# Roadmap-Based Group Behaviors

S. Rodriguez, R. Salazar, N. M. Amato
Dept. of Computer Science
Texas A&M University
{sor8786,rms1454,amato}@cs.tamu.edu

0. B. Bayazit
Dept. of Computer Science & Engineering
Washington University in St. Louis
bayazit@cse.wustl.edu

J.-M. Lien
Dept. of Computer Science
George Mason University
jmlien@cs.gmu.edu

***Abstract*— We explore the benefits of integrating roadmap-based path planning methods with flocking techniques to achieve different behaviors. We show how a wide range of group behaviors can be facilitated by using dynamic roadmaps.**

## I. Introduction

Group behavior is very common in nature, and there have been ongoing research efforts to simulate such behavior in computer animations and robotics applications. Generally, such work considers behaviors that can be determined independently by each group member solely by observing its local environment. We investigate how the addition of global information in the form of a roadmap of the environment can enable more sophisticated flocking behaviors. More information about our work, including animations, can be found on our website: http://parasol.tamu.edu/groups/amatogroup/research/flock/

## II. Roadmap-Based Group Behaviors

In [1]–[3], we explore the benefits of integrating roadmap-based path planning techniques with flocking techniques. We extend ideas from cognitive modeling [4], and embed behavior rules in individual flock members and in the nodes and edges of thae roadmap. We find that the global information provided by our rule-based roadmaps improves the behavior of autonomous characters, and in particular, enables more sophisticated group behaviors than are possible using traditional (local) flocking methods.

Some key features of integrating roadmaps with basic group behavior include:

- The roadmap provides a convenient abstract representation of global information in complex environments.
- Adaptive roadmaps (e.g., modifying node and edge weights) enable communication between agents.
- Associating rules with roadmap nodes and edges enables local customization of behaviors.

### A. Utilizing Roadmaps

Our approach utilizes a roadmap encoding representative feasible paths in the environment. While noting that our techniques could use any roadmap, our current implementation is based on the probabilistic roadmap (PRM) approach to motion planning [5]. Briefly, PRMs work by sampling points 'randomly' from the robot's configuration space (C-space), and retaining those that satisfy certain feasibility requirements (e.g., they must correspond to collision-free configurations of the robot). Then, these points are connected to form a graph, or roadmap, using some simple planning method to connect 'nearby' points. During query processing, the start and goal are connected to the roadmap and a path connecting their connection points is extracted from the roadmap using standard graph search techniques.

We first illustrated the power of our approach by proposing new approaches for four behaviors: homing, goal searching, traversing narrow passages and shepherding. Our new techniques can be applied to an entire flock, to individual flock members, or to an external agent that may influence the flock (e.g., a sheep dog).

### B. Behaviors

**Homing** consists of two sub-models, one representing the individual behavior of flock members and the other influencing the global behavior of the flock. "Boid" dynamics [6] sufficiently model individual behavior in most cases. In this model, individual members should: (i) avoid collision with neighboring flockmates, (ii) match velocity with them, and (iii) stay close to their neighbors. The neighborhood is defined by a distance, and an individual member of the flock is steered by angle and directional vectors satisfying the above criteria. Global behavior is usually simulated using roadmap-based path planning methods. A path is found from the roadmap and the individual flock members then follow the path. The path is discretized to subgoals based on an individual flock member's sensor range. Each member keeps track of subgoals and as soon as a subgoal comes within the sensory range the next subgoal becomes the steering direction for the global goal.

**Goal searching** is a type of exploring behavior. We assume the environment is known and the objective is to search for a goal and then move toward it. We achieve this behavior using a roadmap graph with adaptive edge weights. Each individual member behaves independently from its flock mates and uses the roadmap to wander around. Specifically, they follow roadmap edges and there are no predefined paths. If they reach a roadmap node with several roadmap edges, they probabilistically choose a roadmap edge to follow based on the weight of the edge. The edge weights represent any preferences for the current task, i.e., searching for and reaching the goal.

**Narrow Passage Behavior** for flocks modifies the individual flock members behavior depending on the surrounding environment. For example, different group formations may be used in relatively open areas than when passing through narrow regions. A naive way to achieve narrow passage traversal by the flock is to use the homing behavior and to select two nodes as goals, first a node in front of the entrance to the passage and then a node outside the exit from the passage. One drawback of this approach is that flock members may bunch up and conflict with each other as they try to move through the passage.

A *follow-the-leader* strategy may avoid the congestion problems of the naive strategy. In this strategy, we first assemble the flock in front of the narrow passage, and then select the closest flock member to the entrance to the narrow passage as the leader. Then, the remaining flock members are arranged into a queue that follows the leader.

## III. Shepherding Behaviors

In the next scenario, control is ceded to an outside agent who guides, or shepherds a flock utilizing the roadmap. Although a basic description of this behavior is given in [1] more detailed descriptions and advanced behaviors are presented in [7], [8].

Shepherding behaviors are a type of flocking behavior in which outside agents guide or control members of a flock. Shepherding behaviors can be found in various forms in nature. For example, herding, covering, patrolling and collecting are common types of shepherding behaviors. In this work, we investigate ways to simulate these types of behaviors.

### A. Basic Shepherding Behavior

A *shepherd* is an external agent that influences the movement of the flock. A *flock* is a collection of agents that have basic flocking behaviors [6] and attempt to keep away from the shepherd. The shepherd's task is to steer the flock to desired locations. In addition to steering, the shepherd unites separated flock *groups*. In a group, each member can *see* at least one member in that group. Usually, flock separation is caused by repulsive forces exerted from obstacles or shepherds. A *milestone* is any position toward which the shepherd attempts to *steer* the flock, and a *steering point* is any position toward which the shepherd moves himself in order to influence the movement of the flock.

**Shepherd's Locomotion**. We define a shepherd's locomotion as the manner in which the shepherd will move in order to control the movement of a flock. The shepherd's locomotion remains invariant in different shepherding behaviors and dramatically affects the quality of simulation. We divide the shepherd's locomotion into two sub-problems: *approaching* and *steering*.

In the approaching problem, we study how the shepherd moves to the steering point near the flock from its current position. In the steering problem, we study how the shepherd steers the flock toward the milestone.

### B. Behaviors

Shepherding behaviors can be found in various forms in our physical world and, interestingly, shepherds in these behaviors share similar locomotions. We have simulated four types of shepherding behaviors, i.e., herding, covering, patrolling and collection, using the previously described shepherd locomotions. We also show that our new locomotions improve the shepherd's control of the flock under various conditions.

Herding is a behavior in which a shepherd needs to move all flock members from a start region to a goal region. Herding is the most simple and common shepherding behavior. For the covering behavior, the shepherd guides the flock to areas of the environment that have not been visited. In patrolling, the shepherd needs to guard a designated region called the *forbidden area*. Once the intrusion of the flock is discovered, the shepherd will chase the flock until it vacates the forbidden area. A shepherd in the collecting behavior gathers initially scattered flock members into a designated region, called the *home area*.

### C. Multiple Shepherds

We extended our previous work of shepherding behaviors with a single shepherd to multiple shepherds in [8]. More specifically, we study how a group of shepherds can work cooperatively without communication to efficiently control the flock.

The key contributions of this work include developing herding strategies for multiple shepherds and demonstrating situations in which multiple shepherds can control a flock's motion better than a single shepherd. We study different shepherd formations to steer, turn, stop and merge a flock (of large size) cooperatively.

## IV. Conclusion

We have shown that complex group behaviors can be generated using a roadmap providing global environment information. The information the roadmap contains, such as topological information and adaptive edge weights, enables the flock to achieve behaviors that cannot be modeled with local information alone. Moreover, there are many applications where agents can use roadmaps to effectively perform group behaviors.

## References


[1] O. B. Bayazit, J.-M. Lien, and N. M. Amato, "Roadmap-based flocking for complex environments," in *Proc. Pacific Graphics*, Oct 2002, pp. 104–113.

[2] ——, "Better group behaviors in complex environments using global roadmaps," in *Artif. Life*, Dec 2002, pp. 362–370.

[3] ——, "Better flocking behaviors using rule-based roadmaps," in *Proc. Int. Workshop on Algorithmic Foundations of Robotics (WAFR)*, Dec 2002, pp. 95–111.

[4] J. Funge, X. Tu, and D. Terzopoulos, "Cognitive modeling: Knowledge, reasoning and planning for interlligent characters," in *Computer Graphics*, 1999, pp. 29–38.

[5] L. E. Kavraki, P. Svestka, J. C. Latombe, and M. H. Overmars, "Probabilistic roadmaps for path planning in high-dimensional configuration spaces," *IEEE Trans. Robot. Automat.*, vol. 12, no. 4, pp. 566–580, August 1996.

[6] C. W. Reynolds, "Flocks, herds, and schools: A distributed behaviroal model," in *Computer Graphics*, 1987, pp. 25–34.

[7] J.-M. Lien, O. B. Bayazit, R.-T. Sowell, S. Rodriguez, and N. M. Amato, "Shepherding behaviors," in *Proc. IEEE Int. Conf. Robot. Autom. (ICRA)*, April 2004, pp. 4159–4164.

[8] J.-M. Lien, S. Rodriguez, J.-P. Malric, and N. M. Amato, "Shepherding behaviors with multiple shepherds," in *Proc. IEEE Int. Conf. Robot. Autom. (ICRA)*, April 2005, pp. 3413–3418.