Sociohydrodynamics of polarization and segregation: large-scale spatial patterns in society where noise matters

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Spatial segregation and polarization in socio-economic systems are paradigmatic examples of collective pattern formation emerging from interacting agents. At the microscopic level, exemplary agent-based models for segregation and polarization, such as Schelling's model and the voter model, have long been used to uncover mechanisms that drive spatial pattern formation in society. These models typically take the form of stochastic lattice systems in which local decision rules and interactions between agents generate nontrivial collective behaviors. While such models have provided important conceptual insight, the connection between microscopic decision processes and the large-scale spatial structures observed in real socio-economic systems remains poorly understood.

In this presentation, we discuss a coarse-grained description that bridges this gap by connecting micro-economic decision making at the level of individual households to continuum equations governing the large-scale spatial dynamics of socio-economic variables. Specifically, we construct a continuum theory for a system in which Schelling-type residential dynamics are coupled to voter-like opinion dynamics. The resulting sociohydrodynamic framework can be interpreted as an effective field theory for the coupled evolution of segregation and polarization. Within this description, local incentives, imitation processes, and social interactions collectively generate macroscopic spatial organization.

A central goal of the work is to understand how segregation and polarization interact across spatial scales. In particular, segregation alters mobility patterns and neighborhood composition, while spatial polarization feeds back into the local dynamics of the neighborhood preferences. This mutual feedback leads to a rich set of spatio-temporal dynamics that cannot be captured by either process in isolation. We therefore pay special attention to the role of stochasticity in the theoretical framework, leading to a fluctuating hydrodynamic description of segregation coupled to polarization dynamics.

Using analytical arguments and numerical simulations we investigate how noise influences the resulting collective behavior. We find that stochasticity plays a central role in shaping the emergent structures. Noise can qualitatively modify the coupled segregation and polarization dynamics and leave persistent signatures in the resulting spatial patterns at urban and regional scales. In particular, stochastic fluctuations alter physical behavior of the system and modify the spectral properties of the emerging patterns.

Furthermore, we use the coupling to noise as a link between theoretical predictions, stochastic simulations, and empirical calibration. In particular, the continuum framework allows direct predictions for observables such as spatial correlation functions and power spectra. While empirical calibration is still ongoing, the framework is designed to interface with spatial socio-economic data made available at grid level resolution through Statistics Netherlands. It therefore provides a route toward connecting mechanistic models of collective social dynamics with future data-driven analyses of segregation, polarization, and economic inequality.