

Attractor Based FRAM Analysis

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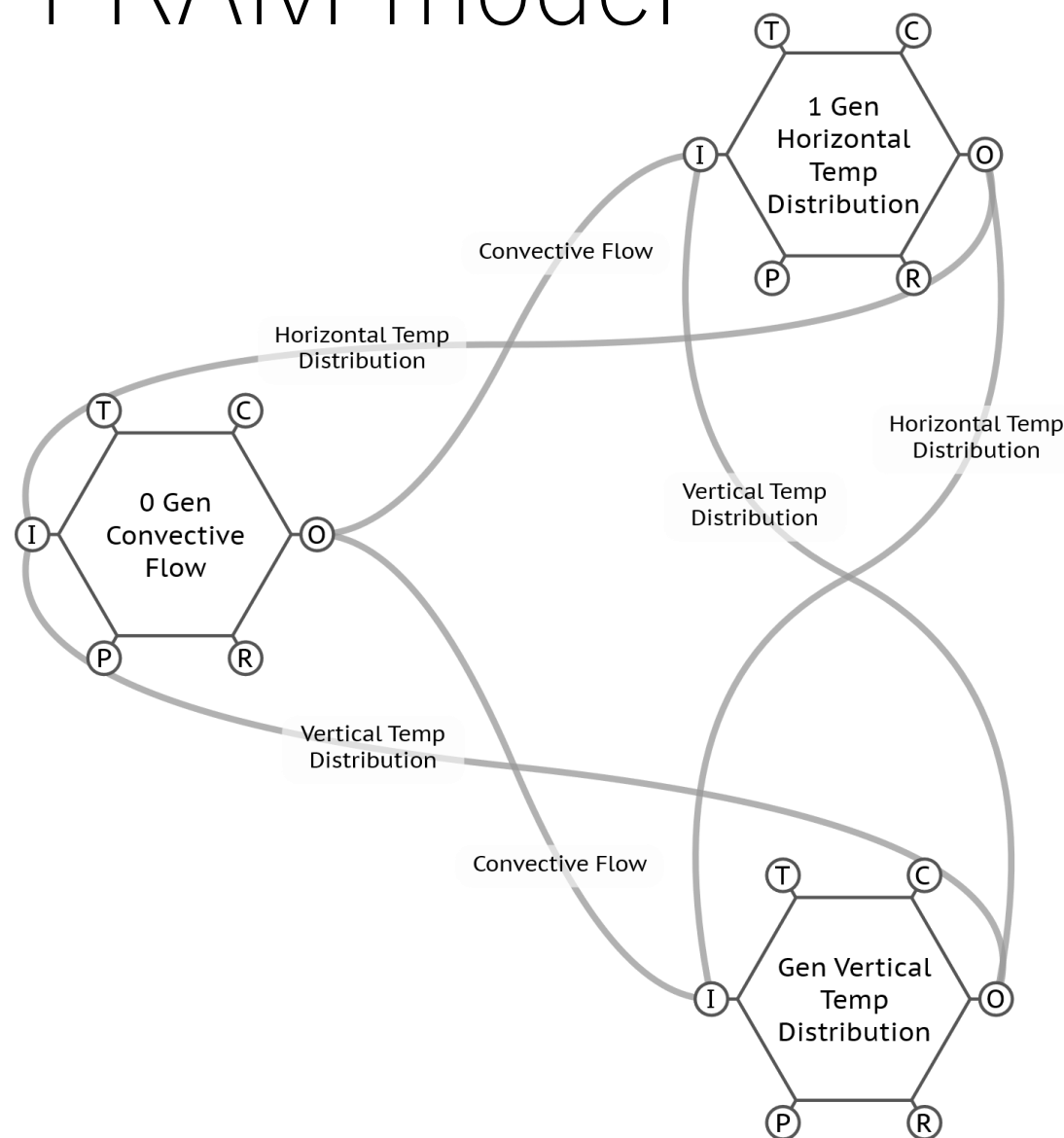
Motivation

- FRAM model is easy to build.
- But it is not easy to **evaluate** the model.
- Especially, if the system behavior is chaotic, it is even harder.
- For effective evaluation support, we propose evaluation method using chaos attractor. (**Attractor-Based FRAM Analysis**)

Example 1: Changing process of weather

- Parameters:
 - x: Convective flow of the air
 - y: Horizontal temperature distribution
 - z: Vertical temperature distribution
- Dependency among the parameters:
 - $dx = \sigma * (y - x)$: $\sigma = 10$
 - $dy = x * (\rho - z) - y$: $\rho = 28$
 - $dz = x * y - \beta * z$; $\beta = 8/3$

FRAM model

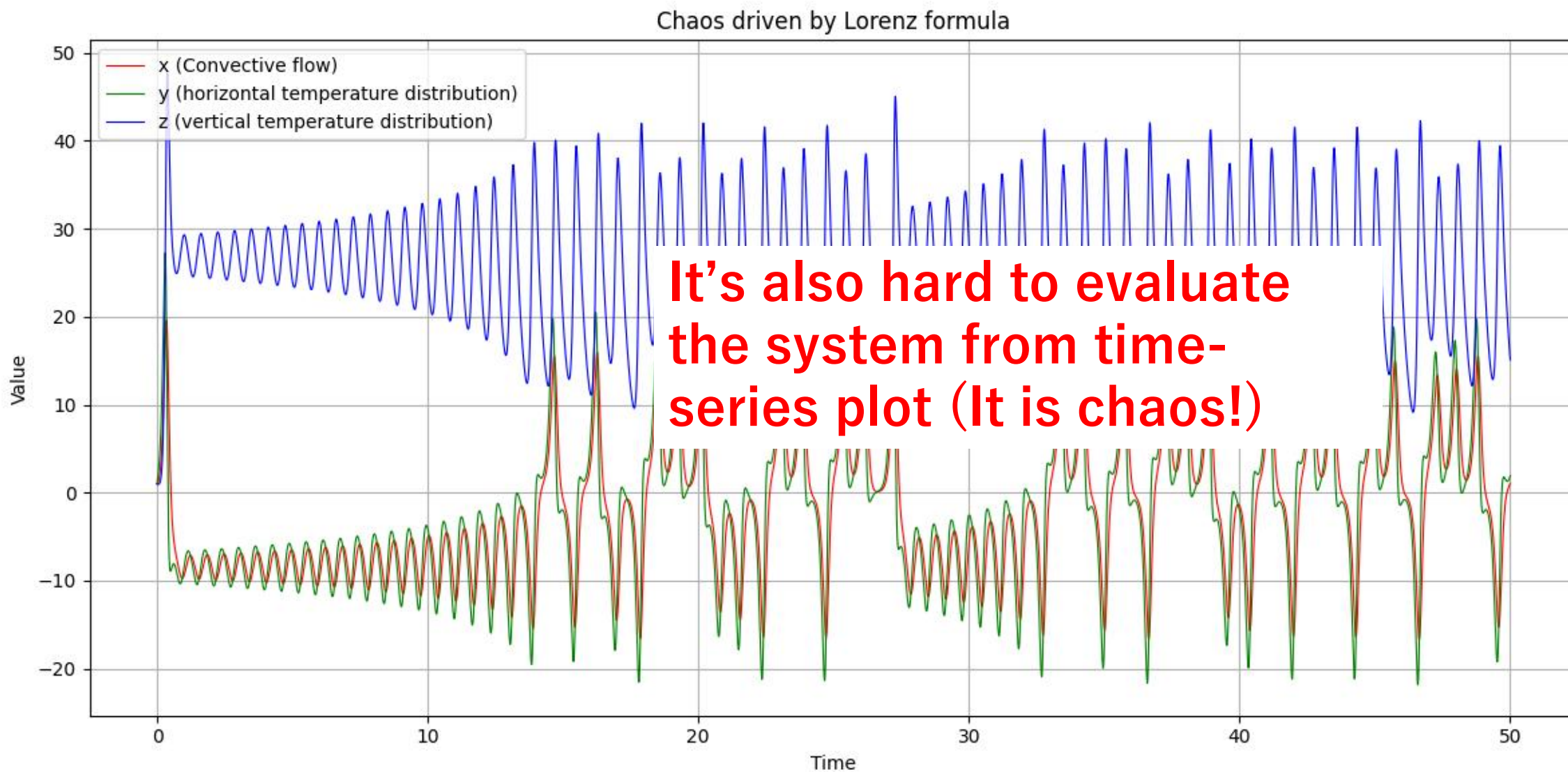


It's hard to evaluate the system straight from the model...

Usually, evaluation of this model would end up with just saying "This loop generates **3-body problem** which leads to **chaos**. It is hard to predict the consequences."

That means we would see only "weak" (unstable) character of the system.

Simulation results in chronological order (Chaos)



Attractor-based Evaluation

FRAM model can be evaluated effectively using the chaos attractor.

Example evaluation:

*The system has two stable states (two wings).
Between the stable states, sometimes, a sudden jump happens.
This jump brings instability into the system.*

Jump happens when:

- 1) x (**convection flow**) is near **zero**
- 2) y (**horizontal temp distribution**) is near **zero**
- 3) z (**vertical temp distribution**) is near **zero**

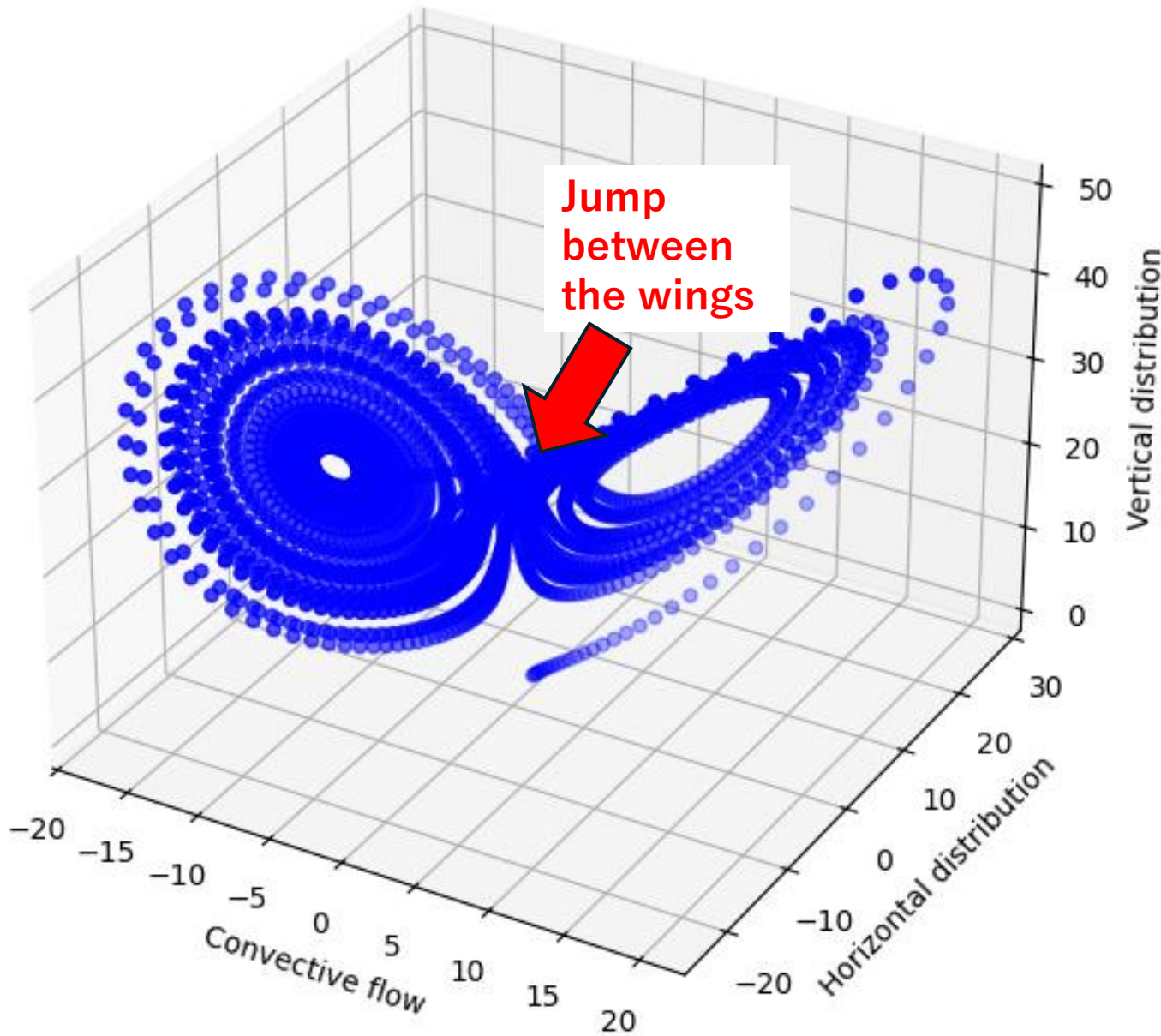
These states (all zero) happen when :

- There are no updraft/downdraft (low x).

➡ **That is spring or fall season.**

Conclusion

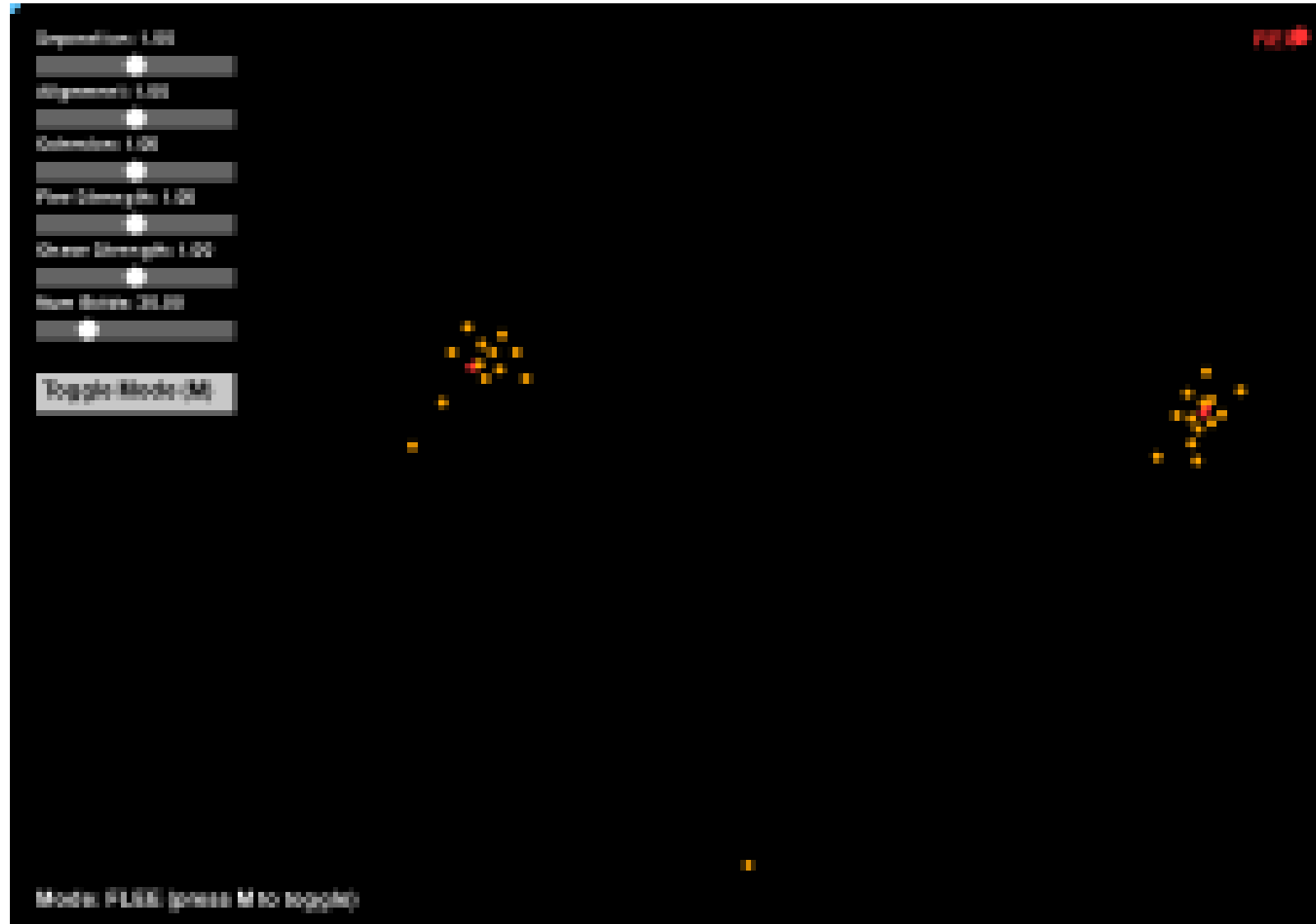
This is a basically stable cyclic system. But it becomes instable in spring or fall.



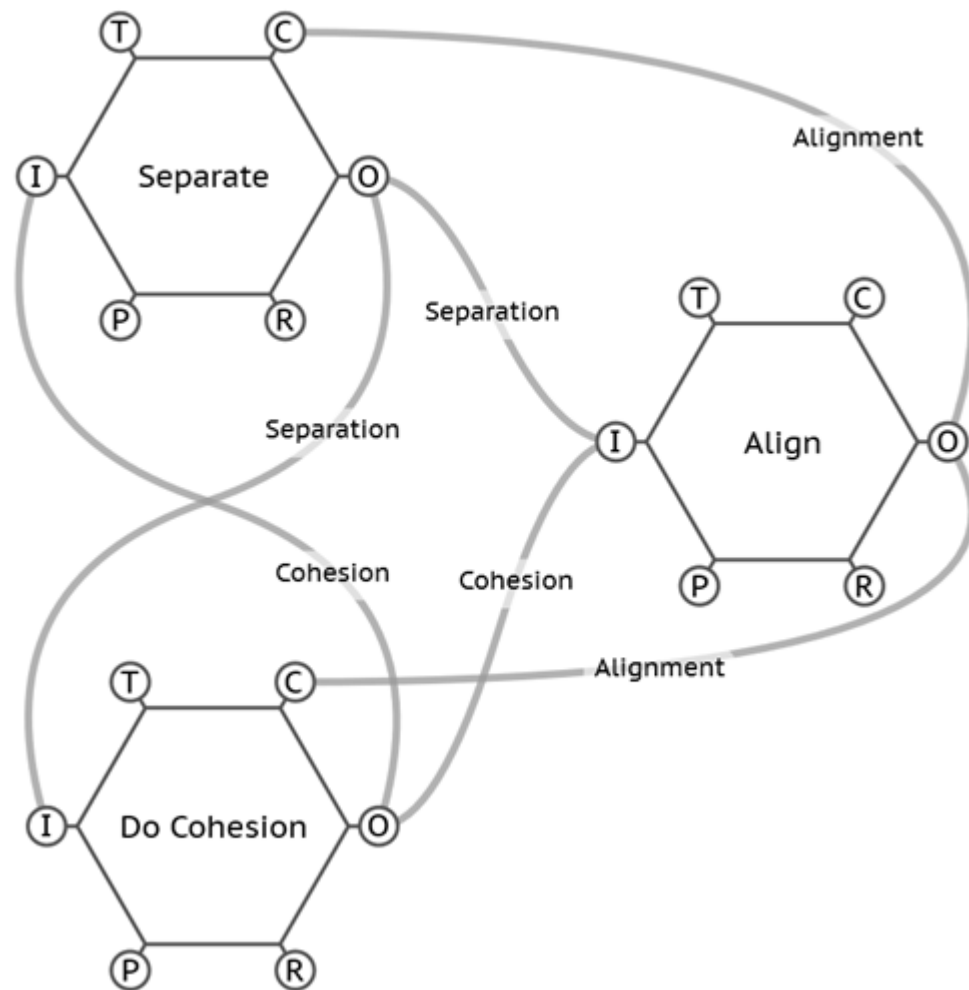
Example 2: Flock of Birds

- Parameters:
 - x: **Separation** (How **separate** the birds should fly)
 - y: **Cohesion** (How **close** the birds should fly)
 - z: **Alignment** (How **aligned** the birds should fly)
- Dependency among the parameters:
 - dx : If $\text{diff}(x_target, \text{current_x}) > x_threshold$ then $dx = \text{diff} * x_gain$
 - dy : If $\text{diff}(y_target, \text{current_y}) > y_threshold$ then $dy = \text{diff} * y_gain$
 - dz : If $\text{diff}(z_target, \text{current_z}) > z_threshold$ then $dz = \text{diff} * z_gain$

Example 2: Flock of Birds



FRAM model

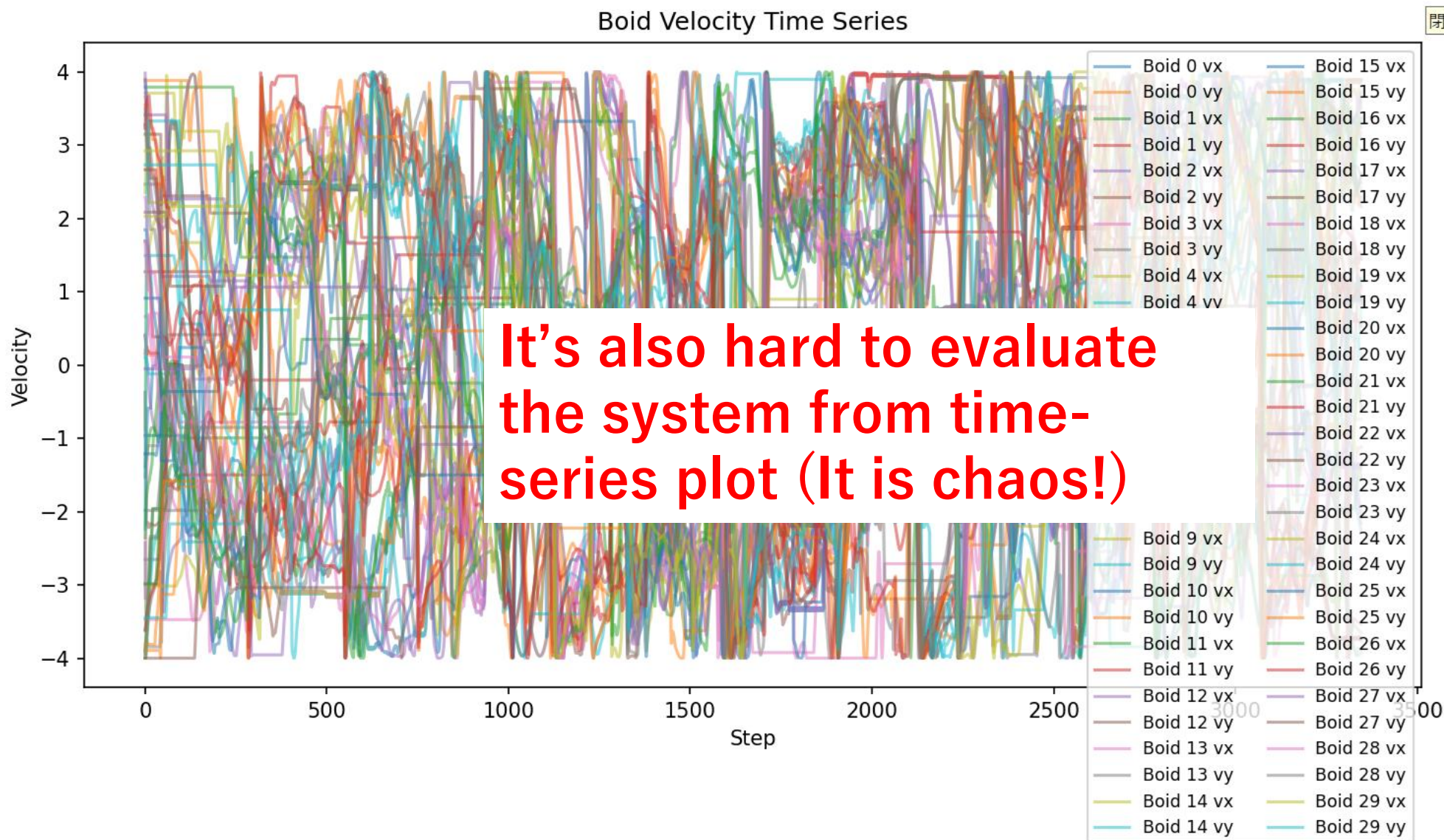


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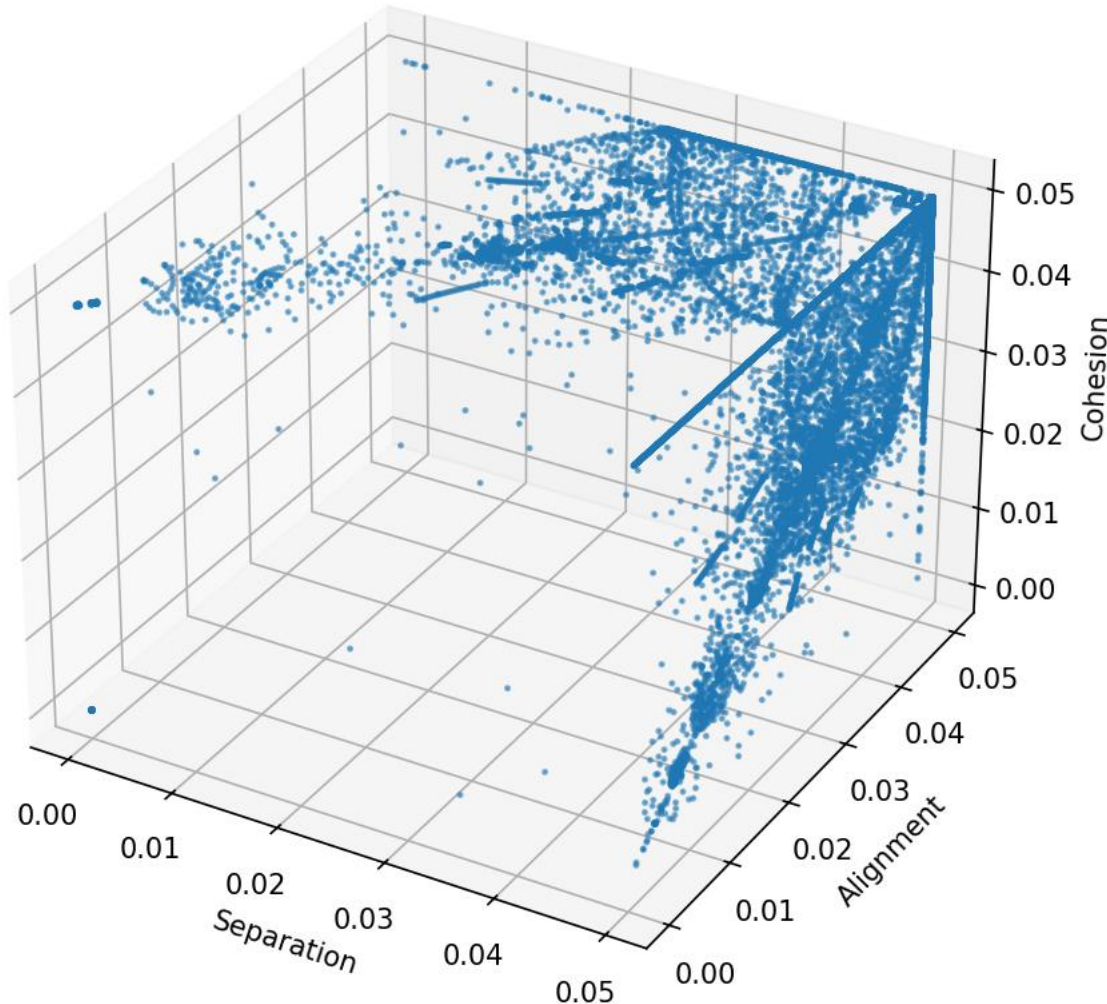
That means we would see only "weak" (unstable) character of the system.

Simulation results in chronological order (Chaos)



Attractor-based Evaluation

Phase Space: Separation vs Alignment vs Cohesion



The system has only two active planes:

- *Separation/Alignment plane*
- *Cohesion/Alignment plane*

Although each bird's movement looks chaotic, flock's hidden structure shows existence of a strongly regulated control. That is the reason why the flock can keep its resilience against predator attacks.

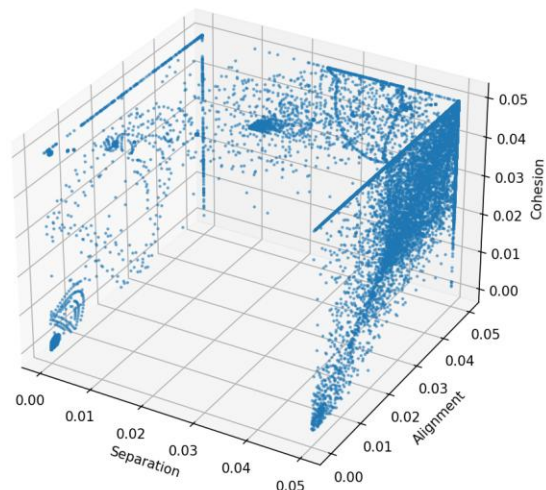
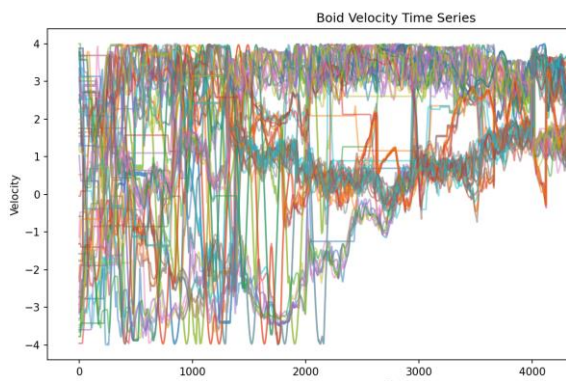
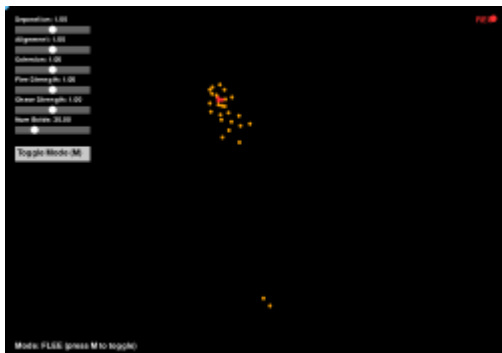
This control is only either between :
Separation & Alignment or
Cohesion & Alignment

- **Strong competition between Separation vs. Cohesion**
- **Coordination via Alignment**

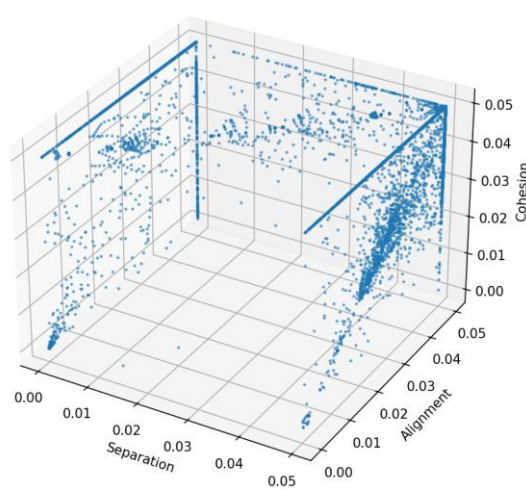
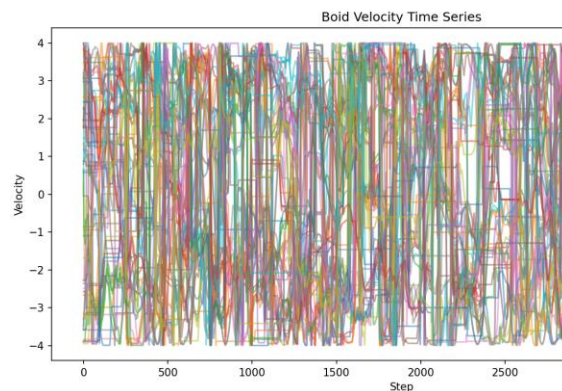
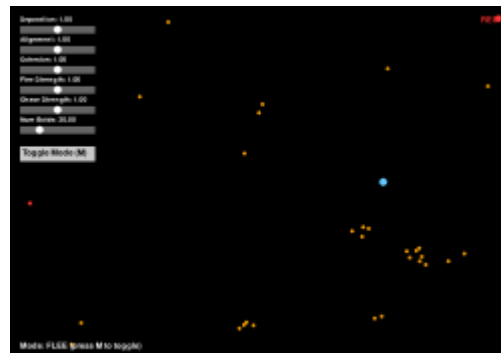
Conclusion

Flock of birds maintains high agility by its chaotic move generated by unbalanced 3-body problem while keeping the harmony by its hidden structure.

No Predator



With Predator



Without a Predator, the birds are flying quite peacefully.

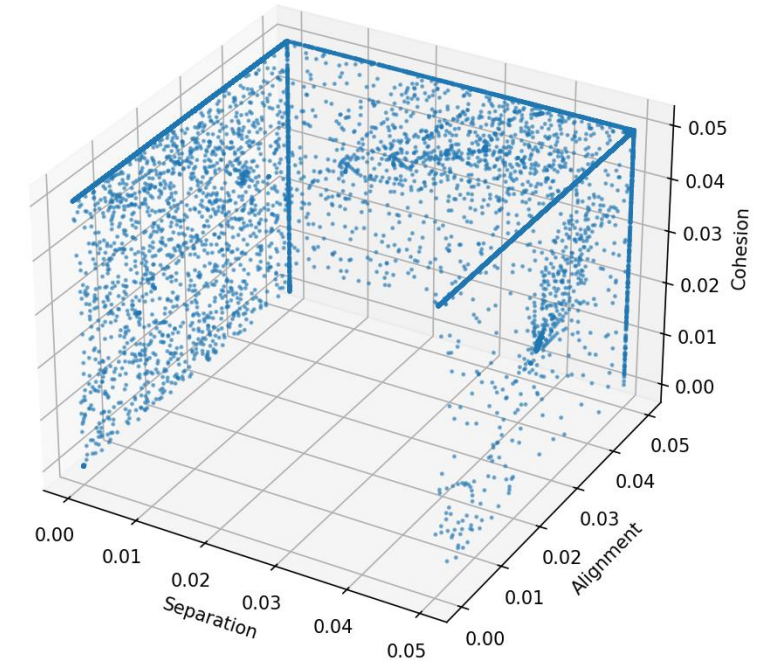
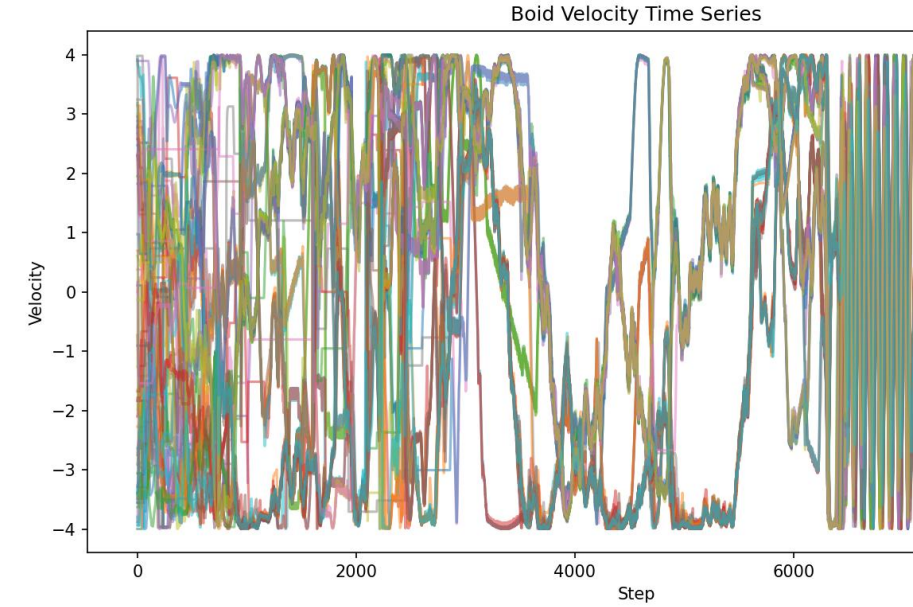
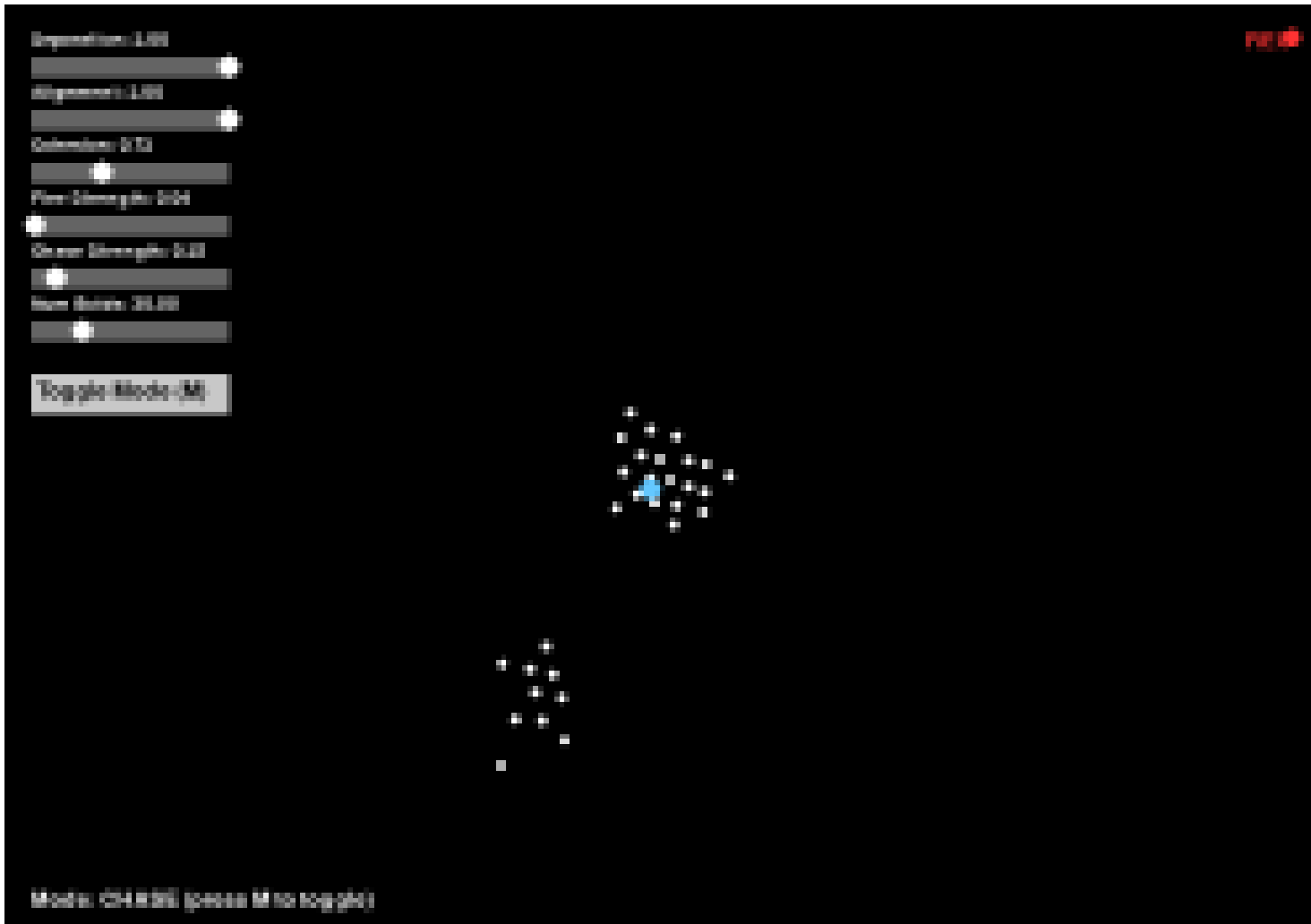
With a Predator, the flock is disturbed significantly.

Without a Predator, trajectory are converged to a major flock.

With a Predator, the birds' trajectories make chaos.

With or Without a predator, attractors are consistent!

If we exchange the predator with an attractor the flock becomes **a galaxy circulating around a blackhole**.



Still, the attractor looks same!