Entropy and Self-Organization in Multi-Agent Systems

CSCE 990 Seminar

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Citation of the Article

H. V. D. Parunak and S. Brueckner, “Entropy and Self Organization in Multi-Agent Systems”, Proceedings of the fifth international conference on Autonomous agents, p. 124-130, May 2001, Montreal, Quebec, Canada.

193 citations.

Outline

- Introduction
- Motivation
- An entropy model for self-organization
- Experimental setup
- Results and discussion
- Summary
- Praises
- Critiques
- Relationship with class project

Entropy and 2nd law of thermodynamics

- Movie clip of “the fabric of the cosmos”
- Entropy

$$S = k_B \ln W = -k_B \sum_i P_i \ln P_i$$

- 2nd law: entropy of an isolated system never decreases.

= isolated systems spontaneously evolve towards the state of maximum entropy.

- The world tends to disorder (entropy increase).

Murphy’s law: Anything can go wrong will go wrong.

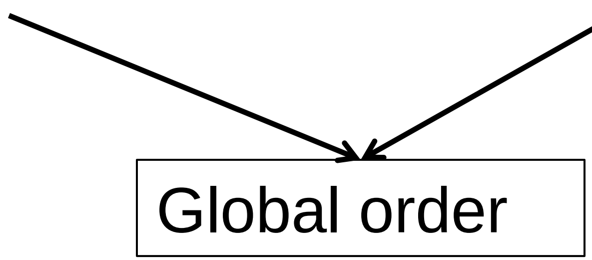
- Organized structure can be achieved only through hard work (entropy decrease).

Self-organization in MAS contradict 2nd law of thermodynamics?

- Examples: insect colonies, human culture
- Individual autonomy + global order

  = individual autonomy of agents spontaneously leads to organized structure (lower entropy).
- Paradox: contradiction of 2nd law of thermodynamics?
- Not really!!!

Thermodynamics system	Multi-agent system
Adding energy	Adding information



Self-organization in MAS contradict 2nd law of thermodynamics?

- The set of agents looks like an isolated system, but it is not!!!
- The isolated system is composed of the set of agents and the dynamic information around them, such as pheromone.
- The source (pheromone deposit) of dynamic information is created by agents themselves.
- Agents react to the dynamic information to self-assemble.
- The entropy increase of dynamic information is sufficient to cover the entropy decrease from the self-organizing process of agents. The total entropy goes up !!!

Objectives

- Link self-organization in MAS to thermodynamics concepts.
- Provide a measure for the behavior of MAS.

Kugler-Turvey model suggests multiple coupled levels of dynamic activity.

- Macro level: self-organizing behavior
- Micro level: dynamics generate increasing disorder
- As a whole: increasingly disordered over time

An example: pheromone

- Scent markers for

  a) recording states

  b) directing movements

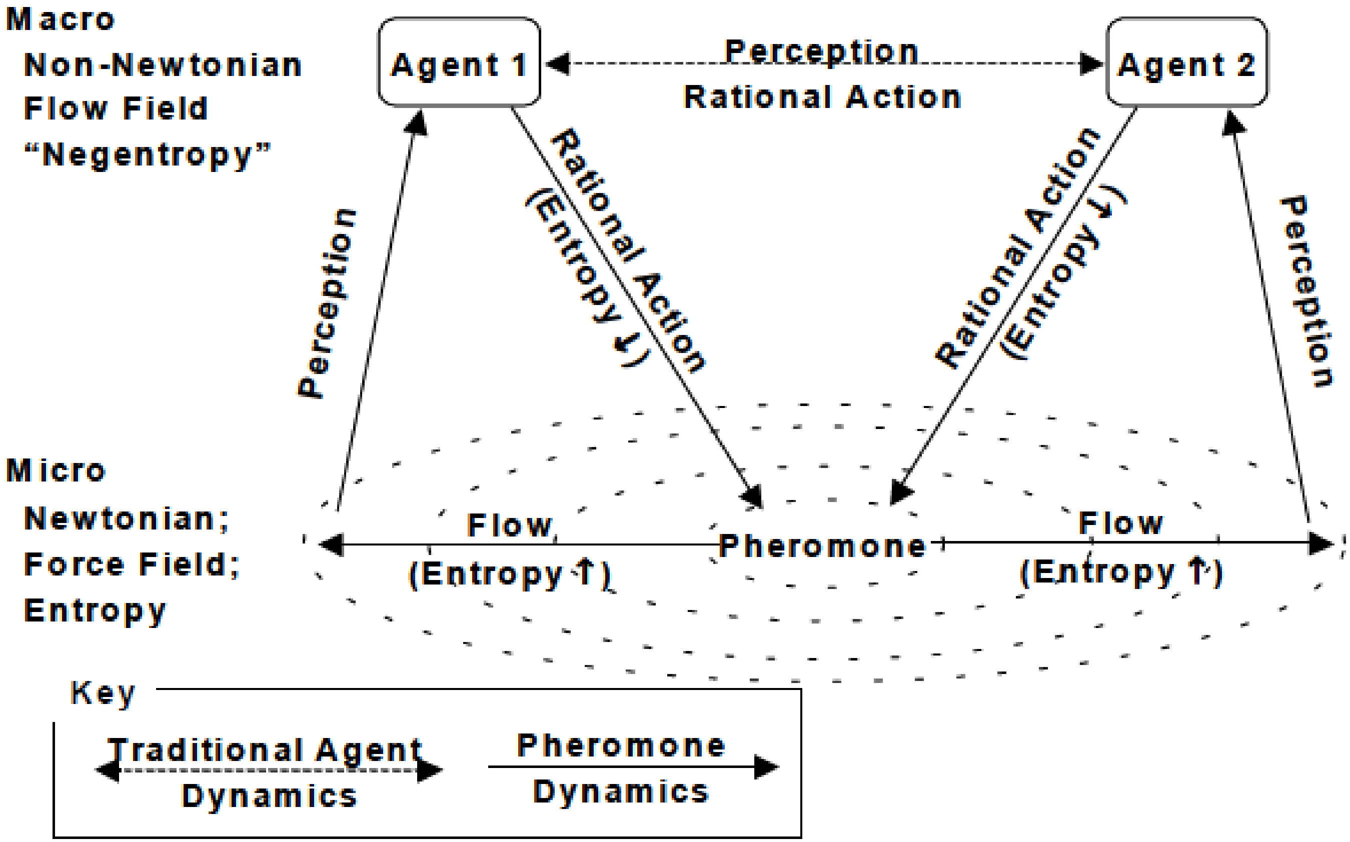
- Three information-processing functions of pheromone field

  a) aggregates pheromone deposits

  b) evaporates pheromones over time

  c) disseminating information

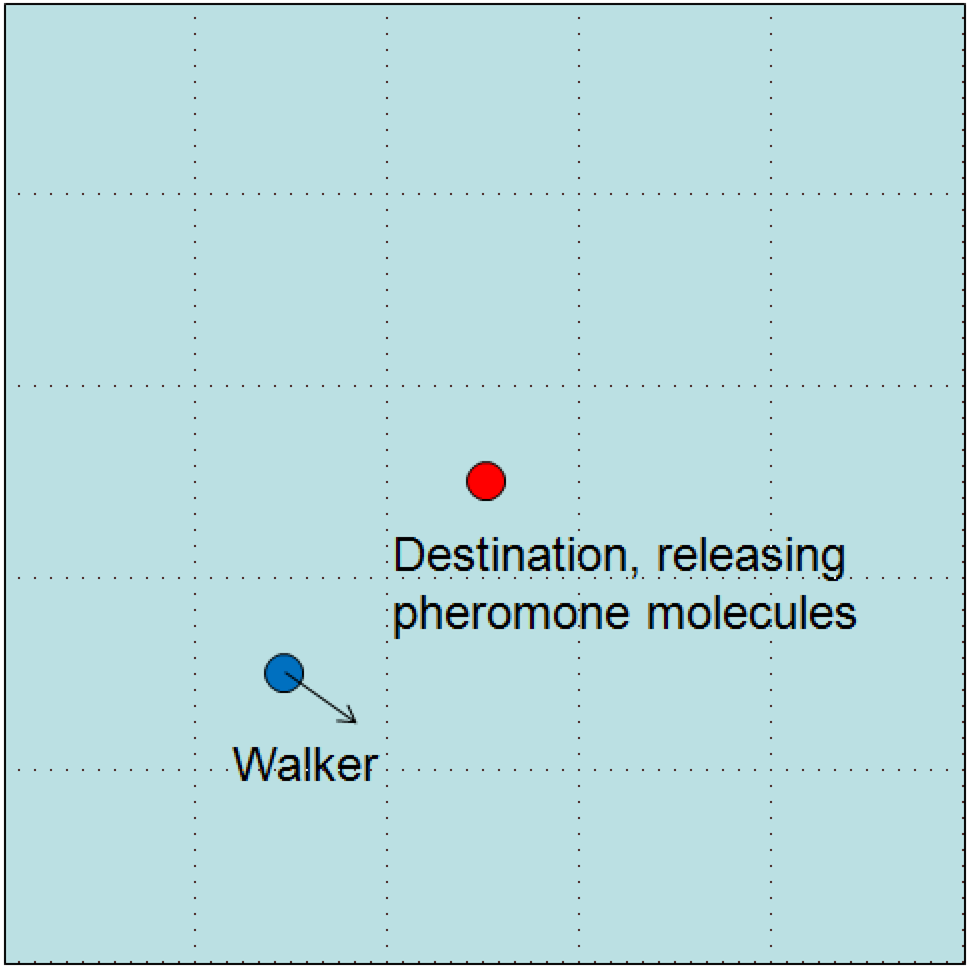
The model in detail



Information entropy

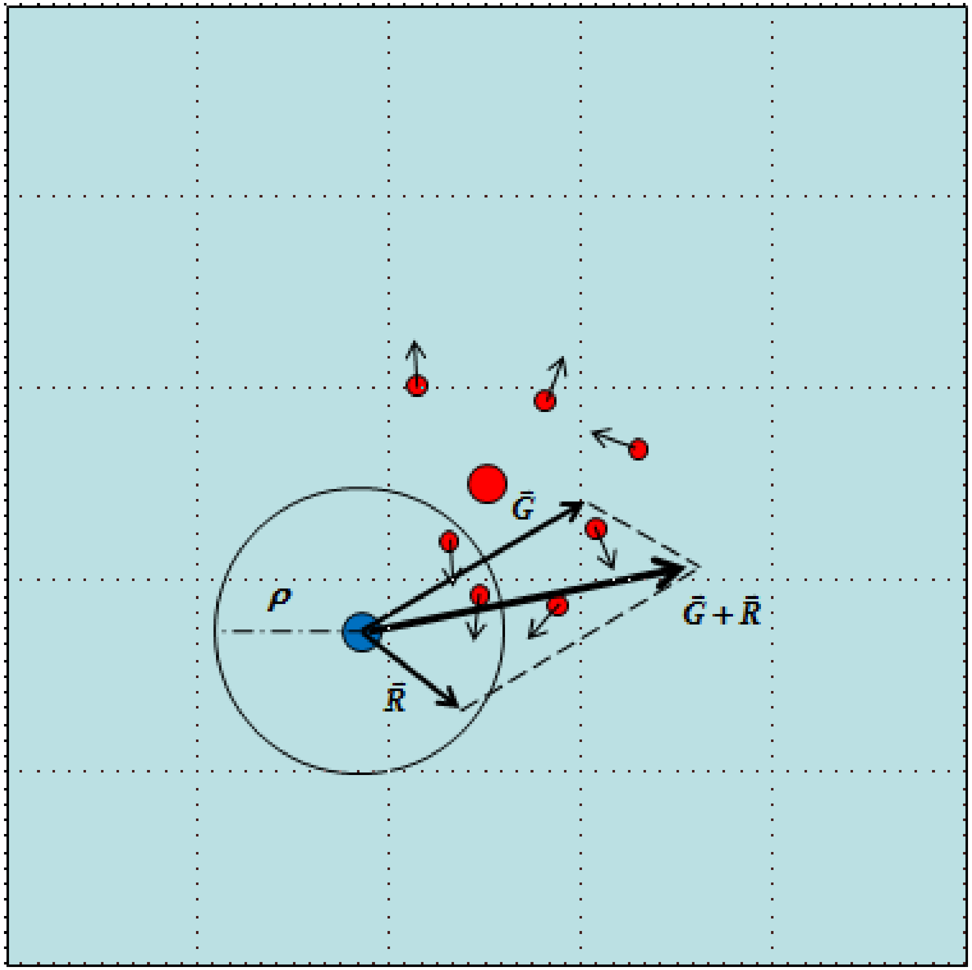
	Thermodynamics	Information
Micro level	$S = k_B \ln W$	$S = -\sum_i P_i \ln P_i$
Macro level	$dS = dQ / T$	

Experimental setup – coordination problem



- Destination release one pheromone molecule (PM) at each time step
- PM moves a distance of 2 every time step
- Walker moves a distance of 1 every 5 time steps
- Overall, PM moves 10 times faster than walker.

Movements of walker and pheromone molecules



Exploitation

$$\left|\vec{G}\right| = \sum_{r_i<\rho} \frac{g}{r_i^2}$$

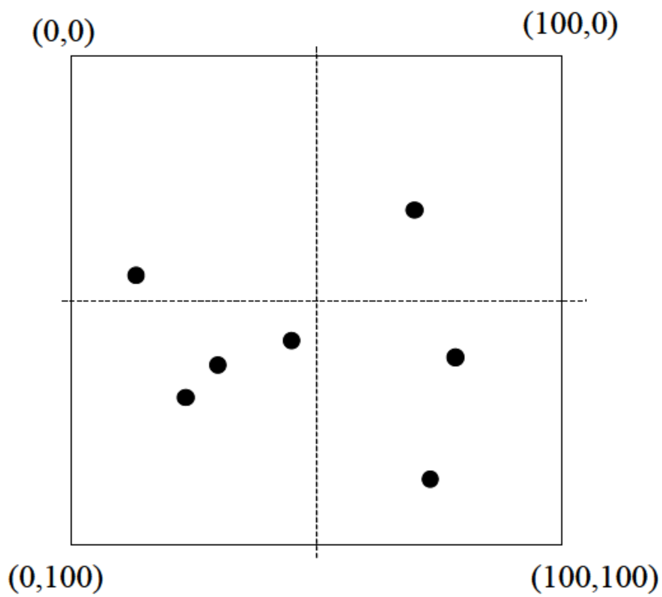
Exploration

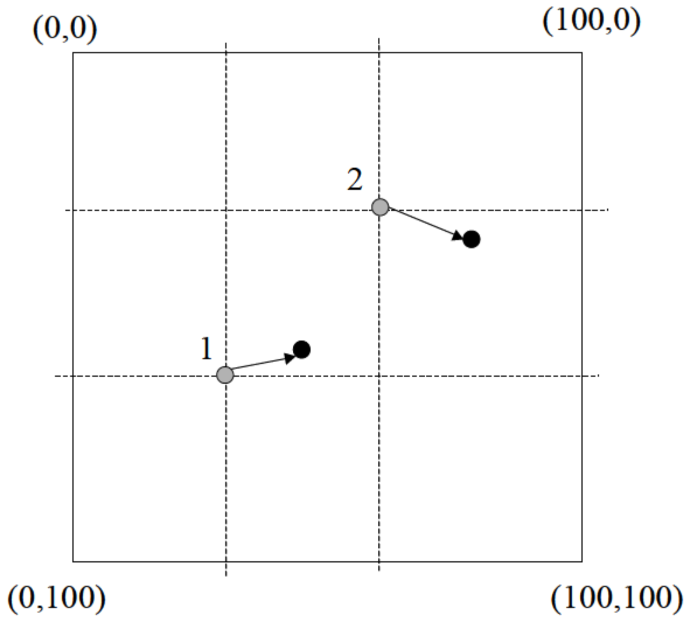
$$\text{random vector } \vec{R}$$

Measuring entropy

- Measuring number of system states
- Measuring the probabilities

Measuring number of system states





Location based gridding
n × n grids, m particles
state count: n^{2m}

Direction based gridding
n - rayed stars, m particles
state count: nm

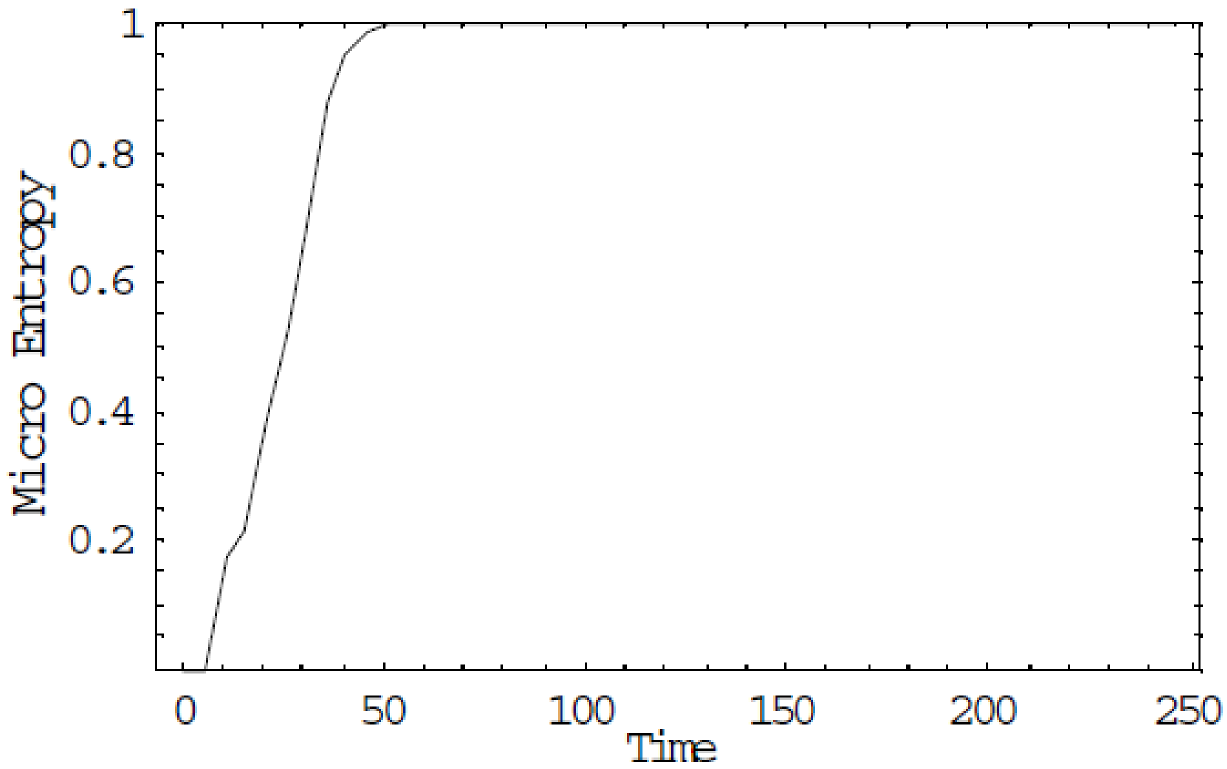
Measuring probabilities

- Analytical approach – impractical

- Monte Carlo approach: count number of replications for states, 30 replications in total at each time step. Entropy is normalized to be [0, 1].

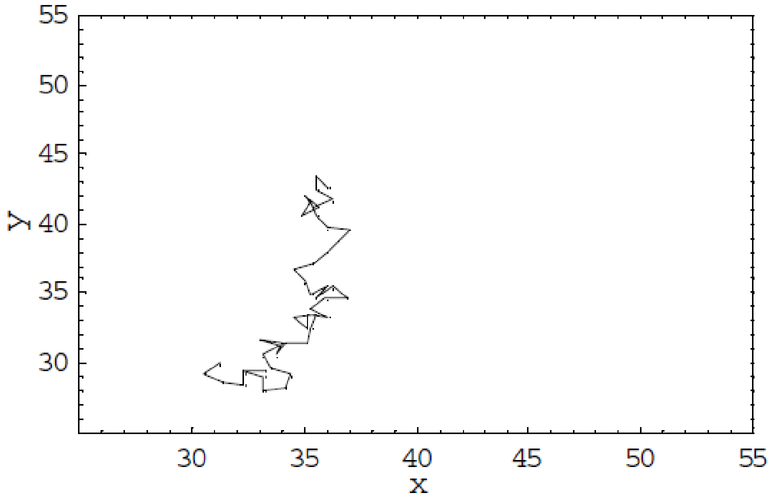
  Example, throw a die.

Results – entropy in the micro system (pheromone)

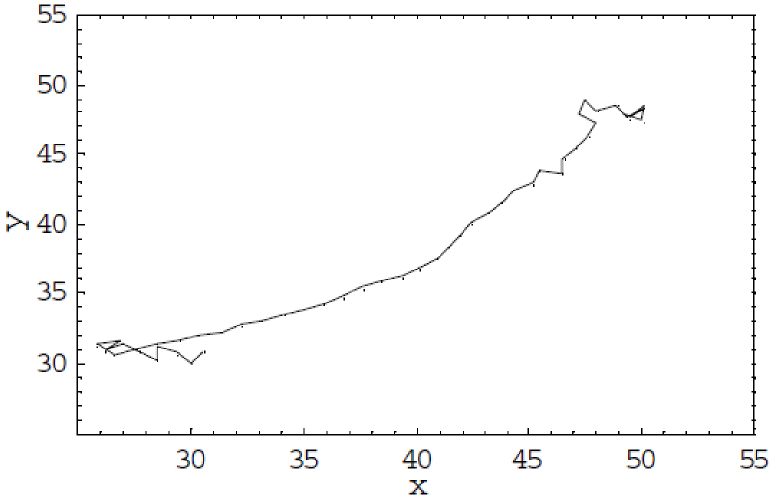


Locational entropy using a 5 × 5 grids
Directional entropy follows similar pattern

Walker path: unguided vs guided



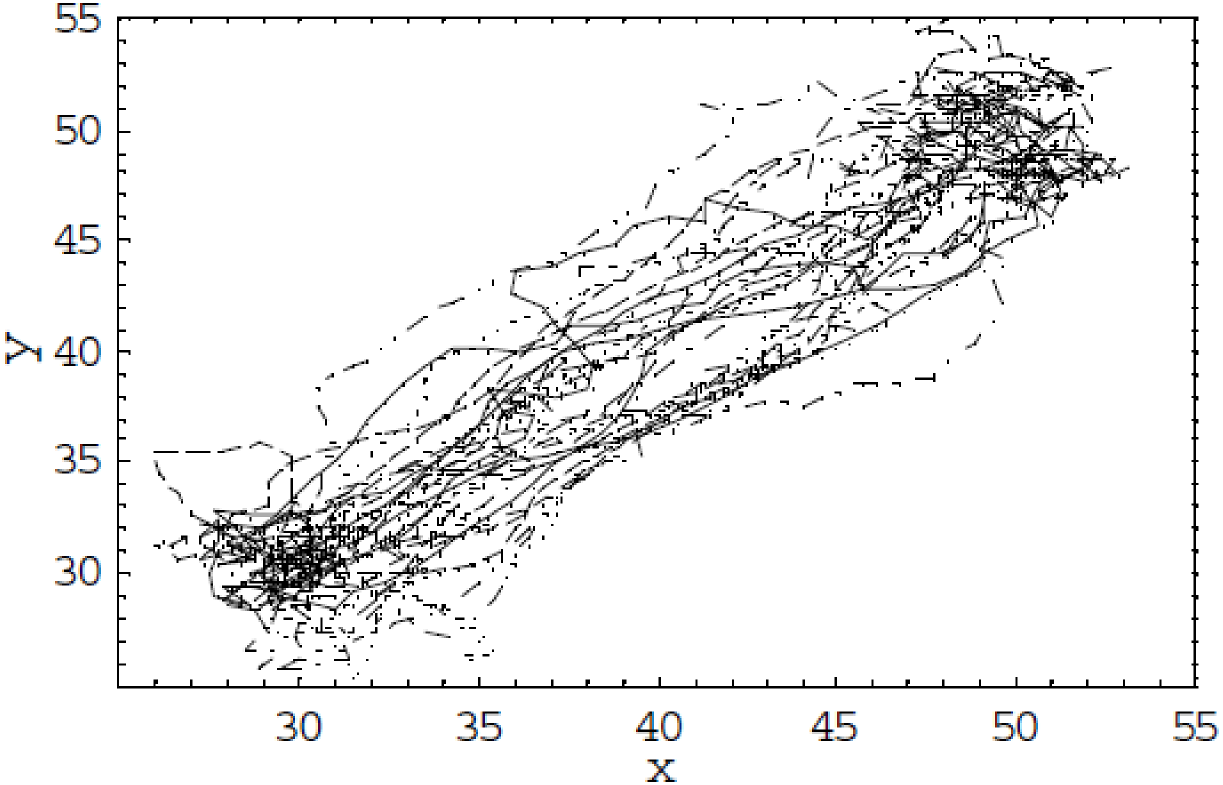
Unguided



Guided

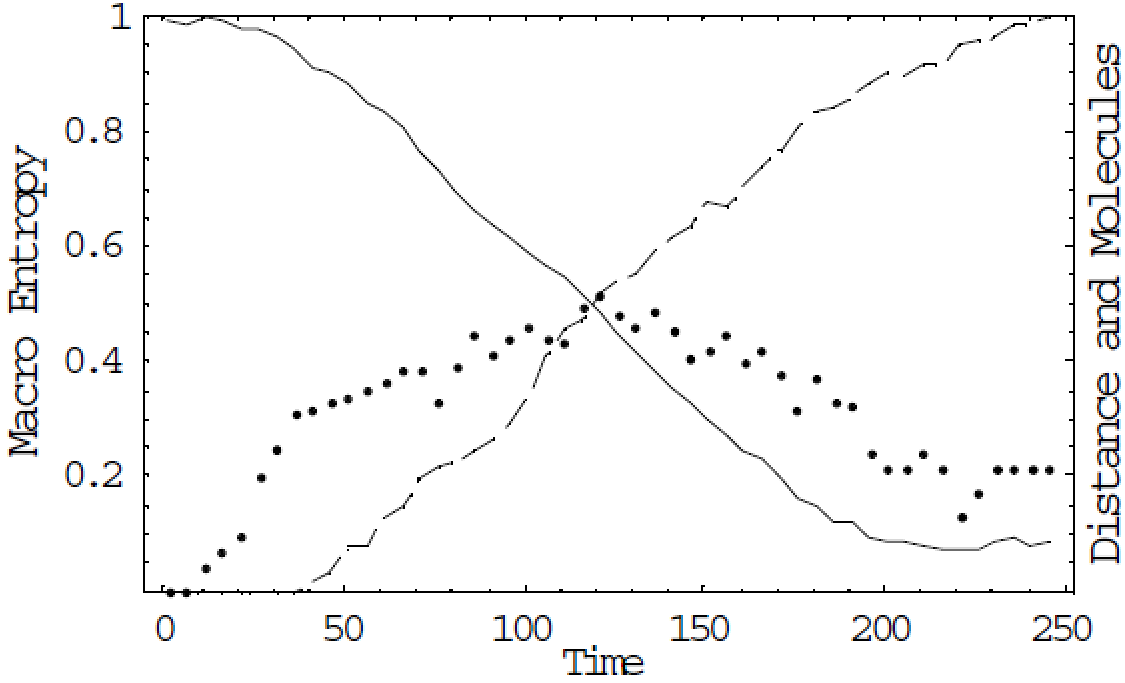
ρ = 20, $\vec{R} = \mathbf{0}$

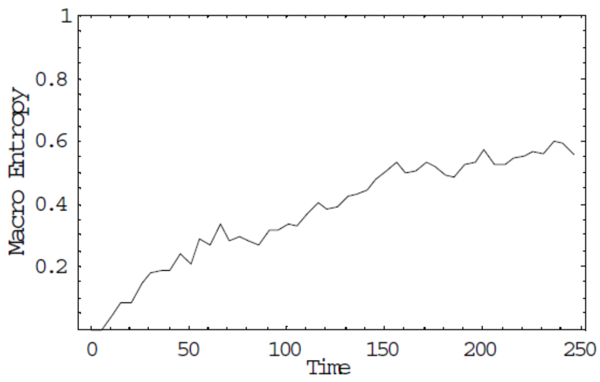
Ensemble of guided walkers



ρ = 20, $\vec{R} = 0$

Macro level: locational entropy - unguided vs guided

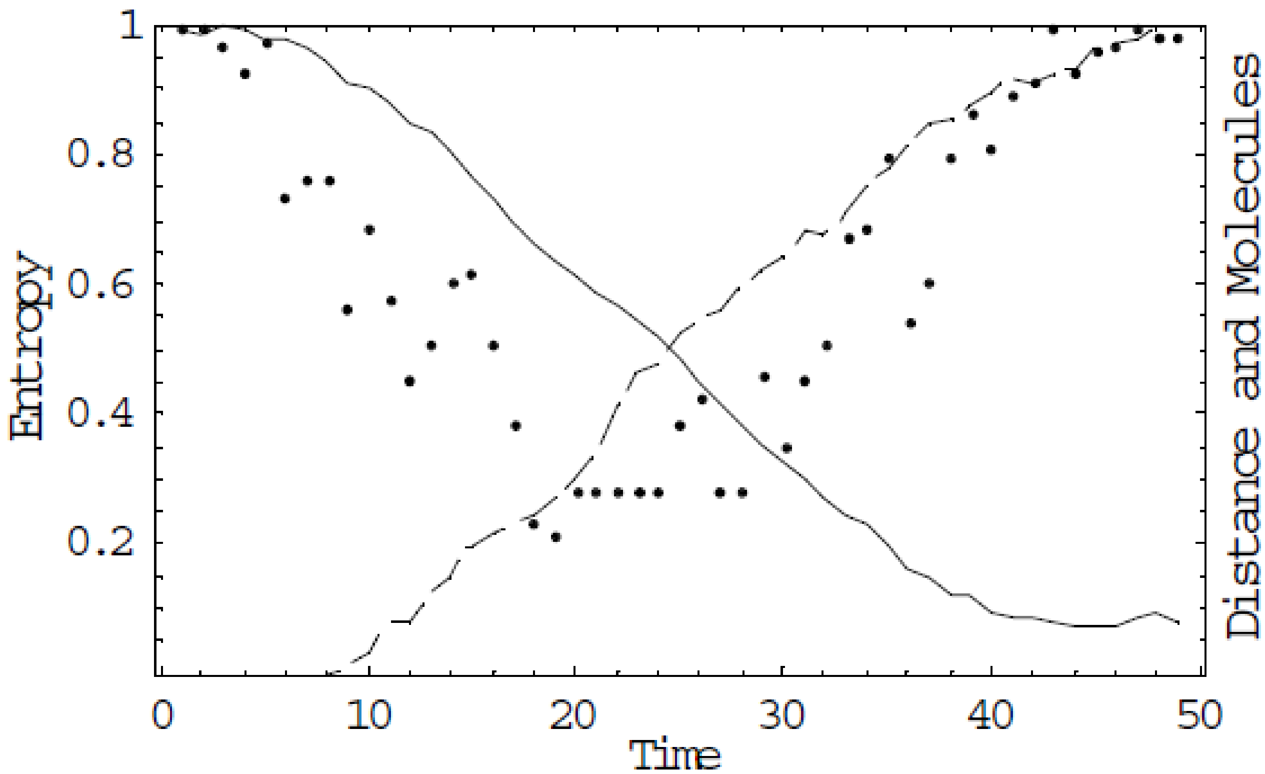




Unguided walker

Guided walker
- • locational entropy (15 × 15 grids)
- – median distance to target
- -- median visible molecules

Macro level: directional entropy - guided

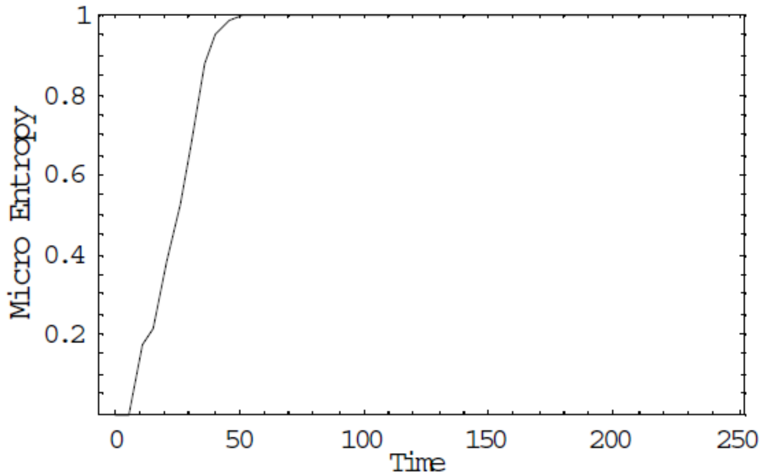


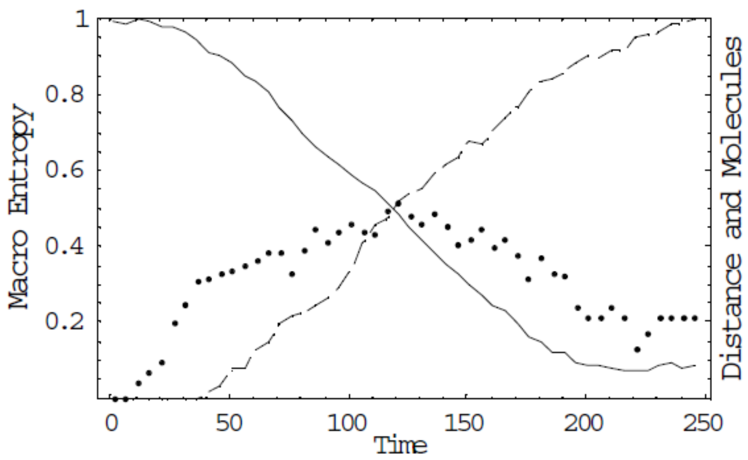
- directional entropy (15 × 15 grids)

– median distance to target

-- median visible molecules

Entropy in the overall system





Entropy gain
at micro level

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Entropy loss
at macro level

Summary

- Concepts from thermodynamics were invoked metaphorically to explain the self-organization in MAS.
- Quantified this metaphor through simple partitioning methods and MC simulations.
- Coupling of self-organizing process at the macro level with an entropy-increasing process at a micro level.
- Some form of pheromone or currency is the underlying mechanism for creating an entropy-increasing process.

Praises

- Multidiscipline knowledge and insightful observation of the metaphor.
- Simple but powerful design of the multi-layer model and entropy quantification.
- ~~Effective communication of the concepts and results.~~

Critiques

- An exploration term was defined, but never used. ($\vec{\boldsymbol{R}} = \mathbf{0}$ all the time)
- The number of replicates (only 30) was low considering the huge amount of the possible states.
- Pheromone agents were added arbitrarily. How multiple walker agents interact through the pheromone field created by themselves?
- Limitations? Energy-based approach rather than entropy-based approach?

Relation to the class project

- Class project: *Multiagent Cooperative Payload Transportation with Modular Self-reconfigurable Robots*

- Load-carrying agents directly interact with neighbors, not through pheromone field.

- Path can be lead by the pheromone field. Scout agent?

Questions?