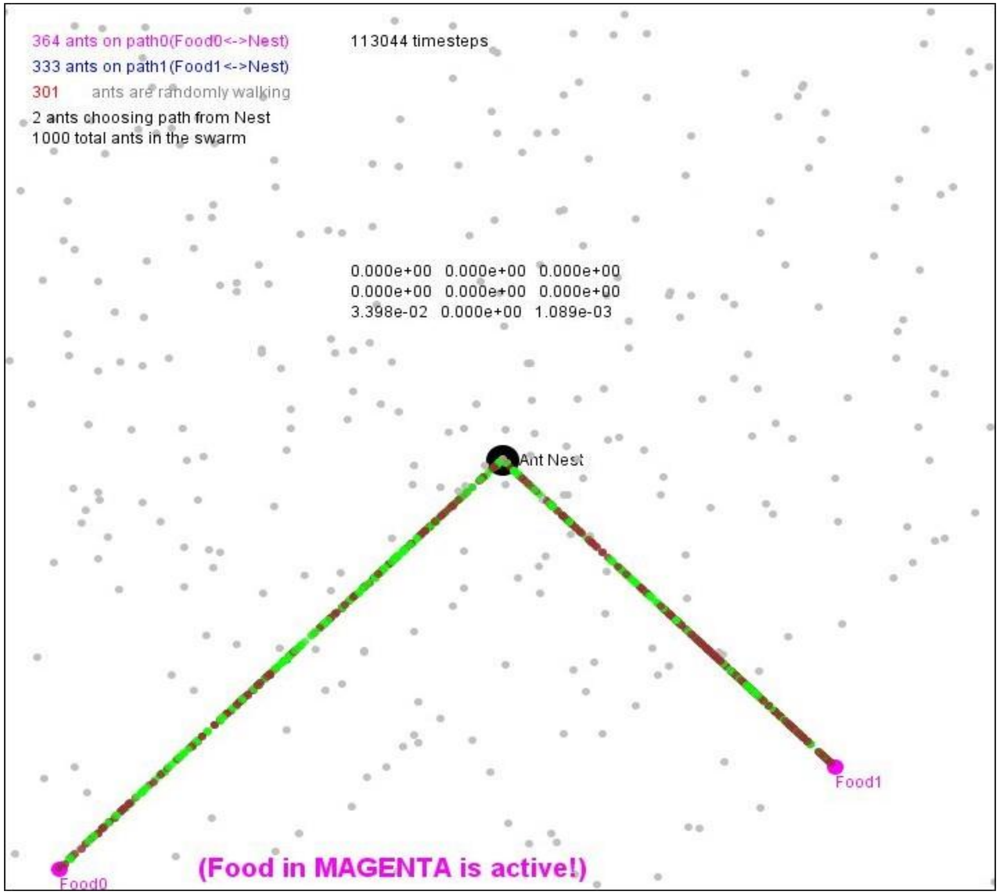
In the phase space, the swarm first converges to the first attractor (representing the first food source. Once the second food source is added, the swarm moves to the second attractor, which represents switching paths.



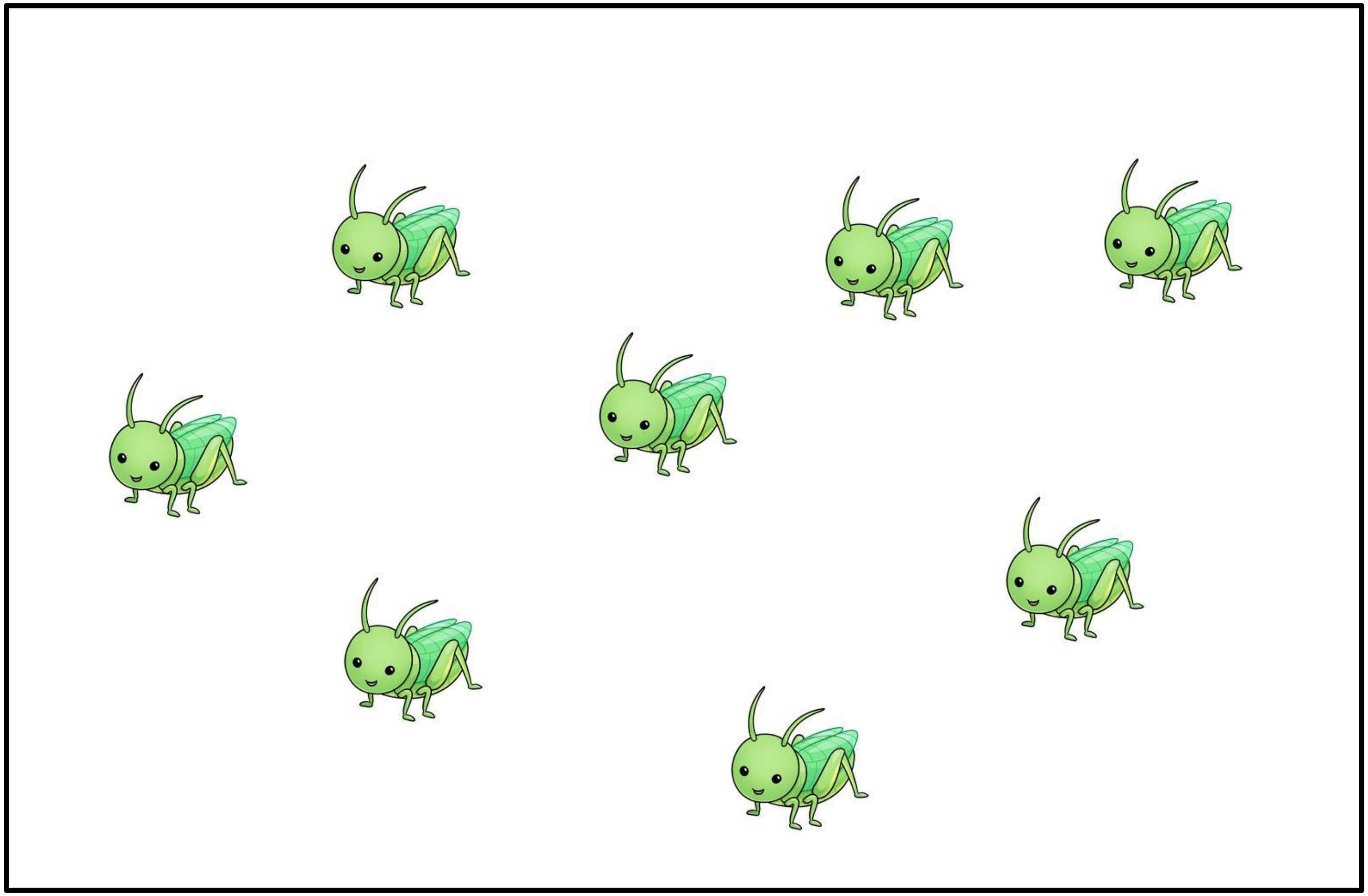
After some mathematical tricks, it can be seen that the dot product of the two global properties needs to be negative in order for the swarm to make the decision. The state change can be seen below.

Swarm Condition:

$$\overrightarrow{d_\tau} \cdot \overrightarrow{dN_\tau} < 0.$$

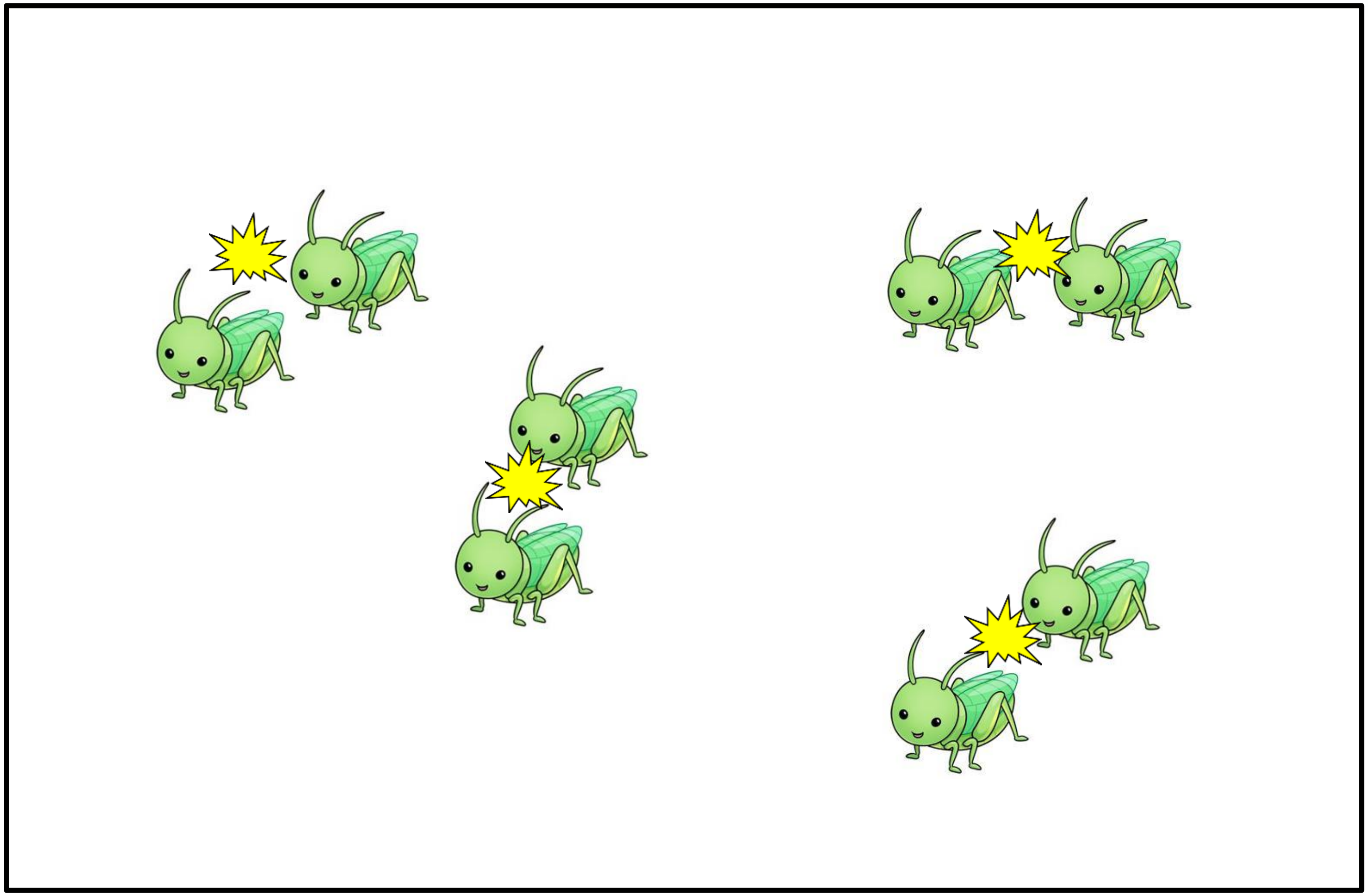


How can we engineer a swarm that can determine the size of a room by merely bumping into each other?



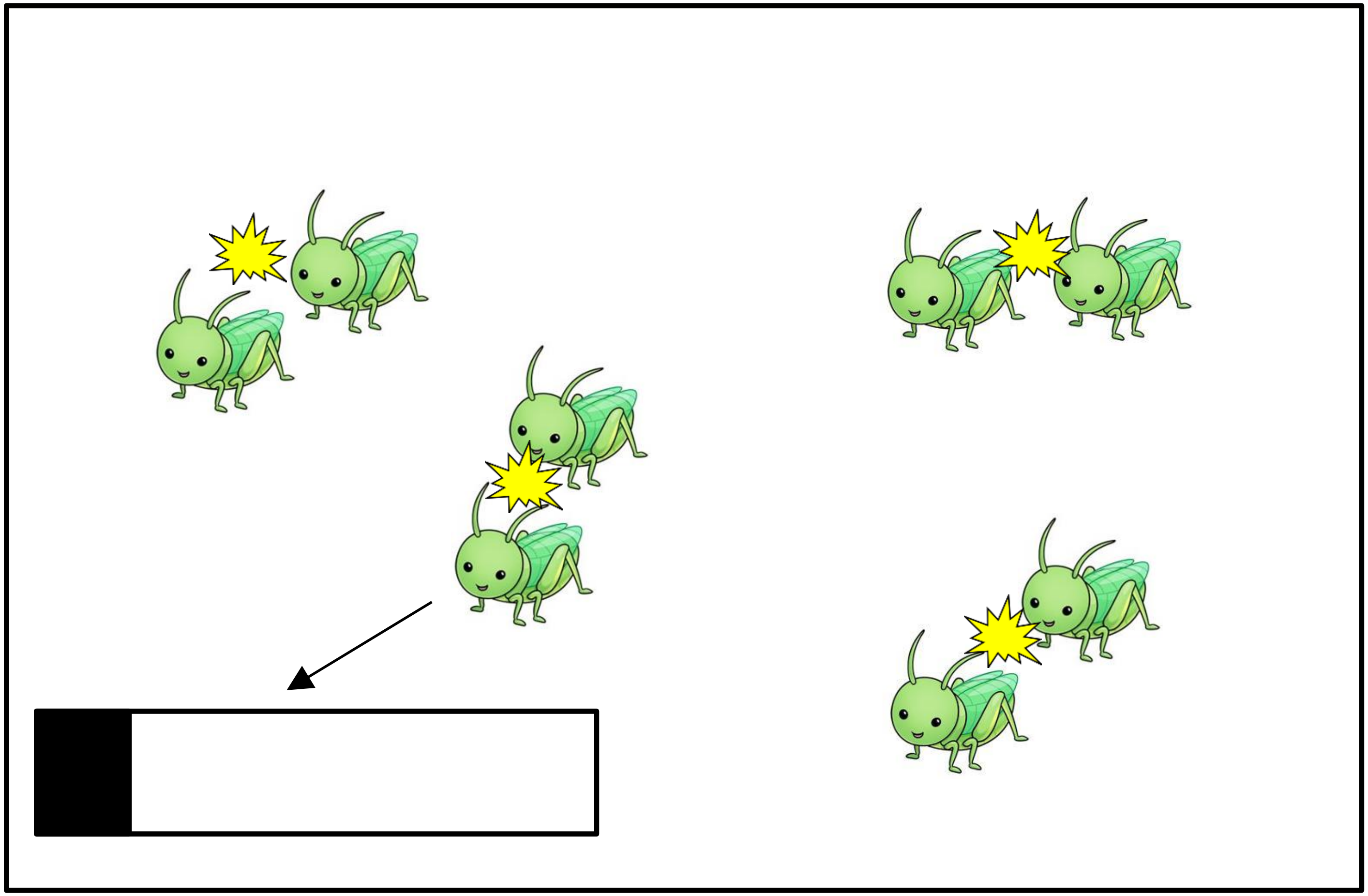
A group of grasshoppers is in an enclosed space

How can we engineer a swarm that can determine the size of a room by merely bumping into each other?



As they move around, they contact each other

How can we engineer a swarm that can determine the size of a room by merely bumping into each other?



Upon contact, the grasshopper’s serotonin level increases

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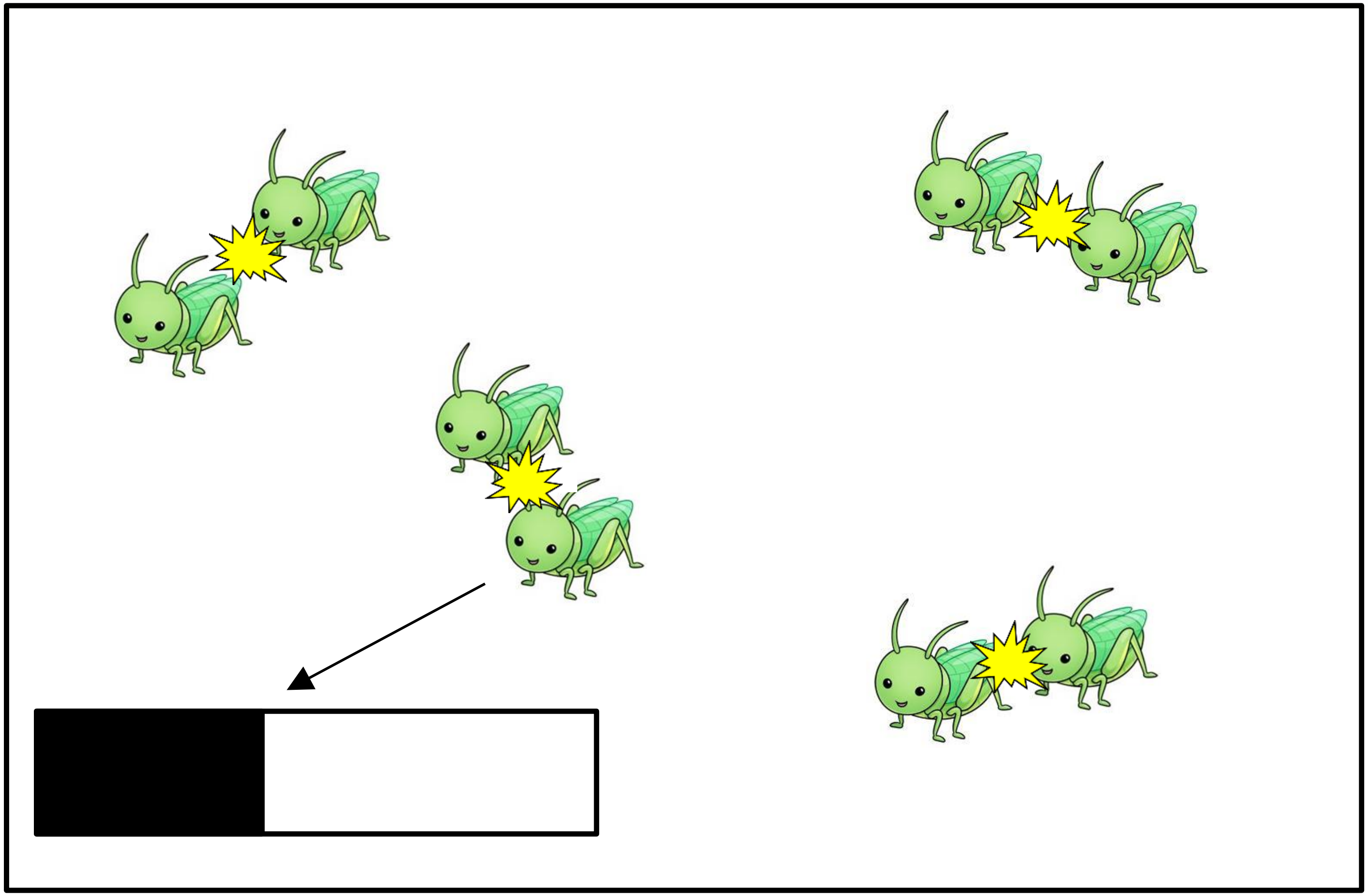

Continued collisions further increase the serotonin levels, until…

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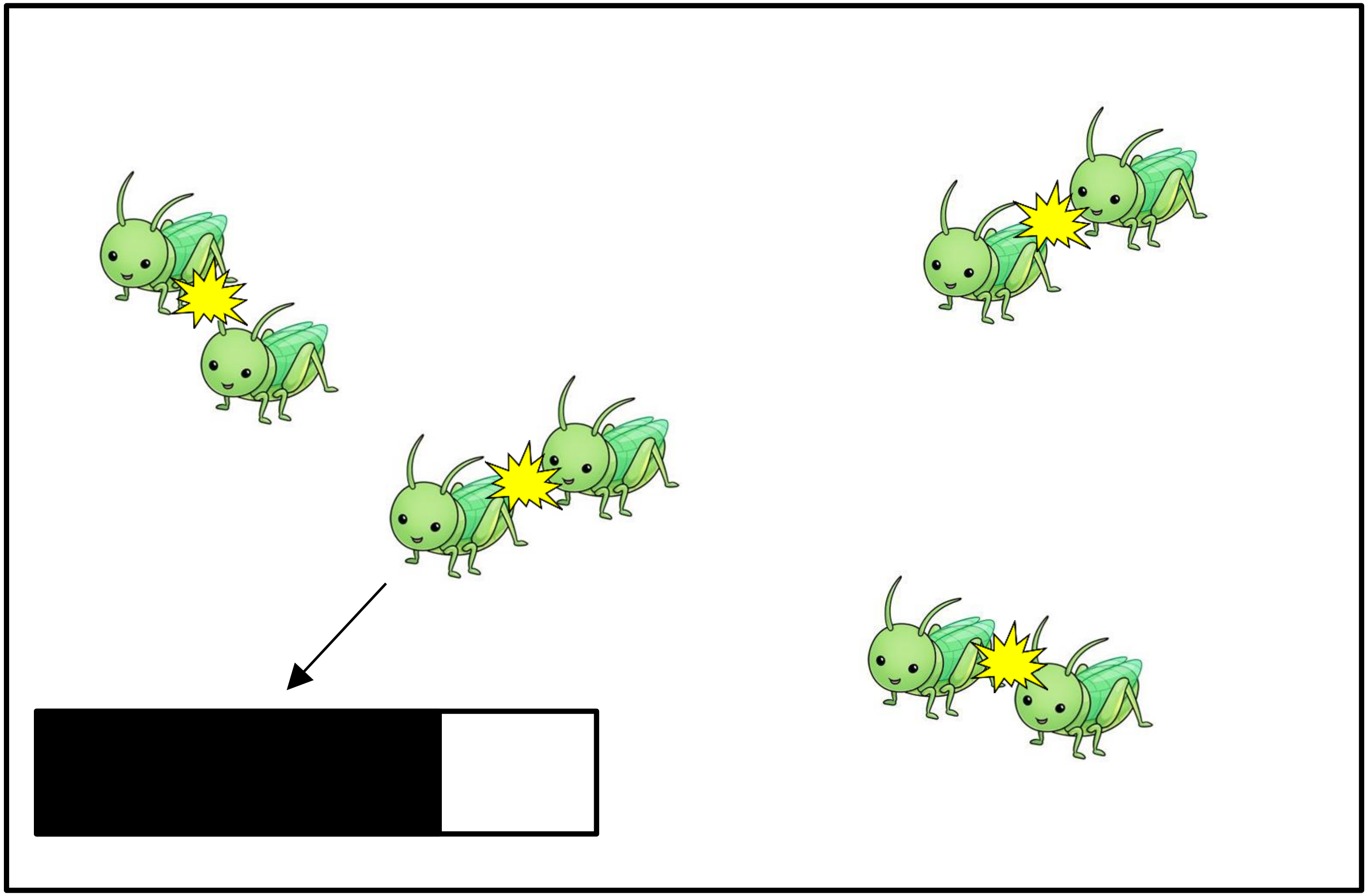

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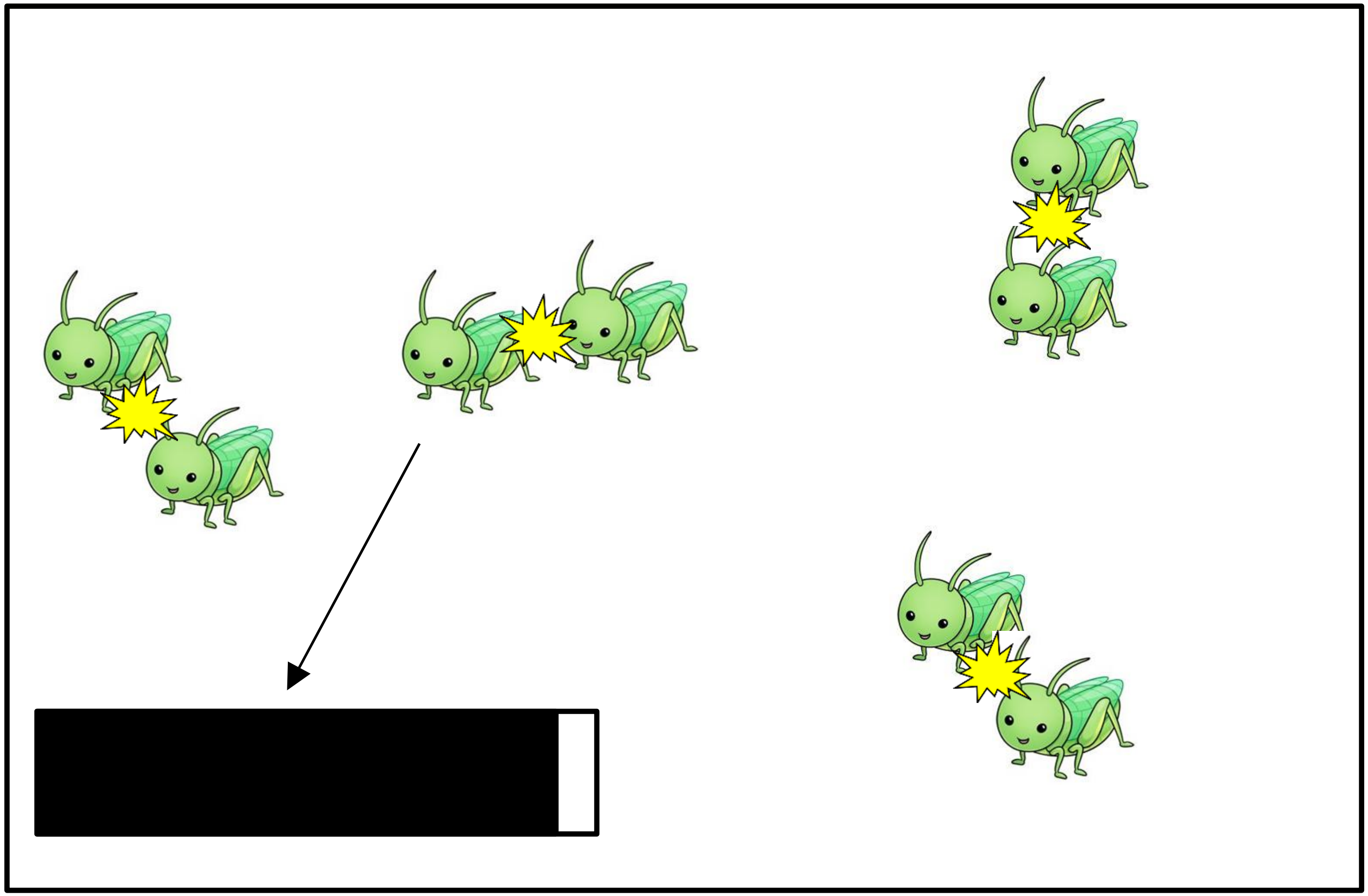

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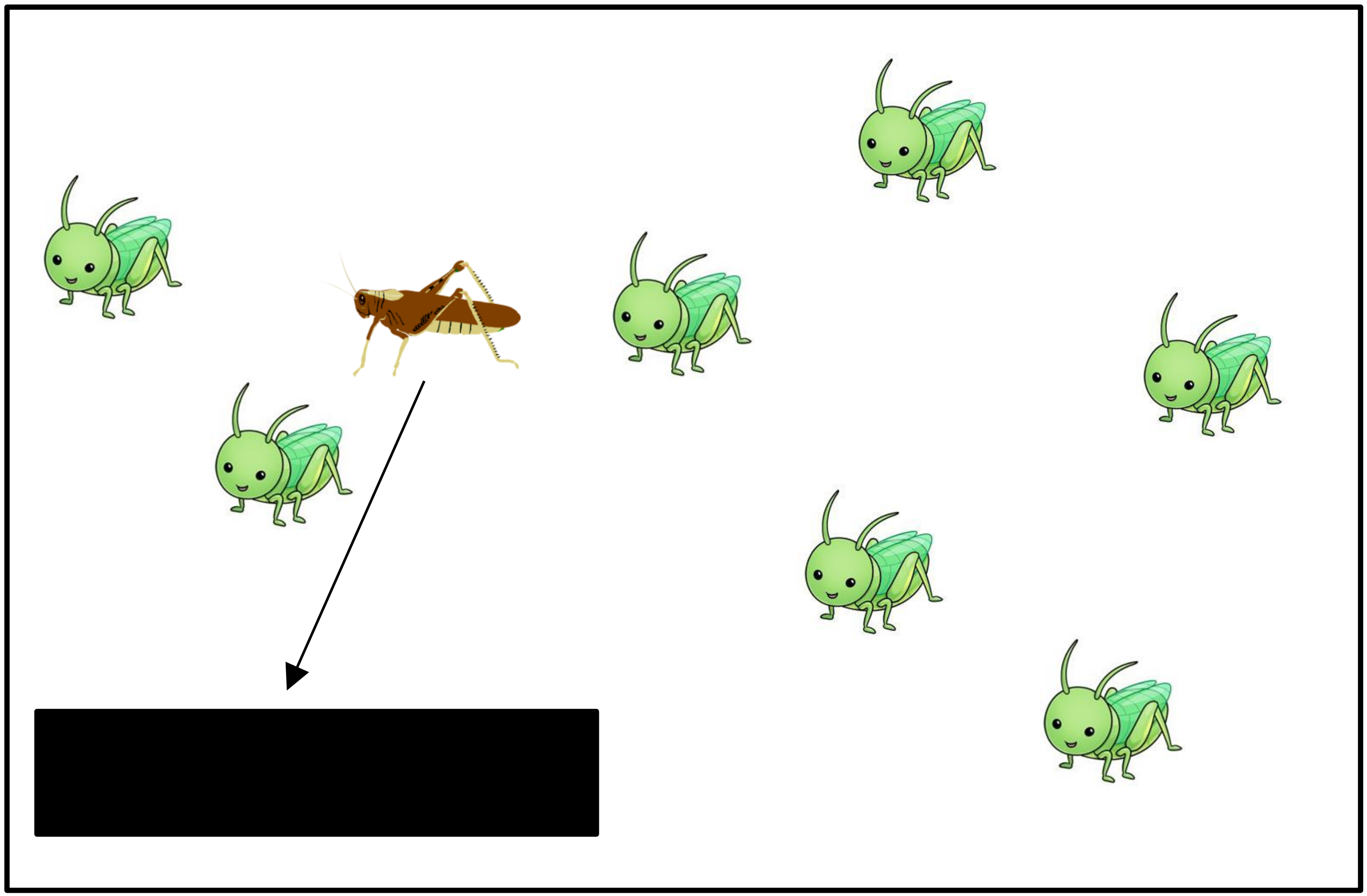
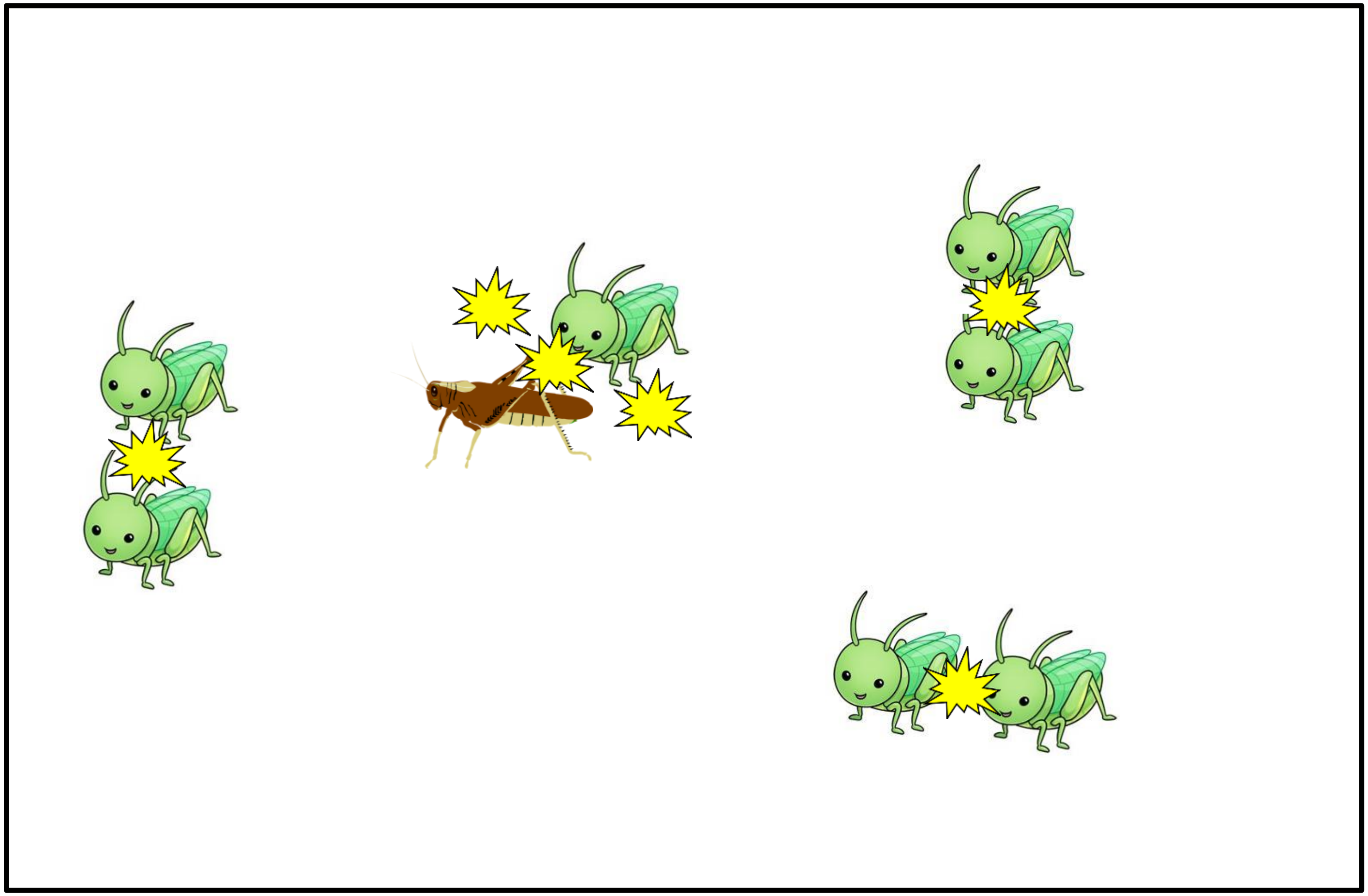


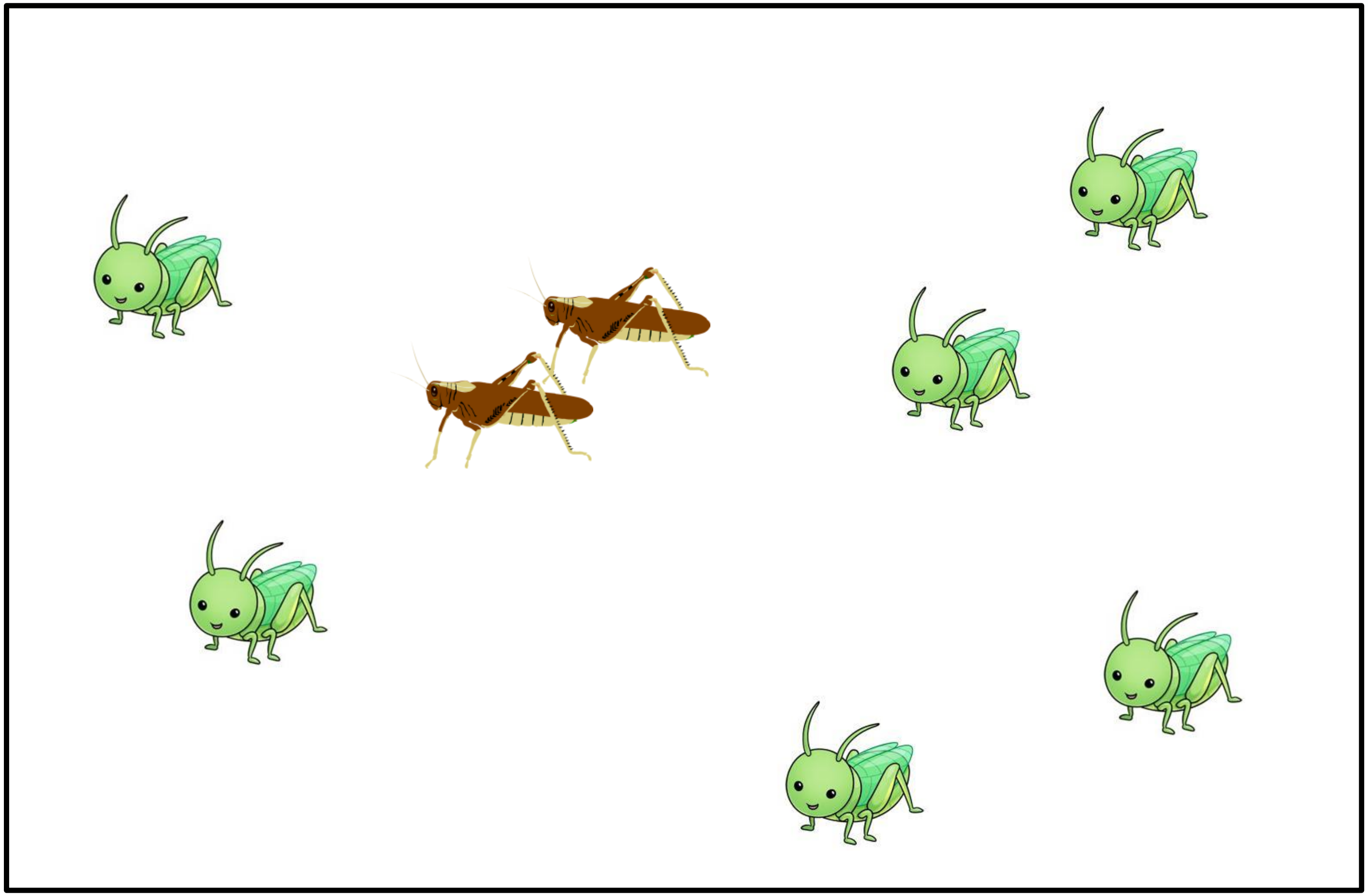
The grasshopper begins its transition into a locust

How can we engineer a swarm that can determine the size of a room by merely bumping into each other?



The erratic behavior of locusts lead to many more collisions, increasing the rate of serotonin increase for surrounding grasshoppers

How can we engineer a swarm that can determine the size of a room by merely bumping into each other?



As a result, more grasshoppers turn into locusts

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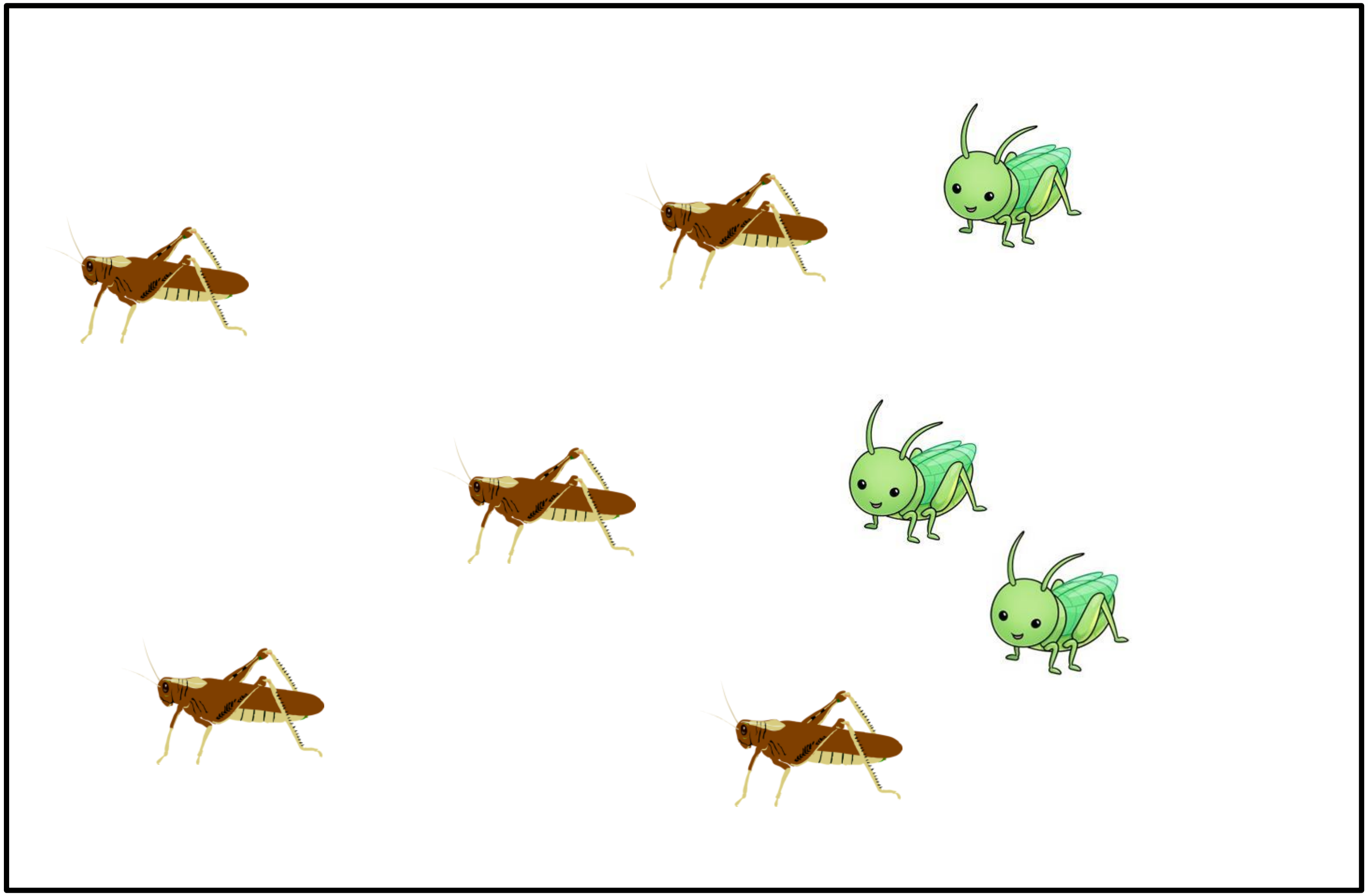

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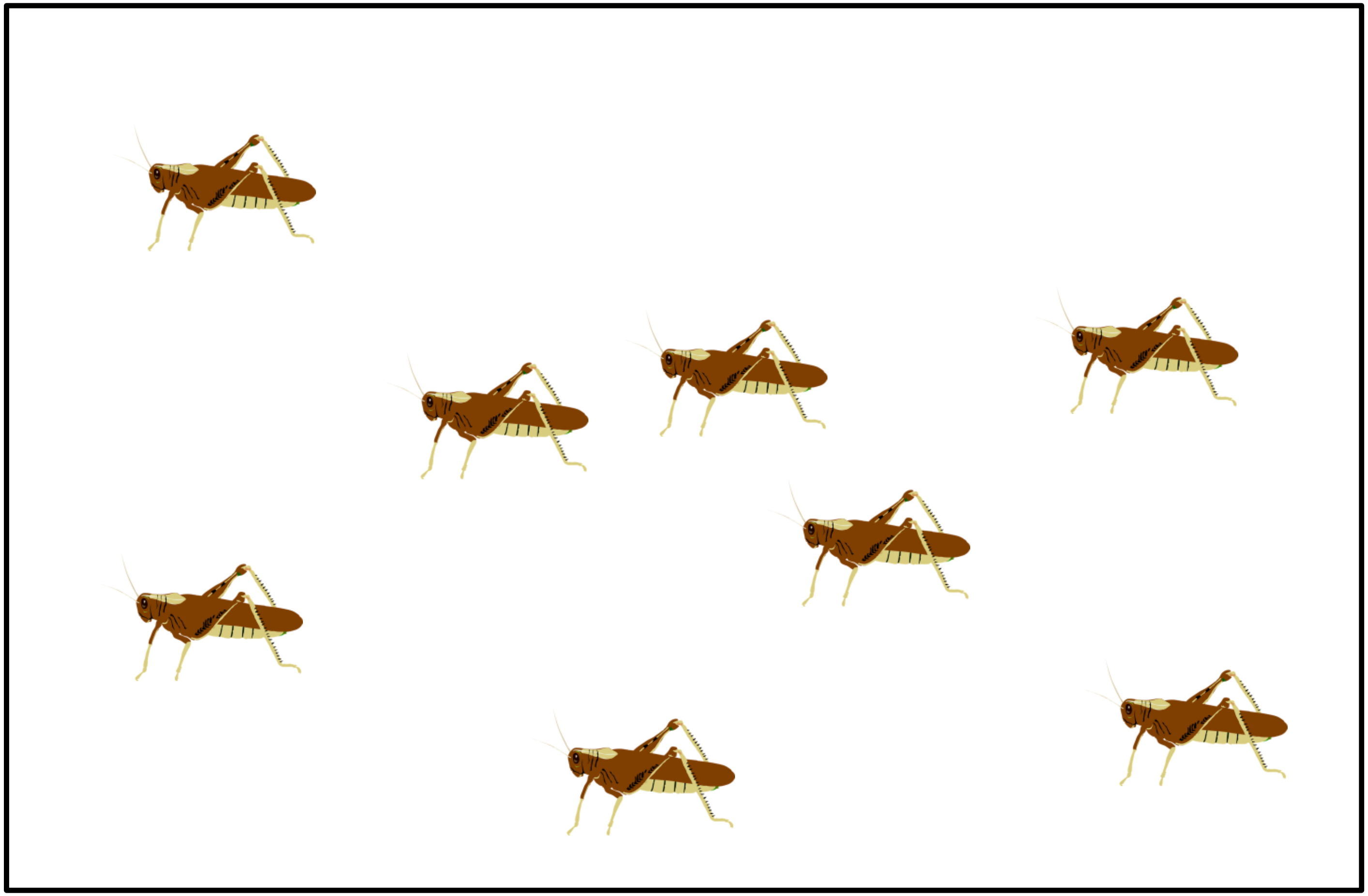

Eventually, all of the grasshoppers have transitioned into locusts

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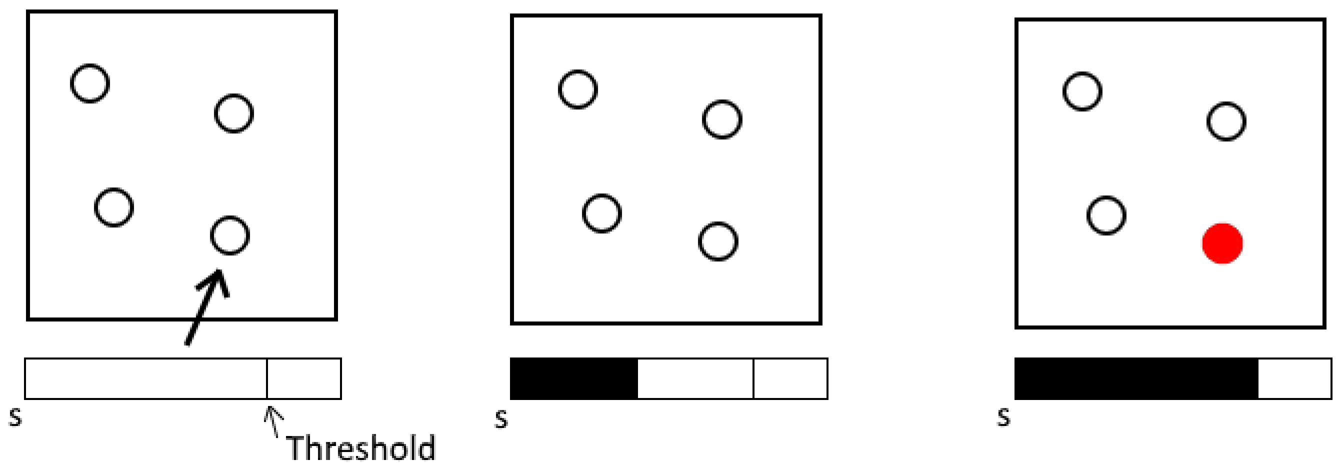
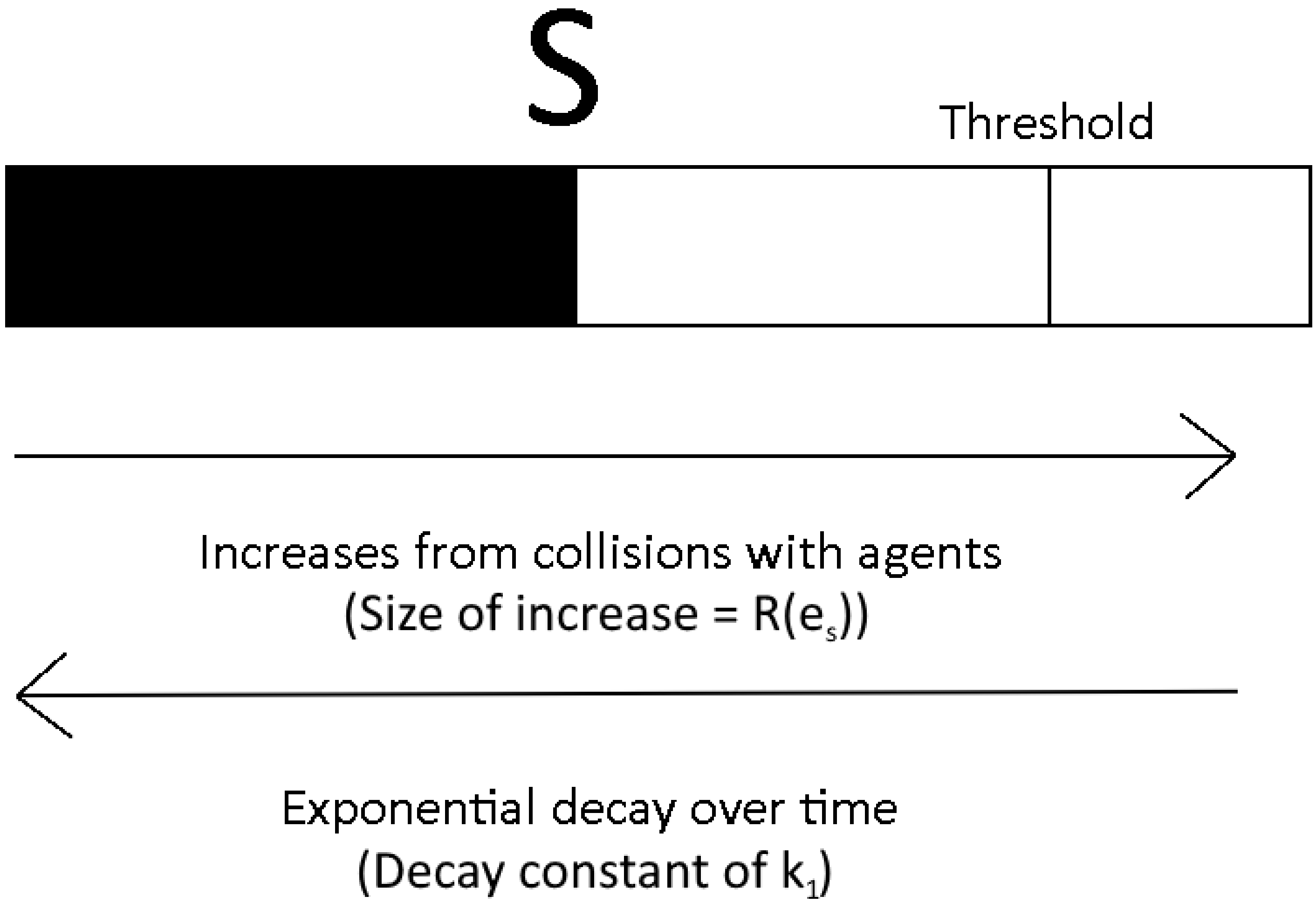


Unique state

Increases through contact with agents

Transitions once state reaches threshold

The internal state of the agent increases by a constant amount for collisions with other agents. This state also decays exponentially over time. After the threshold, the agent is triggered.



The global property is the sum of each agent's internal property, and so the swarm condition is that the global property must increase over time.

- Global Property

$$P = \sum_{i=1}^{N_a} s_i.$$

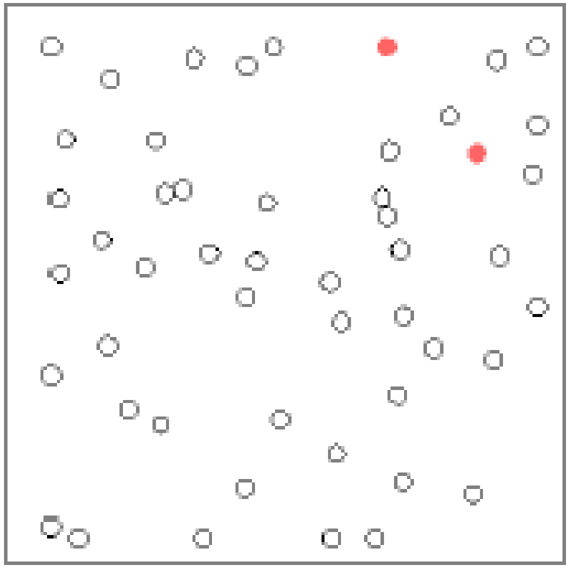
- Desired Behavior in a Small Room

$$\frac{dP}{dt} > 0$$

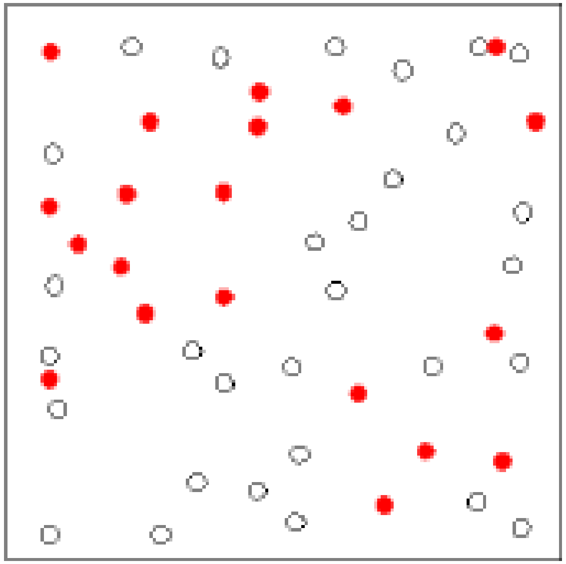
The swarm condition can be expressed in terms of parameters that determine the dynamics of the internal state.

- Swarm condition

$$\frac{k_1 P}{R_{max}} < N_{trigger}.$$

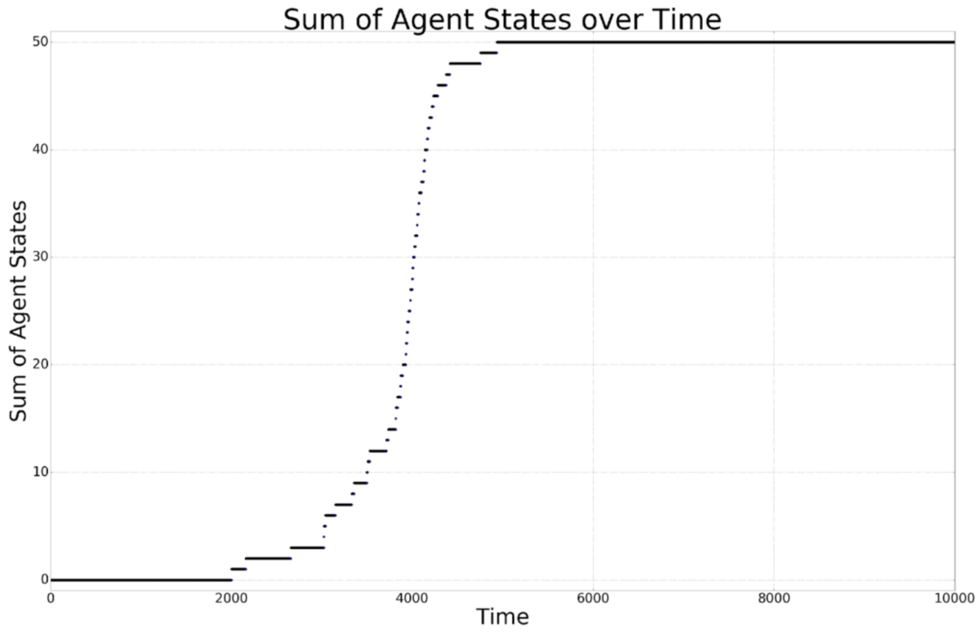


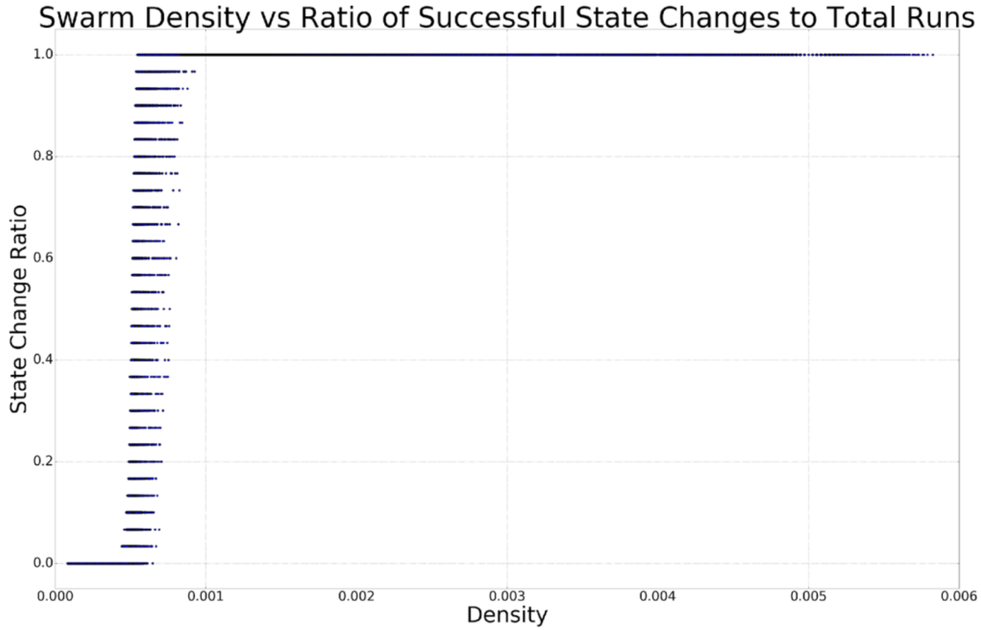
$N_{trigger} = 2$



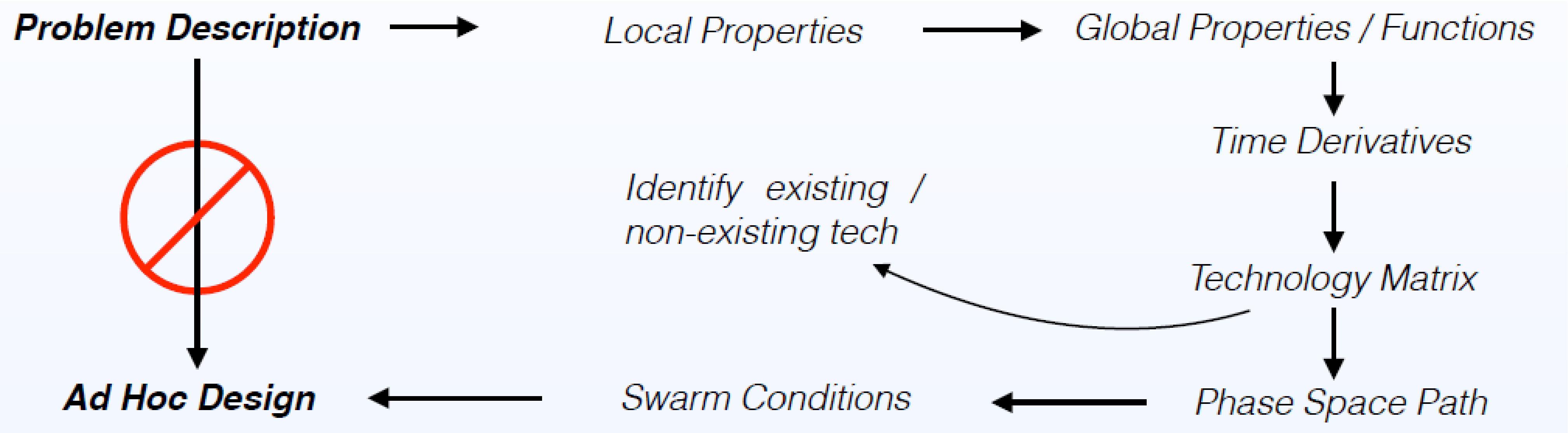
$N_{trigger} = 20$

The state change can be seen below. The swarm condition is verified through experimental data.





How do we engineer swarms to make decisions provably?



Thank you!