Heterogeneity-induced lane and band formation in self-driven particle systems

Antoine Tordeux[1,*], Basma Khelfa[1], and Andreas Schadschneider[2]

[1]School for Mechanical Engineering and Safety Engineering, University of Wuppertal, Wuppertal, Germany
[2]Institute for Theoretical Physics, University of Cologne, Cologne, Germany
[*]e-mail: tordeux@uni-wuppertal.de, webpage: vzu.uni-wuppertal.de

ABSTRACT

Flows of self-avoiding agents such as pedestrians or road vehicles can describe many types of collective dynamics[1,2]. Examples are coordinated motion, stop-and-go waves in polarised flow, lane formation in counter flow, or jamming, oscillation, and pattern at bottlenecks and intersections. Collective dynamics and self-organization of agents raise interesting theoretical questions related to stability properties, nonlinear effects, phase transition, and metastability. Furthermore, controlling collective performances from individual interaction rules are, besides scientific interests, useful to authorities.

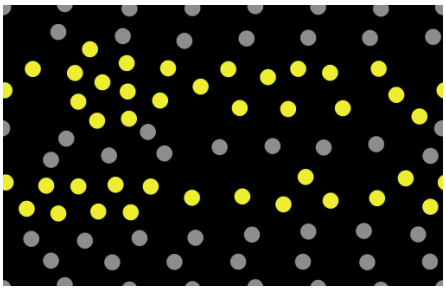
In this contribution, we show using two species agent-based-simulation that heterogeneity of the agent behaviors in polarised flow can initiate segregation and the spontaneous formation of lane or band patterns. We consider two types of agents and two modeling approaches of heterogeneity :

M1: Heterogeneity of the agents — We attribute statically two different values for model's parameters to the two types of agents. We aim to model different types of agents (for instance pedestrians and bicycles) with specific characteristics in term of desired speed, size, etc.

M2: Heterogeneity of the interactions — We attribute dynamically two different values for model's parameters according to the type of the neighboring agent in interaction. In contrast to model M1 for which the heterogeneity lies in agent characteristics, we aim to model heterogeneity in the interactions. Such a case may correspond for instance to a pedestrian adapting his/her behaviour when interacting with a bicycle.

Simulation results show that phase transition and self-organized lane and band formations spontaneously arrise when the difference between the two attributed parameter values is sufficiently high. More precisely, we observe the emergence of horizontal lanes when the heterogeneity lies in the agents (model *M1*, see Fig. 1 left panel), while vertical bands arise if we assume heterogeneity in the interactions (model *M2*, see Fig. 1 right panel). The lane and band already emerge during the first simulation instants and are partly robust to stochastic perturbations. The different organizations of the flow highly influence the system performances. Lane patterns significantly improve the flow, while band patterns result in low performances. The collective dynamics occur in relatively short time intervals and are partly robust to stochastic perturbations.

Self-organised segregation in lanes
M1: Heterogeneity of the agents



Self-organised segregation in bands
M2: Heterogeneity of the interactions

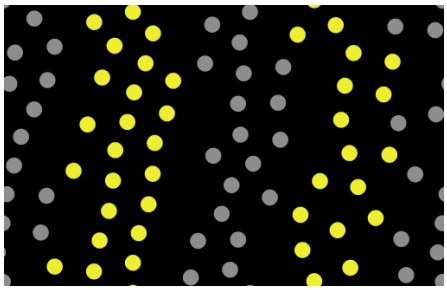


Figure 1. Screenshots for the model *M1* with heterogeneity in the agent characteristics for which lanes emerge (left panel), and for the model *M2* with heterogeneity in the interactions where bands emerge (right panel). Simulations can be implemented online : https://www.vzu.uni-wuppertal.de/fileadmin/site/vzu/Lane-Formation.html

References

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2. Boltes, M., Zhang, J., Tordeux, A., Schadschneider, A. & Seyfried, A. 1–29 (Springer, Berlin, Heidelberg, 2018).