Fuzzy clustering of active matter

András Libál, Horia F. Pop

Department of Mathematics and Computer Science, Babeş-Bolyai University, Cluj, Romania

alibal@cs.ubbcluj.ro, hfpop@hfpop,ro

Fuzzy logic has been applied to clustering problems in multiple fields, such as biology where it helps identifying gene expression data, image analysis where it can improve parsing pixels into separate objects and marketing, where it can identify target customer groups based on their needs. In contrast to hard (non-fuzzy) clustering, soft or fuzzy clustering includes the possibility of each point belonging to multiple clusters. We propose to apply this technique to a class of materials studied by soft matter physics called active matter. To the best of our knowledge, soft clustering algorithms have not been used for this purpose to date.

Active matter behaves differently from ordinary matter, as the individual particles (or components) of the ensemble have their own mechanism of propulsion.[1] In ordinary (non-active) matter we have a Boltzmann distribution of kinetic energy that causes particles to diffuse and find an equilibrium distribution. In active matter the particles have a driving force that moves them around, leading to interesting non-equilibrium behavior. Active matter systems are ubiquitous in nature, from schools of fish, flocks of birds down to bacterial colonies moving and foraging together. Recently it has been possible to create artificial active matter systems, from small robotic ensembles to biologically activated matter or by the creation of the so called Janus particles, that are particles with two sides, an inert and an active or catalytic side. Such Janus particles move about by facilitating a chemical reaction on one side (dissolution of the peroxide by the platinum) or propelling themselves by thermophoresis (where the metal-coated side heats up more in the defocused laser irradiation)[2].

Clustering was observed as a characteristic phenomena in all active matter systems. It has been hypothesized that clustering and collective motion can help bacteria to escape confinement, and as a better strategy to forage for food. The description of active matter motion can be donw by the Vicsek model[3], where all active particles adjust their direction according to their neighbors and the run-and-tumble model [4] where the alignment emerges naturally from the formation of clusters. Identifying clusters in active matter has been done based on the contact of the particles[5] While this method suffices for some applications, we propose a soft (fuzzy) clustering method that allows for better identification and persistence of clusters in the case of an external drive applied to the particles traversing a disordered landscape. The fuzzy clustering algorithm assigns a continuously changing value signifying the belonging of a particle to multiple clusters and can serve to identify memory effects, cluster reconnection and and serve as a measure for flow efficiencies in active matter.

References

[1] S. Ramaswamy, J. Stat. Mech. 054002 (2017)

[2] W. He, J. Frueh, N. Hu, L. Liu, M. Gai, Q. He Adv. Sci. 3,1600206 (2016)

[3] T. Vicsek, A. Czirk, E. Ben-Jacob, I. Cohen, O. Shochet Phys. Rev. Lett. 75, 1226 (1995)

[4] A. E. Patteson, A. Gopinath, M. Goulian, P. E. Arratia Sci. Rep. 5, 15761 (2015)

[5] C. Sándor, A. Libál, C Reichhardt, C.J.O Reichhardt Phys. Rev. E 95, 012607 (2017)