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Feedback and teaching in reaction-diffusion information processing

Abstract

The PhD thesis is focused on applicability of Belousov-Zhabotinsky (BZ) reaction as an information processing medium. The following problems are concerned: physico-chemical phenomena allowing for information encoding, inputting information into a chemical medium and teaching a chemical system to perform a certain function.

The major part of the work is concerned with systems composed of droplets containing BZ solution, surrounded by an organic phase. The following chapters of the thesis describe general properties of BZ reaction in droplets, methods of excitations control in such a medium, experimental studies on a simple memory cell and the results of in-silico simulations of chemical classifiers, based on a network of BZ droplets.

The most important result of the thesis is the presentation of teaching strategy, based on the flow of mutual information. The developed method was applied to 25 droplets arranged into a square lattice, in order to create a chemical classifier for different datasets. Illumination with blue light was used to introduce input information and to control the time evolution of the medium. For linearly separable, binary classification problems (CANCER) the obtained accuracy was over 93%. In case of a complex synthetic dataset (SPHERE), the accuracy was above 70%. For a dataset with four output classes accuracy was approx. 80%, however, by introducing more sophisticated classification rules it can be increased to 90%.

A few control methods of BZ reaction were examined. Among them, the mechanism of photoinhibition for the reaction catalyzed with a mixture of bathoferroin and the ruthenium catalyst seems to be the most reliable. The author constructed a computer controller of LED-based lightsource that allows to illuminate the system with a high temporal resolution. Optical fibers were used to direct light to individual droplets, providing a high spatial resolution.

Experiments with two and three interacting droplets were performed. For a pair of droplets a stable forcing mode was dominant (one droplet stimulates the other). In case of triplet systems, two rotational modes (clockwise and anti-clockwise), i.e. modes in which the first droplet stimulates the second one, then the second droplet stimulate the third one and the third one again stimulates the first one, are equally stable. It was demonstrated experimentally, that light-triggered switching between these modes is possible. Therefore, a system consisting of three droplets seems to be an interesting candidate for a basic, chemical memory cell.

The dissertation describes the use of microfluidic technique to create structures of coupled BZ droplets. Application of microfluidic devices allows to obtain reproducible droplets and to observe many copies of the same system simultaneously. Therefore the technique simplifies statistical analysis of observed phenomena.