Optimization of artificial flocks by anisotropy measurements

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Recently, Ballerini *et. al.* [1, 2] measured each bird's position in the flocks of starling (*Sturnus vulgaris*) for 8 seconds in three dimension. To get such three dimensional data, they used 'Stereo Matching' which reconstructs three dimensional object from a set of stereo photographs. From these data, they calculated the angle between the direction of nearest neighbours and the direction of the flock's motion for all birds in the flock. They measured the angles (ϕ, α), where ϕ means the latitude ($\in [-90°, 90°]$) of nearest neighbour for each bird measured from the direction of the flock's motion, whereas the vertical axis α denotes longitude ($\in [-180°, 180°]$) which specifies the position of the nearest neighbour for each bird around the flock's motion, of the nearest neighbour for all birds in the flock, and plot these angles in the two-dimensional map using the so-called *Mollweide projection.* Inspired by their empirical findings, we simulated the distribution map by BOIDS for the case of metric definition of neighbor of each bird. The resultant angular distribution map is shown in Fig. 1. This figure clearly shows that the density is not uniform but obviously biased. However, from the view point of anisotropy measurement, what we call γ-value, there

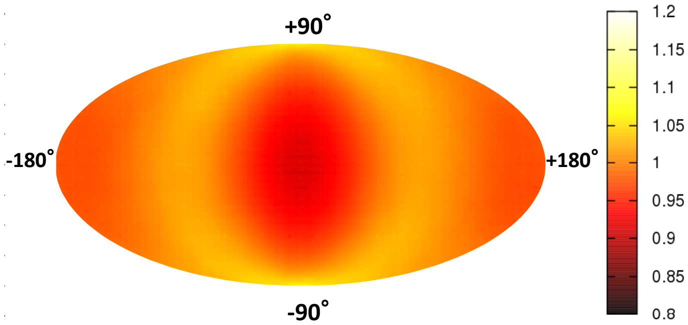

Fig. 1. Angular distribution map simulated by BOIDS modeling (from Makiguchi and Inoue (2010) [3]).

is still gap between our simulation and empirical findings. Here we should mention two distinct definitions of neighbours. In Fig.2, we show the cartoons for these two definitions. The left panel shows the metric definition of neighbours which we used in the previous sections. As we explained, each agent interacts with the others when the distance between mates becomes shorter than the constant radius of the visual field R. In the case shown in this panel, the agent located at the center of the circle interacts with four neighbours. On the other hand, the same agent as in the left panel interacts with six neighbours in the case of the right panel. The definition of the neighbours shown in this right panel is referred to as *topological.* Apparently, in the topological definition of neighbours, the number of mates interacting with a given arbitrary agent is a fixed constant and we define the number as n_c. Thus, the n_c in the right panel of Fig. 2 is $n_c = 6$.

With the above empirical find in mind, in this paper, an effective procedure to determine the optimal parameters appearing in artificial flockings is proposed in terms of optimization problems. We numerically examine genetic algorithms (GAs) to determine the optimal set of such parameters such as the weights for three essential interactions in BOIDS by Reynolds (1987) under 'zero-collision' and 'no-breaking-up' constraints. As a fitness function (the energy function) to be maximized by the GA, we choose the so-called the γ-value of anisotropy which can be observed empirically in typical flocks of starling. We confirm that the GA successfully finds the solution having a large γ-value leading-up to a strong anisotropy. The numerical experience shows that the procedure might enable us to make more realistic and efficient artificial flocking of starling even in our personal computers.

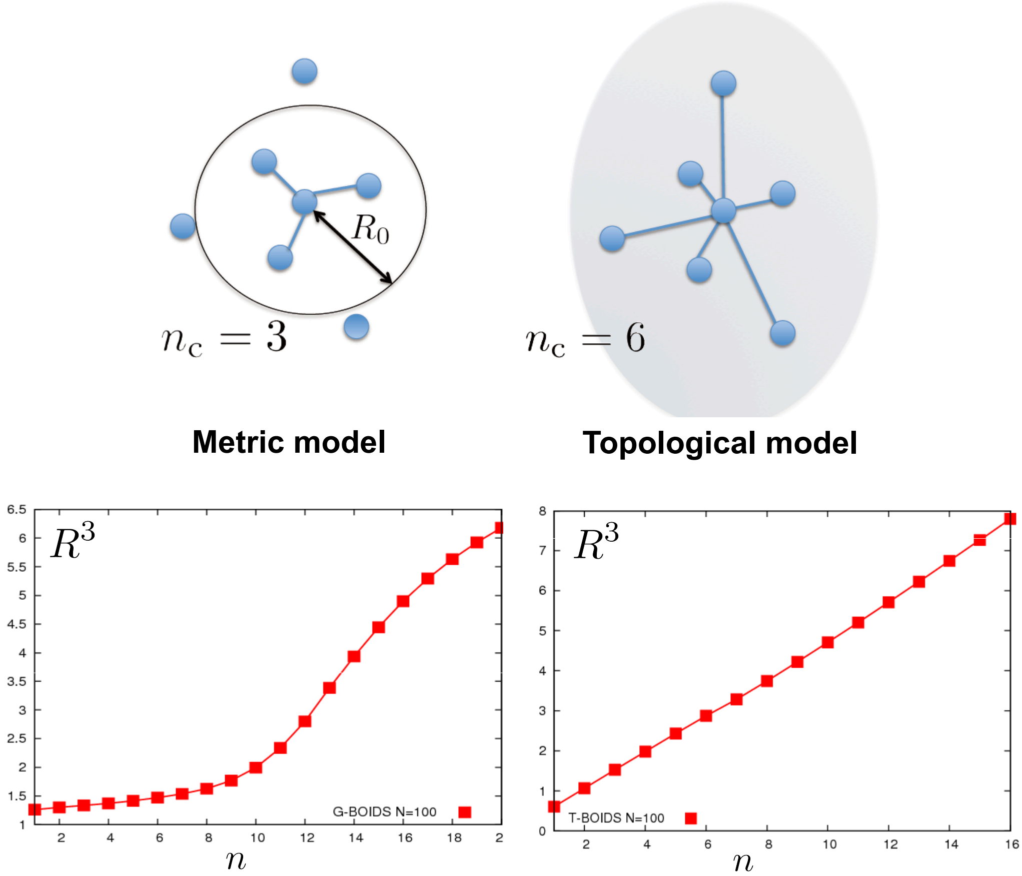

Fig. 2. Two types of the definition for interacting neighbours (upper panels). The left panel shows the *metric* definition, whereas the right panel corresponds to the *topological* definition. The number of mates interacting with a given arbitrary agent is $n_c = 6$. The lower panels are plotted as third-power of average distance R between an arbitrary agent and the n-th nearest neighbouring mate as a function of order of neighbour n. We set $n_c = 6$ for the topological model, which is indicated by empirical evidence [2].

We show our limited result in Fig.2 (lower two panels). From this figure (right panel), we are confirmed that the regular-polygon structures which is usually observed as in the lept panel never emerges in the flock because the R^3 monotonically increases as the n increases. The result might justify that the flock in the metric model behaves as a 'crystal form', whereas the flock in the topological model looks like 'gas' which is much closer to real flockings.

References

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