

COLLECTIVE MOTION: JAMMING AND CROWD DYNAMICS

Team Swarm
Harvard SEAS REU
TRiCAM Program

COLLECTIVE MOTION



COLLECTIVE MOTION

- Ordered movement in a system consisting of many self-propelled agents following local rules
- Global behavior varies from local rules
- Collective Motion of Locusts



VICSEK MODEL

- Direction and Position Update

$$\mathbf{x}_i(t + \Delta t) = \mathbf{x}_i(t) + \mathbf{v}_i(t)\Delta t$$

- Summation Term

- Averages the neighboring particles' angles

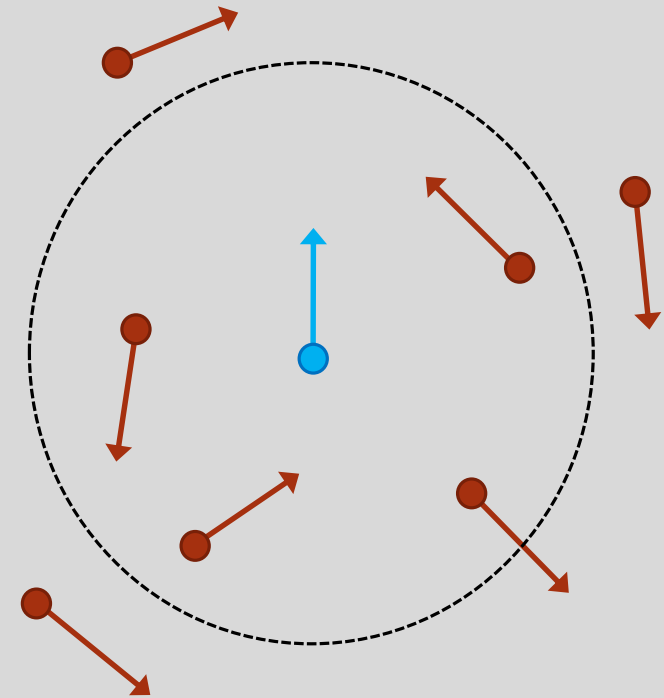
$$\mathbf{v}_i(t + \Delta t) = \frac{\sum_{j \in R_i} \mathbf{v}_j}{|\sum_{j \in R_i} \mathbf{v}_j|} + \eta \zeta(t)$$

- Noise Term

- Samples from a distribution – uniform
- Strength coefficient

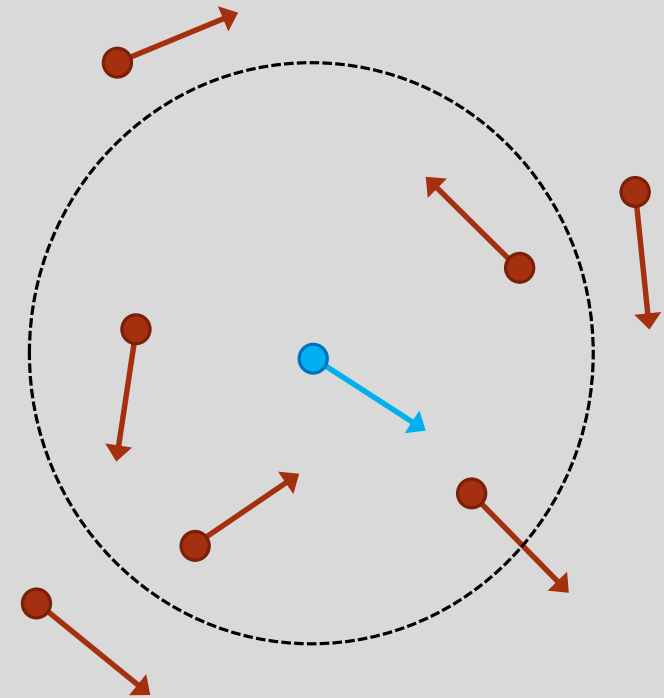
VICSEK MODEL

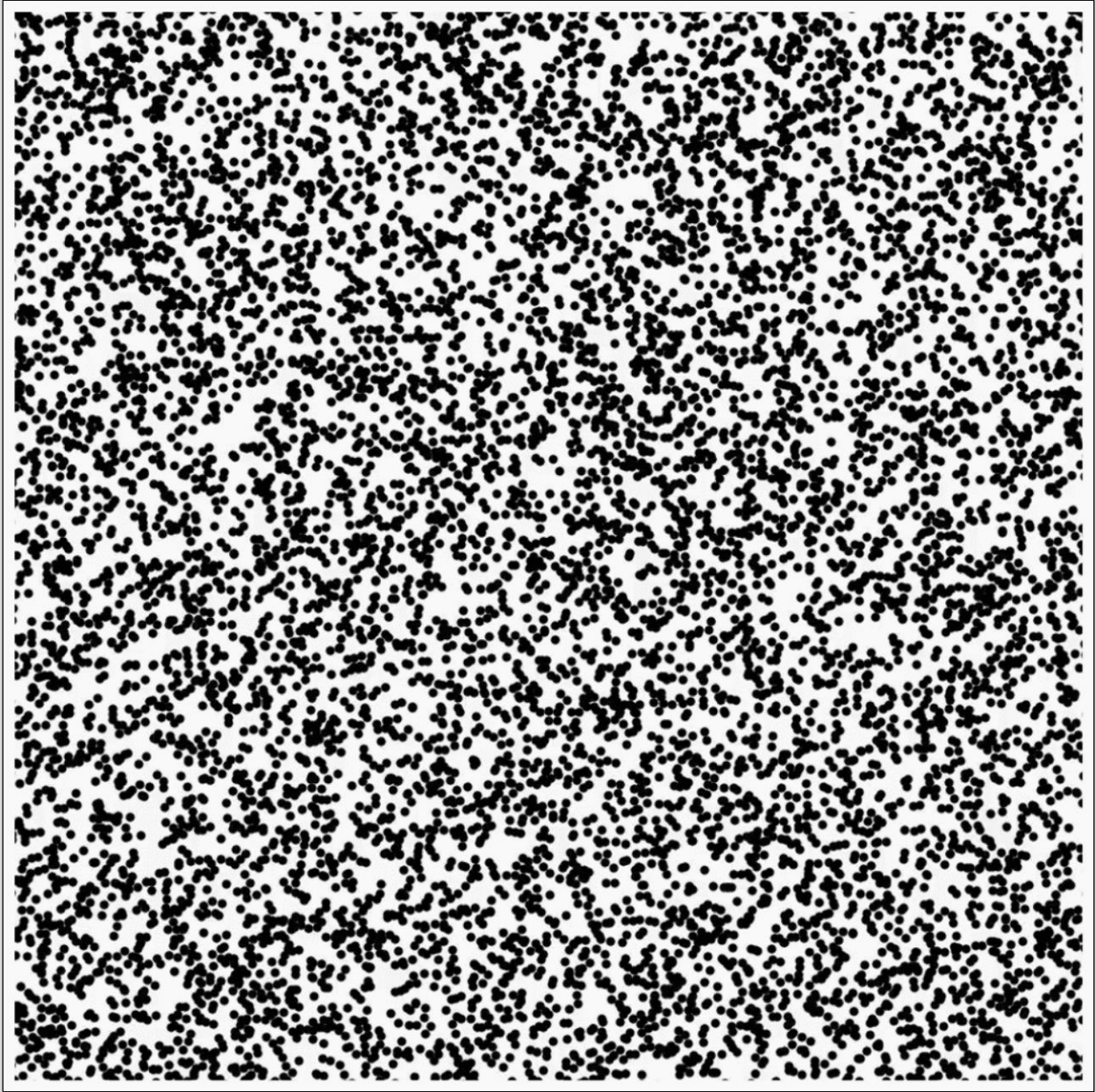
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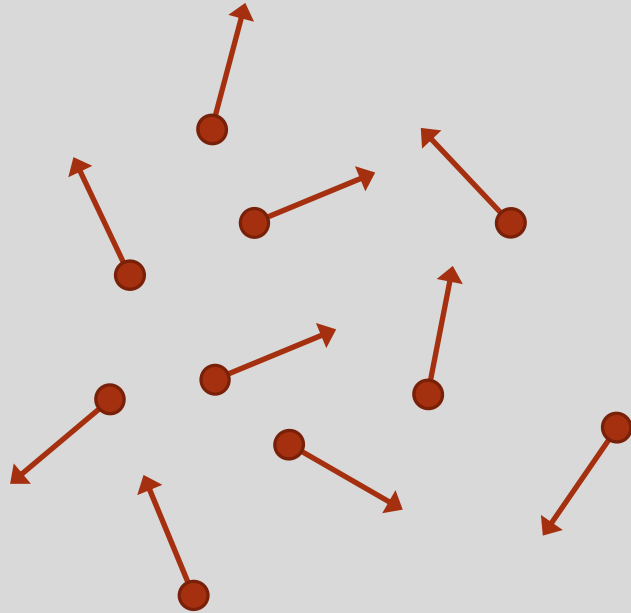




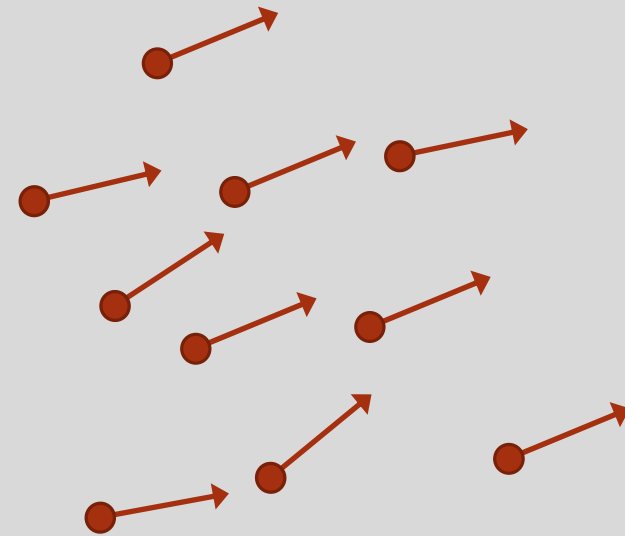
ORDER PARAMETER

- Order: Magnitude of average of all direction vectors

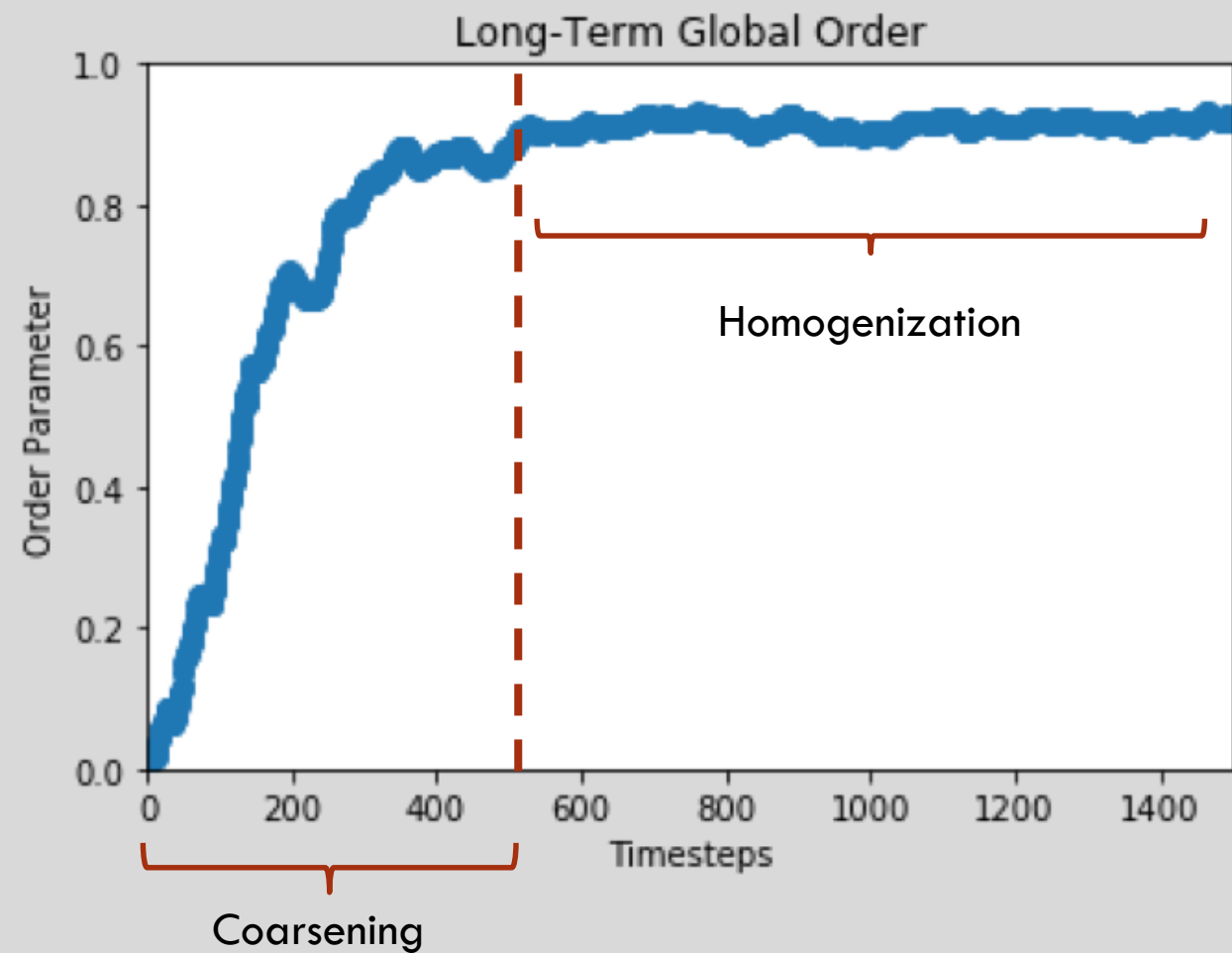
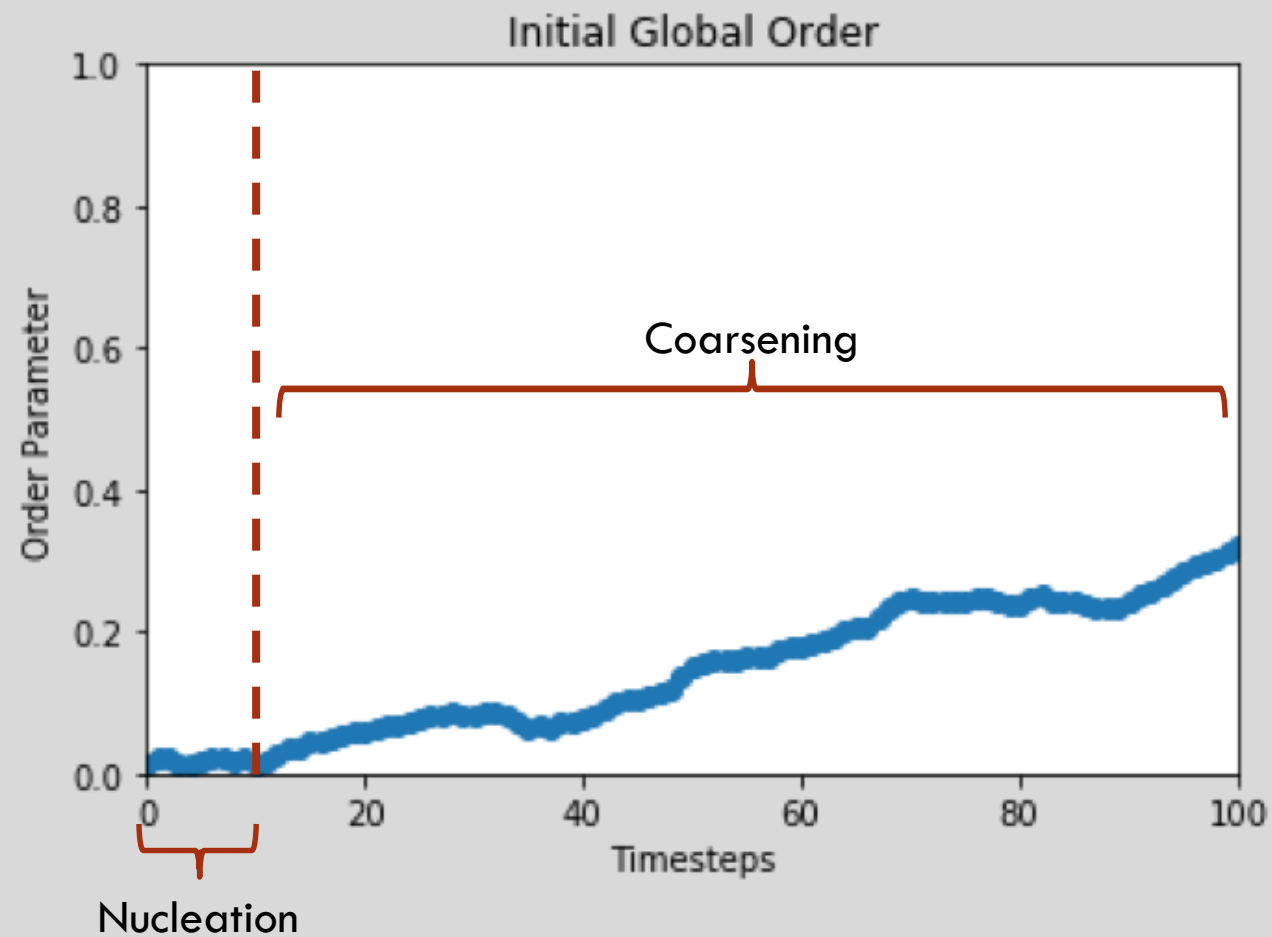
Low Order



High Order



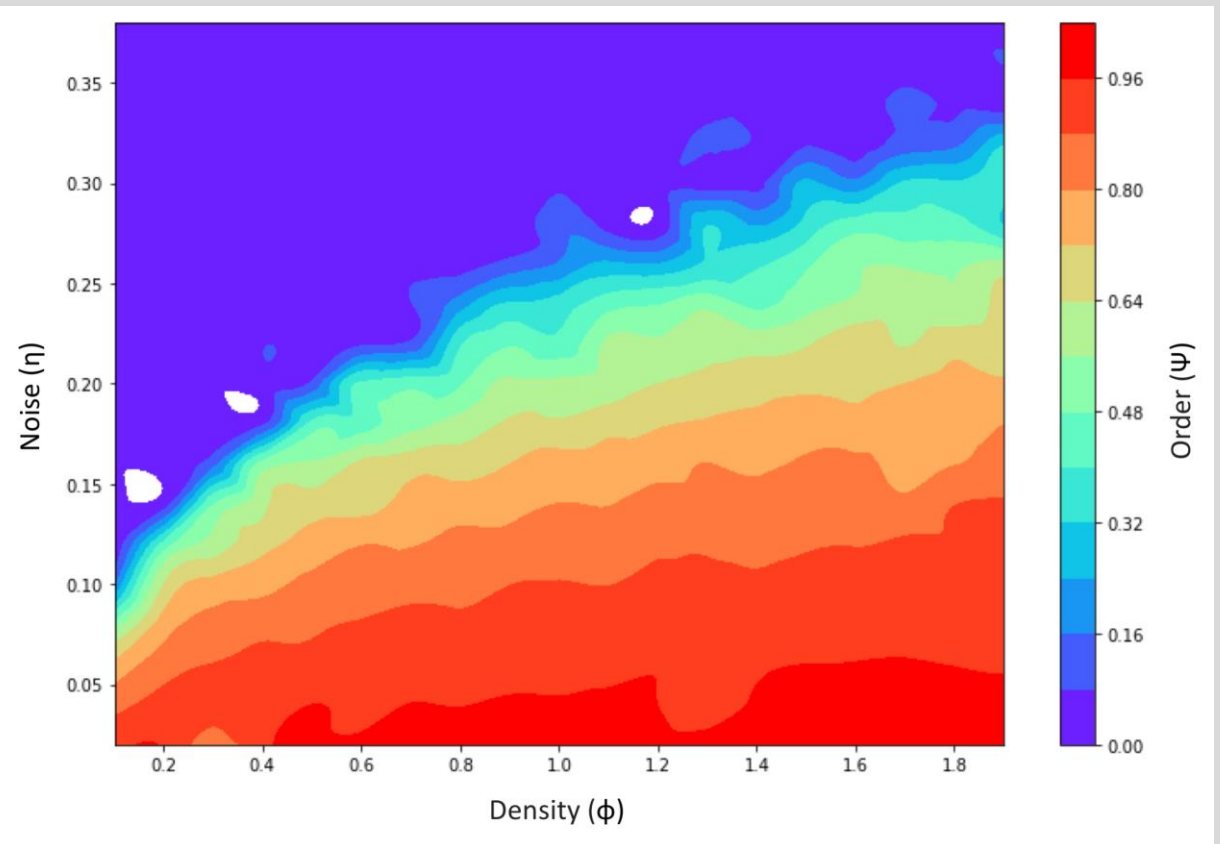
ORDER PARAMETER



VICSEK MODEL

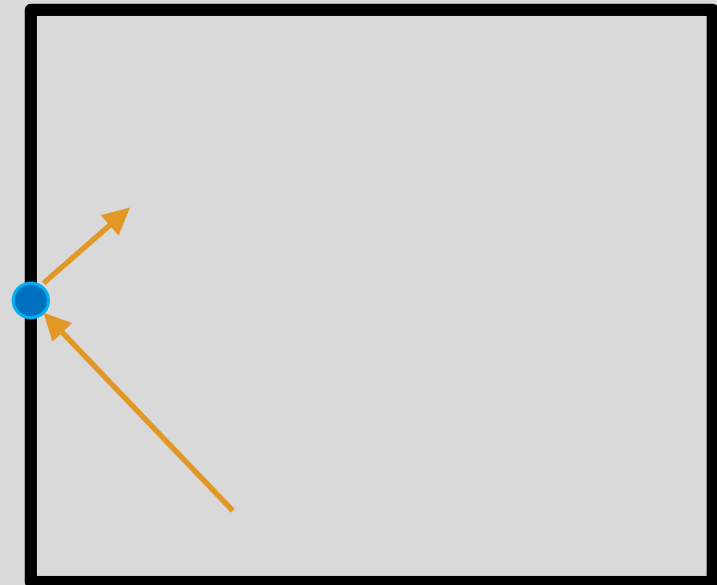
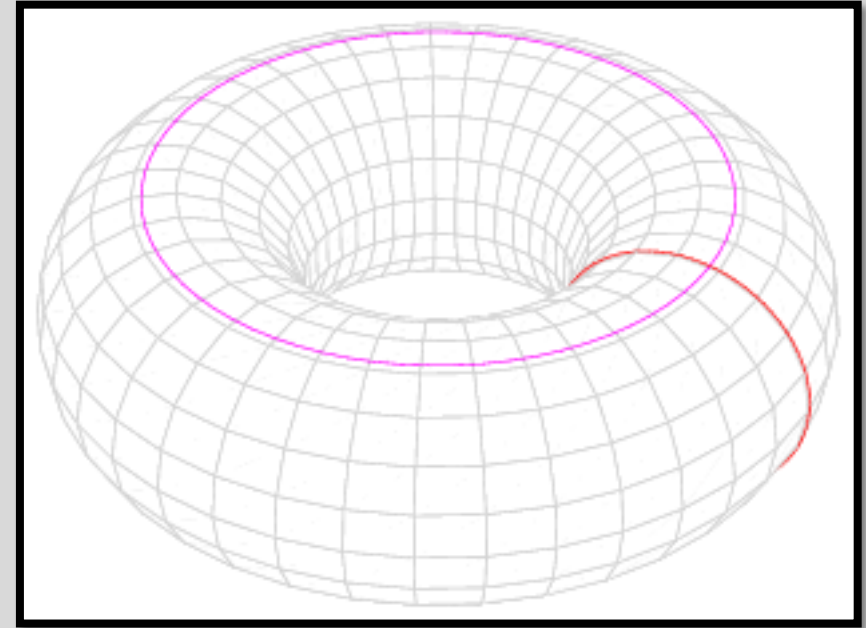
- Noise: Random Directional deflection angle within a certain range.
- Phase Diagram – Long-term order as a function of noise and density
- Final States

Order vs. Density and Noise coefficient



BOUNDARIES

- Periodic
 - No hard edges
 - Everything wraps around
- Closed
 - Reflect the direction
 - Reduce the outgoing speed



SMART AGENTS

- Naïve Agent
 - Basic system information
- Smart Agent
 - Given additional information
 - Understands the crowd's pressure
- Goal of Smart Agent
 - Trying to get the closest to the stage as possible using different paths



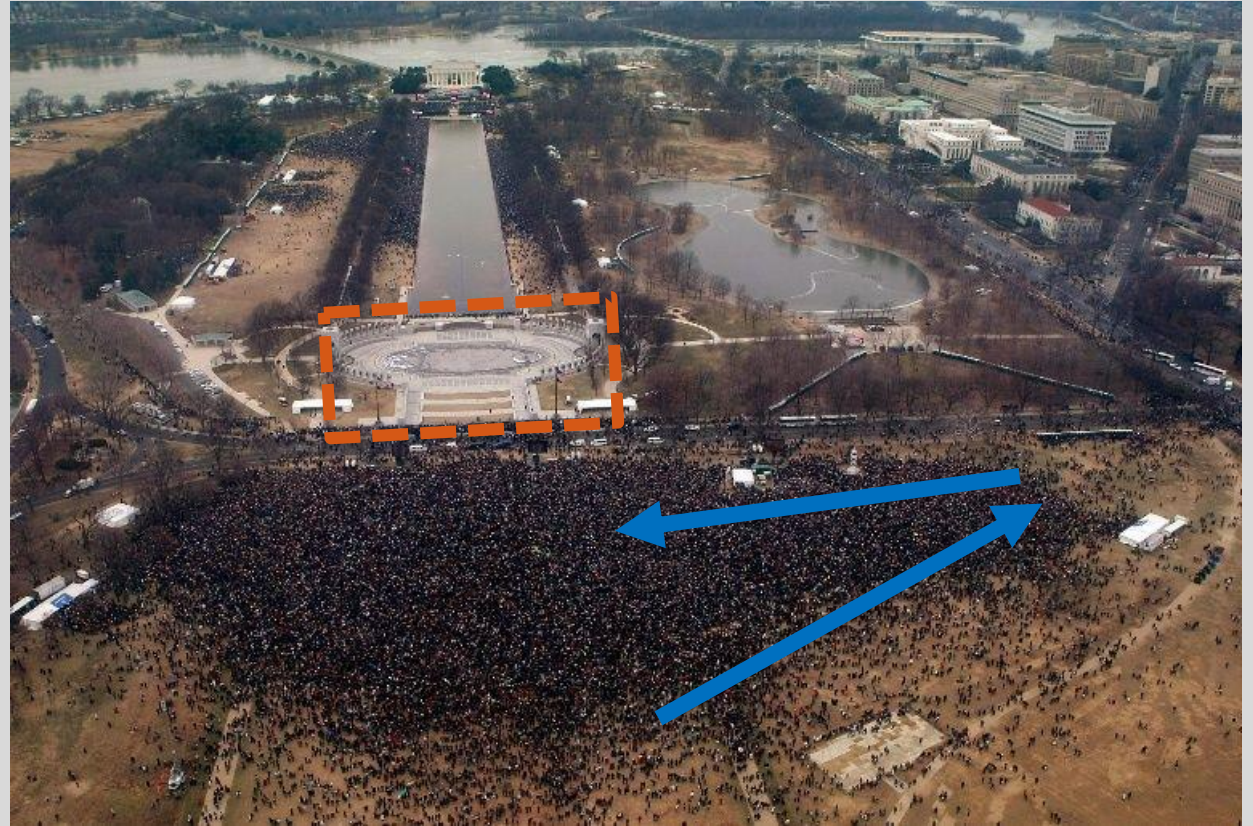
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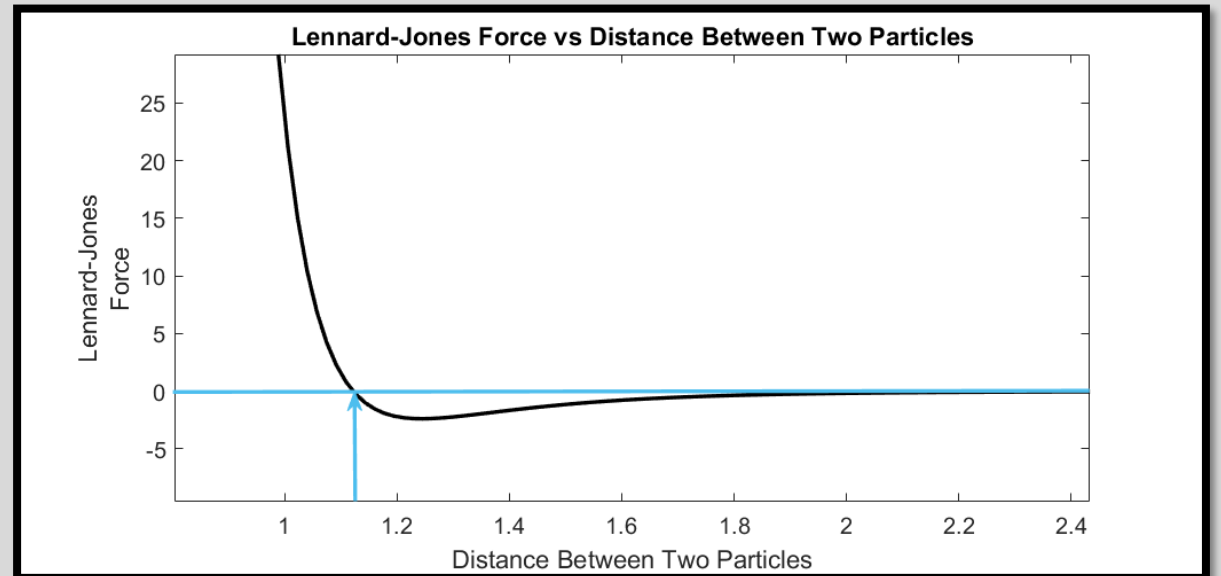
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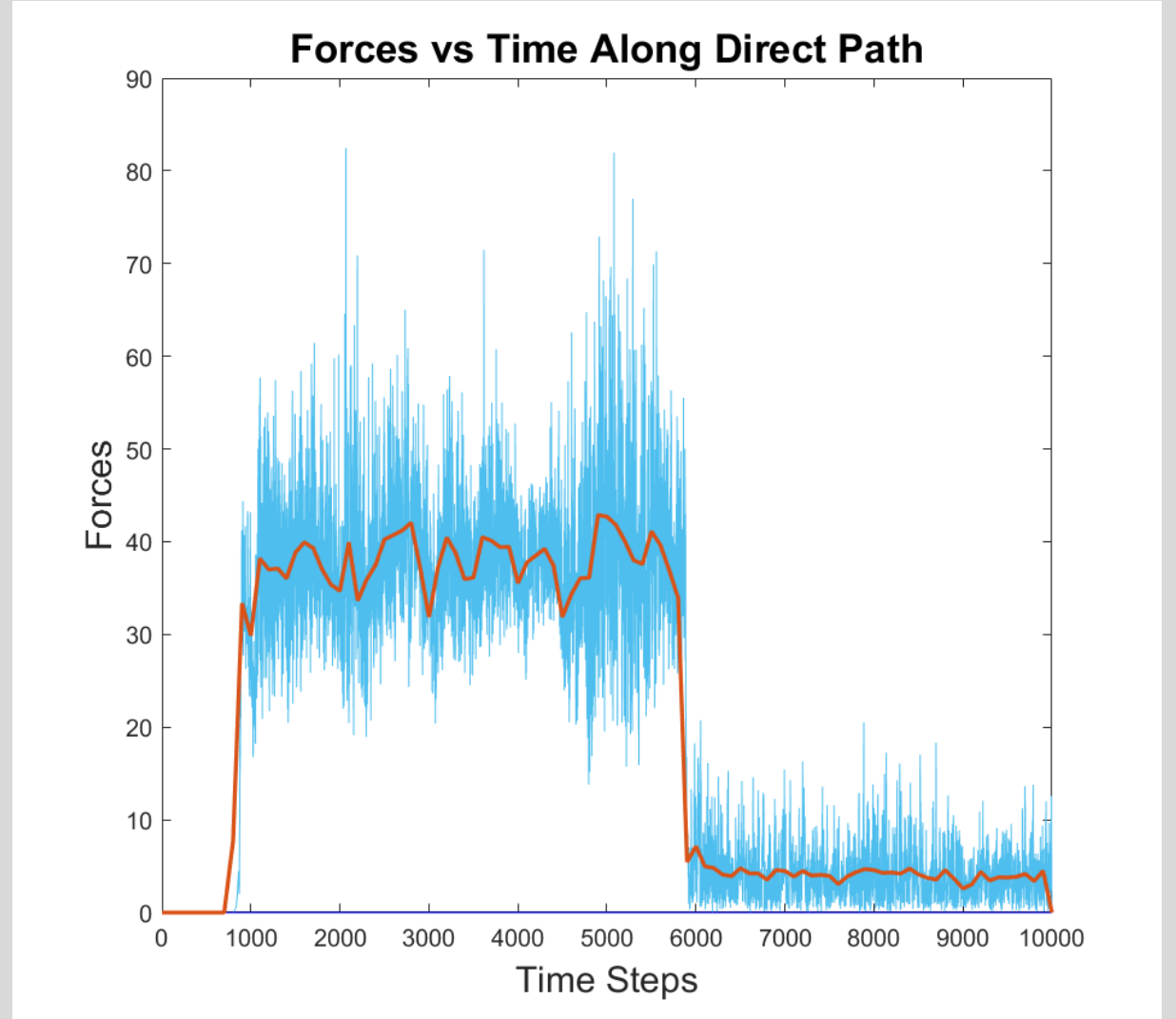
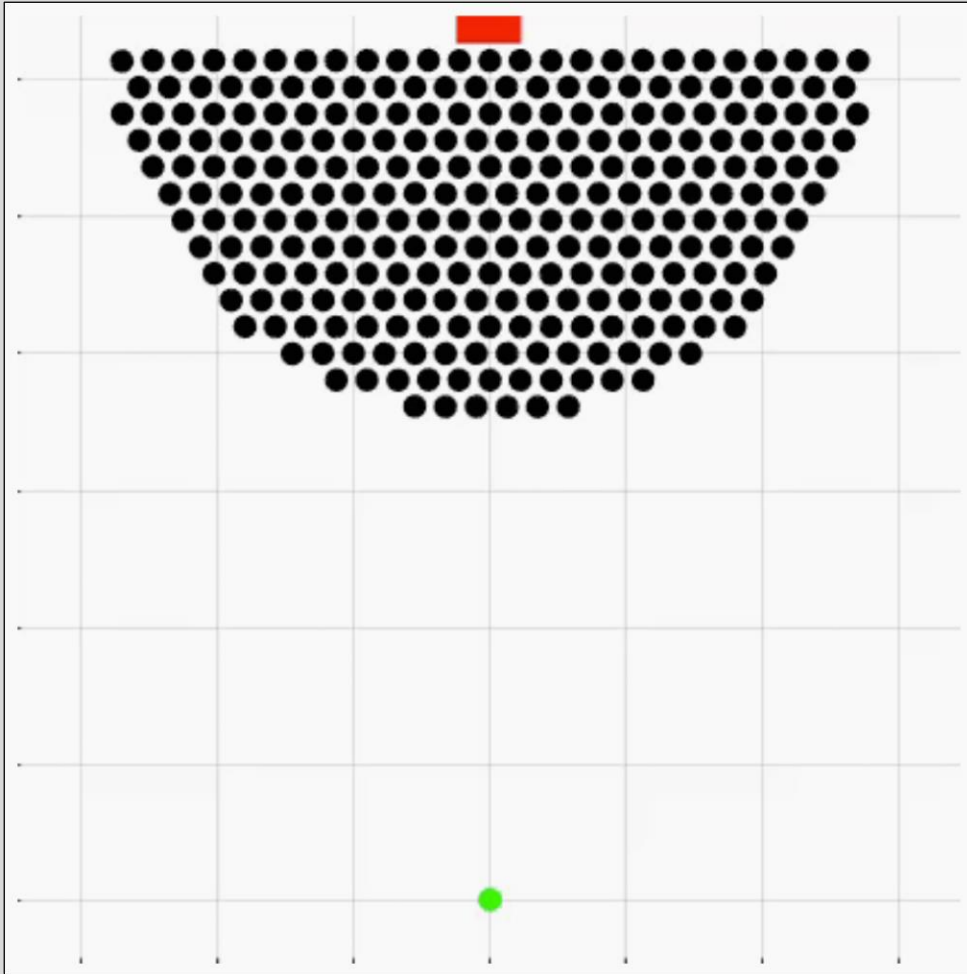
SYSTEM DYNAMICS

- Steepest Descent Equation
 - Forces particles to go towards the area of lowest force
- Lennard-Jones Force
 - Models interactions between particles
 - Prevents particle overlap

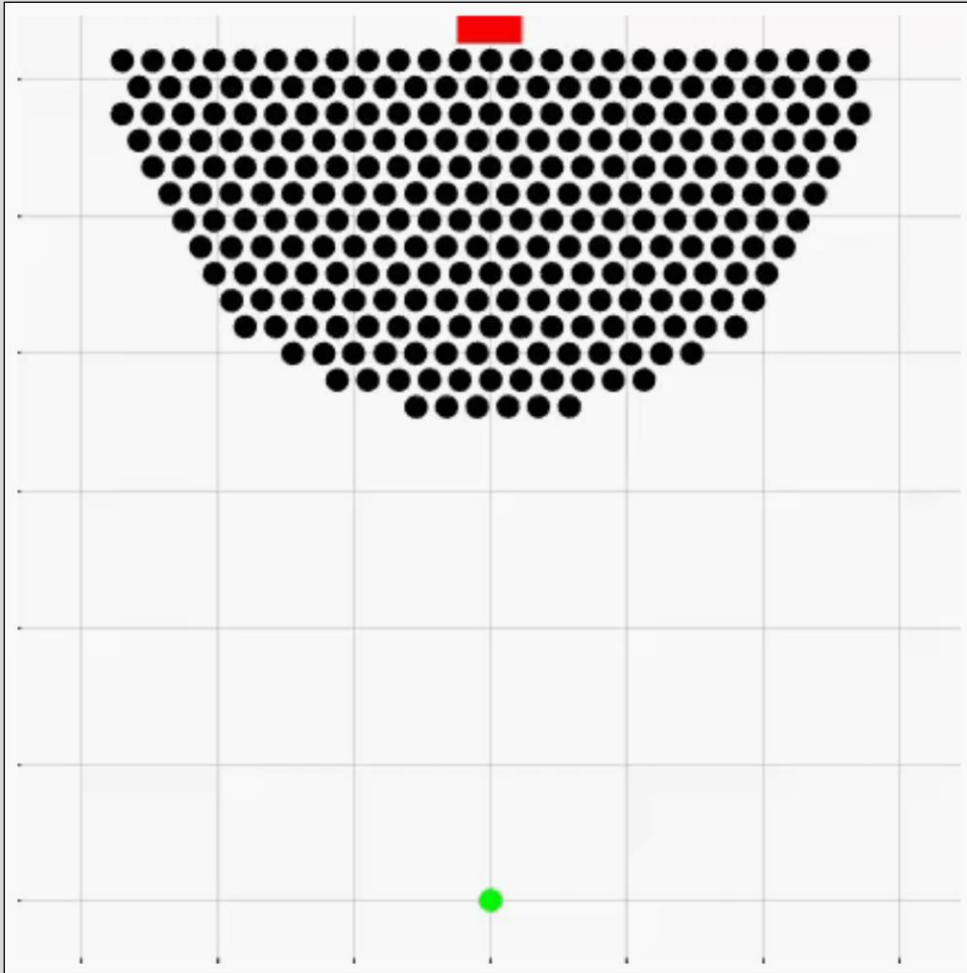
$$\mathbf{x}_i(t + \Delta t) = \mathbf{x}_i(t) - \mathbf{F}_i \Delta t + T \zeta_i$$



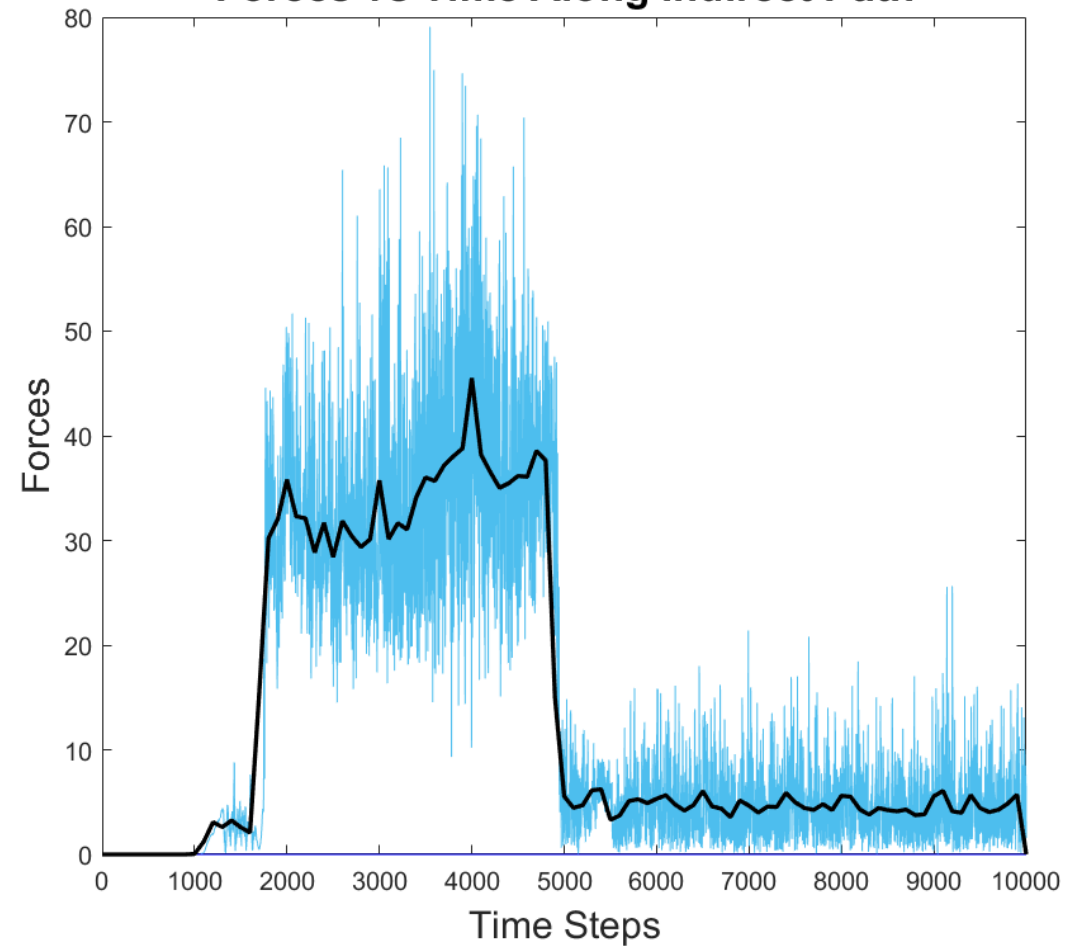
DIRECT PATH



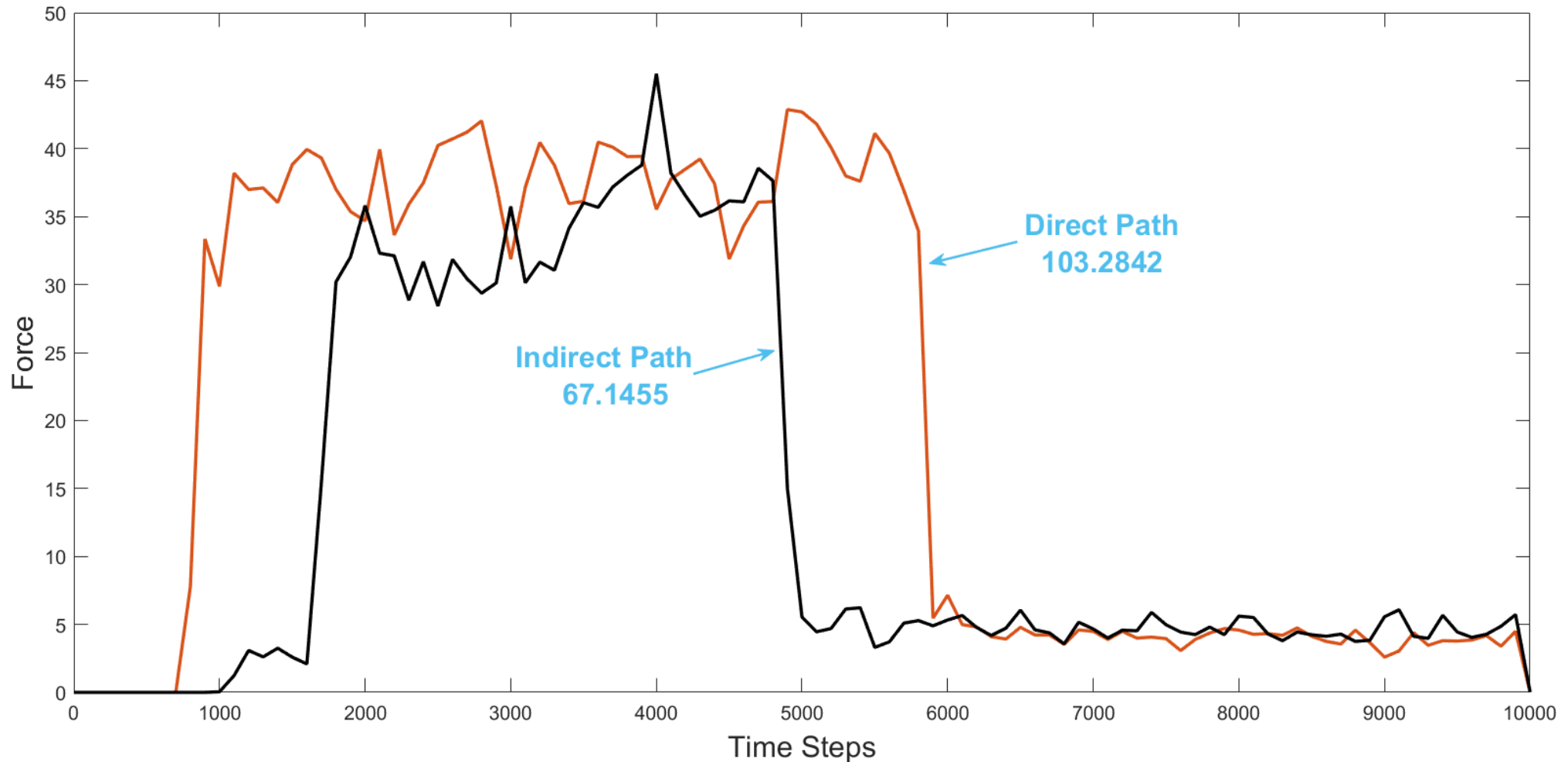
INDIRECT PATH



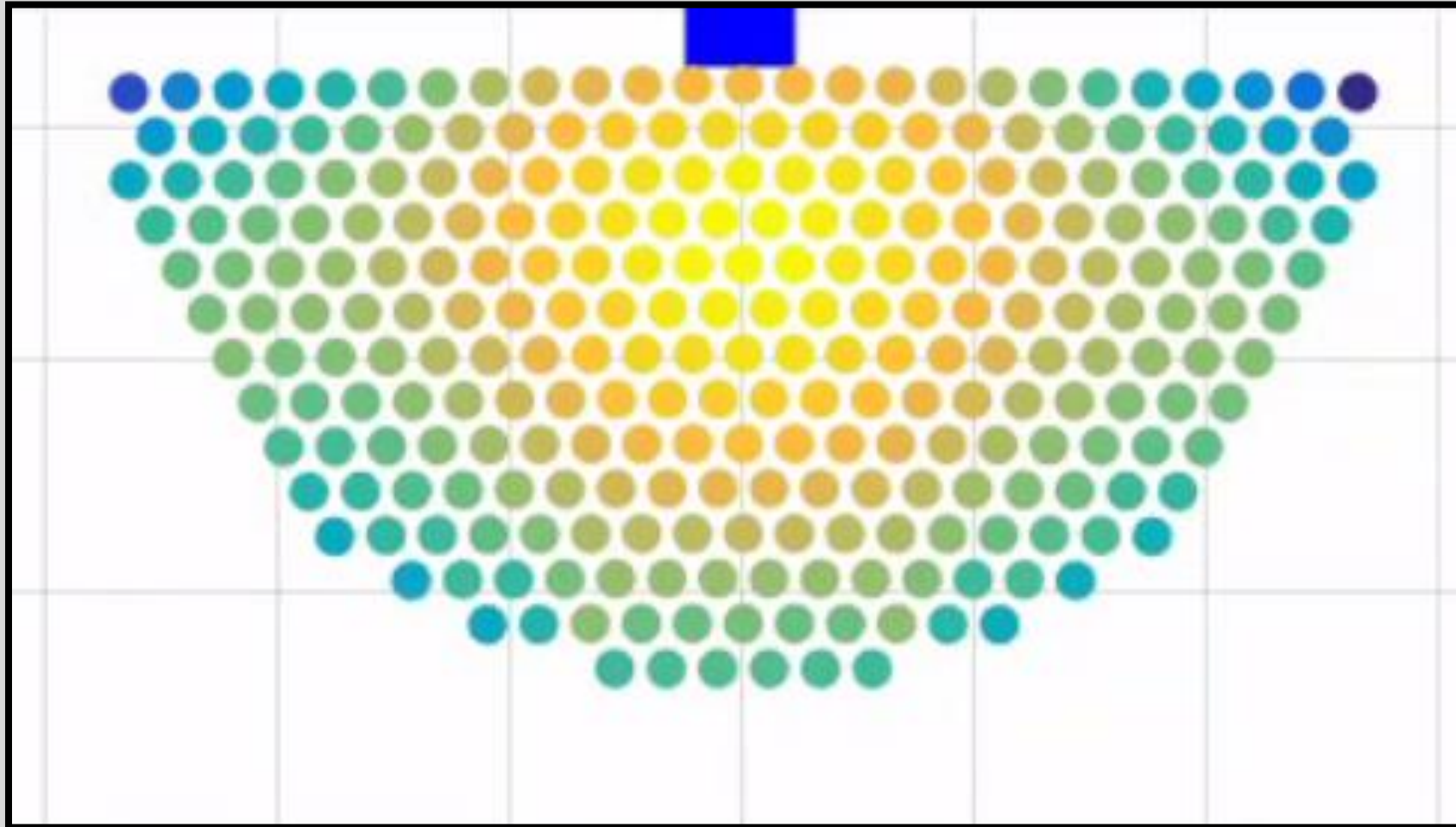
Forces vs Time Along Indirect Path



COMPARISON — DIRECT VS. INDIRECT



PRESSURE GRADIENT

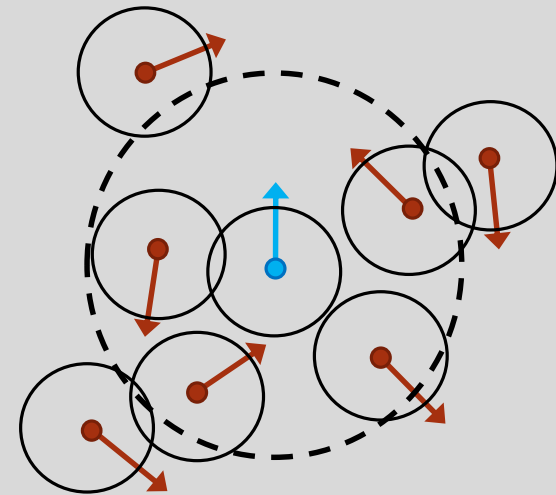


SUDDEN UNJAMMING VIA COLLECTIVE MOTION

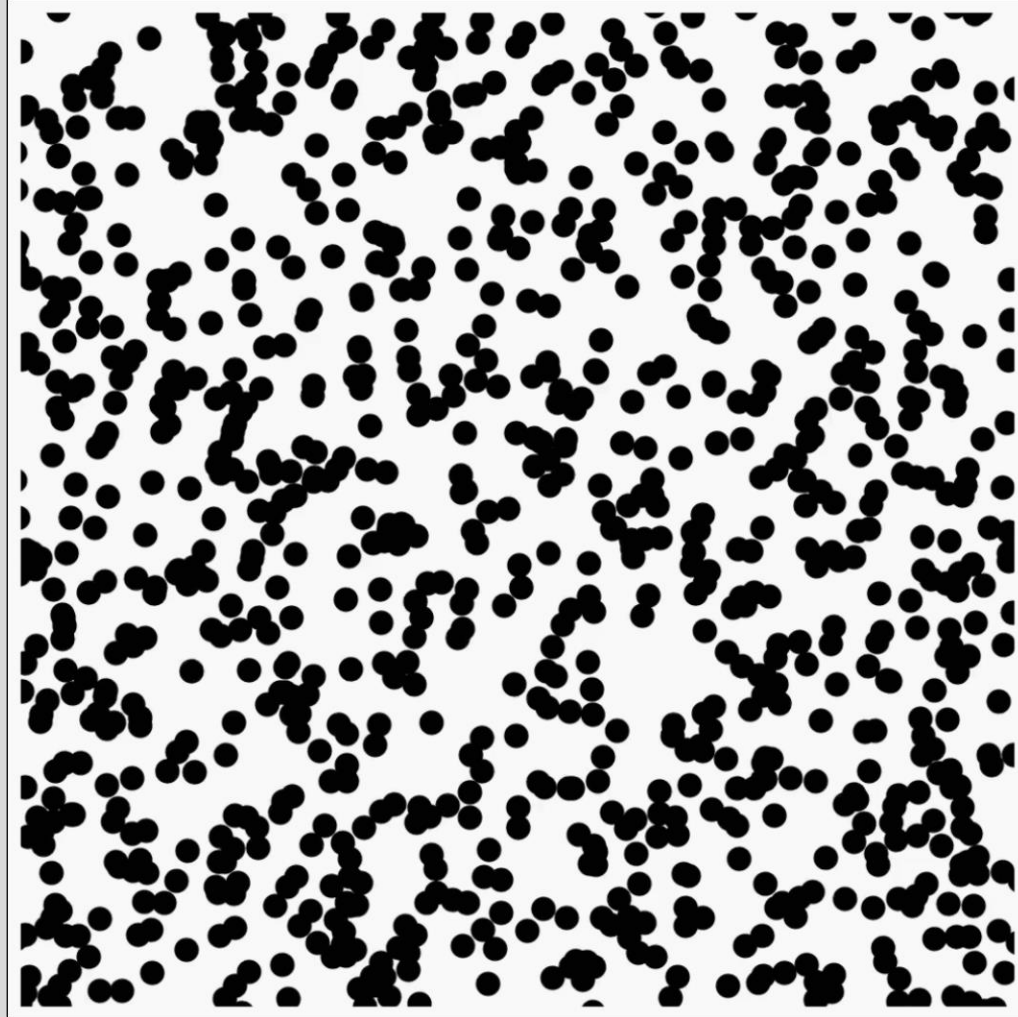
- Goal: Get rid of jammed condition, minimize stress

- New Model

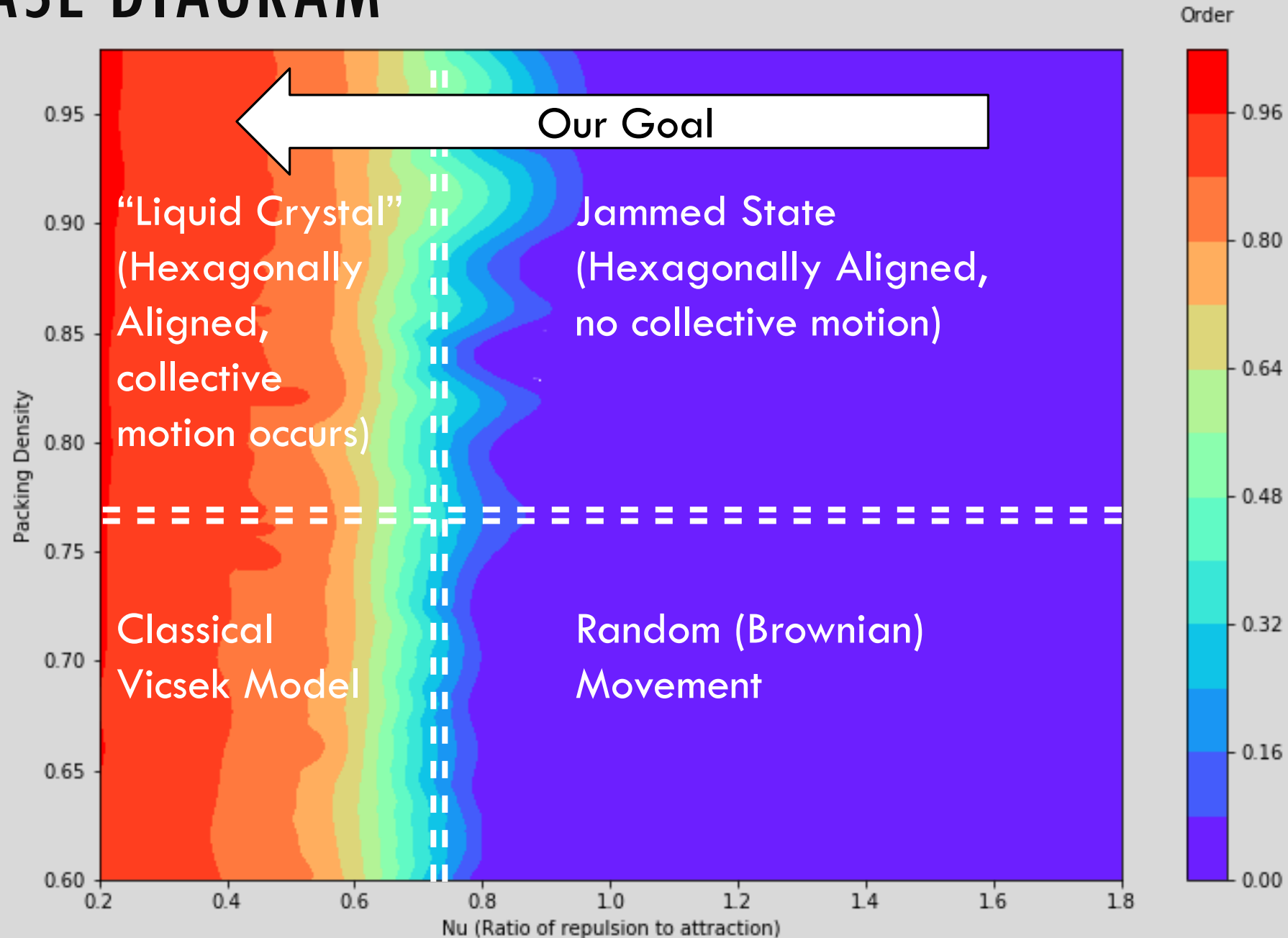
$$\mathbf{v}_i(t + \Delta t) = \underbrace{v_a \frac{\sum_{j \in R_{a,i}} \mathbf{v}_j}{|\sum_{j \in R_{a,i}} \mathbf{v}_j|}}_{\text{Alignment}} + \underbrace{v_r \sum_{j \in R_{r,i}} \frac{\mathbf{x}_{ij}(t)}{|\mathbf{x}_{ij}(t)|}}_{\text{Repulsion}}$$



JAMMED CONDITION



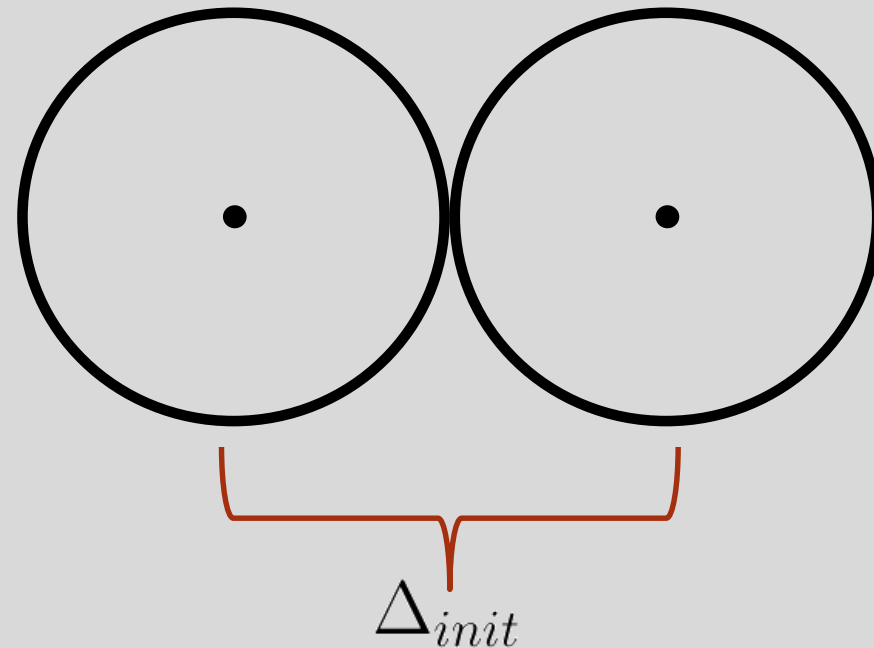
PHASE DIAGRAM



STRESS

- Measured in our simulation with Mean Particle Overlap with nearby neighbors

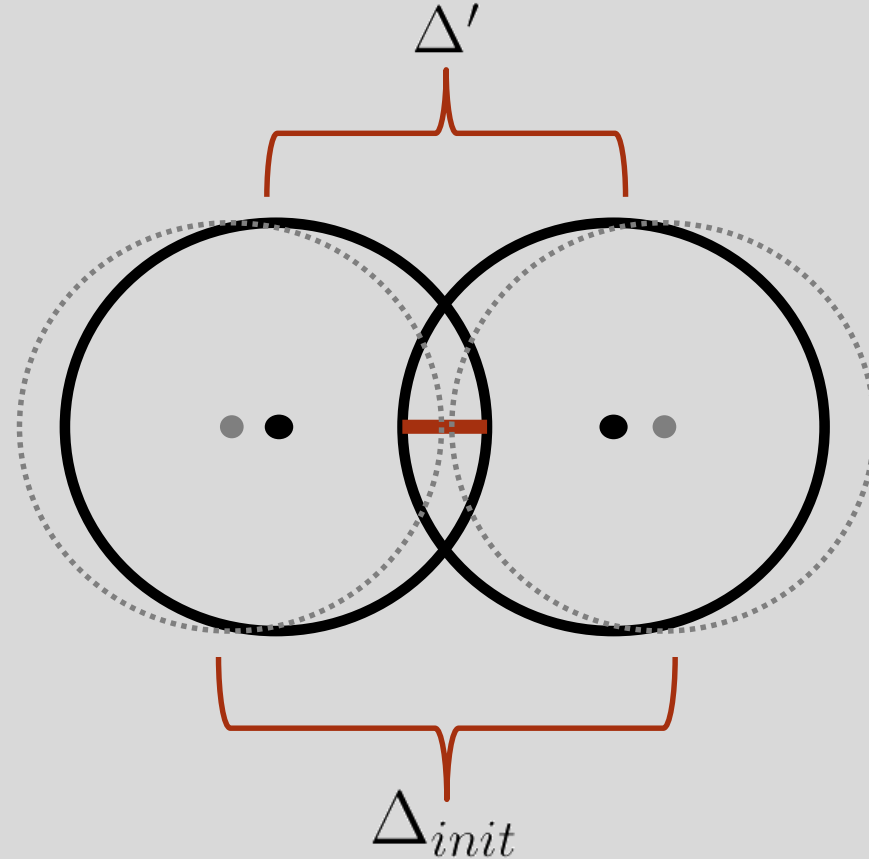
$$\left\langle \frac{\Delta' - \Delta_{init}}{\Delta_{init}} \right\rangle$$



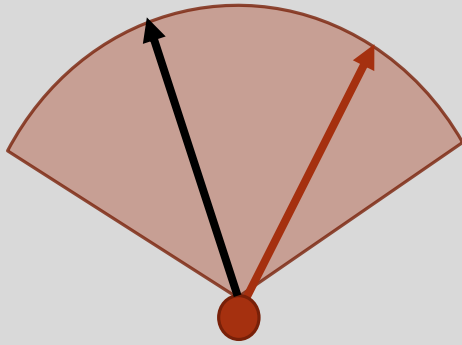
STRESS

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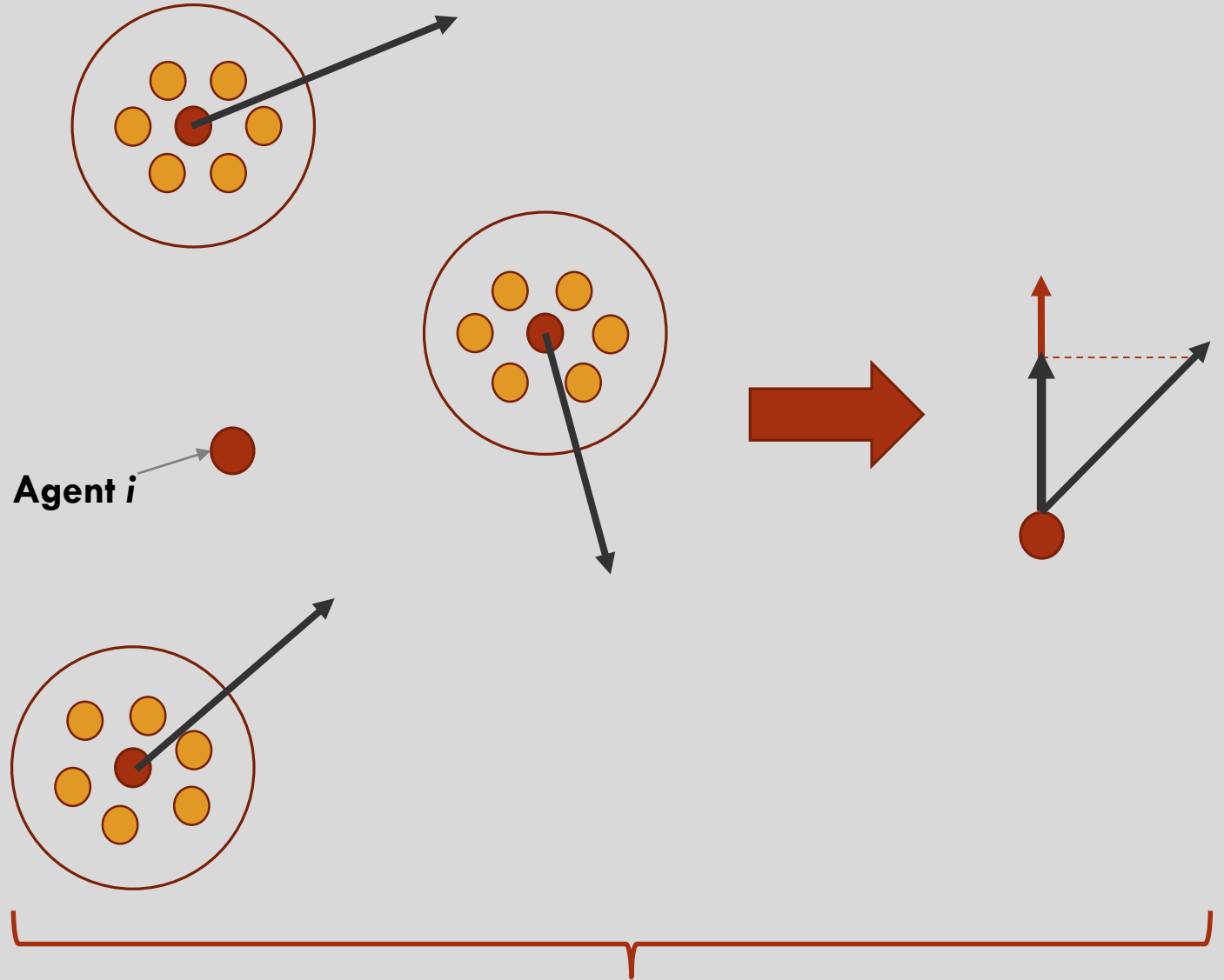
$$\left\langle \frac{\Delta' - \Delta_{init}}{\Delta_{init}} \right\rangle$$



THE NEW RULE



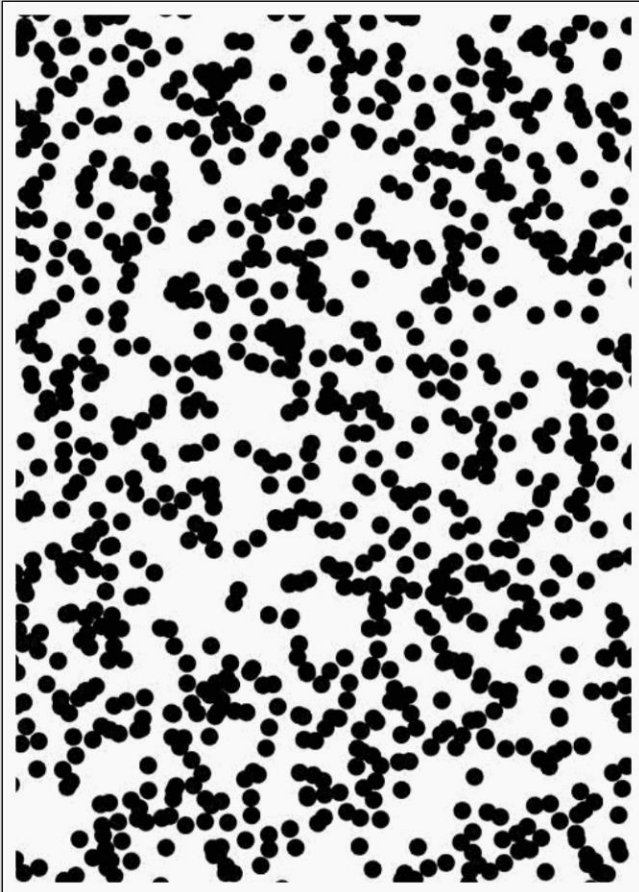
Locate the Border



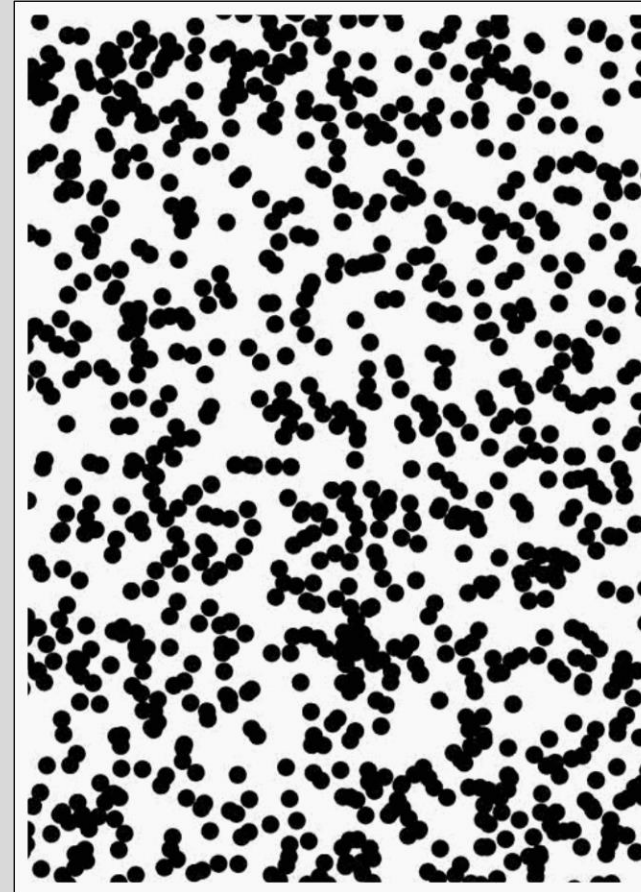
Decide how much to follow the border

NEW RULE'S EFFECT ON JAMMED SYSTEM

Jammed Condition

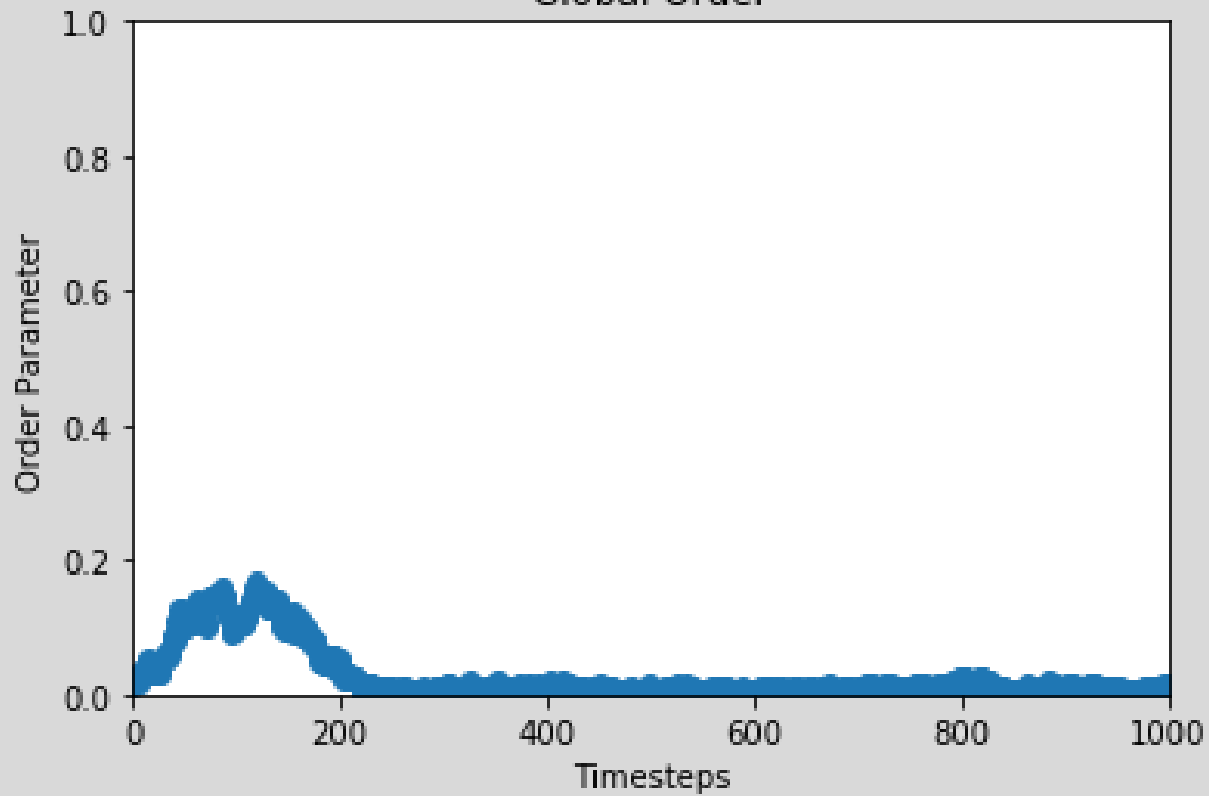


Boundary Rule Implemented



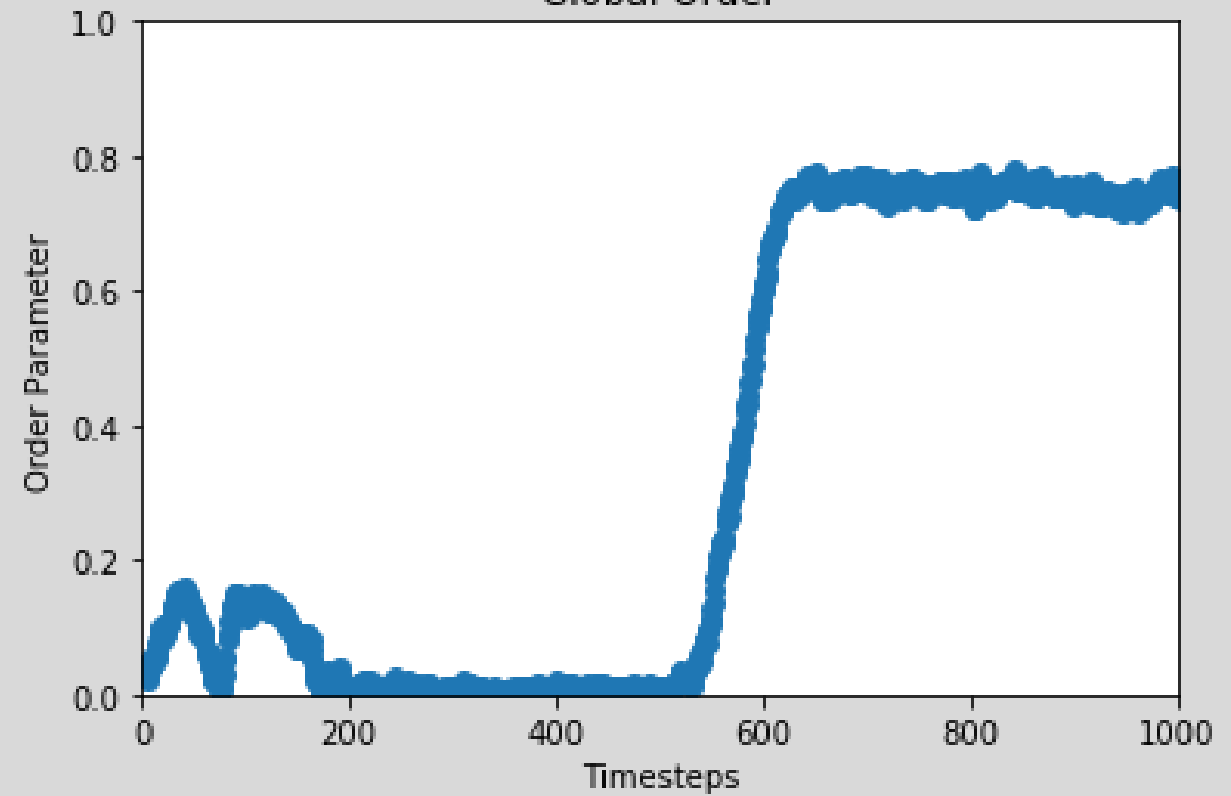
EFFECT ON ORDER PARAMETER

Global Order



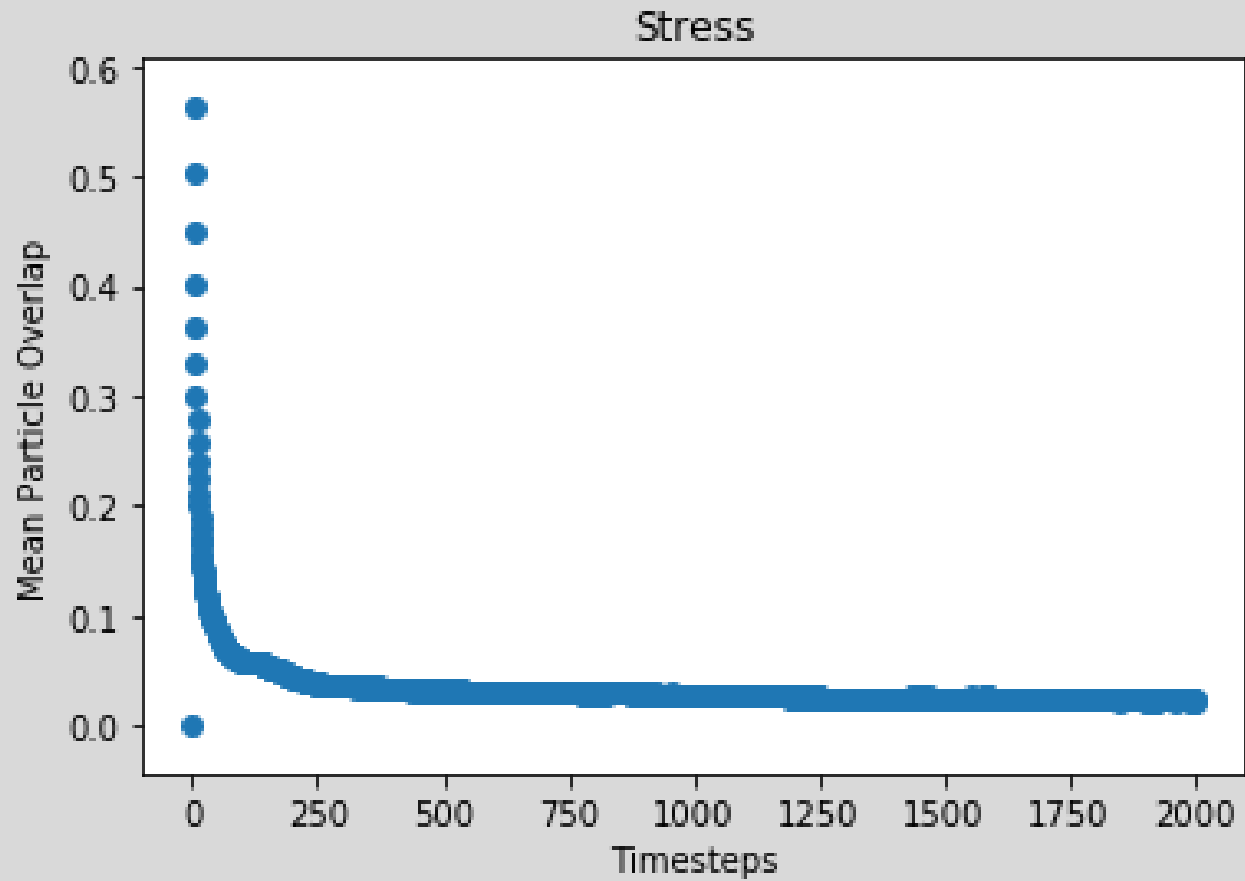
No New Rule

Global Order

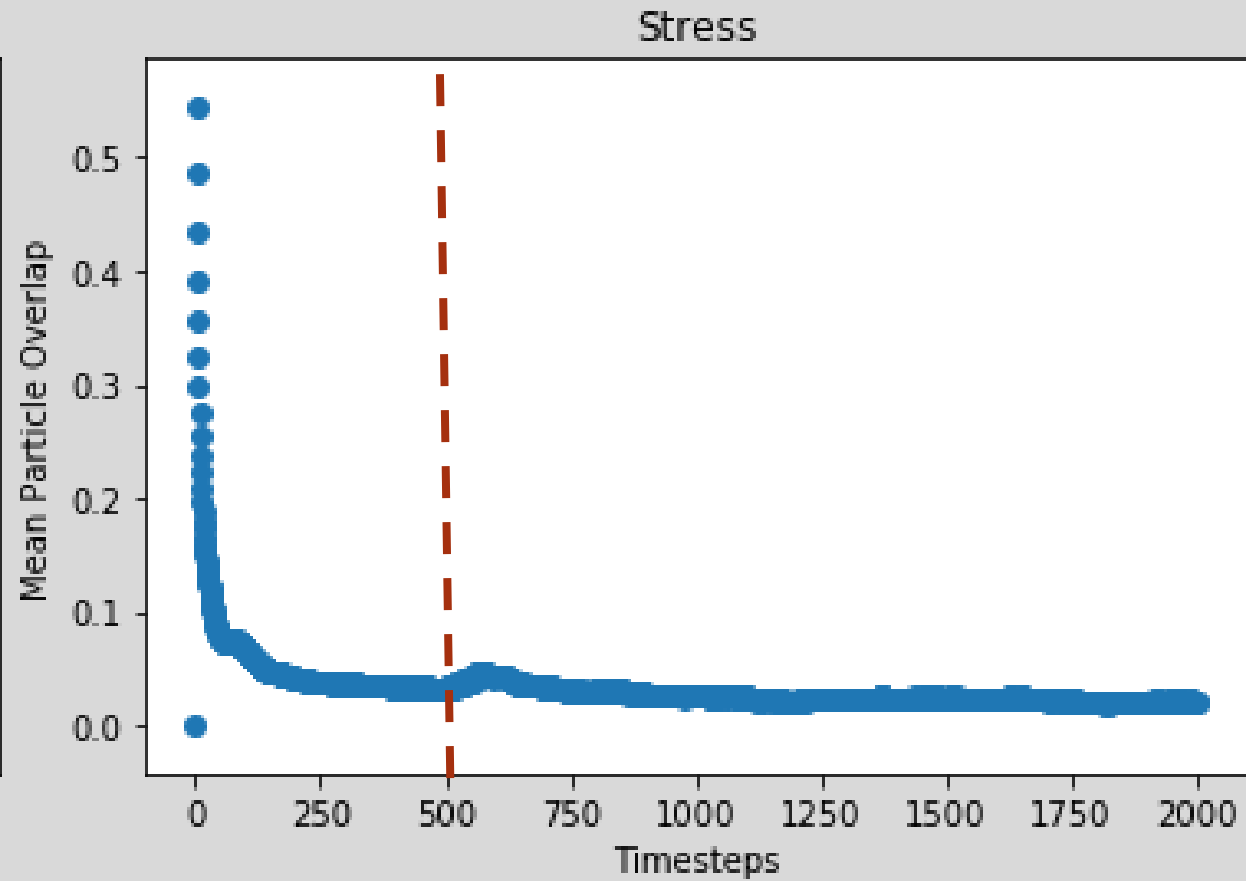


New Rule

EFFECT ON STRESS



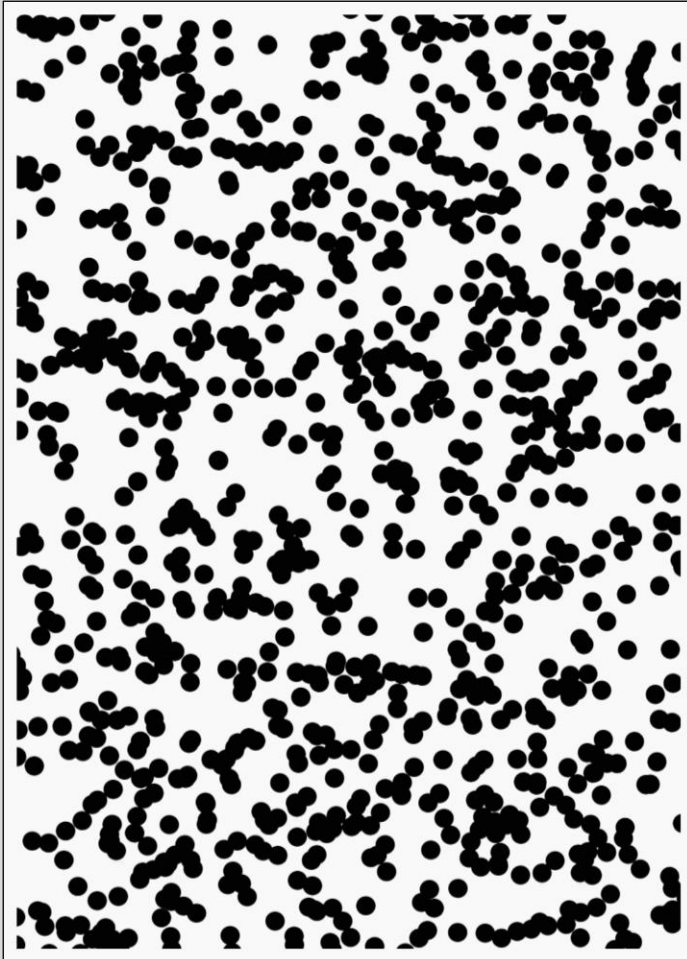
No New Rule



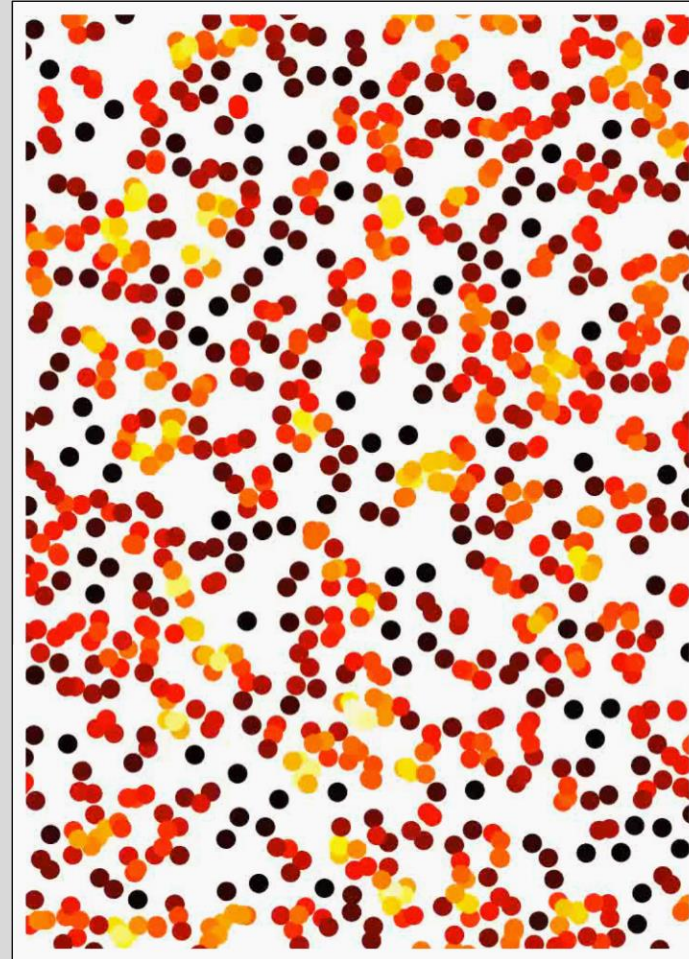
New Rule

FURTHER EXPLORATION

Band Formation

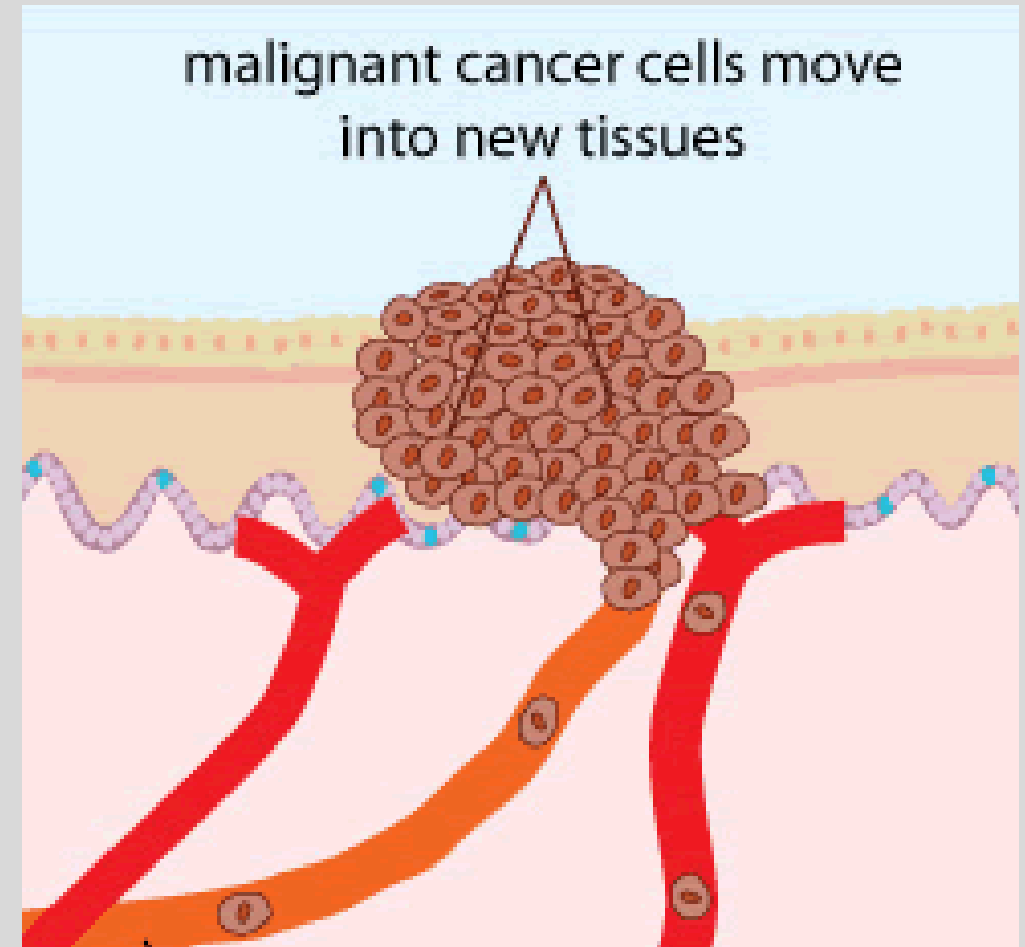


Stress



EXTENSIONS

- Cancer cells
 - Want to remain jammed
 - Prevention of metastasis
- Introduce smart particles to the system



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TRiCAM Research Program

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CITATIONS

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