Droplet traffic at a junction: dynamics of path selection

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Understanding the flow of discrete elements through networks is of importance for diverse phenomena, for example, multiphase flows in porous media and microfluidic devices, and repartition of cells in blood flows. Addressing this issue requires a description of the mechanisms that govern flow partitioning at a node. In the case of diluted flows of droplets in microfluidic devices, it is known that a droplet reaching a node flows into the arm having the smallest hydrodynamic resistance. Despite this robust and simple rule, complex dynamics of the path selection can be observed, even for a simple and widely-studied system consisting of a train of droplets reaching the inlet node of an asymmetric loop. In particular, periodic and aperiodic behaviors with complex patterns of the droplets partitioning have been reported. Such complexity emerges from time-delayed feedback: the presence of droplets in a channel modifies its hydrodynamic resistance, so that the path selection of a droplet at a node is affected by the trajectories of the previous ones. To our knowledge, a complete understanding of the physical parameters and relations that govern the dynamical response of these systems is still lacking.

We present a numerical, theoretical, and experimental investigation of droplets partitioning at the inlet node of an asymmetric loop. Our model which describes the discrete dynamics of a binary variable can be viewed as a type of cellular automata. We obtain discrete bifurcations between periodic regimes and we show that these dynamics can be characterized by two invariants for a set of parameters. We predict theoretically the bifurcations between consecutive periodical regimes and account for the variations of the invariants with the relevant physical parameters of the system. To demonstrate the pertinence of our model, we perform experiments using a microfluidic device. We observe experimentally complex dynamics of droplet partitioning; these results are well described by our theoretical predictions. Specifically, our experiments show the existence of multistability between different periodical regimes. Multistability can be reproduced numerically by introducing noise in our simulations, an intrinsic feature of experimental systems. Our results, which provide a complete description of droplet partitioning at a single node, suggest that microfluidic experiments are model systems for the study of more complicated networks.