Flocking

The problem

Flocking is a form of collective motion that naturally occurs in many animals, like birds, sheep or fish (for which it is sometimes called schooling). Interestingly, there is no leader in the flock, yet as a whole the flock manages to move towards a common goal while maintaining its internal structure. Related to the problem of flocking is the problem of robot pattern formation. The robot swarm should create (and hold) a predefined pattern. A pattern is an arrangement of objects displaying mathematical, geometric or statistic relationships (e.g., atoms organized in molecules, and molecules that in a big scale can form crystals). In swarm robotics, robots can form patterns by strategically positioning themselves in regard to the position of other robots they perceive. By following simple positioning rules at the individual level, a robot swarm can distribute itself in the form of organized structures.

Experiment layout

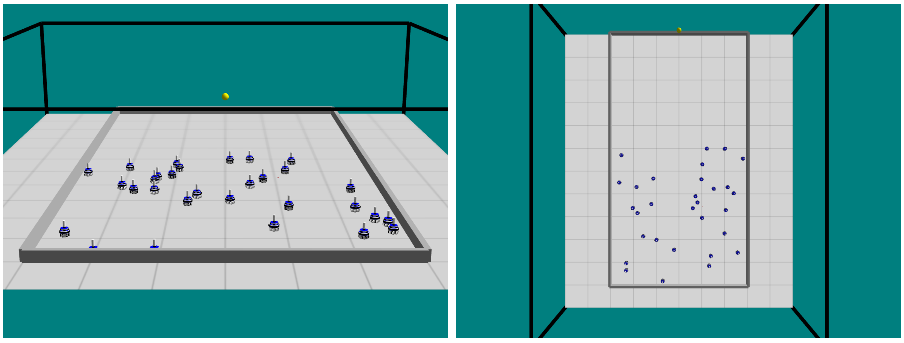

Figure 1: The flocking experiment from one side (left) and from the top (right).

In the experiment, thirty footbots are distributed randomly on one side of the experimental arena that is bounded by walls. One red LED is placed over the arena and a light source is placed at the far end of the arena.

Robot layout

In this experiment, the robot has access to the following sensors and actuators:

Available sensors	Available actuators
`robot.id`	`robot.wheels`
`robot.random`	`robot.leds`
`robot.range_and_bearing`	`robot.range_and_bearing`
`robot.colored_blob_omnidirectional_camera`	
`robot.proximity`	
`robot.light`	

Objective

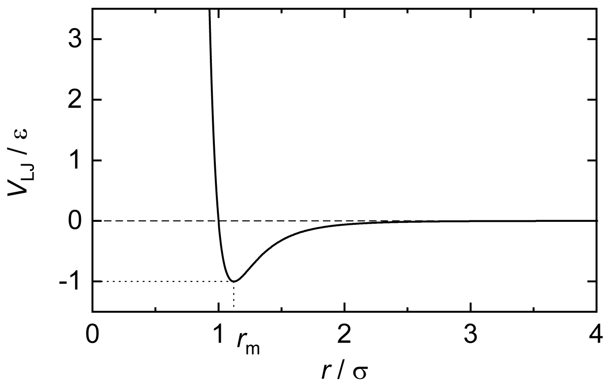

Figure 2: Graph of the Lennard-Jones potential (from Wikipedia).

This exercise is composed of three parts. In the first two parts, you will develop control software for pattern formation experiments (`flocking.argos`). First, you will program the robots in the swarm to achieve a simple hexagonal pattern; that is, the robots should arrange themselves so that the structure of the swarm is approximately a hexagonal lattice. The experiment will end when the lattice remains stable.

In swarm robotics, we can use artificial potentials to achieve pattern formation. Artificial potentials are functions that are computed by the individual robots to allow them to interact with their environment by emulating a physical potential field. For example, we can achieve pattern formation using an artificial potential that emulates the Lennard-Jones (LJ) potential. The LJ potential models repulsive and attractive forces between pairs of electronically neutral molecules. Two such molecules will repel each other if they are very close together and attract each other at a moderate distance, but they will not interact when they are at an infinite distance from each other. Figure 2 shows a graph of the LJ potential. The graph features a potential well, whose minimum (r_m) splits the repulsive ($r/\sigma < r_m$) and attractive ($r/\sigma > r_m$) regions. The distance r_m thus represents a stable point of equilibrium for the separation between the two molecules: if two molecules that are separated by a distance σr_m undergo a small perturbation, they will eventually return to being separated by a distance σr_m.

We can express the LJ potential as

$$V_{LJ}(r) = \epsilon \left[\left(\frac{\sigma}{r} \right)^{12} - 2 \left(\frac{\sigma}{r} \right)^{6} \right], \tag{1}$$

where ϵ and σ are constants. The magnitude of the corresponding force between a pair of molecules that are separated by a distance r can be obtained from the derivative:

$$F_{LJ}(r) = -\frac{\mathrm{d}V_{LJ}(r)}{\mathrm{d}r} = \frac{12\epsilon}{r} \left[\left(\frac{\sigma}{r} \right)^{12} - \left(\frac{\sigma}{r} \right)^{6} \right]. \tag{2}$$

However, smaller exponential values could also work. For example,

$$F_{LJ}(r) = -\frac{\mathrm{d}V_{LJ}(r)}{\mathrm{d}r} = \frac{4\epsilon}{r} \left[\left(\frac{\sigma}{r} \right)^{4} - \left(\frac{\sigma}{r} \right)^{2} \right]. \tag{3}$$

In a robot swarm, each individual robot takes the role of a molecule. To form a stable pattern, each robot must reach an appropriate equilibrium with its neighbours (i.e., $F_{LJ}(r) = 0$ for all pairs of robots). You can start from the `flocking.lua` file, where we already provide you with the constant values ϵ and σ, as well as a function to move robots in the desired direction.

For the second part, you will extend the control software written in the first step. Modify your control software, so that the robots form a circular pattern around the LED. The experiment will end when the lattice remains stable.

In the last part, you will implement flocking. Have the robots group together (you can use your software from the first or second step as a base). Once the group is complete, move the swarm as a whole towards the light at the end of the arena, while maintaining the internal structure of the swarm.

General remarks

The control software of the robots is executed in the form of time steps–that is, the script is executed in the simulator once for each time step. In this experiment, the time step has a length of 100ms. In other words, each of the actions defined in the Lua script will be executed 10 times per second.

Many basic robotic behaviors follow the *Sense-Think-Act* scheme.

Remember that the individual actions of each robot are the ones that lead to the robot swarm achieving the desired behavior.