Emergence of Coherent Behavior in Networked Agents

Masaru Aoyagi and Akira Namatame

{ g45074, nama } @nda.ac.jp
Dept. of Computer Science, National Defense Academy of Japan,
Yokosuka, Hashirimizu 1-10-20, Japan

Extended Abstruct

This paper addresses the convergence of coherent motion in networked agents by studying the flocking behavior of automobile agents in 3D. It has been shown that flocking behavior results from the class of local control laws for the collection of agents. Flocking can occur when local action exploits the network properties of the underlying interconnection among agents. Network connectivity affects the performance and robustness properties of a system of networked agents. It is important for the agents to act in coordination with the other agents. To achieve coordination, individual agent doesn't need to share information but to refer others action. Therefore, in order to achieve a certain convergence and robustness in environmental change, an appropriate network protocol must be designed.

Reynolds developed a method that creates realistic simulations of bird flocking [1][2]. Traditionally, in order to simulate a flock of birds, the simulation would consider the path of each bird individually. However, in Raynolds method, there is no central authority for each flock. Instead, local interaction rules between the adjacent birds would be used to determine the flocking behavior. This model is known as "Boids Model". In Boids model, there are three interaction rules: 1) attraction (cohesion rule), 2) collision avoidance (separation rule), and 3) velocity matching (alignment rule) between the boids located within a certain radius. When properly applied, these 3 local rules create a collection of autonomous agents that produce realistic flocking behavior.

This behavior is interesting in that not only must the individual behavior of the birds be evaluated, but also the overall flocking behavior needs to be considered.

Based on the Boids model, local control laws for a collection of mobile agents that result in self-organization have been investigated. A collection of agents, like birds in a flock, must be able to align their velocities, to move with a common speed, and to achieve the desired interagent distances while avoiding collisions with each other.

Watts and Strogatz [3] introduced a network model called a small-world network that was capable of interpolating between a regular network and a random network using a single parameter. A small-world is a network with a relatively small characteristic length. In a small-world, any two nodes can be linked using a few steps despite the large size of the network.

The small-world model of Watts and Strogatz has led researchers working in many different fields to study the topological properties of complex networks [4]. These properties include degree distribution, characteristic length, clustering coefficient, robustness to node failure, and search issues. The researchers who have most contributed to this effort are in such diverse fields as statistical physics, computer science, economics, mathematical biology, communication networks, and power networks.

Olfati-Saber et al. [5] theoretically established the stability properties of an interconnected closed loop system by combining results from classical and non-smooth control theory, robot navigation, mechanics, and algebraic graph theory. Stability is shown to rely on the connectivity properties of the graph that represents agent interconnections, in terms of not only asymptotic convergence but also convergence speed and robustness with respect to arbitrary changes in the interconnection topology. Exploiting modern results from algebraic graph theory, these properties are directly related to the topology of the network through the eigenvalues of the Laplacian of the graph.

Olfati-Saber[6] also demonstrated a phase transition phenomenon in the algebraic connectivity of flocking behavior on small-world networks. Algebraic connectivity of a graph is the second smallest eigenvalue of its Laplacian matrix and represents the speed required to solve consensus problems in the network. Hovareshti et al. [7] made the same conclusions for a discrete-time consensus algorithm.

We are interested in self-organization and group behavior about independent and autonomous agent. They are decentralized and doesn't share information. This paper examines the conjecture using simulations that show the emergence of flocking behavior on small-world type networks. As well, the emergence of flocking behavior is directly associated with the connectivity properties of the interconnection network. To achieve coordination, individual reactive autonomous agent doesn't need to share information but only to refer others action. Furthermore, Autonomous agents of conventional model need conneted network structure as a prerequisite for the emergence of flocking behavior. On the other hand, Autonomous agents of our model does't need conneted network structure and emerge flocking behavior. Finally, it will be shown that small-world networks are robust to arbitrary switching of the network topology.

A consensus protocol is an interactive method that provides the group with a common coordination variable. Thus, a probable conjecture is that a small-world type network should result in flocking behavior. This paper examines the conjecture by describing the occurrence of flocking behavior and the underlying connection between agents. It is shown that the occurrence of flocking behavior in the coherent motion of networked agents is directly associated with the connectivity properties of the interconnection network. The robustness of the system to arbitrary switching of the network topology was also examined.

References

1. Reynolds, C.W.: Flocks, herds, and schools: A distributed behavioral model, in computer graphics. In: SIGGRAPH '87 Conference Proceedings, SIGGRAPH (1987) 25–34
2. Reynolds, C.: Steering behaviors for autonomous characters. In: Proceedings of Game Developers Conference. (1999) 763–782
3. Watts, D.J., Strogatz, S.H.: Collective dynamics of 'small-world' networks. Nature **393**(6684) (1998) 440–442
4. Newman, M.: The structure and function of complex networks. SIAM Review **45** (2003) 167–256
5. Olfati-Saber, R., Murray, R.M.: Consensus problems in networks of agents with switching topology and time-delays. IEEE Transactions on Automatic Control **49** (2004) 1520–1533
6. Olfati-Saber, R.: Ultrafast consensus in small-world networks. In: Proceedings Proc. of American Control Conference. (2005) 2371–2378
7. Hovareshti, P., Baras, J.: Consensus problems on small world graphs: A structural study. In: The Sixth International Conference on Complex Systems. (2006)