Course title: Bio-inspired Autonomous System **Hand-in date and time: 18-05-2022, 23h59**

Semester: Spring 2022 **Hand-in page limit (max.): 8**

Assignment #3 – Swarm Robotics

In this assignment, you will experiment with two fundamental swarm robotics behaviors where simple, local interactions lead to coordinated, global behaviors. More specifically, you will experiment with boids in 2D [1] and firefly-like synchronization [2] in a simulated swarm of robots.

Simulation environment

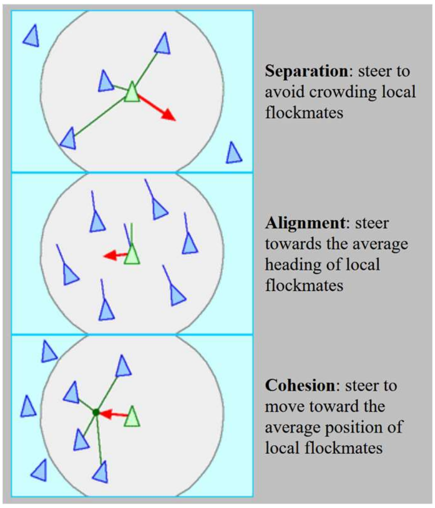
For this assignment, you can use any simulation platform you wish – the simpler the better. You need not be concerned with any particular robot model or realism, but you can use an abstract 2D environment with point-sized robots. For instance, you can use https://processing.org/examples/flocking.html as a basis or the Python code below (see course webpage for the .py file):

```python
import numpy as np
from matplotlib import pyplot as plt
from matplotlib import animation
from matplotlib.animation import FuncAnimation

plt.style.use('seaborn-pastel')

ARENA_SIDE_LENGTH = 10
NUMBER_OF_ROBOTS  = 50
STEPS             = 100
MAX_SPEED         = 0.1

# Positions
x = np.random.uniform(low=0, high=ARENA_SIDE_LENGTH, size=(NUMBER_OF_ROBOTS,))
y = np.random.uniform(low=0, high=ARENA_SIDE_LENGTH, size=(NUMBER_OF_ROBOTS,))

# Velocities
vx = np.random.uniform(low=-MAX_SPEED, high=MAX_SPEED, size=(NUMBER_OF_ROBOTS,))
vy = np.random.uniform(low=-MAX_SPEED, high=MAX_SPEED, size=(NUMBER_OF_ROBOTS,))

# Set up the output (1024 x 768):
fig = plt.figure(figsize=(10.24, 7.68), dpi=100)
ax = plt.axes(xlim=(0, ARENA_SIDE_LENGTH), ylim=(0, ARENA_SIDE_LENGTH))
points, = ax.plot([], [], 'bo', lw=0, )

# Make the environment toroidal
def wrap(z):
    return z % ARENA_SIDE_LENGTH

def init():
    points.set_data([], [])
    return points,

def animate(i):
    global x, y, vx, vy
    x = np.array(list(map(wrap, x + vx)))
    y = np.array(list(map(wrap, y + vy)))

    points.set_data(x, y)
    print('Step ', i + 1, '/', STEPS, end='\r')

    return points,

anim = FuncAnimation(fig, animate, init_func=init,
                              frames=STEPS, interval=1, blit=True)

writervideo = animation.FFMpegWriter(fps=60)
anim.save("output.mp4", writer=writervideo)
```

Note, that you are free to choose an entirely different simulation environment, but it is recommended that you stick to one that is simple and fast to allow for large simulations. It is also recommended that you use a toroidal environment (boids exiting on the left-hand side of the environment enter on the right, boids exiting through the bottom of the environment enter on top, and so on).

2D boids

To simulate boids, you need to apply Reynolds' three rules:



http://www.red3d.com/cwr/boids/

The *separation* behavior prevents the boids from colliding - computed as the average of the difference vector between the current *boid* position its neighbors.

The *alignment* behavior makes boids move in a common direction. The steering force is computed by taking the average of the neighbors' direction.

The *cohesion* behavior moves the boid towards the center of its neighbors. The steering force is computed to move the boid towards the average position of the neighbors.

Experiment with different swarm sizes, neighborhood distances (how far each boid can see neighboring boids), and weights on the three different rules. For each setting, how long does it take for the boid to converge into one or more coherent flocks, where all boids move roughly in the same direction?

In your report, briefly explain your implementation (max. one page) and present the results and conclusions of your experiments.

Firefly-inspired synchronization

Give your boids firefly-like flashing behavior by having them act as discrete pulse-coupled oscillators (see [2] or slides from lesson #9 for details):

$$x_i(n+1) = x_i(n) + \frac{1}{T} + \epsilon\, \alpha_i(n)\, h\big(x_i(n)\big)$$

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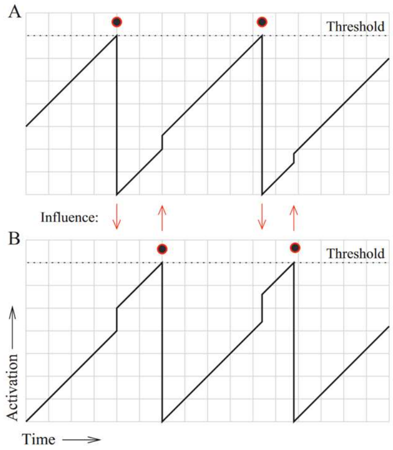

How long does it take to achieve global synchronization for different swarm size if (i) the boids are flocking, or (ii) if they move randomly for different coupling constants?

Remember that your report should be 8 pages at most.

References

[1] Reynolds, C. W. (1987) Flocks, Herds, and Schools: A Distributed Behavioral Model, in Computer Graphics, 21(4) (SIGGRAPH '87 Conference Proceedings) pages 25-34.

[2] A. L. Christensen, R. O'Grady, and M. Dorigo (2009), "From Fireflies to Fault Tolerant Swarms of Robots". IEEE Transactions on Evolutionary Computation 13(4):754-766.