Task Sheet 2 - Emergent taxis and rock-paper-scissors

In this task sheet, we examine emergent taxis and analyze an extended rock-paper-scissors model. Please save all plots to files, so they are available without executing the code. All results should be bundled in an archive file with your name as the file name.

Deliverables:

- A set of plots (saved to file)
- Code

The submission should be bundled in a single zip file. The file should be named `yourname.zip`. Please check the LEA course page for your submission deadline.

1 Exercise 1 Emergent taxis

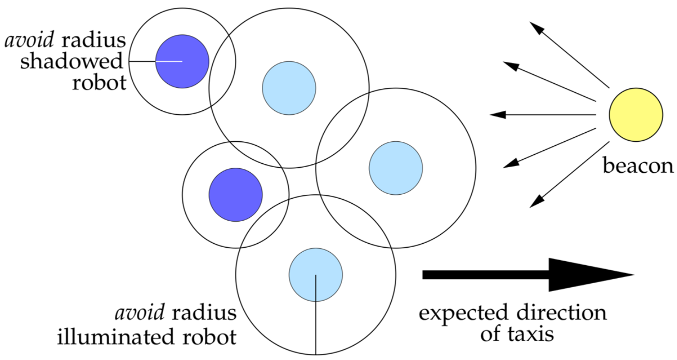

Figure 1: Emergent taxis: schematic drawing from the lecture.

In the lecture, we presented emergent taxis.[1] It is a swarm taxis (i.e., beacon searching) algorithm for simple robots and based on the interactions between a few basic robot behaviors. The beacon and its light can be occluded by other robots and based on that information the robots execute different behaviors.

The robot is spherical and has a physical radius of $r = 0.3$. In its default state, the robot moves forward with a speed of $v = 0.05$ per time step and periodically checks the number of robots that are in communication range $r_w = 2.5$. If this number falls below the threshold $\alpha = N$, the robot switches to its coherence behavior. In this behavior the robot turns 180° before resuming the default state. If the number of robots in the neighborhood rises again, the robot turns randomly before going back to the default state.

[1] paper online: https://ieeexplore.ieee.org/document/4223154 or via moodle

Depending on the illumination of the robot by the beacon, one of two avoidance behaviors is executed. For an illuminated robot, the avoidance radius is $r_{ai} = 0.51$. For a shadowed robot, it is $r_{as} = 0.4$. In both cases, the robot turns away from the obstacle and resumes the default behavior.

All turns are immediate and don't consume simulation time. This means that the robot does his standard forward move in every time step, even after potentially turning.

a) Implement emergent taxis and execute a run with $N = 10$ robots and 1,000 time steps. Every 5 time steps, plot the positions of all robots in 2D space. Show the illumination status and avoidance radius for each robot in the same plot.

   You are free to use a programming language of your choice, but please include a guide how to execute your code. You may model the beacon as an area light source with parallel rays of light. Make sure that all robots are initialized fully connected.

b) Plot the average distance of the swarm to the light source and the cohesion of the swarm over time. The cohesion is the average distance of the robots to the centroid of the swarm. The centroid is the average X and Y position of all robots. Execute at least 20 independent runs.

c) Plot the average distance of the swarm to the light source and the cohesion of the swarm after 1,000 time steps for varied values of r_{ai} and r_{as}. Show the influence of the different values on the behavior of the swarm.

2 Exercise 2 - rock-paper-scissors with degradation

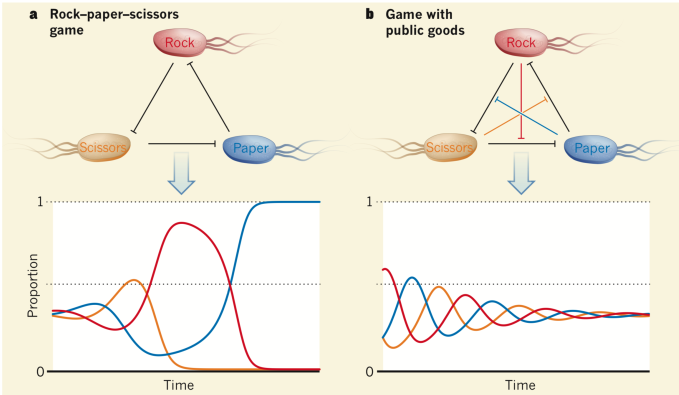

Figure 2: Cyclical dynamics in a 'rock–paper–scissors' game with public goods (see https://doi.org/10.1038/nature14525).

The interplay of multiple species of antibiotics producing and inhibiting bacteria can be shown through an extended rock-paper-scissors model.[2]

For this analytical model, we have three species of bacteria. Each species of bacteria produces a specific type of antibiotics. These bacteria show cyclic dominance: species X_1 degrades (i.e., removes) the antibiotics produced by species X_2, making it effectively immune to X_2's antibiotics. Species X_2 degrades the antibiotics of X_3 and X_3 degrades the antibiotics of X_1. Antibiotics are dispersed in a circle with radius K_P around the bacteria. The bacteria degrade the antibiotics around them in a circle with radius K_D.

After the deployment and degradation of antibiotics, the bacteria reproduce. The growth of a bacteria population X_i depends on the population size in the previous time step t, a growth factor g_i and the fraction P_{kill_i} of area that is covered in antibiotics that degrade X_i:

$$X_i(t+1) = \frac{X_i(t) g_i (1 - P_{kill_i})}{\sum_j X_j(t) g_j (1 - P_{kill_j})} \, .$$

Since P_{kill_i} depends on the random placement of the bacteria, the number of bacteria in the neighborhood is Poisson distributed. This means that the probability to find no other cell in the neighborhood is $1 - e^{-\lambda}$. Applying this to calculate the probability that the new bacteria emerges in a place covered in undegraded antibiotics, we get

$$P_{kill_i} = e^{-K_D X_D}(1 - e^{-K_P X_P}) \, ,$$

where X_P represents the population of bacteria that produce antibiotics harmful to X_i and X_D represents the population that degrades the antibiotics of X_P.

a) Implement the analytical rock-paper-scissors model with degradation.

b) Try and find parameters K_P, K_D and g_1, g_2, g_3, X_1, X_2, X_3 that create stable bacteria populations $X_1, X_2, X_3 > 0$. Plot the populations over time.

[2]paper online: https://www.nature.com/articles/nature14485

c) Keep your parameters from task b). Now try to make the bacteria populations unstable by changing only K_D. Plot the populations over time. Why and how does this happen? What special 'form of collaboration' do we observe here?