Collective Behavior as Assembling of Spatial Puzzles

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Abstract. This paper describes how collective behavior can be achieved using simple mechanisms based on local information and low-level cognition. Collective behavior is modeled and analyzed from the spatial point of view. Robots have a set of internal tendencies, such as association and repulsion, that enable them to interact with other robots. Each robot has a space around its body that represents a piece of the puzzle. The robots' goal is to find other pieces of the puzzle, associate with them and remain associated for as long as possible. Experiments on queuing using this puzzle-like mechanism are analyzed.

Keywords: collective robotics, spatial coordination, proxemics.

1 Introduction

This research focuses on the design of collective behavior for autonomous mobile robots based on simple mechanisms. By simple mechanisms we denote those that depend on local information and low-level cognition, i.e. mechanisms used by robots that have limited capabilities and limited knowledge of the environment. The kind of collective behavior we are interested in involves the arrangement and maintaining of spatial patterns by a multi-robot system, such as formation and flocking. These behaviors are useful for a number of applications such as material transportation, hazardous material handling and terrain coverage. The central idea of our work is to implement collective behavior using a domain independent mechanism [4].

The paper presents the proxemic coordination, a situated distributed method for collective problem solving. It is situated because it relies mainly on the information perceived by robots, instead of on a description of the environment. As robots determine their actions locally, the model is distributed. This mechanism is based on the spatial coordination of a group of robots in approximate patterns. For that, each robot has a space around its body called the proxemic
space, that should be preserved from contact with objects and kin. Robots also have a set of internal tendencies, such as association and repulsion, that enable them to interact with others. A robot looks for its kin in order to associate with them and remain associated for as long as possible. But if the internal tendencies are modified, it can then avoid its kin. The association is performed by assembling the frontiers of proxemic spaces. In contrast, the repulsion supposes the moving away of robots. Robots and their territories are the pieces of a puzzle whose shape is defined by the application: a column for queuing or a square for formations.

The paper is organized as follows: section 2 addresses related work. Section 3 presents our proposal. Sections 4 and 5 describe various experiments and give some technical details. Section 6 examines results, and section 7 discusses conclusions and perspectives.

2 Related Work

Spatial coordination in groups of agents has mainly been studied in simulation [3, 14]. Interesting experiments where several agents [6] or robots [9] coordinate and synchronize their movements have also been reported. Spatial organization and flocking have been largely studied in the literature and a variety of simulated experiments has been presented [12, 14].

Social potential field [15] are very close to our research. In this, artificial force laws between robots producing both attraction and repulsion are defined. The method is robust and efficient, it relies on a certain amount of global information and on a direct communication between robots. Thus, robots have to exchange their absolute positions in order to perform force calculations and to coordinate their movements. The method has been applied to model collective behaviors such as clustering and guarding, but only using simulated robots. This is due to the difficulties to calculate social potential fields in real-time.

A similar method using motor-shema instead of force laws has also been explored [1]. In this approach, modular behaviors are composed in order to achieve spatial formations such as lines, columns and diamonds. The method has been tested using simulated and physical robots. More recent results of this work [2] describe robots with attachments sites in their body that determine the spatial structure formed by robots.

Self-assembling robots is a very active research avenue in the robotics community [10]. Mechanisms composed of simple robots that are able to adopt various shapes and reconfigure themselves have been physically built [5, 17] and simulated [13]. The design and implementation of these systems, which combine a lot of computing and engineering skills, are beyond of the goals of our current research. However, the general principle that enables robot-pieces to attract and assemble, has inspired us to propose a puzzle-like mechanism to display collective behavior in robotics.

The research reported in this paper is similar to social potential fields and to spatial formation with attachments sites. Our approach is different from the
first in the application of repulsion and attraction forces. Whereas in the work
mentioned these forces are used to avoid obstacles and guide robots to the goal,
in ours they are directed to the spatial dynamic coordination of robots. Our
work is also different in that our robots do not exchange information about their
positions. In contrast with the second method, we use hierarchical behaviors
instead of motor schema and the attachment sites of our robots are not fixed.
These sites can be modified during an experiment resulting in a different global
behavior.

3 Proposal

Coordination is at the core of puzzle-like mechanisms. But if self-assembling
demands a lot of exactness, queuing and formations are less demanding as to
the precision of the movements executed by participants. From a global point of
view, the area formed by a group of robots coordinating their movements can be
considered as a shape that robots are trying to preserve. This shape is of course
non-fixed, it can be reconfigured according to the rules of assembling applied by
robots.

We propose a method to coordinate approximately the movements of a group
of mobile robots that have to organize themselves spatially. Neither direct com-
unication nor centralized control is involved in this strategy. Instead, a robot
must be able to delimit a space around itself, a proxemic space, and perceive its
kin. Both capabilities are necessary to define the internal tendencies of robots.
This method is called proxemic coordination.

The notions of proxemic space, kin recognition and internal tendency are
discussed below.

3.1 Proxemic Space

The proxemics is a notion introduced by the anthropologist Edward Hall [7].
According to him, the space plays an essential role in social systems. Individuals
define and organize the space around their bodies. Their behavior is then closely
related with the interactions perceived within this space.

The idea that an individual moves surrounded by a bubble and that the
bubble arrangement influences his behavior, inspired us to propose a method
of proxemic coordination for a group of robots. The proxemic space is for us, a
virtual space defined by a robot as an extension of its body.

3.2 Kin Perception

Kin recognition is a requirement for the generation of complex behavior in groups
of robots [8]. Spatial coordination needs often mechanisms of kin perception and
recognition. Robots should be able to distinguish not only their environment, but also their kin.
4. Kin Perception

A robot can detect if another robot is located one unit directly in front of its proxemic space. The robot will then move 0.1 steps forward in the direction it is facing and turn right by 5 degrees.

4.1 Proxemic Space

The proxemic space is a rectangle in front of a robot. A robot can perceive if its one-unit dimension space is clear or not. The proxemic space is clear if a robot is not a border of the environment. Proxemic orientation is used by robots in order to determine which behavior to execute. The robots are able to execute three behaviors: wander, avoid obstacles, and queue. A robot can move 0.1 steps forward and turn right by 5 degrees.

4.2 Simulated Experiments

We have programmed a virtual environment using Starlogo, in order to implement our proposal. The rules of proxemic coordination are used in this experiment. The rules are as follows: robots can move in a predefined path, form a group of robots to reach a global formation, robots have a right to change their polarities and withdraw from collective formation.

4.3 Tendencies

In addition to the ability to define a proxemic space, robots must be able to assemble their spaces in appropriate manners. Like in previous work, the tendency of these robots determines how they are assembled. The robots have attachment labels that are used to connect their spaces. These labels may be viewed as plus (+) and minus (-) polarities that are used for attachment. Attachment labels may also change during an experiment according to specific situations. A robot with flat-battery taking part in a formation, has the right to change its polarities and withdraw from collective formation.

Being able to recognize their kin is considered a basic skill to apply proxemic coordination. In order to recognize their kin, robots use a set of features such as colors or visual cues to distinguish between their kin and other elements of the environment. These mechanisms are as we see below, based on local robots perception.
4.3 Tendencies

Two attachments labels were defined. A label plus was situated on the robot’s head and a label minus on the robot’s rear. Robots are attracted by attachments labels minus and by the landmark indicating the beginning of the line.

Depending on the distance between attachments labels, robots assemble their proxemic spaces in three different manners: approximate, standard and accurate. That is, a robot can be attracted by an attachment label situated, respectively, ±20°, ±10° and ±5° away from its own attachment label. The quality of a formation depends on this assembling precision.

This tendency enables robots to follow themselves and to form breakable lines. That is, lines that are easily unarranged when an object is perceived within proxemic space, what happens often in an environment where various robots are wandering (see figure 1(a)). In order to remain still and form static lines robots change their attachment labels once they are assembled. This modification acts as a blocking mechanism that protect formations and contribute to solve conflictive situations (see figure 1(b)).

![Figure 1](image1.png)

Fig. 1. Number of robots in formation in two groups of robots during 60 sec. The experiments were performed using subgroups of 5, 10 and 15 robots that were randomly located in the environment. The attachment labels of the first group (a) were fixed whereas those of the second group (b) were modified during experiments. The second group managed to solve conflicts when two robots are attracted by a same third robot.

Figure 2 shows some snapshots of our system. As we can see, the robots did not form fine lines, but they reached global formations using only local information.
Fig. 2. Two snapshots of our system with 10 robots that were randomly placed. Robots assembled their proxemic spaces using approximate (a) and accurate (b) precision. The location and the state of the robots at three different instants are also shown. During these experiments the attachment labels changed once robots were assembled.
5  Physical Experiments

We have used the rules of proxemic coordination in order to enable a group of physical mobile robots to form a line in front of a landmark. The experiments described in this section were conducted using three Pioneer 2-DX mobile robots of Active Media©, provided with odometers, bumpers, sonars, radio modems, video-cameras and onboard computer.

5.1  Proxemic Space

A robot uses two sonar arrays to delimit its proxemic space. Based on sonar readings, the robot can determine whether or not its proxemic space is clear (see figure 3). The sonars' sensitivity ranges from 10 centimeters to more than 5 meters and can be adjusted in order to see small objects at great distances. The sensors' sensitivity determines the possible limits of proxemic spaces.

Robots are able to execute four behaviors: wander, avoid obstacles, queue and adjust position. The last behavior enables robots to assemble the frontiers of their proxemic spaces as accurate as possible.

Fig. 3. A robot is equipped with 2 sonar arrays of 8 sonar each (left). In our experiments, proxemic space is a virtual rectangle situated ahead of the robot (right). Sonars are used to calculate the distances along $x$, $dx$, or along $y$, $dy$, to the nearest object within this rectangle.

Fig. 4. An environmental landmark (right) and a robot with a cylinder covered by a visual cue set horizontally (left).

5.2  Kin Perception

We have developed a cue-based recognition system in order to differentiate visually the environment and the kin using the CCD cameras of the robots [16]. A cue consists of black bars on a white background. This system is based on the recognition of two kinds of cues: environmental landmarks and robots cues. The
former distinguish elements of the environment, such as objects and walls, the latter are worn by the robots as identity cues (see figure 4).

Recognition is based on a picture analysis method that we call the railroad method. This name comes from the following analogy: when someone who is wandering comes upon a railroad, he follows it. As he follows the rails, he counts the railway sleepers. Similarly, in our method the pictures are scanned and if a succession of three black bars are encountered (the rails) we follow their direction and count the bits (the railway sleepers). For details see [16].

This system can obtain the position of the cues in the picture, their own identifiers, the distance between the cues and the camera, and their orientation. Additionally, the system enables us to distinguish correctly eight angles of identity cues worn by robots in movement (\(0^\circ, 45^\circ, \ldots, 315^\circ\)). These angles are used to put virtual attachment labels on our robots.

5.3 Tendencies

As in line-formation simulated experiments, two attachment labels were defined: a label plus on the angle \(0^\circ\) and a label minus on the angle \(180^\circ\) of identity cues. Robots are attracted by labels minus and by an specific environmental landmark indicating the beginning of the line.

Once a robot has assembled its proxemic space, it changes its attachment labels in order to remain still. Since attachment labels are virtual, robots communicate and update the state of their labels continually.\(^2\)

Figure 5 illustrates the environment and the robots in action. Figure 6 illustrates the trajectories followed by robots during this experiment.

\[\text{Fig. 5. Snapshots of three mobile robots wandering in a corridor and assembling their proxemic spaces in line.}\]

\(^2\) Although physical robots communicate, this communication is not intended to improve their coordination efforts, but to inform about the polarities of their proxemic spaces.
6 Discussion

Reproducing simulated experiments using physical robots is a major challenge for roboticists. Most of the rules used in simulation are poorly situated and are only useful for idealized robots that are equipped with perfect sensors and actuators, and are able to perform actions without fault.

Our method of proxemic coordination is well adapted for solving problems of spatial coordination using simulated and physical robots. As we could see, robots reached global spatial structures taking into account local information.

Robots using the rules of proxemic coordination depend mainly on their sensors in order to operate. If the landmark indicating the beginning of the line is moved, for example, robots are able to arrange the formation and to redo it in front of a new location.

Proxemic coordination is not intended to solve problems of coordination involving fine assembling, but it has been applied to a number of collective robotics applications, such as collective box-pushing and dynamic formations (for preliminary results see [11]).

![Graph](image)

Fig. 6. Trajectories followed by three physical robots that form a line using the method of proxemic coordination.

7 Conclusions and Perspectives

In this paper we have described proxemic coordination, a simple method to enable mobile robots to coordinate their movements in order to reach a global spatial formation. Spatial coordination is important for solving problems of collective robotics such as material transportation and terrain coverage.

The experiments described are in progress and future work will focus on defining more flexible proxemic spaces. We are working on various shapes of proxemic spaces, as well as on resizeable proxemic spaces.
We are also using the method of proxemic coordination in the design of the behavior of self-assembling robots.

References