A Novel Pheromone Approach to Spatial Clustering

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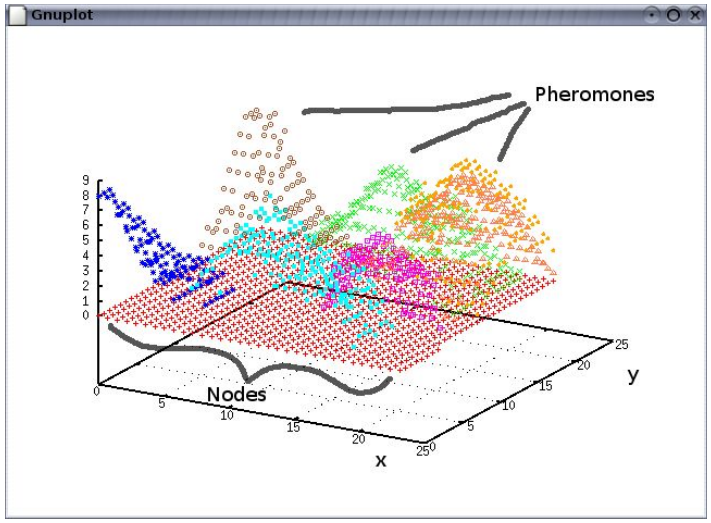


Illustration 1: Pheromone fields in a network of 500 nodes (nodes deployed in a lattice for clarity).

Introduction

My research focuses on agent-oriented programming techniques for sensor networks, with an emphasis on emergent behavior. I have been implementing an agent framework for sensor networks along with sample applications to drive the development. One such application is perimeter-based entity tracking, presented in previous work [1], in which agents are deployed to the network perimeter and track any events that pass by. For sufficiently large networks, it would be useful to define *internal perimeters* so that a failed track can be resumed, and to allow for detection of events originating within the network.

An internal perimeter might have a coverage of 10%, with the critical requirement that those nodes form a tree. This allows agents to be deployed evenly throughout a subset of the network. Participating nodes can be rotated over time to spread the energy drain.

Merits

In solving this problem, I have found a general solution similar to cluster-formation that should be useful in many collaborative algorithms. My simulation results show that the overhead is very low (see examples in the Results section), yet this mechanism is very powerful. A pheromone signal encapsulates *spatial and temporal* relevance of information—the further from the source (in space or time), the less relevant the information becomes. Eventually, any pheromone will decay below detectable levels.

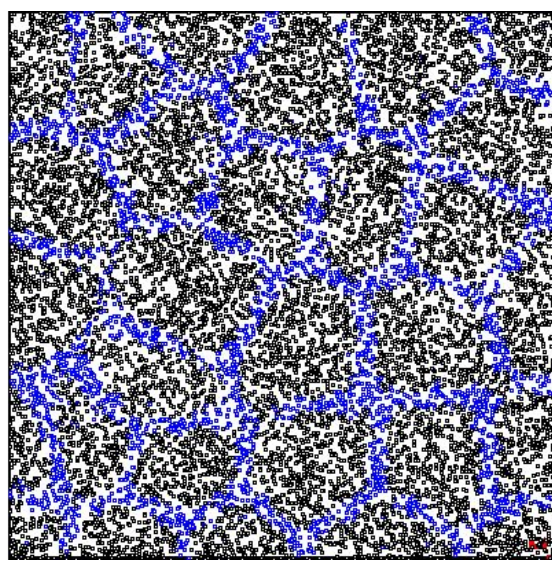


Illustration 2: Adaptively formed clusters in a uniformly random deployment.

The main contributions of this poster are:

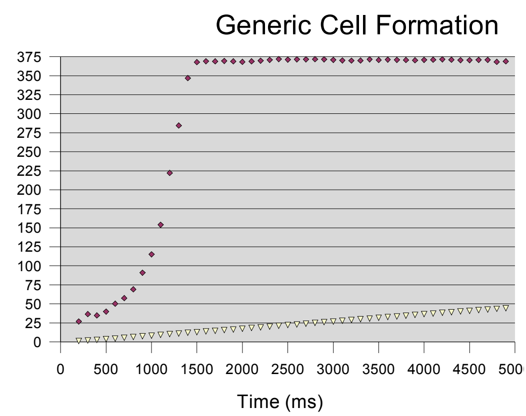
1. The formulation and analysis of an efficient pheromone distribution algorithm

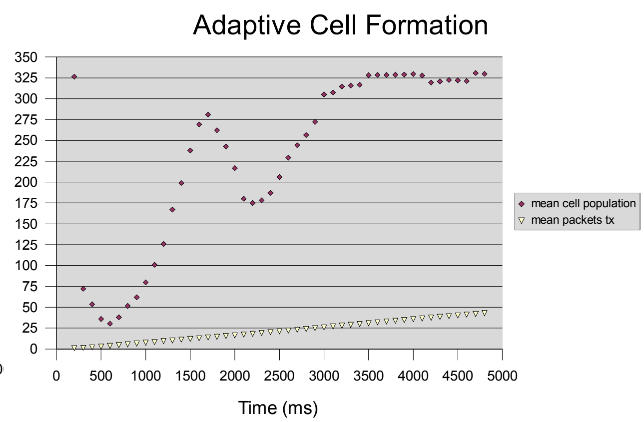
2. Presentation of a scalable phermone-based cluster formation algorithm. The neighborhood is defined by rough geographic range (specified by a number of radio hops), and yet does not require localized nodes.

Pheromone fields provide a very powerful side effect: the creation of a well-formed gradient. For instance, in a clustering scenario, the gradient provides a redundant routing path to the cluster head.

Current Results

Presently I have achieved exciting results for the cluster-forming algorithm. It exists in two forms: *generic,* and *adaptive*. The generic form relies on a static cluster head probability which must be tuned according to the network's characteristics (e.g., density). The adaptive form dynamically generates cluster heads depending on the present network state. Properly tuned, the generic version provides the fastest convergence and a slightly lower overhead than the adaptive version. Adaptive, however, requires no tuning and provides acceptable settle time with a reasonable increase in packet overhead. Below are charts of the each algorithm's progress in a network of 5000 nodes. It is clear that the packet overhead is similar over time; however the generic algorithm reaches a steady state using about half as many packets as the adaptive algorithm.





Because pheromone fields are constrained by *hop distance* rather than *hop count*, varying the density of a deployment does not affect the geographic properties of the clusters formed. Below are plots of density 4.0 and 8.0; in the latter case, cell population increases and *geographic size* remains the same.

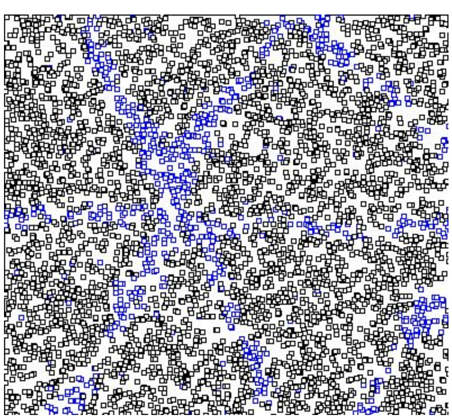


Illustration 3: Density: 4 nodes per square meter.

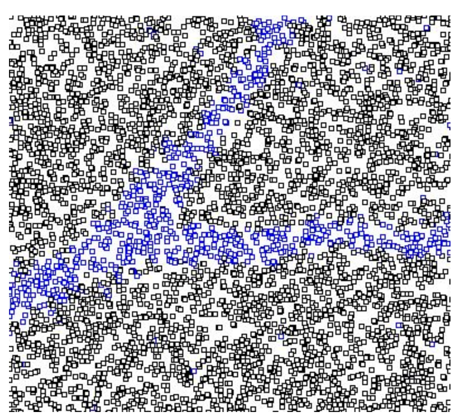


Illustration 4: Density: 10 nodes per square meter.

Pending Results

In addition to cleaner presentations of the plots in this proposal, I will have results from more in depth study of the packet transmission behavior and will explore optimizations of the generic and adaptive algorithms. Further, I have animations of cluster formation that can be presented from my laptop.

I will be implementing the algorithm in my agent framework and can run it on our 25-mote testbed; however, it is not yet clear if cluster formation will be observable in such a small network.

Ongoing Research

This research represents one component of my research on creating emergent behavior in sensor networks. I am also investigating other communication primitives for agents' use, issues of resource sharing between users (and between applications), and, ultimately, sensor-actuator feedback loops.

Challenges

Although care has been taken to minimize parameters which must be tuned, any application of emergent behavior will result in tunable parameters. As a result, some sort of *training* is a requisite. Training should be done in simulation whenever possible, but some post-deployment learning will likely be required. The adaptive clustering algorithm presented is one step in this direction.

Discussion Topics

Exploiting emergent behavior in sensor networks is an exciting and challenging topic. I expect this poster to spur discussions on additional algorithms that can benefit from the pheromone mechanism, as well as applications that can use this clustering scheme to facilitate efficient in-network processing.

References

Leo Szumel, Jason LeBrun, and John D. Owens.
Towards a Mobile Agent Framework for Sensor Networks. In the Second IEEE Workshop on Embedded Networked Sensors, Sydney, Australia, 2005.