Abstract: “Analysis, modeling and forecasting of the provision of birds on electrical wires”

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The problem addressed is "the spontaneous arrangement of birds on a wire horizontally." We evaluated several models and, starting from biological and ethological basis, we defined a new one then checked for consistency with experimental observations.

The starting model, chosen as a reference, has been the one proposed by Piccoli-Cristiani-Frasca characterized by the following aspects:

- the velocity of movement of each entity within the group depends on the local interactions between the individuals themselves;
- interactions are mainly attractive and repulsive forces;
- hierarchies do not exist among individuals (there isn't any leader);
- each individual is affected only by individuals who fall within its "sphere of influence" (you can model not-symmetrical interactions, since an individual may fall within the zone of influence of another individual which, however, is out of the sensitive area of the first one);
- each individual is affected only by the n closest individuals..

Inspired by this model, a new 1D has been defined the specific problem, thus characterizing the speed of the i-th individual:

$$\dot{x}_i = \sum_{j \in N_i} \left[|x_j - x_i|^{m_a - 1} - \xi^{\,m_a - m_r} |x_j - x_i|^{m_r - 1} \right] (x_j - x_i) \quad \forall i \in \{1, \dots, N\}$$

$i > j \Rightarrow x_i > x_j$

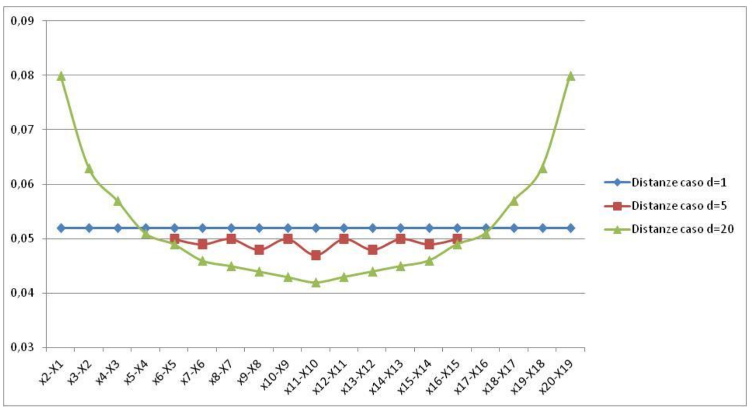
with:

- $m_a \geq 0$ representative of attraction among individuals,
- $m_r < 0$ representative of the repulsion among individuals,
- $N_i = \{k \in \{1, \dots, N\} \mid |i - k| \leq d\}$, with d representative of the maximum number of individuals that are able to exert influence on each side (the interaction depends on the number and not by the distances of individuals),
- $\xi > 0$ distance characteristic related to the ratio of repulsive forces and attractive forces.

Compared to the starting model, we considered the following additional properties:

- the exchange of positions is not allowed;
- are omitted cases of abandonment of a group, as well as cases of approach to a new group;
- each individual is affected only by the n closest individuals (6-7 in case of medium-small sparrows) on each side.

In case of N = 20, $\xi = 1$, $m_a = 0$ e $m_r = -2$ the numerical solution provided the following trend for distances between consecutive subjects:

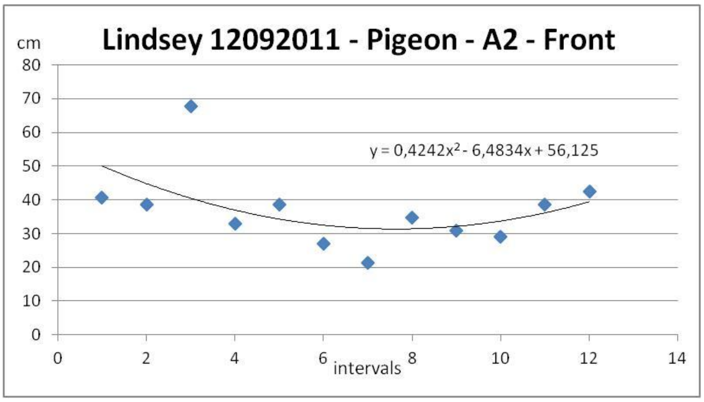


For the numerical solution we used a fourth-order Runge-Kutta: [t,x]=ode45(@funcsoluz,[0,s],x0), with @funcsoluz function that includes the parameters of the law of interaction (including for each i-th individual, what are the individuals interacting), s the number of time steps, ode45 is the solver function (RK fourth order), x0 the initial positions of the N birds.

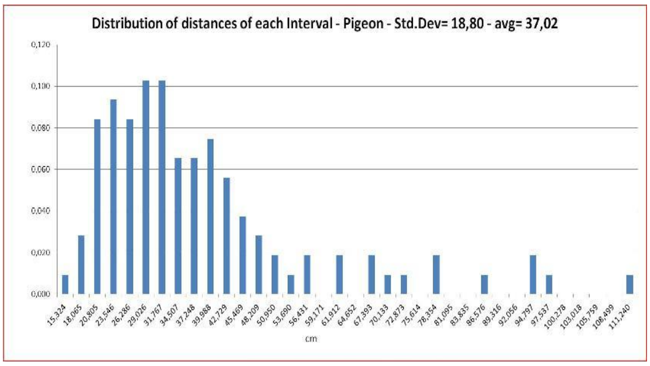
For the experimental validation 114 pictures, of birds arranged on electric cables supported by poles, were analyzed (taken in Lindsey, Tuckerton, Deptford and Camden in New Jersey by the team of Professor Bill Saidel) with actual dimensions, even if the criteria of eligibility groups has reduced to only 24 the number of significant groups of birds (pigeons and starlings).

The criteria used were as follows:

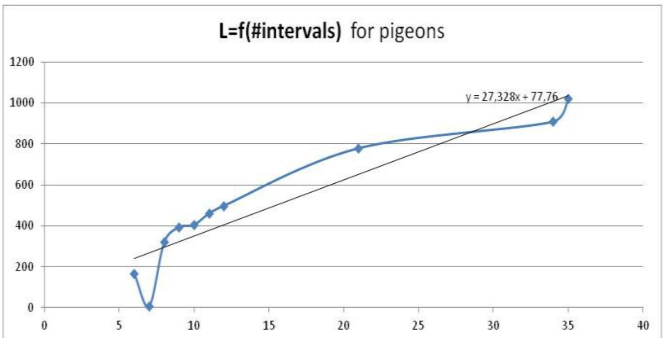
- we only considered groups of at least 5 elements;
- we considered the end of a group in case last bird is close to the support (for example pole that supports the electric cables), as also in the obvious case in which there were no other birds or in the case the following is found at a distance greater to twice the wingspan of the bird;
- • all members of each group should be directed to the same side with respect to the photographer;
- • all members must belong to the same species;
- • the subjects are all still on the cable (there are no birds leaving or arriving on the cable);
- • were excluded groups of birds arranged on crossing cables, because there would be interactions among stakeholders (e.g. arranged opposite one another) not handled by the model.



The experimental diagrams obtained for the distances between consecutive individuals (or rather the regression curves of the second order) show a similar trend for pigeons and starlings, and a good consistency with what found numerically (for d = 20): distances increase as individuals get closer to the end of the group.



Further interesting experimental evidence was the distribution of the distances between adjacent birds (for example, in the case of all groups of pigeons): the most likely distance is a small distance, even if not the smallest.



Another interesting result was the length of the performance of the group as a function of the number of pairs of consecutive birds. This trend, rather than linear, confirms the output obtained in the numerical case.