ABSTRACT

Innovative Coupled Map Lattices for food chains, astronomical patterns, and food textures

An approach to interdisciplinary issues through simulators reproducing the dynamic behavior of complex systems with simple but essential algorithms

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Various complex phenomena have been studied from the viewpoint of nonlinear science, such as chaos and fractals. This viewpoint may reveal to us some dynamic property universally underlying such phenomena, and those dynamic properties may give us a new aspect to understand them. In this thesis, we apply Coupled Map Lattice (CML), well known in nonlinear science, to interdisciplinary issues, food chains (in biology and physics), astronomical patterns (in astrophysics and condensed matter physics), and food textures (in biology, chemistry, and physics).

CML simulates the dynamic behavior of complex phenomena by constructing a sequence of simple procedures. It is useful to find necessary (and therefore essential) procedures for reproducing the dynamic behavior, as argued in terms of the "reductionism in procedure". This advantage allows CML to approach many interdisciplinary issues. In this thesis, we study complex phenomena induced by some flow, which is formulated as the Lagrange procedure in CML: a nutrient flow derived from intraspecific competition and predator-prey interactions in the CML for food chains; a gas and dust flow derived from gravity in the CML for astronomical patterns; an emulsion flow derived from whipping and flocculation in the CML for food textures. Furthermore, we propose a new type of CML with long-range interactions, Globally Coupled Map Lattice (GCML), in the CML for astronomical patterns.

This thesis consists of three parts: food chains, astronomical patterns and food textures. Each part is written independently.

In Part I, we propose a CML for food chains of multiple species with non-overlapping generations. The simulations for three species show the conventional food chain behavior, and a new mutualistic behavior with interspecific cooperation. In Chapter 1, we introduce food chains and their numerical model, the generalized Lotka-Volterra equation. In Chapter 2, we construct the CML for food chains, based on the intraspecific and interspecific flow of nutrients. The proposed CML corresponds to some typical ecological models, and also the discretization of the generalized Lotka-Volterra equation. In Chapter 3, we examine in detail the two different dynamic behaviors, food chains and mutualism, from the viewpoint of dynamical systems: bifurcation diagrams, maximal Lyapunov exponent, time series and attractors. In Chapter 4, we characterize the mutualistic behavior with the Kaplan-Yorke dimension and the Kolmogorov-Sinai entropy which are obtained from the Lyapunov spectrum, and discuss the property of chaotic itinerancy in hetero systems including the proposed CML. Summary is given in Chapter 5.

In Part II, we propose a CML for astronomical patterns consisting of gas and dust with long-range interactions. The simulations show the formation process of grand design spiral patterns (i.e., two-arm spiral patterns), such as seen in spiral galaxy or protoplanetary disks, and a new formation process of stars through the crossing of spiral arms. In Chapter 1, we introduce grand design spiral patterns observed in spiral galaxies and protoplanetary disks, and the unsettled issues related to their formation

mechanism. In Chapter 2, we construct the CML for astronomical patterns, based on the gas and dust flow derived from gravitational interactions, and the flow relaxation. In Chapter 3, we explain a new formation process of the grand design spiral patterns obtained in the simulations by using the spatial patterns of gas clump mass. In Chapter 4, we examine in detail the dynamic properties of the spiral patterns and stars, and compare the results with the observations in spiral galaxies and protoplanetary disks. Summary is given in Chapter 5.

In Part III, we propose a CML for food textures in phase inversion phenomena from cream to butter by whipping. We challenge the visualization and design of food textures, changing dynamically and diversely through the phase inversion process. In Chapter 1, we introduce an episode of phase inversion phenomena from cream to butter. In Chapter 2, we briefly explain phase inversion phenomena from O/W emulsion (i.e., cream) to W/O emulsion (i.e., butter). In Chapter 3, we observe the emulsion behavior in the phase inversion process through experiment (or cooking). In Chapter 4, we construct the CML for food textures, based on the emulsion flow derived from whipping and flocculation, and the flow relaxation. In Chapter 5, we explain two different phase inversion processes at high and low whipping temperatures obtained in the simulations by using the spatial patterns of overrun (surface energy) and viscosity (cohesive energy). In Chapter 6, we characterize these processes on the rheological property plane, the viscosity-overrun plane, and discuss texture visualization based on the simulated overrun and viscosity patterns. Summary is given in Chapter 7.