Comment

Ecological patterns emerging as a result of the density distribution of organisms

Comment on “Phase separation driven by density-dependent movement: A novel mechanism for ecological patterns” by Quan-Xing Liu et al.

Tamas Vicsek

Department of Biological Physics, Eötvös University, Pázmány Péter sétány 1A, H-1117, Budapest, Hungary

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Placing a well-known phenomenon into a new context has always been one of the most successful approaches to highlight the basic features of the system under consideration. The main novelty of the review by Liu et al. [1] is the reviving of the machinery of the famous Cahn–Hilliard (C–H) equation with the purpose of interpreting the processes taking place in ecology. Interestingly enough – although the C–H theory was conceived in the context of phase separation in binary fluids – when one considers the analogies between the motion of atoms and those of animals, even the original C–H equation is put into a new limelight.

The various patterns that can be observed in nature have important functions as is well spelled out in the paper by Liu et al. [1]. In addition, their origin is related to a wide class of mechanisms (see, e.g., Ref. [2]), ranging from diffusion through being due to instabilities depending on external fields to many others. The authors of the present article concentrate on the ecological contexts of the related universally applicable ideas about pattern formation in various systems. Furthermore, their main point is concerned with the density-dependent movements of the living entities (from bacteria to elks) forming the patterns which are mostly associated with the spatial density dependence of some substances or the involved organisms themselves.

They use the term “movement” for the locomotion of a single individual. Movement is a quite general notion and it can stand for many different ways of relocation. Let us first consider a single living entity, a tissue cell, for example. Its locomotion can be fully unbiased, i.e., a completely random process, very much like that of a diffusing particle. In some other cases we also have to assume that the motion is less random: it is biased by the distribution of either an external field-like variable or simply, instead of being a random walk, better described by a process called Levy flight (randomly changing angle, but a length of “jumps” scaling like a power law [3]). Furthermore, a “persistent” random walk represents a typical phenomenon, during which the direction of motion changes randomly, but only to a small degree during a unit of time.

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E-mail address: vicsek@hal.elte.hu.
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Density dependence takes place when the movements depend on the presence of the other units. This dependence can be manifested in various forms as well. In its simples version the members of the group either block the movements of the others, or in contrary, they tend to synchronize and of them move in the same direction, as, in the case of flocks or fish schools. Furthermore, if the organisms secrete a chemoattractant or a repellent, the motion of the individuals becomes highly dependent on the density of the other organisms around them [4].

The above mentioned mechanisms matter a lot when considering the final patterns. Such questions come at play in most of the cases: What is the dominant mechanism, diffusion or tendency to move together, or slowing down when others are around? In Fig. 1 is shown a “simple” system, in which several mechanisms determine movements at the same time. The example is simple in the sense that the system is made of bacteria, but is less trivial, if we consider the processes taking place and the complexity of the bacterial colony pattern.

I highly appreciate the attempt of the authors to integrate into the ecological sciences the quantitative approaches achieved by (statistical and other) physicists and mathematicians describing the behaviour of many, but two different kinds of coexisting identical units (atoms and/or molecules). On the other hand, it should also be mentioned that this is likely to be a time demanding process. Even the authors of this nice review have missed a few points which I would have preferred to read about. Just to mention a few: The Cahn–Hillard theory is very general, and indeed, it describes a situation, when the movements are strongly limited by the presence of the other units. There are two important versions of the initial conditions: either (a) the space occupied by one of the two phases (animals versus empty space) is about being equal occupied by the other phase (this gives rise to stripes and labyrinths, mentioned for mussels) while the case of (b) significantly less organism leads to the kinds of patterns produced by the ant cemeteries, this version is being called as Ostwald ripening [5], long known in, e.g., metallurgy. Even the simplest physical models produce this sort of behaviour, e.g., the Ising model with Kawasaki dynamics [6]. Collective animal movement is by now a field of its own, and I do not find it fortunate to classify it as density dependent movement. Indeed, there is a density dependent phase transition from the disordered to the ordered phase in the so called self-propelled particles (SPP) systems, but it’s well elaborated theoretical treatment is rather different from that of the C–H equation [7]. In addition, in an ecological system there are several interacting species which complicate the complete picture further.
Finally, the question of novelty should be addressed in my Comment since it is what the authors claim in the title of their paper. For those, who are closely familiar with the phenomena which can and have been addressed by using equations and computer simulations using the widely known machinery of statistical physics, the fact their methods can be applied to living systems is not a revelation since starting about two decades ago a number of exciting works have been published in this spirit. However, if the authors indeed succeed in stimulating the mainstream ecological research community to perform research assuming that their results can be interpreted within the framework of standard statistical mechanics, it will be a great step forward for all of us.

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