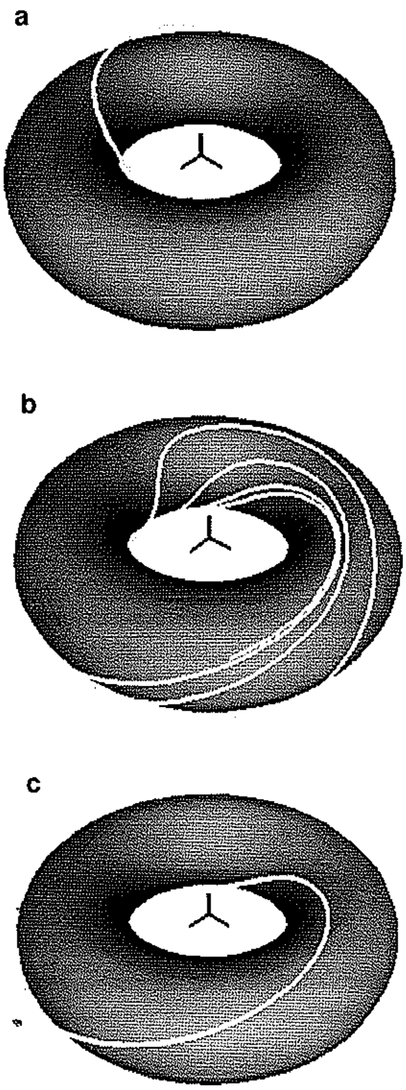

Figure 2.12 Same transition as in figure 2.11 but now displayed on the torus. As coupling is varied a stable antiphase trajectory (a), loses stability (b), and switches to a stable in-phase trajectory (c).

attribute the system's collective or coordinative capabilities to couplings per se. Many mechanisms, both physiological and mathematical, can instantiate or realize the same function. The conspicuous lack of a one-to-one relationship between self-organized coordination patterns and the structures that realize them is a central feature of the present theory, and surely constitutes one of the basic differences between living things and mechanisms or machine.[46]

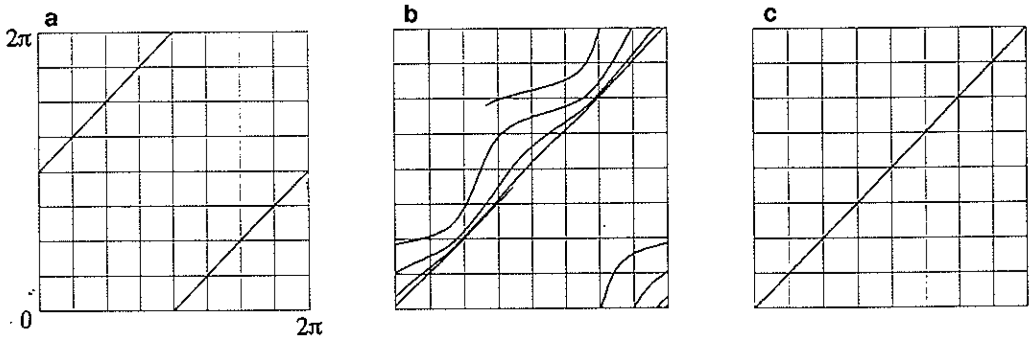

Figure 2.13 Flat representation of the torus displaying the phase of each oscillator on the horizontal and vertical axis. The transition is the same as shown in figure 2.12.

The Tripartite Scheme—Once More with Feeling

It may be possible to carry out this level-independent analysis when we step down to other scales, such as that of neurons and neuronal assemblies (see chapter 8). But for now, let's pull together the main conceptual themes that emerge from the walking fingers example. Figure 2.14 represents the linkages between phenomena and dynamic pattern theory (horizontal mapping) and between levels of description (vertical mapping). Here are the key points to keep in mind.

- A minimum of three levels (the task or goal level as a special kind of boundary constraint, collective variable level, and component level) is required to provide a complete understanding of any *single* level of description.
- Mutability exists among levels. For instance, the component level defined here in terms of nonlinear oscillators may be viewed as a collective variable level for finer-grained descriptions such as the way agonist and antagonist muscles generate kinematic patterns.
- Patterns at all levels are governed by the dynamics of collective variables. In this sense, no single level is any more important or fundamental than any other.
- Boundary constraints, at least in complex biological systems, necessarily mean that the coordination dynamics are context or task dependent. I take this to be another major distinction between the usual conception of physical law (as purely syntactic, nonsemantic statements) and the self-organized, semantically meaningful laws of biological coordination. Order parameters and their dynamics are always *functionally* defined in biological systems. They therefore exist only as meaningful characteristic quantities, unique and specific to tasks.

Reprise

I have demonstrated that simple behavioral patterns and considerable pattern complexity may arise from the process of self-organization, as emergent con-

Phenomena	Pattern Dynamics
Boundary constraints	
Initial conditions: e.g., oscillate fingers in a given fashion...	$\phi = 0$ *or* $\pm\pi$
Non-specific parameters: e.g., change frequency, spatial orientation...	b/a
⇕	⇓
Collective variable	
characterizes coordinated states, e.g., relative phase (ϕ)	$V(\phi) = -a\cos(\phi) - b\cos(2\phi)$
⇕	⇑
Components	
nonlinearly coupled oscillators	$\ddot{x}_1 + f(x_1, \dot{x}_1) = G(x_1, \dot{x}_1; x_2, \dot{x}_2)$ $\ddot{x}_2 + f(x_2, \dot{x}_2) = G(x_2, \dot{x}_2; x_1, \dot{x}_1)$

Figure 2.14 The tripartite scheme applied to understanding coordination: the bimanual coordination example (see text for details).

sequences of nonlinear interactions among active components. Ironically, the very aspect of behavior that scientists, especially psychologists and biologists, usually try to avoid—instability of motion—turns out to be the key generic mechanism of self-organization. The very many neurons, muscles, and joints act together in such a way that the entire system acts as a single coherent unit.

The discovery and consequent analysis of phase transitions in human hand movements introduces a new paradigm into biology.[47] It appears also that a comparison of nonequilibrium phase transitions in physics and discontinuities in coordinated action goes beyond mere analogy.[48] Of course, in physics, phase transitions remain objects of concentrated research. But the basic events that we have found in voluntary human hand movements, critical fluctuations and critical slowing down, occur over and over again in nonequilibrium systems, and suggest that the same laws and principles are in operation. The step we have tried to take in this chapter, albeit a baby step, is from the identification and descriptive language of functional synergies in action, to synergetics, a theory of how synergies are created, sustained, and dissolved. This is the conceptual and methodological foundation on which I believe a scientific psychology should be built, a science that bridges mental, brain, and behavioral events.