Slime Mold Inspired Coordination for Wireless Sensor and Actor Networks

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Motivation

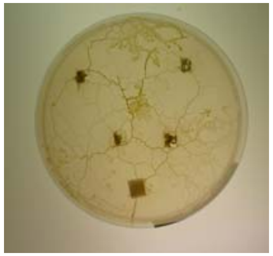
- Sensor-actor/actor-actor coordination in wireless sensor and actor networks (WSAN) demand both efficiency and robustness in routing
- While one can achieve optimal solutions with global information, such algorithms require global coordination and do not scale well
- Self-assembled biological systems solve similar problems without global knowledge, e.g., to connect multiple food sources, the **slime mold** generates a tubular nutrient distribution network that balances both efficiency (total tube length) and robustness (multiple paths)

Contributions

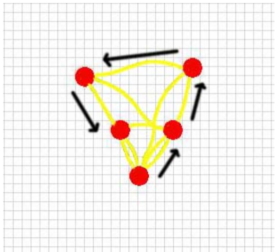
- Mathematical model for the tubular network formation behavior of slime mold has been validated via experiments
- Mapping the slime mold model to networking protocols for WSAN coordination

Experiments

- Slime mold *physarum polycephalum* (a single, multinuclear cell) is grown in petri dishes on agar
- Nutrient sources of blended oats in gelatin are placed at point of interests on the agar
- Assuming constant consumption rate -- one CC of nutrient blend would be consumed in 2 days
- A comparison between one laboratory experiment (a) and the solution using the **singular potential** model (b) is shown below. The slime mold started at the bottom most one of the five food sources. The black arrows in (b) indicate the order of reaching food sources.



(a)



(b)

Slime Mold Model using Singular Potential

1. Initialize the slime mold at one or more food sources
2. The slime mold pseudopodia would stream out randomly for a new food source at a fixed rate, while food sources that have already been discovered would decay linearly
3. When a new food source is reached, it's connected to those already discovered food sources using the **minimal field lines** defined by the following **singular potential** model:

$$\Psi(X)=\Sigma_{i=1}^{N} (f_i-f_{avg}) \ln(|X - X_i|^2)$$

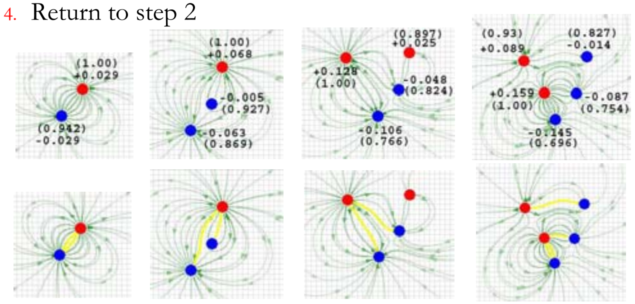
where:

- N is the number of discovered food sources including the new found one
- f_i is the current nutrient value at the i^{th} food source
- f_{avg} is the mean of all f_i's
- X_i is the position vector of the i^{th} food source
- $\Psi(X)$ is the potential energy at position X of the nutrient pressure field

Interpretations:

- (f_i-f_{avg}) is the relative nutrient value at the i^{th} food source after a new food source is found
- $|X - X_i|$ is the distance from the i^{th} food source
- By conservation law, the gradient of the potential drops off as $1/r$, where r is the distance from the food source
- Since $(d \ln r / d r) = 1/r$, the gradient of the potential field Ψ represents the tangent of the field lines where the potential energy changes most

4. Return to step 2



Incremental moves computed by above model in the same experiment as left. The upper figures show nodes nutrient value (values before subtraction of the mean in parentheses). The second row highlights the chosen paths -- the minimal field lines connecting two nodes

Inspired WSAN Coordination

Data flux capability (capability, for short), mapped to the nutrient value in slime mold, is defined as the available uplink (connection to sink) bandwidth of network nodes, i.e., uplink connection bandwidth (zero if not connected) minus actual data influx

- capability for actors: available processing potential, never negative
- capability for sensors: initially zero since neither connected uplink nor gathering any data, then negative if not yet connected but having data collected, positive after connected for uploading own data or relaying for others until all uplink bandwidth occupied

Preliminary algorithm:

- Initialize capabilities at each node -- Initially, no connections among sensors and actors. The actor has a large positive capability. Sensors that collect data have negative capabilities
- Using the singular potential model to compute the data flux field, and connect the actor to sensors within its transmission range following the paths of minimal filed lines
- Upon including a new node into the network, update the capabilities of nodes on its uplink path
- Repeat above two steps until no nodes with negative capabilities or all actors' positive capabilities consumed up

Conclusions and Future Work

- The singular potential model/algorithm for the tubular network formation behavior of slime mold is validated via laboratory experiments
- The slime mold model can be mapped to networking protocol for efficient and robust coordination in WSAN
- Develop simulation model of the above algorithm to study its performance in realistic WSAN scenarios

Thanks

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