# SYNERGETIC APPROACH TO PATTERN GENERATION AND PATTERN RECOGNITION

Organized by Scott Kelso and Hermann Haken

## Introduction

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Synergetics (Haken, 1988/83) provides a theoretical language, (the concepts of self organization and the mathematical tools of nonlinear dynamical systems) as well as an empirical strategy for understanding pattern formation and change in nonequilibrium systems. In particular, self-organization is apparent at phase transitions where instabilities create new (or different) patterns and structures. As an introduction to this symposium I summarize some recent applications and developments of synergetics in psychology and biology. Emphasis is on experimental model systems where the concepts have been implemented and specific predictions tested.

# Basic Concepts of Synergetics

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The interdisciplinary field of Synergetics deals with complex systems that may produce spatial, temporal, or functional structures. As a strategy it deals with those situations in which systems change their macroscopic behavior qualitatively. Under these circumstances, in a great variety of cases the dynamics is governed by a few variables, the order parameters. An outline is given of the concepts of stability and instability, order parameters, slaving, critical fluctuations and critical slowing down, and symmetry breaking. If the microscopic dynamics of the system can be described mathematically, the order parameters may be derived by a well-known procedure. If the microscopic dynamics are not known, the order parameters may be derived either from methods related to the maximum information principle or in a phenomenological fashion. In both cases, equations of motion for order parameters can be formulated. Examples are provided from the fields of movement coordination, EEG-analysis, and pattern recognition.

## Control Variables Underlying Human Arm and Jaw Movements

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A further development of the equilibrium point hypothesis (λ model) is presented with the focus on the control of multi-muscle systems during goal directed movements. According to this hypothesis, control is associated with changes of neurophysiological parameters (λs) which define the equilibrium state of the system. Muscle activations, forces, and movement arise as a natural dynamic reaction of the system to the shift in the equilibrium. Changes in λs for a set of muscles can be coordinated directly by central commands or conditioned by the intermuscular interaction mediated by muscle afferents and interneurons. The afferent interaction is also under central control. In the λ model, multi-muscle commands are represented by vectors. Each vector is associated with a linear combination of λ parameters for a set of muscles and its length represents the strength of the corresponding command. In this space, there are basic vectors which represent functionally different types of coordination. For example, one vector command produces activation of muscles without changes in arm position while another may control motions about an individual joint without other joint motions. Any other control signal can be represented as a linear combination (superposition) of the basic control signals. Two versions of the model are presented. One for goal directed arm movements and the other for mandibular movements. Both versions reproduce characteristic kinematic and EMG patterns of natural movements. In particular, experimental trajectories of the planar hand movements to different targets located in a horizontal plane were compared with simulated trajctories based on the λ model. The findings are consistent with the view that the movements are associated with a shift of the equilibrium position of the hand at a constant velocity, in a straight line, toward the target. One advantage of the planning of the rate and the direction of the shift in the equilibrium position of the endpoint is that information concerning movement amplitude is not required. The amplitude can be specified during the course of the movement as the duration of the shift. Thus, the nervous system reserves the possibility to stop the shift earlier or continue further if the position of the target changes. The λ model, with constant velocity shifts in the equilibrium position of the endpoint, is able to produce smooth, bell-shaped tangential velocity profiles of the actual movement. Thus, the natural dynamics of the system provide for the smoothness of the movement. Hence, it is unnecessary to posit control signals which meet the maximal smoothness criterion.

# Patternings of Relative Phase in Rhythmic Coordinations Within and Between People

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The relative phasing of limbs has been established as a macroscopic, qualitative variable or order parameter that indexes the patterning of limbs in bimanual rhythmic coordinations. A coupled oscillator model by Haken, Kelso, and Bunz (1985) provides an underpinning for the observed properties of this variable (stable phase modes at 0° and 180°, and 180° mode less stable than 0° mode) and its change (sudden transition from 180° to 0° mode at higher frequencies of oscillation, critical fluctuations before the transition, etc.). Not only have these properties been found in the coordination of limbs within a single person but they have been found in the optical coordination of limbs between two people. These results lead to the profound conclusion that the control mechanism underlying coordination of rhythmically moving limbs within a person or between two people appropriates the dynamics of coupled oscillators in producing the coordination. The phase transition results occur under the manipulation of the frequency of oscillation as a control parameter.

Another control parameter that reveals perspicuous changes in the patterning of relative phase in both within- and between-person coordinations is the eigenfrequency difference between the two oscillators. As the eigenfrequencies of the two oscillators become increasingly different, a number of changes occur: (a) the mean phase angle deviates from the intended phase angle (0° or 180°); (b) the fluctuation (*SD* or total power) in phase angle increases; (c) the fluctuation in the 180° mode increases at a faster rate than in the 0° mode; (d) the increased fluctuation is concentrated locally at increasingly higher integer multiples of the frequency of oscillation; and (e) the global distribution of the fluctuations changes from $1/f^2$ to near $1/f^1$. Of interest is how a coupled oscillator model can accommodate the results of the eigenfrequency difference manipulation.

# The Structure of the Ground on which Figures are Perceived: Physical Texture or Cognitive Field?

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The ecological approach favors the assumption that the geometry of perception is determined directly by the geometry of the physical surfaces of the environment. The main argument is that the elements from which a surface is composed are similar in size and distributed regularly over the whole area. In several same-sized sections, therefore, the same number of elements are met. An equal distribution of elements on the field causes the perception of a fronto-parallel surface while a linear condensation leads to a surface extending in depth.

Regarding quite a lot of perceptual phenomena one may suppose, on the other hand, that figural and depth perception is governed by nonlinear dynamics. For the examination of this gestalt psychological hypothesis some experiments were designed to measure the cognitive structure in order to calculate the field dynamics of homogeneous areas. In rectangular potential fields, for instance, two orthogonal bifurcation axes were found with deep attractors near the corners, and homogeneous circular fields exhibited a 'mexican hat'-structure. Simple model calculations show that some perceptual phenomena may be explained by these nonlinearities.

It is argued that the perceptual dynamics are underdetermined in the ecological approach and that direct perception should be supplemented by the nonlinear characteristics of cognitive systems.

# Serial Order as Parallel Articulation of Higher-Order Invariants: An Experimental Analysis of Pattern Formation and Practice Conditions in a Simple Motor Task

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At present, the problem of serial order in behavior is only beginning to form a research focus in ecological psychology. On the one hand, this may be due to its general strategy to avoid the arbitrary introduction of representational concepts and to focus on constraints on the immediate control of action which arise from the perception-action-cyclicity. On the other hand, the serial order problem is too obvious and too ubiquitous to be ignored in the conceptualization of a general theory of human motor behavior.

In the present paper, results from a series of experiments employing a one-dimensional pattern reproduction task (5 s in duration) are presented which demonstrate that most of the variance to be observed in the early learning (or pattern formation-)stage and in performance errors at later stages of practice can be explained on the basis of time-invariant or non-serial information (higher order invariants). In consequence, learning a movement form is described as the acquisition of a sufficient 'number' of these invariant aspects which, in correct performances, are articulated in a parallel manner. Theoretical correspondences and differences of the proposed model to other models of seriality such as the Fourier coding model are discussed.

A second set of results refers to the effect of four practice conditions (physical practice/feedback; physical practice/no feedback; mental practice; observation of the criterion pattern only) on the performance in immediate and 1-day-delayed retention tests. The results indicate that physical practice as well as feedback are *not* crucial for an adequate production of a (qualitative) movement form. In this respect, Keele's (1986) statement that motor learning may, to a considerable degree, involve 'nonmotoric' (and amodal) pattern learning, is substantiated. Further analyses will reveal the effects of practice and feedback on parameters such as fluency and stability of movement.