# Life-like Behavior of a Self-Propelled Oil Droplet: Comparative Analysis with *Tetrahymena* Movement and Numerical Investigation <u>Riku Adachi\*</u> Supervisor: Takashi Ikegami\*

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## Background

Transition from non-life to life: Universal narrative of life

Pillars of "Lyfe" rather than "Life"

Q. What is life and what could be? Q. What constitutes life?

AUTOCATALYSIS positive feedback, exponential growth of a representative size metric 3 6 8 9 lyfe LEARNING

<u>Fundamental steps necessary for abiogenesis,</u> transcending specific details of constitutive materials



数物フロンティア

Maxwell-Boltzmann &



Behaviors (spontaneous motion) in the far-from-equilibrium environment

#### Bartlett S, Wong ML. (2020). Life, 10(4):42.

### Self-Propelled Particles spanning non-living to living systems



Cells invading an wound

Colloids

O'Byrne J et al. (2022).

## Nonliving and living on the same spectrum



Bird flocks

### Sensory Motor Coupling (SMC)

- <u>Input:</u> acquire information about the external environment (e.g., Chemical gradient, surface tension gradient)
- <u>Communication</u>: via physicochemical nonlinear coupuling between the environment
- Internal state: changes in internal state variables

# <u>Trajectories and statistics of Tetrahymena cells</u>



Oil droplet systems exhibited various motion patterns, characterized by distinctive basic oscillation modes in velocities. The behavioral patterns of *Tetrahymena* were far more random, with differences observed in the distribution of kinetic energy among genetically identical cells.

### Embedding dimension and the Lyapunov spectrum

Embedding dimension: complexity of the system as the minimum number of variables necessary to reconstruct in the state space (Optimal dimension : Oil droplet ~ 5, Tetrahymena 7 (5 ~ 11) )



#### Input (Information of environments)

(Hanczyc et al., 2010)

determine the next strategies

- <u>Output:</u> several types of 'taxis' behavior emerge as a result of spontaneous symmetry breaking

### Spontaneous behavior and its deimensionality: Physics of Behavior

"Life-like" properties are expected to be imprinted within behavioral dynamics (e.g., dimensionality), not necessarily relying on the anatomical structure of nonliving and living systems.

## **METHOD - Experimental Setup**

### Experiment Design

An aqueous solution of Sodium Dodecyl Sulfate (SDS), a typical anionic surfactant, is placed in a Petri dish and an oil droplet consisting of a mixture of Ethyl Salicylate (ES) and paraffin is dropped (Tanaka et al., 2015, 2017).

### Experimental conditions

Number of droplets:

 # 1

 Volume:

 5 μL / 10 μL / 15 μL / 20 μL / 25 μL / 30 μL



Oil droplet systems are governed by low-dimensional deterministic dynamical systems that stem from Hamiltonian dynamics, as evidenced by the symmetry in the Lyapunov spectra.

## **RESULTS - Numerical Simulation**

Two-dimensional Langevin equation

$$\frac{d\mathbf{v}}{dt} = F\hat{\mathbf{u}} - \gamma \mathbf{v}(t) + \sqrt{2D}\xi(t)$$
$$\frac{d\phi}{dt} = M + \sqrt{2D}\xi(t)$$

v: velocity
φ: Orientations of particle
γ: Viscosity
ξ: Gaussian noise
û: (cosφ, sinφ)
D: Diffusion coefficient
F: Driving force
M: Torque

**Reproducing trajectories and KE distributions** 



 <u>ES concentration (ES: Paraffin):</u> 50 % / 60 % / 70 % / 80 % / 90 %
 <u>SDS concentration:</u> 60 mM 20 c

60 mM, 30 g (Critical micelle concentration: 8 mM) For *Tetrahymena*, individuals are confined in a two-dimensional microculture arena and observed their cruising motions under a stereomicroscope with sufficient nutrition.

## DISCUSSION



	Oil droplet	Tetrahymena	Langevin eqation
Embedding dimension	~ 5	7 (5 ~ 11)	~ 3
Lyapunov Spectrum & exponent λ	Nearly Symmetric -0.47 $\leq \lambda \leq 0.44$	Asymmetric -0.58 $\leq \lambda \leq 0.35$	Asymmetric -0.57 $\leq \lambda \leq 0.66$
KE distribution	$H_{10}^{10^{4}} = \frac{10^{4}}{10^{4}} = 10^{$	Gell #1 Cell #2 Cell #2 Cell #3 Cell #4 Output 0 0 0 0 0 0 0 0 0 0 0 0 0	Gaussian, Exponential, Maxwell-Boltzmann

## [Origins of "life-like" behavior and spatial ariabilities of dimensionality]

Oil droplet: Global attractor corresponding to a basic oscillation mode *Tetrahymena*: Local attractors as a result of dimension reduction

See also: Riku Adachi, Hiroki Kojima, and Takashi Ikegami. "Life-like Behavior of an Oil Droplet in an Aqueous Surfactant Solution: Comparative Analysis with Tetrahymena Movement and Numerical Investigation." ALIFE 2023: Proceedings of the 2023 Artificial Life Conference. MIT Press, 2023.

