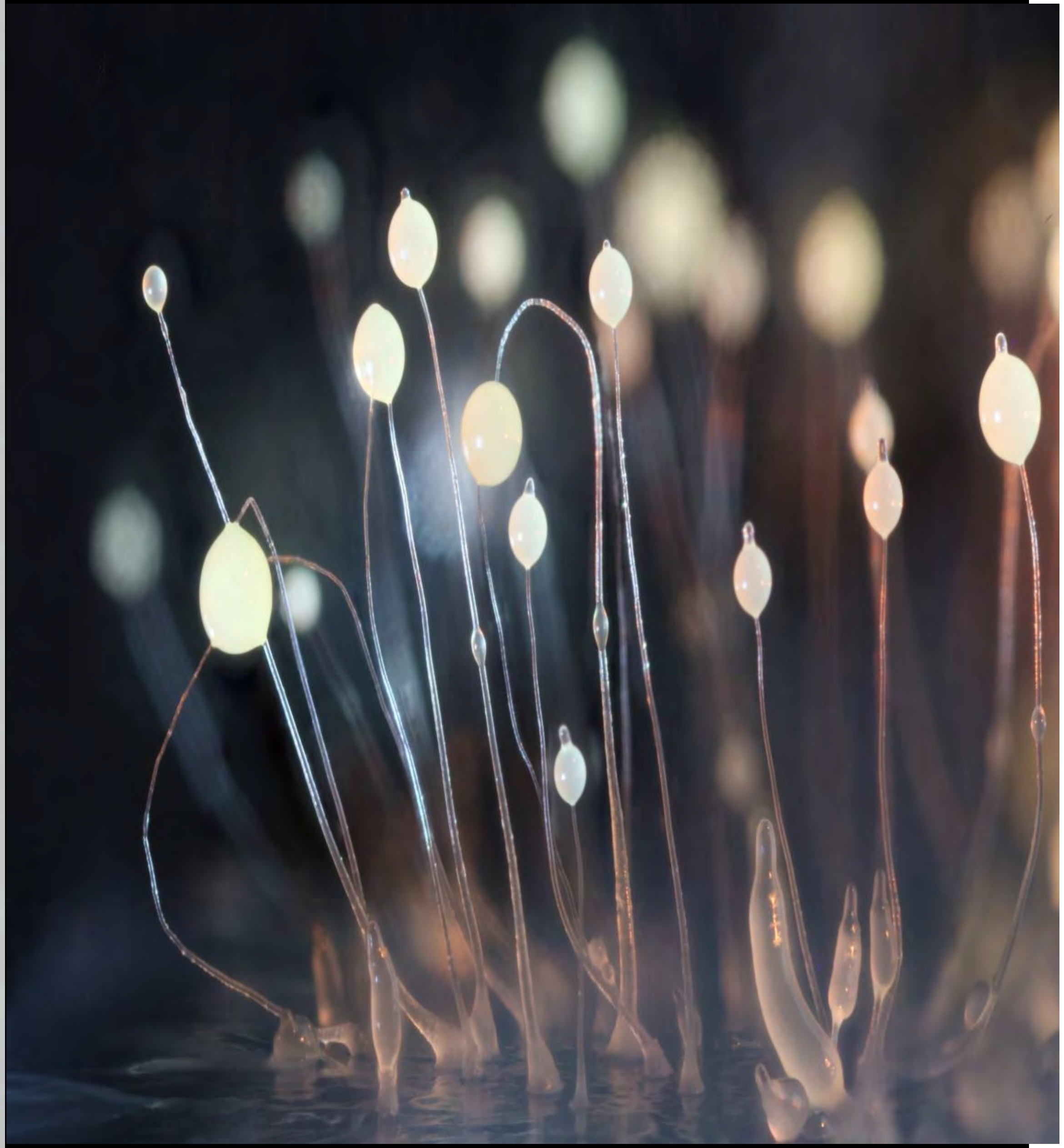

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An example of a biological social system with a multi-agent approach

Simposietto,
March 27, 2021

OUTLINE

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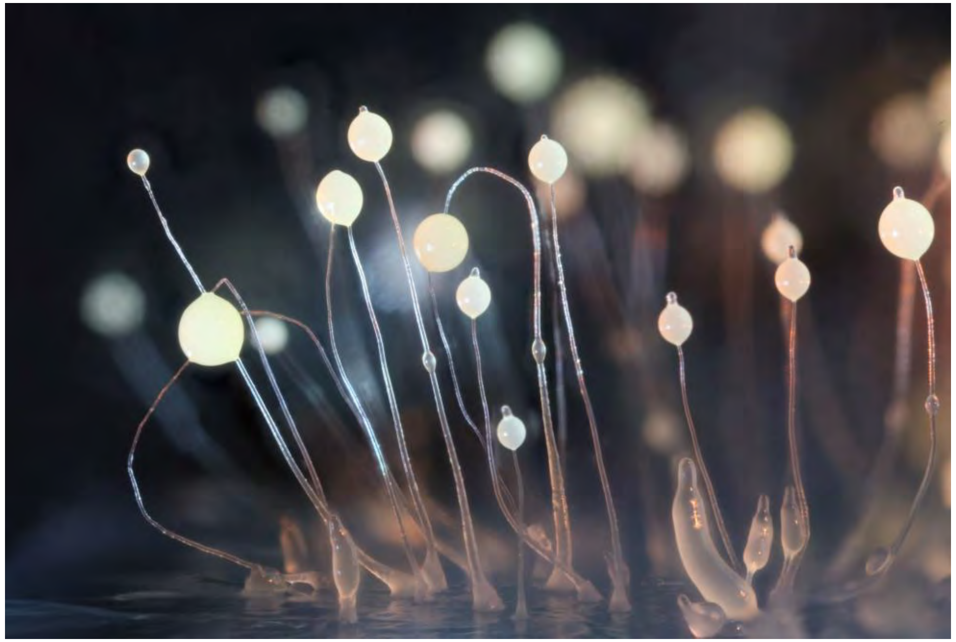
INTRODUCTION

A biological social system: D. discoideum

Social amoeba: Dyctiostelium discoideum



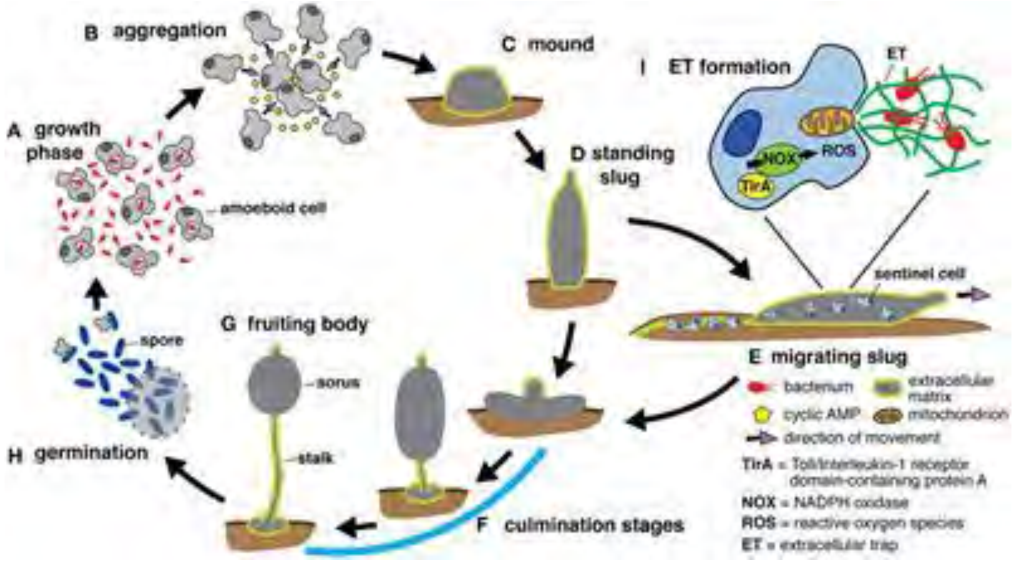
Life – 4 stages:

-vegetative

-aggregation

-migration

-culmination



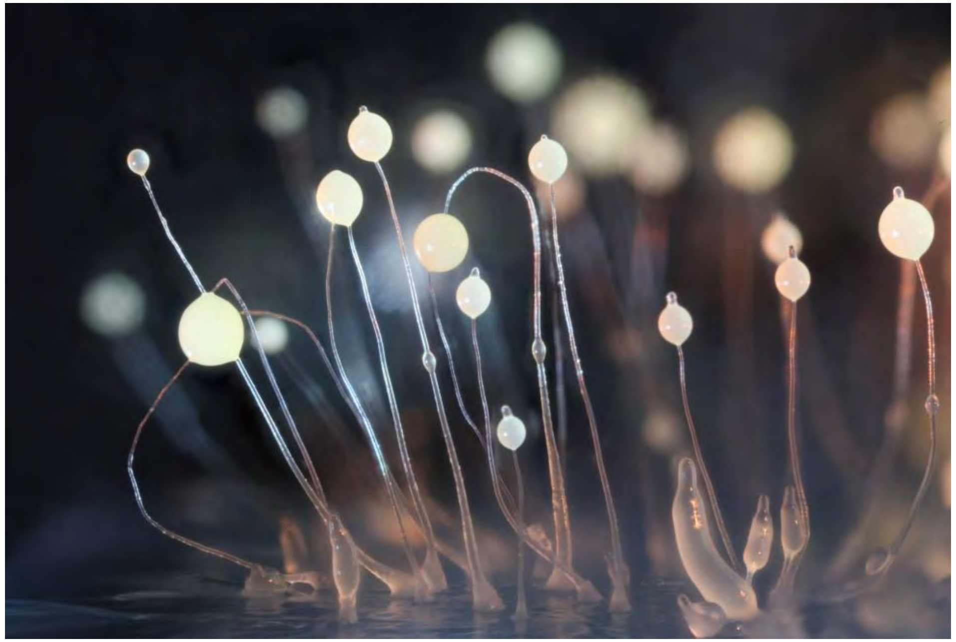
If food sources (bacteria or agar) are avaiable, each cell lives and proliferates individually. Once starving a moltitude (up to 100000 cells) of single amoebas start sending pulses of 3’,5’ cyclic adenosine monophosphate (cAMP) molecules to its sourrandings

→ Multicellular slug organism

Dictyostelium: Evolution , cell biology, and the development of multicellularity Kessin R., Cambridge; Cambridge University Press 2001

A biological social system: D. discoideum

Social amoeba: Dyctiostelium discoideum



Modeling approach:

- Continuous diffusion equations:

1. MonteCarlo methods
2. In-lattice discrete simulation

Problems:

- Macroscopic scale -> how behaviour emerge?
- Hybrid continuous-discrete modeling approach

→ **Multi-scale model with Multi-agent System approach**

- Agent architecture consistent with biological knowledge
- Define metrics
- Qualitative comparison and generation of predictive data

PDEs for self-organization in cellular and developmental biology , Baker R. et al., Nonlinearity, 21(11), 251-290, 2008

Multi-Agent System framework

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Agent: is an individual computer system that is capable of independent action on behalf of its user or owner […]

A multi-agent system is one that consists of a number of agents, which interact with one another, tipically by exchanging messages through some computer network infrastructure

- Model intracellular decision process which are triggered by biochemical cell-cell or cell-matrix interactions
- Natural management of communication among individuals

→

- Signals as discrete traveling packages
- $O(N)$ computational complexity
- Comparison data with the literature
- Generate predictive data

An introduction to multiagent system, Wooldridge M. New York: Wiley (2002)

DESIGN AND IMPLEMENTATION

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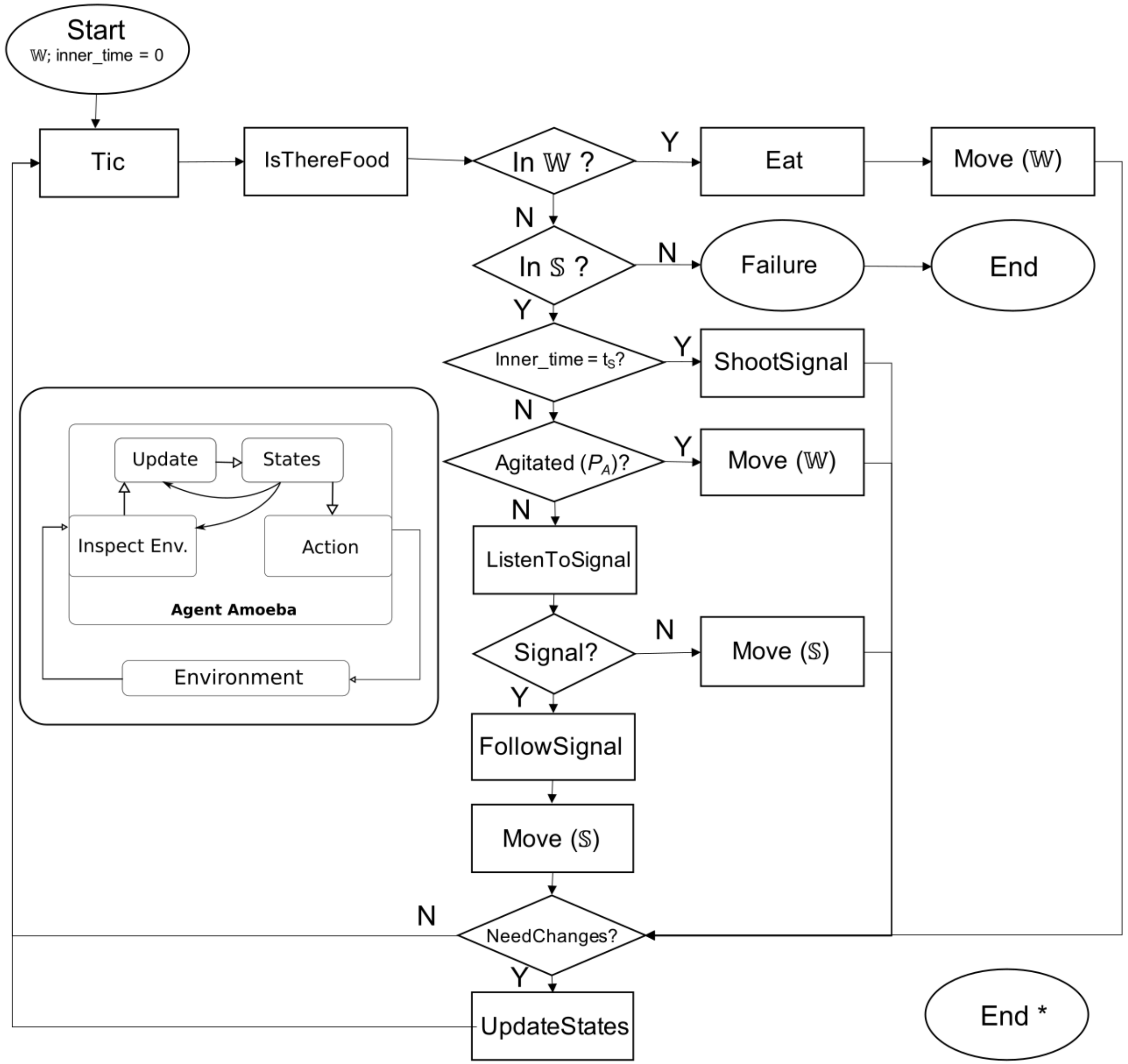
MAS Architecture



- Two states: Wandering and Starving
- If S -> shoot signals
- If reached by cAMP agent -> orientate and move on

Parameters and variables

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Diameter of amoeba: D=1.8 u

Speed of amoeba: $v_a = 0.3 \frac{u}{cycle}$

Diffusion speed of cAMP $v_c = 0.9 \frac{u}{cycle}$

Shooting time $t_s = 10\ cycles$

Dim=100 units

Noise parameters:

- P_G growth probability of food sources in the environment
- P_A agitation probability that prevents the amoeba to inspect the environment

$v_{\mathrm{Am}}\left(\frac{\mathrm{unit}}{\mathrm{s}}\right)$	$v_{\mathrm{c}}\left(\frac{\mathrm{unit}}{\mathrm{s}}\right)$	t_{S} (s)	P_{A}	P_{G}
0.3	0.9	10	0.001	0

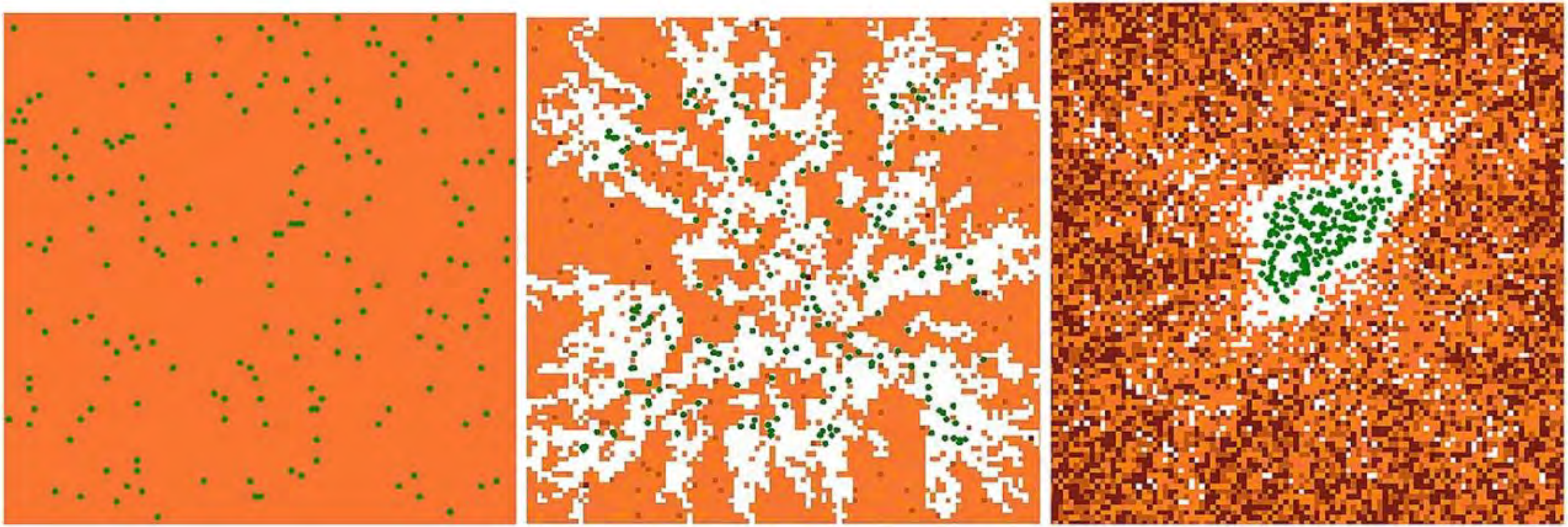
Variables:

N number of amoebas

$\rho = \frac{N\ A}{Dim^2}$ density

Macroscopic and microscopic scale

Simulations



The behaviors observed in animations have been compared to biological snapshot

Measurements

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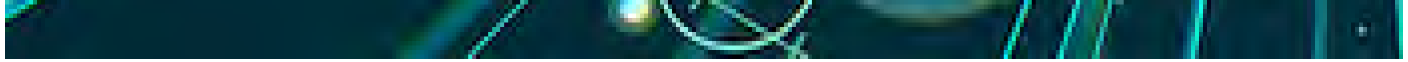
To quantitatively asses the colony dispersion around a center, variance-like estimator.

$$\mathrm{var}^i(t) = \frac{1}{\mathrm{Dim}^2}\frac{1}{N}\sum_{n=1}^{N} ||\bar{\mathbf{x}}(t) - \mathbf{x_n}(\mathbf{t})||^2$$

t is defined by simulation cycles
$x(t) = \{x_n, y_n\}$ the coordinate vector of the nth amoeba in Env at time t for each ith simulation
$\bar{x}(t)$ is the mean value of amoebas spatial coordinates at each cycle t

Information on the global behavior towards final clustering around a specific center as the dispersion of the colony

- Repeated simulations
- Overall mean value and associated statistical error
- Exponential dependence of varx on t
- 400 cycles ->aggregation (biologist after 6h)



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RESULTS

Dependencies

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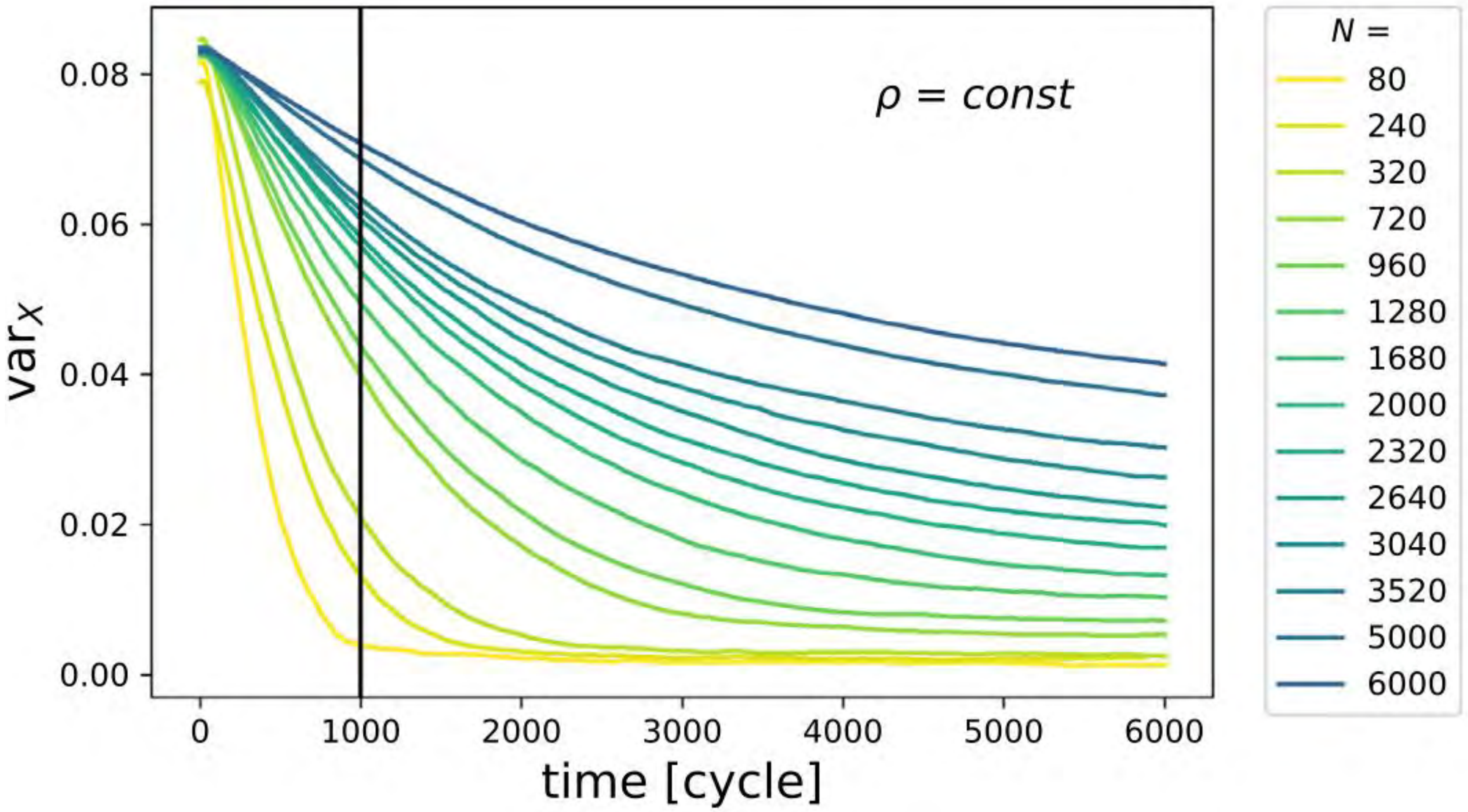
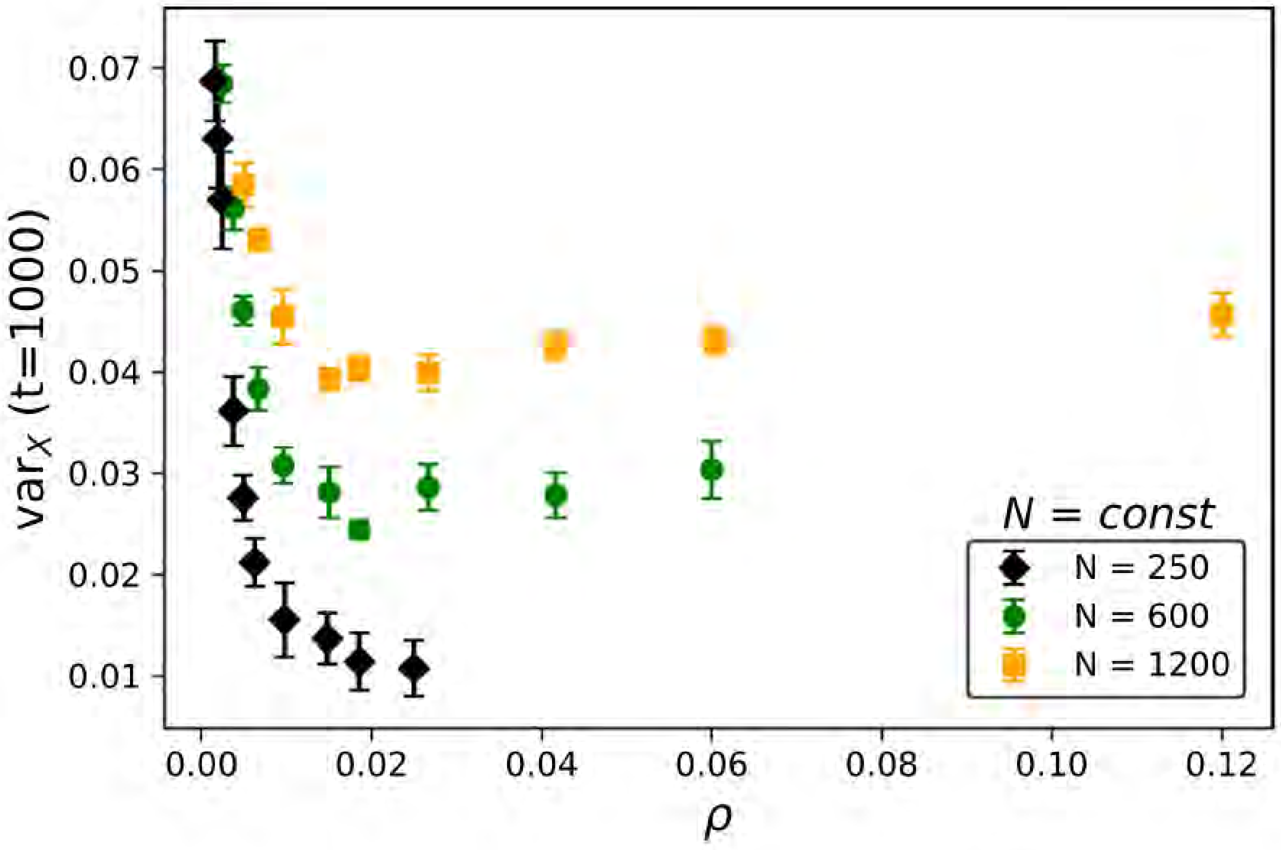


Cell food source and amoebas uniformly distributed over the environment

Exponential dependence

Dependencies



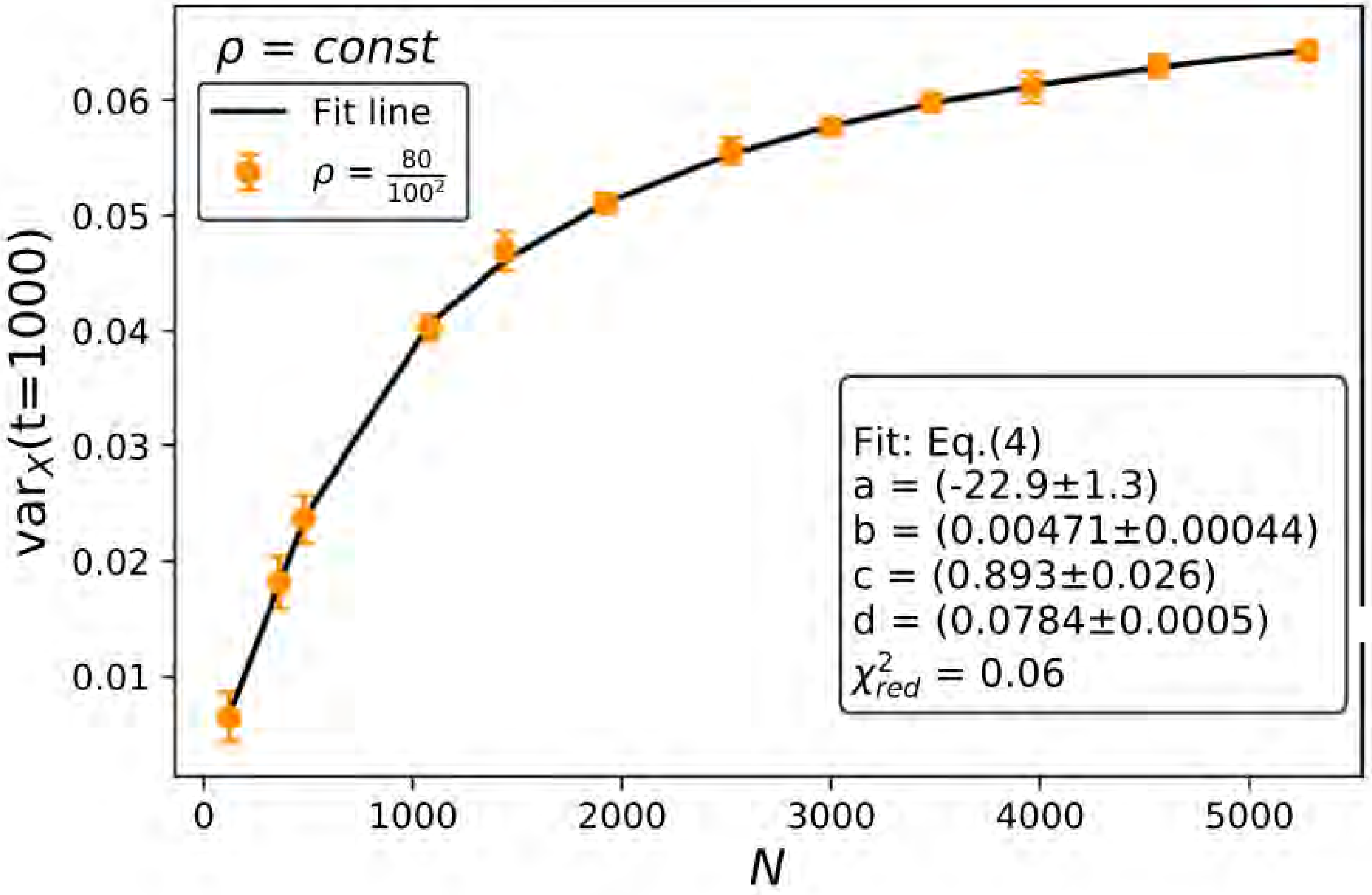
For smaller values of ρ varx decreases as the density increases, for bigger values varx shows a saturation effect toward a «plateau»

Different efficiency

«plateau» represents a region where the dispersion is independent of the density

cAMP concentration?

Dependencies



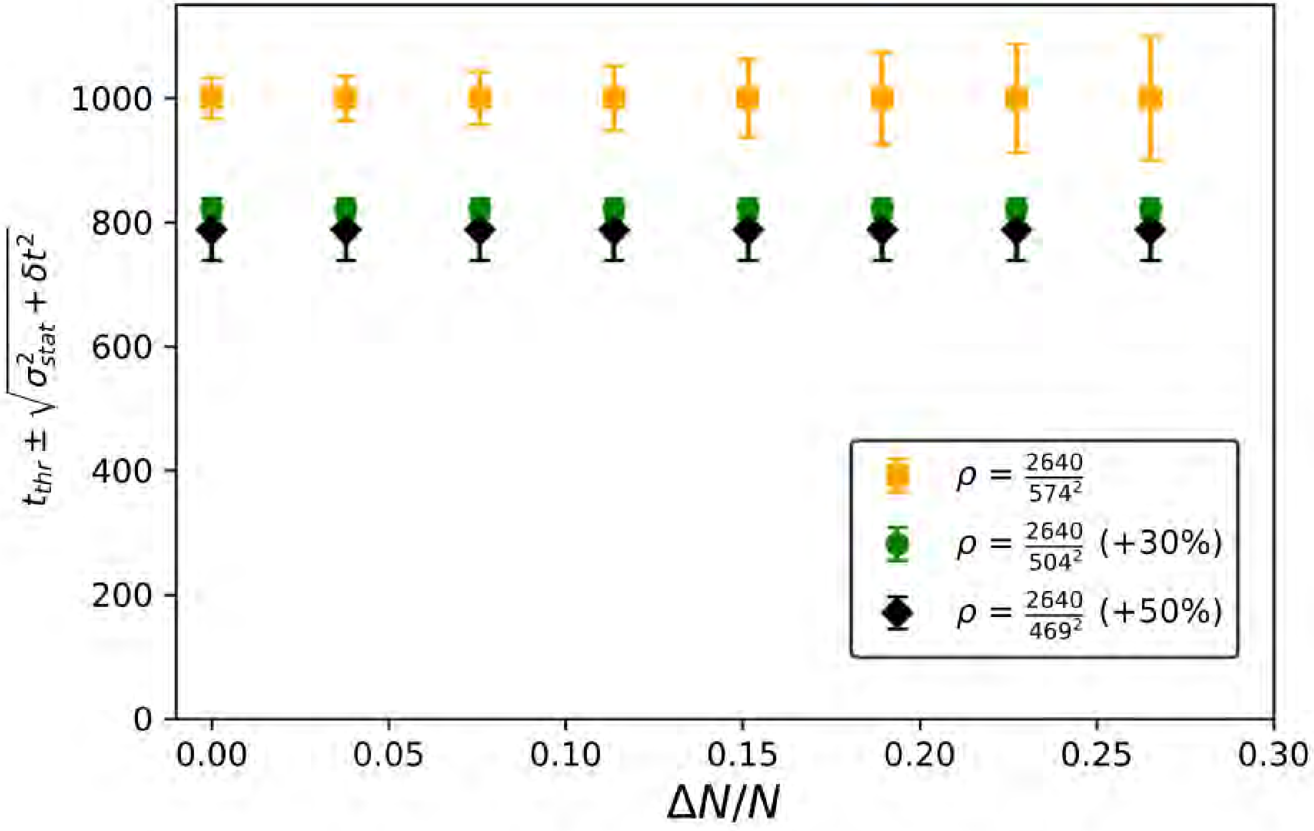
Dependency is not uniform

Fitting function:

$$var_x(t = 1000) = a\,\frac{\log(b\,N + c)}{N} + d$$

Asymptotic behaviour -> scale-free range for the variable N

Systematic uncertainties



t time needed to reach a cluster state

Dependence t on N

$$t(N) = -\frac{1}{B}\log\left(\frac{\left(\frac{a\log(b\,N + c)}{N} + d\ - C\right)}{A}\right)$$

Linear dependence

System robustness

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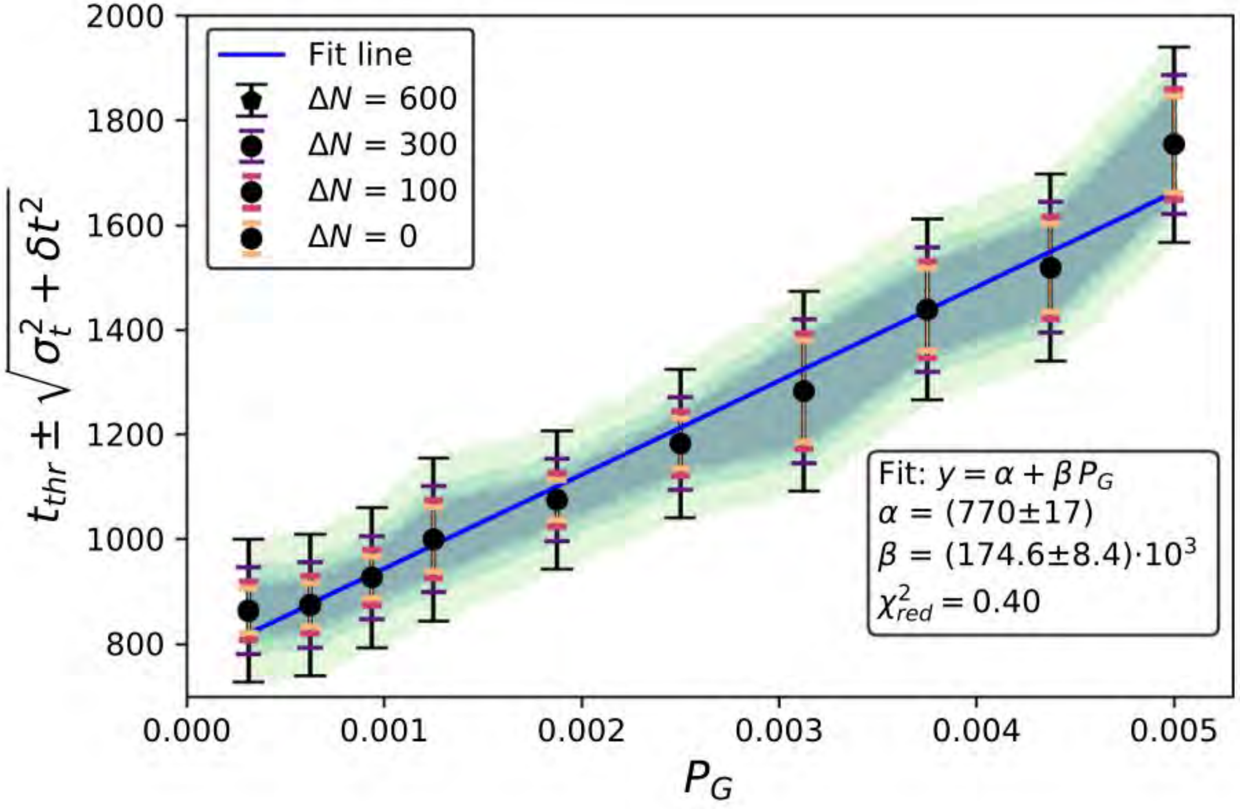

Robustness: the ability to maintain functionality in the presence of internal and external perturbations

Pg growth probability: the probability that environmental scalars increase during simulations

System robustness

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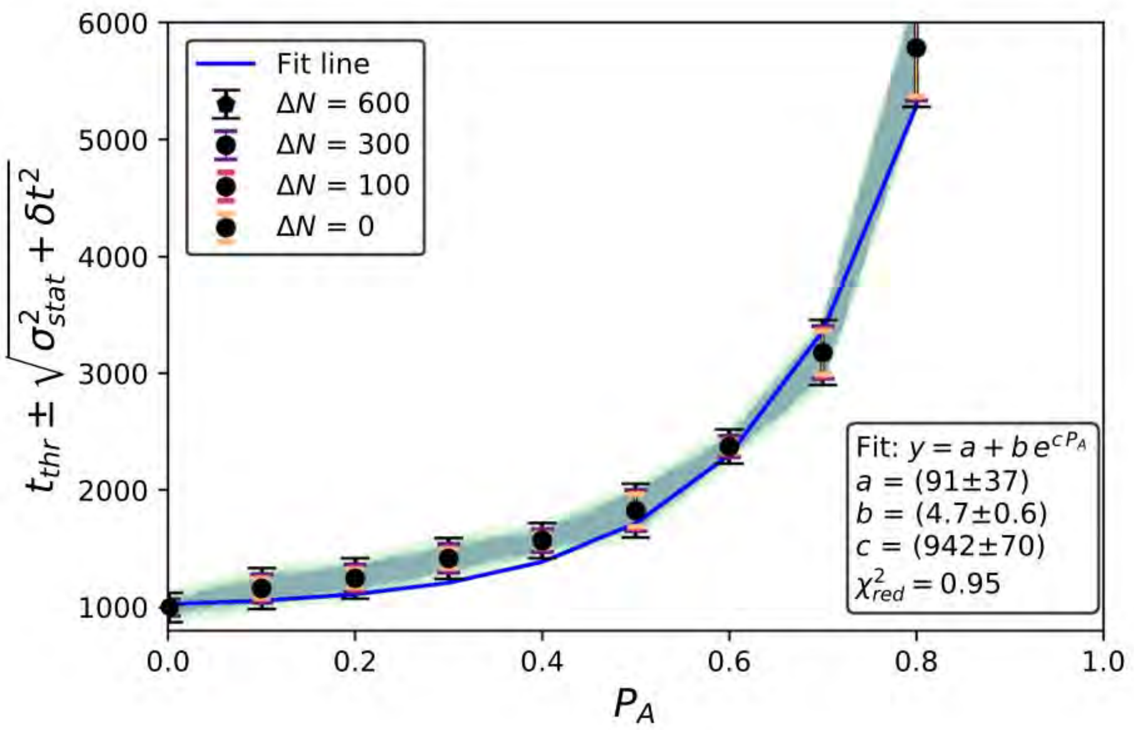

Pa: probability of an individual to fail the signal processing

Internal source of noise

For larger than Pa=0.5 diverges exponentially

CONCLUSIONS

Conclusions

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SUMMARY

- Developed, implemented and tested a MAS model
- Analyzed the dependence of the system dynamics on the main physical variables
- Observed a density-scale-free-region
- N-density-quasi-scale-free region
- Evaluated system robustness against internal and external sources of noise

Next steps

- Researchers need to carefully consider the microscopic variable N
- Computational constraints
- Good interpretability
- Helpful to overcome some of experimental limitations of in vivo or in vitro observation
- Practical application in the field of system control and self-synchronization of robotic populations
- Decentralized control

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Thanks!