Assignment 7:
Self-organized mussel patterns

Luca Bertoni
Alice Hartog

Environmental Systems Analysis

Faculty of Geoscience
Utrecht University
The Netherlands
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Exercise 1

The paper by Van de Koppel et al., *"Experimental evidence for spatial self-organization and its emergent effects in mussel beds"*, observes that in general mussels tend to stay in groups with a high density in order to minimize predation, while when the density is low they are more isolated. The patterns formed in the experiment were given by mussels interactions between individuals.
Density also influences the velocity each mussel moves: when the density is high they move less (negative effect), but when the group becomes quite large (more than 32 individuals) their velocity increases again. Another interesting observation regards supply of algal food: when a group of 128 mussels gets food the individual movement decreases, suggesting that food supply inhibits the formation of large groups. So mussels movement speed depends both on local density and on local availability of algal food.
An obtained result is that isolated mussels have grown more than groups because of less food division.
Thus, in the end, the experiment found out that patterns depend on both positive and negative interactions between mussels.

In the video of mussels pattern formation can be seen. The initial disposition is random in the arena and then, step by step, individuals interact and move towards neighbours and create groups.

This entire process can be classified as self-organization. In fact, each agent is moving in a stochastic way without any specific goal. The interaction of multiple agents lead to the creation of spatial patterns that cannot be deducted from the movement of 1 single agent.

Exercise 2

Exercise 2.1

To calculate the distance of mussels the following code has to be used:

```
for Time=1:EndTime
    for i=1:N
        for j=1:N
        Distance(i,j)= sqrt((X(i)-X(j))^2+(Y(i)-Y(j))^2);
        end
    end
```

For each (i,j) is done the Pythagora's theorem.

Exercise 2.2

X and Y of each mussel change over time since they keep moving. Movement has a certain stepsize and a certain angle, defined as:

$$StepSize = -beta. * log(rand(N, 1)) \tag{1}$$

$$Angle = rand(N, 1) * 360 \tag{2}$$

So the change in X and Y is given by

```
X = X+StepSize.*cos(Angle);
Y = Y+StepSize.*sin(Angle);
```

Exercise 2.3

Mussels are in the arena if their coordinates X and Y are within the total length (50 cm). In order to have all the mussles inside the arena, periodic boundaries conditions are implemented. In the case a mussel goes outside the arena, it is moved back into it from the opposite side.

```
for i = 1:N
    if X(i) > Length
        X(i) = X(i)-Length;
    end
    if X(i) < 0
        X(i) = X(i)+Length;
    end
    if Y(i) > Length
        Y(i) = Y(i)-Length;
    end
    if Y(i) < 0
        Y(i) = Y(i)+Length;
    end
end
```

Exercise 2.4

The last timestep of the dynamic visualization for the mussel movement is showed in Figure 1.

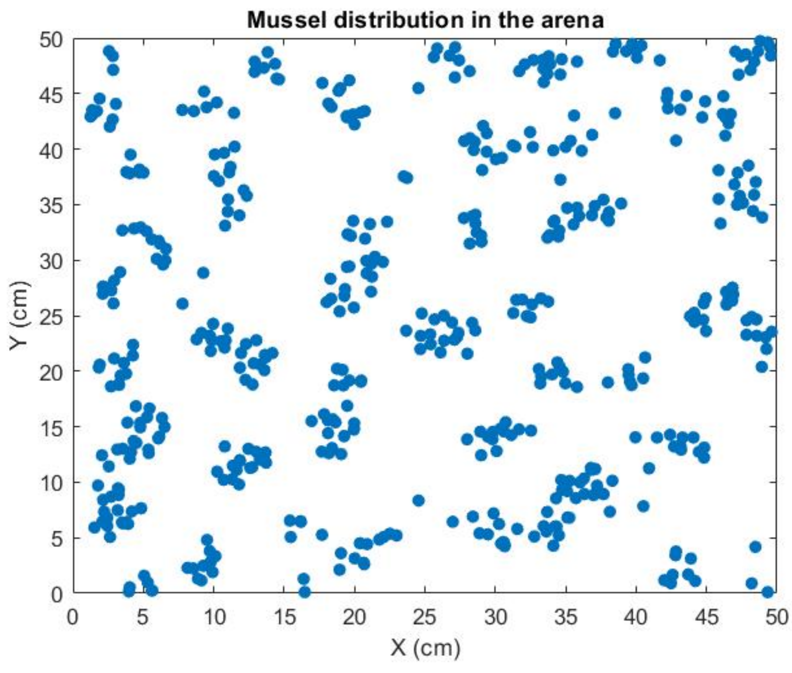

Figure 1: *Mussel movement (N=500) in the arena after 500 minutes*

The code used to represent it is

```
plot(X, Y, '.', 'MarkerSize', 20);
```

```
title('Mussel distribution in the arena (N=2000) with inhibition blocked');
xlabel('X (cm)');
ylabel('Y (cm)');
drawnow;
```

Exercise 3

Figure 2 and 3 show respectively the distribution of 100 and 2000 mussels in the arena after 500 minutes.

A higher number of individuals leads to bigger groups (higher density) and the dynamic visualization shows clearly how each of them "decides" to move towards a higher density. Moreover, higher number of individuals means more interactions, that leads to a faster self-organization.
Hypothesis 1 is not strictly true, since there's not a defined critical value (except for the threshold N=2, below which there's no interaction at all). Instead, it is more a continuous process: the lower the number of individuals, the higher the probability to have solitary individuals and therefore the organization will take more time.

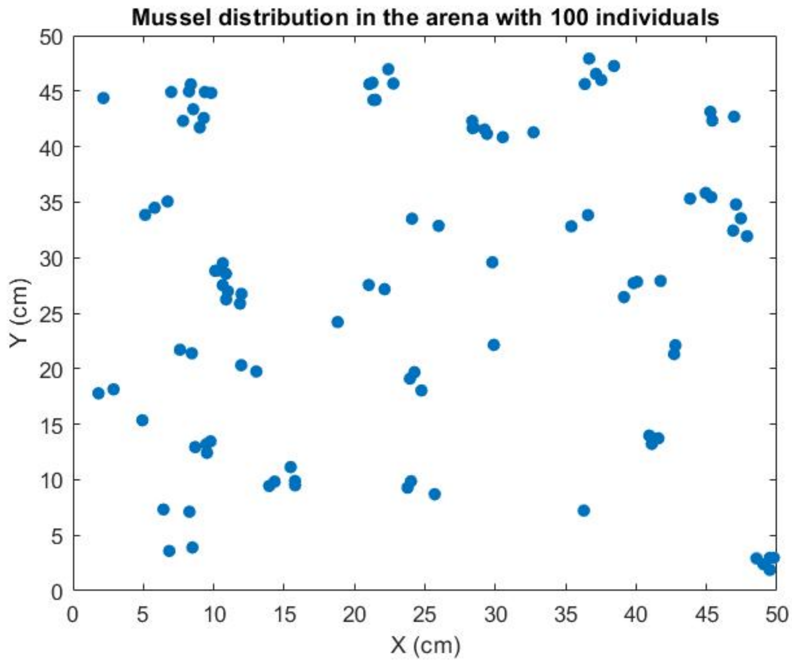

Figure 2: *Mussel movement (N=100) in the arena after 500 minutes*

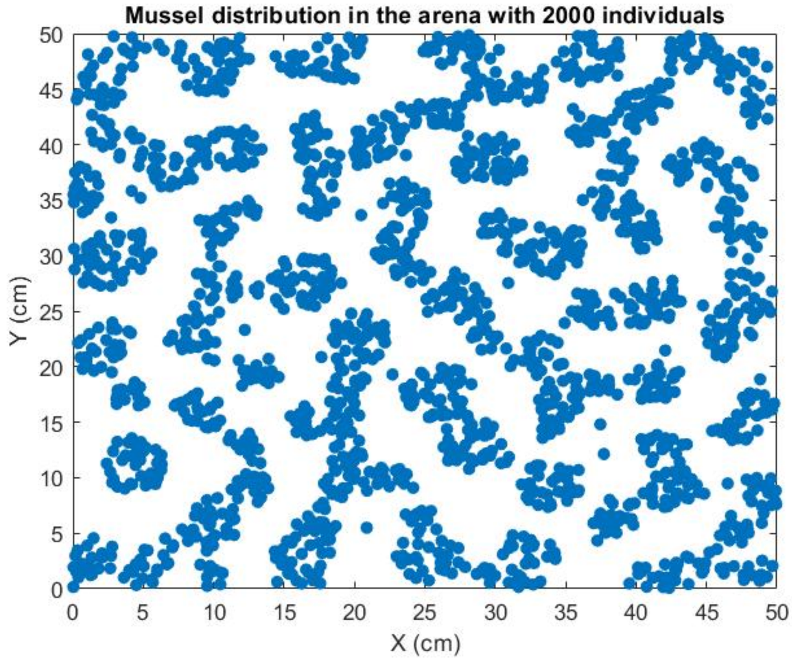

Figure 3: *Mussel movement (N=2000) in the arena after 500 minutes*

Exercise 4

Setting P2=0 makes the cluster density irrelevant for the stepsize of each mussel. Since P2 was negative, setting it to 0 means that the mussels are making on average shorter steps. This implies also that the self-organization will take longer to happen (thus, the end time of the simulation is set to 10000 minutes). To partially balance this, the parameter P1 is decreased from 100 to 20.

During the dynamic modelling individuals still tend to create groups but the clusters are less and the stepsize is lower. In addition, the clusters tend to be less connected to each other.

This is clear when comparing Figure 3 with Figure 4. Therefore, the second hypothesis is true.

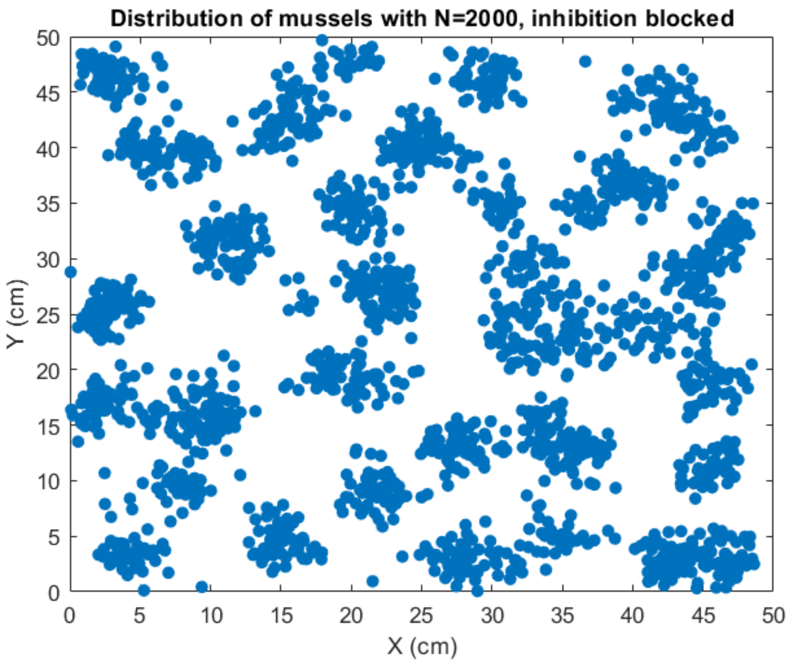

Figure 4: *Mussel movement (N=2000) in the arena after 1000 minutes*