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Contrasting Approaches to Perceiving and Acting With Others

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How and why the presence of a person directly affects the perception and action of another person is a phenomenon that has been approached in a limited and piecemeal fashion within psychology. This kind of diffuse strategy has failed to capture the jointness of perception and action within and between people. In contradistinction, the authors offer a perspective that retains both integrally social features (e.g., involves interaction) and yet adequately exploits the current state of knowledge regarding the ecological properties of perception-action, while at the same time drawing on aspects of dynamic systems theory. In this article the authors review the best attempts to examine how one individual affects another's perceptions and actions in the emergence of a social unit of action. Two important approaches, the individual-level and cognitive dynamics approaches, have yielded insights that derive in significant degree from principles of ecological psychology and/or dynamical systems theory. Prototypic of the individual-level approach is a focus on what can be perceived by coactors with the aim of uncovering how the dispositional qualities (affordances) of another person are informationally specified during social interaction. In contrast, the cognitive dynamics approach simulates dynamical characteristics of cognition and psychological influence with the aim of uncovering how cooperative interaction emerges out of its component parts. The authors argue that these approaches involve, respectively, insufficient mutuality and insufficient embodiment. Consequently, a social synergy perspective is discussed that approaches the problem of socially cooperative interaction at the relational, nonreductive level, using novel methods to examine how social perception and action emerge through self-organizing processes.

The coupling of Gibson's ideas with those of Bernstein forms a natural basis for looking at the traditional psychological topics of perceiving, acting, and knowing as activities of ecosystems rather than isolated animals. (Shaw, Mace, & Turvey, 2001, p. xiv)

Direct physical contact with other animals, particularly humans, matters a great deal for shared perceiving, acting, and knowing—it allows us the deepest expression of comfort, understanding, connection, intimacy, and affection, as well as hostile challenge and aggressive intent. But direct physical contact is not the primary means by which the physical presence of another is more commonly experienced. Rather, visual and auditory contact with others is much more frequent and ubiquitous in everyday life. And yet we know very little about how the physical and psychoperceptual dynamics of one individual affect another. In this article, we address the broad question of deciding what criteria should be used for studying the way one individual's perceptions and actions have implications for the perception and action possibilities of another individual in social interaction.

We take as a starting assumption that the dominant social-cognitive perspective in social psychology has little to offer with regard to these issues because of its focus on the individual as the sole unit of analysis and its default assumptions that inferential processes are the only acceptable explanatory mechanisms. Instead, we review perspectives that we feel have attempted (albeit in a limited manner) to understand social perceiving and acting from an ecological or dynamical systems perspective. The purpose of this article is to describe the two primary perspectives that have generated research to date and to introduce what we think of as a third perspective. In doing so, we wish to provide some impetus for an ecological approach to social perceiving and acting that can provide a starting direction for the next era of research.

The first 25 years since an ecological social psychological perspective was introduced (Baron, 1980, 1981; McArthur & Baron, 1983; Newton, 1980) have generated a number of stimulating theoretical statements about the relevance of direct perception (McArthur & Baron, 1983) and dynamical systems approaches to social processes (Baron, Amazeen, & Beek, 1994; Vallacher & Nowak, 1997). Moreover, empirical research has focused on how informational features (e.g., facial features associated with age; Mark, Shaw, & Pittenger, 1988; Zebrowitz, 1997) affect social judgments, and how kinematics (movement style) veridically specify the lawful constraints that determine various actions and features of social relevance (e.g., gender and identity; Runeson & Frykholm, 1983). Other research has used dynamical systems to simulate societal-level processes (e.g., formation of pockets of majority and minority opinion) and to describe individuals' cognitive dynamics (Nowak & Vallacher, 1998). However, our recent research in two areas—on how individuals spontaneously coordinate movement as described by a coupled oscillator dynamic (Richardson, Marsh, & Schmidt, 2005; Schmidt, Carello, & Turvey, 1990) and on the emergence of cooperative action from an affordance perspective (Richardson, Marsh, & Baron, 2005)—led us to realize that the perspective we

were taking differed in some significant ways from that of previous researchers. We have come to the conclusion that the coordination research is not just an extension of motor control research (Bernstein, 1967) to social psychology, but rather the emergence of an alternative core for social and, perhaps, ecological psychology, based on real interpersonal or synergistic perception–action systems. That is, we have come to the conclusion that our way of viewing affordances as emerging from the social animal–environment system, as opposed to the egocentric animal–environment system, provides a way to take more seriously perceiving, acting, and knowing as “activities of ecosystems rather than isolated animals” (Shaw et al., 2001, p. xiv)—where the ecosystem is composed of multiple, cooperative conspecifics. This article introduces this perspective as well as two other perspectives that have generated research to date.

One perspective, which we refer to as the individual-level approach, examines how others influence either perceptions or actions using the individual as the unit of analysis. Figure 1 provides a schematic that emphasizes that the unit of analysis is the individual, and that perception and action processes are represented by disconnected arrows rather than a perception–action loop. This reflects that perception processes are studied in isolation from action processes. The other perspective, which we refer to as the cognitive dynamics approach, focuses on the internal, psychological dynamics that occur when other people influence an individual. Figure 2 illustrates that the internal dynamics of a solo individual (rather than, for instance, interactional dynamics) is the primary focus of this perspective.

We then introduce our third perspective that derives in some part from each of the other two, but also differs in important ways. In discussing the three perspectives, the criteria we compare them against is how well they capture the fundamental qualities of any perception–action system, as we describe later. Moreover,

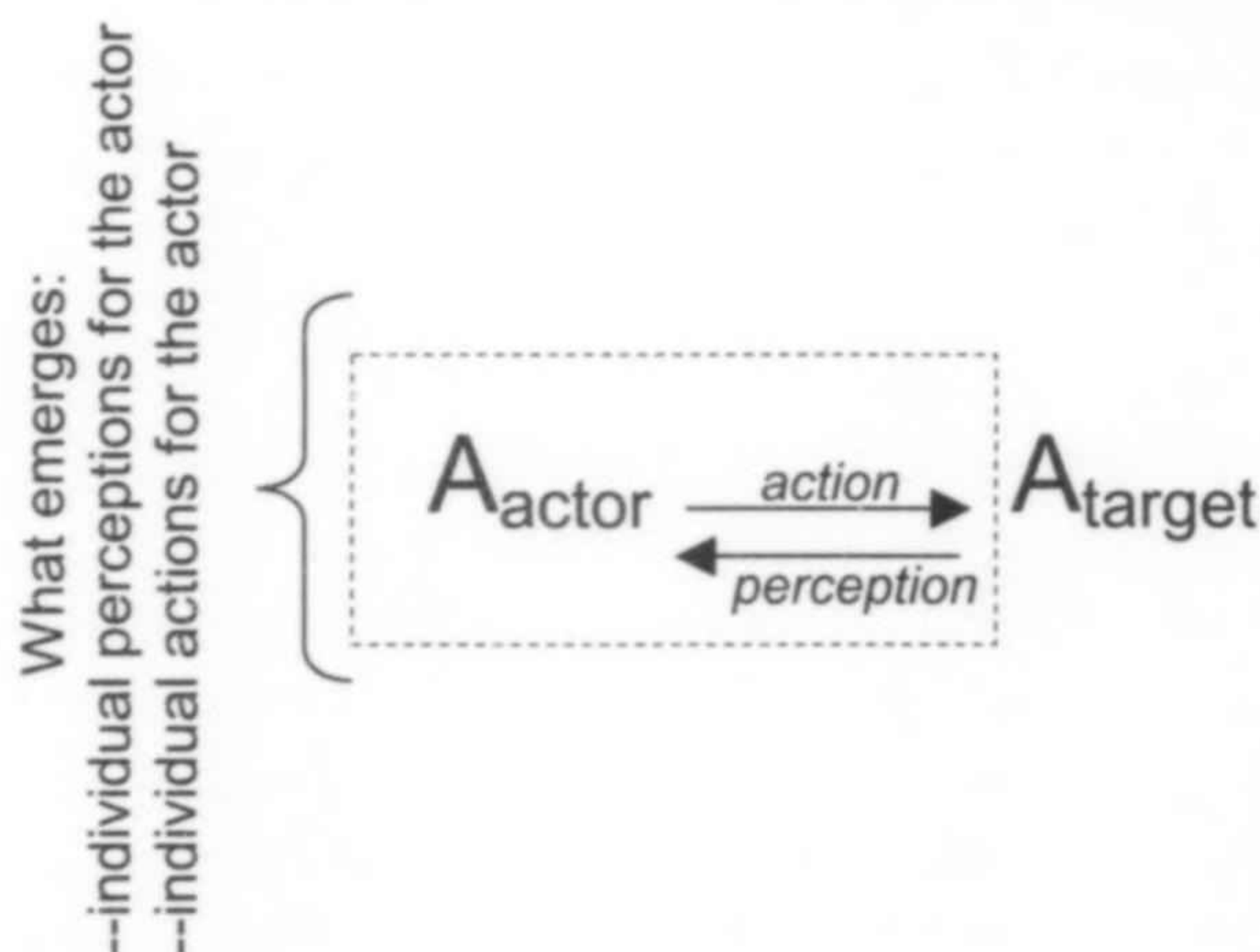


FIGURE 1 From the individual-level approach, the influence of the target on the actor's perceptions and actions is understood in terms of either how the individual actor picks up information that specifies the target's affordances, or, in a separate research tradition, how the behavior emitted by the target leads to mimicked or synchronized actions by the actor.

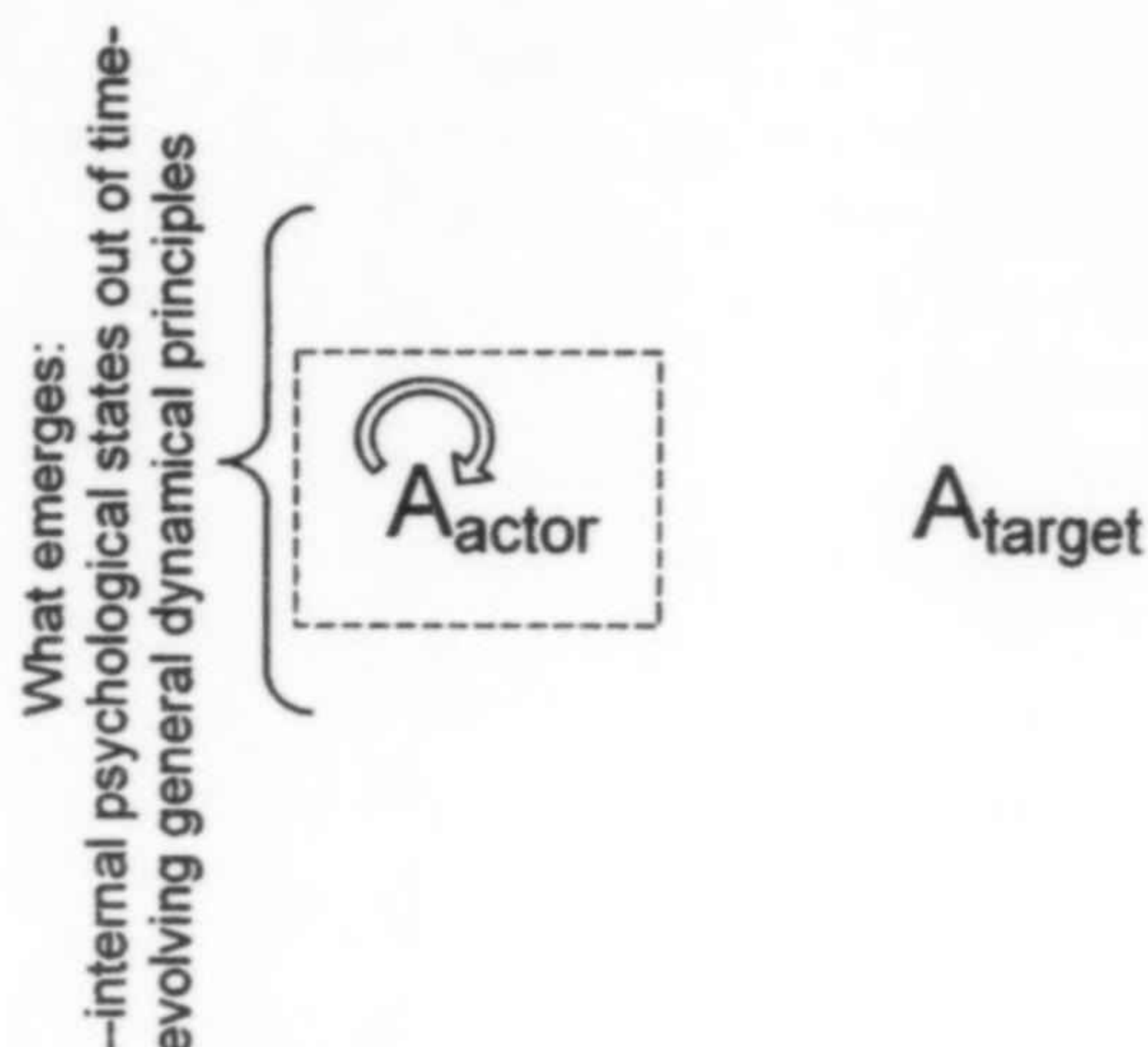


FIGURE 2 From the cognitive dynamics approach, the influence of a target person on the actor is described in terms of dynamical principles with a primary emphasis on how internal psychological states are affected.

throughout much of the article, by way of illustration we often use the example of the formation of a macroscopic, cooperative social unit—a dyad or a larger group, or, as we term this, a “collective” of some size. This is not the only phenomenon we wish to describe from this perspective—our interest is in understanding the perception–action processes involved with social interaction more generally—but we use it as an illustrative example of the emergence of a social unit of action in which individual actors become part of a larger social entity, a collective, because it characterizes social interactions in their most abstract and basic form—how two or more individuals function as one entity. For a human’s ecological niche, other people are an essential part of the environment, social interaction is a significant source of meaning, and a collective is the minimal unit of survival. Thus explanation of the essential nature of sociality (M. Gilbert, 2000) is a particularly useful test of each perspective, although the researchers’ purposes in most programs of research were admittedly not these.

Our criteria are based on the fundamental features that are characteristic of perception–action systems. We suggest that these crucial features need not be restricted to individual perception–action systems, but can also be used to determine the adequacy of each perspective for understanding a perception–action system comprised of more than one person. These features are explicit or implied in current understanding of ecological psychology and human movement science with regard to what perception–action systems involve: mutuality, reliance on dynamical principles, and embodied processes of meaning.

As Figure 3A illustrates, perception–action processes are viewed as involving mutuality of animal and environment rather than being solely focused on the animal (e.g., the animal’s interpretations) or on the environment (e.g., as a stimulus

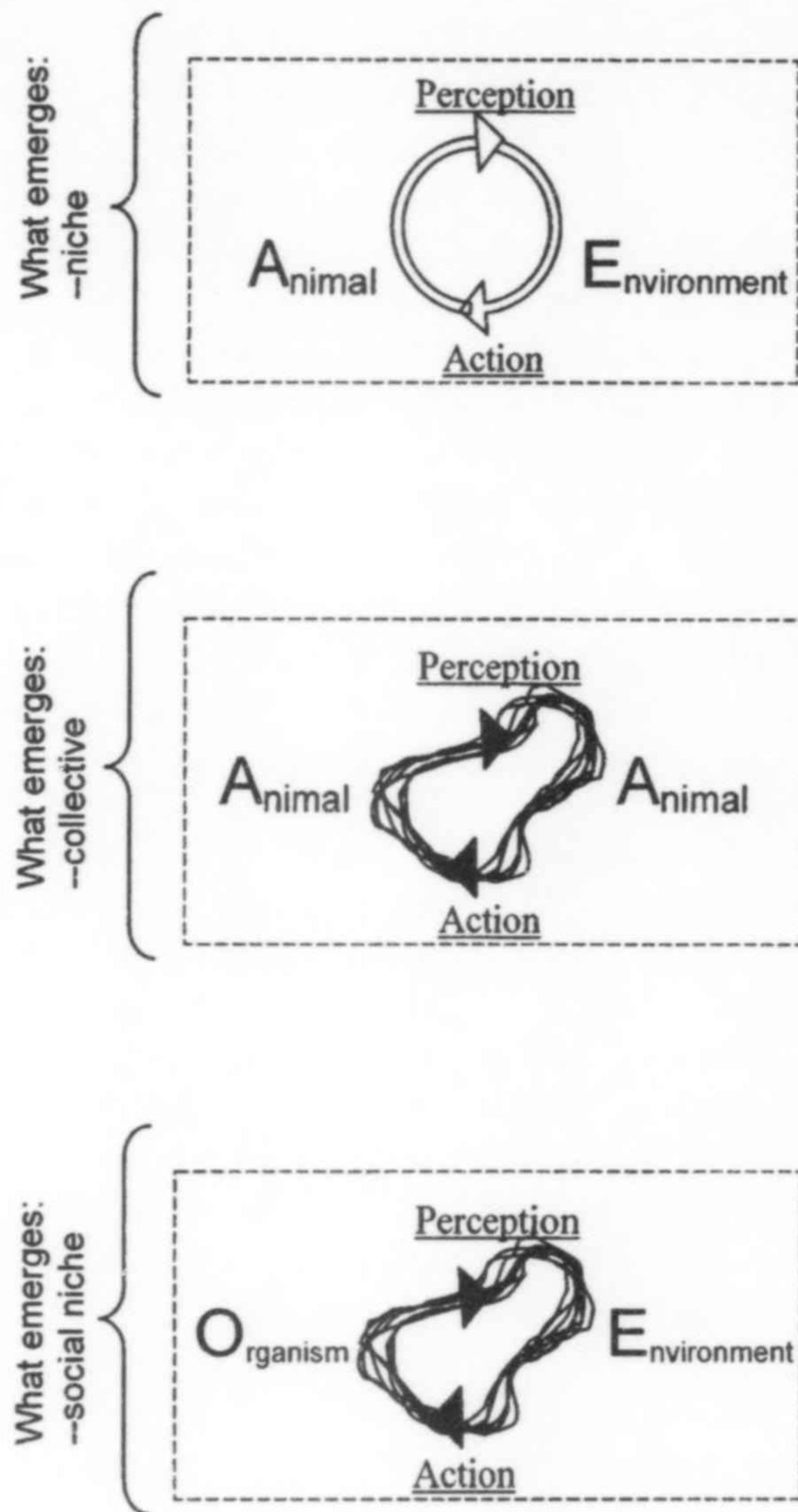


FIGURE 3A: The ecological perspective focuses on relational properties defined over an animal–environment system, in which meaning is captured at the level of the niche. B: A synergistic perspective builds on ecological and dynamical approaches. Other conspecifics are viewed as a part of an individual’s environment. Mutuality between two or more individuals yields perceptions and actions that obey time-evolving general dynamical principles, and yields a social unit or “collective.” C: The collective that emerges can then be understood as a new organism within the animal–environment system. Meaning within a synergistic perspective is understood in terms of this new social niche.

for triggering responses). This attribute of mutuality is captured by the concept of an ecological niche. When one considers that other people are a significant aspect of one's environment (see Figure 3B), mutuality implies not only the intertwined perception-action processes that occur in an animal's interaction with a non-animate environment, but also the mutuality of one person's perceptions and actions with another person's perceptions and actions. (At the most basic level of sociality, mutuality translates to mere formation of a temporary unit of social interaction: coordinated action. At a more enmeshed level of sociality, such a unity would involve cooperation—reciprocal influence between individuals that also involves outcome dependency.) A second implication of the term *mutuality* is that the collective illustrated in Figure 3B is a "coordinative structure"¹ that is not merely the sum of the individuals. A collective is mutually linked with the environment, forming a social niche, as Figure 3C illustrates.

A second crucial quality of perception-action systems is that they are dynamic (Figure 3B). A social perception-action perspective would be considered dynamic not only because it describes changes over time, but also because the described changes are consistent with natural law and principles of self-organization. Whereas a traditional approach to explaining change only looks at the correlation between variables over time, an approach that builds on the current knowledge of complex dynamical systems needs to describe how behavioral influences between individuals "balance" and tend toward equilibrium states (Boker & Rotondo, 2003; Kugler, Kelso, & Turvey, 1980). From this view, a collective is self-organized; it is not "directed" in some way by something or someone, but the basic structure of the social world is viewed as an extension of the stratified structure of the natural world in which atomistic units interact at a more microscopic scale to produce cooperative states at a more macroscopic scale (Iberall, 1987; Kelso, 1995; Kugler & Turvey, 1987; Soodak & Iberall, 1987). A "social physics" view on dynamics, for instance (Iberall, 1987; Iberall & Soodak, 1987; Iberall & Wilkinson, 1993), suggests that a basic social unit emerges in response to natural attractive forces among atomisms (i.e., individuals) that pull them toward each other temporarily (i.e., a brief social exchange, perhaps) or in a more lasting fashion (i.e., formation of a relationship, perhaps). In addition, pressures from the environment (i.e., the need to

¹This term is borrowed from the motor control literature, in which it refers to relatively independent muscles that are constrained to act as a unitary functional unit (Tuller, Turvey, & Fitch, 1982). We use the term here to emphasize that individuals in a collective operate as a "plural subject" (M. Gilbert, 2000) of action rather than as individuals with solitary and disconnected wills. As such, each individual's action constrains and creates balancing and reciprocating actions toward the implied common goal of a collective. A collective also implies the concept of "distributed" action. Just as muscular forces in a coordinative structure are distributed in patterned ways across a range of velocities (Tuller et al., 1982), so are the actions of a soccer team distributed (Jordet, 2005), the movements of termites building a nest distributed (Kugler & Turvey, 1987; Resnick, 1994), and the knowledge and activities of a ship's crew distributed (Hutchins, 1995). What patterns and tunes the coordinative structure of a collective (Fitch, Tuller, & Turvey, 1982) is presumably information about the actions of other near neighbors.

complete some goal) provides the increase in energy that allows patterned movement to emerge (the "social eddy" of an interaction) out of previous random movement of individuals moving in disconnect from one another, much as heating a pan of oil leads to patterned flow of convection (convection rolls in the Bénard instability; Anderson & Stein, 1987).

The final quality of perception–action systems is that they involve embodied processes of meaning. That is, the ecological approach to perceiving and acting uses external, behavioral observables rather than mentalistic psychological processes and measurement of internal representations to explain how mind exists in nature. Applied to the challenge of how one should conceptualize an emergent collective and describe social niches, embodiment means that a perspective will not rely merely on internal properties of social systems such as thoughts, feelings, attitudes, and belief structures to explain a social unit. Rather, following Gibson (1979/1986) and his concept of affordance, one needs to acknowledge that meaning is in the world—in the relations between the person and the environment and between an individual and other people. A perspective will be embodied to the extent to which it examines actual behavior rather than measuring and describing internal properties solely. We believe the task is, ultimately, to explain real interaction among embodied selves, and not only the interactions between two cognitive systems (or interactions within a cognitive system). Rather, a social perception–action perspective that is embodied will ideally explain the dynamic interaction of individuals as well.²

The prototypic example of the social phenomena of interest to us is illustrated in an example provided by Asch (1952) over 50 years ago when he wrote about two boys moving an obstacle:

The boys are fitting their actions to each other and to the object and are involved in a give-and-take requiring considerable sensitiveness. The two do not apply force in succession, or in opposite directions; they bring a common force to bear simultaneously. If one moves somewhat faster or swerves slightly, the other adapts his movement correspondingly. There is an immediate, direct communication between them through the object. The amount of movement, timing, pace, and direction are regulated and continuously checked by the corresponding action of the partner. Here is a unity of action that embraces the participants and the common object. The perfor-

²Weakly embodied approaches to understanding sociality will recognize that bodily expressions of internal states have particular primacy in cognitive processes such as person perception, attributions, emotions, attitudes, and social cognition (Barsalou, Niedenthal, Barbey, & Ruppert, 2003; Feldman Barrett, Niedenthal, & Winkielman, 2005; Zajonc, 1980). Such approaches are deficient in that they are not grounded in ecological perception (Gibson, 1979/1986) and thus fail to understand the perception–action cycle. Strongly embodied approaches, in contrast, will also recognize that internal properties are embodied in observable actions both individually and in regard to reciprocal changes in action. Most important, strongly embodied approaches will offer new phenomena to measure—qualities that capture relational features of physical social interaction.

mance is a new product, strictly unlike the sum of their separate exertions. ... Neither boy would act in just the same way in the absence of the other; what each contributes is a function of his relation to the other in the task. (pp. 173–174)

We regard this example as a case that represents fundamental issues that social psychology should be able to explain. Other examples abound in relatively unconstrained, simple dyadic actions such as “taking a walk together” (M. Gilbert, 1996) or in highly polished and complicated acts of multiple-person coordination such as in playing a professional soccer game (Jordet, 2005). All examples have the features in common that we described previously. In each, the perceptions and actions of individuals jointly influence each other and there is an “embodiment” of social influence and a grounding of these individuals within an environment that entails joint action. Moreover, each of these examples recognizes the intrinsic uniqueness of the social unit that emerges out of such joint perception–action influence. A coordinative structure at a new level of analysis (i.e., the social scale) is created from interacting components (i.e., people). In Asch’s example a simple physical action such as two people lifting a log captures the essence of the emergent social unit as the creation of a new product, a “unity of action” understood at the level of the animal–animal–environment relation. Another aspect of these examples is that they all illustrate in some sense a simultaneous, joint commitment of individuals as a body to cooperate. For example, even in an antagonistic or competitive exchange such as competing against another team, one social unit (team) is necessarily pulled to coordinate with the other in the goal to compete. The philosopher Margaret Gilbert (1996, 2000) argued that the nature of sociality requires that “individual wills are bound *simultaneously and interdependently*” (1996, p. 185) to commit to be a plural subject in the course of joint goal-directed activities such as moving a log or even walking together. Gilbert explains that

if a goal has a plural subject, each of a number of persons (two or more) has, in effect, offered his will to be a part of a pool of wills that is dedicated, as one, to that goal. ... Thus what is achieved is a binding together of a set of individual wills so as to constitute a single, “plural will” dedicated to a particular goal. (p. 185)

In addition, our paradigmatic examples involve dynamic social actions. Rather than a static, discrete series of decisions to cooperate, they reflect a continuous flow of adjustments in the actions of one individual in response to perceiving the actions of the other and the flow of information from the individual’s own movement.

In this article, we use the criteria detailed previously to evaluate the approaches to joint perception–action influence in social interaction. Our conclusion that these perspectives offer the only serious contending explanations of joint perception and action, in contrast to current social cognitive approaches, is not a novel suggestion (McArthur & Baron, 1983; Valenti & Good, 1991; Valenti & Stoffregen, 2001). In part we offer in this article an update on the current state of

knowledge in addressing such problems. One conclusion that can be drawn in the 15 years since the last review of such issues in this journal (Valenti & Good, 1991) is, on the one hand, that insufficient advances have been made overall, but on the other hand, that the start of the most promising directions of current research made its first appearance at about that time (e.g., Schmidt et al., 1990).

INDIVIDUAL-LEVEL APPROACH

The individual-level approach, the first attempt to apply Gibson's (1979/1986) theory of ecological perception to social psychology, was a dramatic improvement over previous social psychological research in that it investigated embodied meaning using the concept of social affordance. When an ecological approach was first introduced in social psychological theorizing (Baron, 1980, 1981; McArthur & Baron, 1983; Newton, 1980), one particular area of promise was in the possibility that individual dispositions might be directly perceived in interaction with others. The suggestion was that an individual's psychological attributes (e.g., personality traits) could be conceptualized as affordances—attributes or properties of an individual with implications for good or ill (e.g., helpfulness or hostility)—and could be perceived by an observer directly from embodied information without requiring inferential processes. This application of an ecological perspective emphasized pick-up of information relevant to action, with little focus on the action side of the perception-action cycle. In contrast, research that has examined action effects, for example, how individuals mimic or synchronize with another's movements, was guided solely by the descriptive orientation of nonverbal communication researchers or by the cognitive emphasis of social psychologists. Such research ignores information pickup and the mutuality of perception and action.

Thus, as Figure 1 indicates, one focus of the individual-level approach is on an individual's pickup of information about another individual's qualities. Mutuality of an individual's perception and action is not apparent in research based in this perspective; instead, social perception and social action are studied independently. Moreover, the focus is on the individual and thus rarely speaks to the emergence of a collective. This is not surprising because the goals of the researchers were not framed with that problem in mind. Nevertheless, considerable knowledge about the direct perception of others and the effects of one individual's actions on another come from this first perspective and inform us about issues relevant to understanding social units as a basic perception-action system. Therefore we review each of these areas of research in the sections following.

Social Perception

For the individual-level approach to speak to the emergence of a social unit, the challenge is determining what information specifies another individual's willing-

ness or intention to engage in a cooperative exchange (either temporarily, to engage with another in a brief joint task; or more stably, to form a relationship). For example, how would the individual-level perspective approach the pickup of information between two basketball players moving a ball downcourt? Information (Gibson, 1979/1986) refers to structured distribution of energy that is lawfully related to aspects of an individual and is specific to that source of information. In the fast-paced action of a team sport (Jordet, 2004), a player is presumably more likely to determine that a teammate has readiness and willingness to receive a pass if the information specifies that the trajectory to the teammate appears to not be obstructed by the time a pass would arrive, and the trajectory of passing is outside of an opposing member's likely trajectory should the pass be initiated. Thus, the richest information relevant to emergence of a social unit will likely involve dynamic change in another's movement, as occurs when interacting with them. The validity of our speculations in the previous several sentences is unclear, however, because the focus of research in this area is relatively unchanged in 15 years (Valenti & Good, 1991). As Valenti and Good noted about research to date in 1989, research is generally about social perception of specific person attributes and not about the uncovering of information within social interaction.

One advance in 15 years, however, is in perception of affordances for others. Some recent research examines whether perceivers detect the animal-environment relations for another actor in the same way that they do for themselves. Research suggests that affordances (action possibilities) for others are detectable—for example, whether a surface is sittable (Stoffregen, Gorday, Sheng, & Flynn, 1999) or whether an object is reachable (Ramenzoni, Riley, Davis, & Snyder, 2005; P. Rochat, 1995). However, sensitivity to detecting affordances for others is more readily perturbed by situational variables (Ramenzoni et al., 2005) than is sensitivity to detecting affordances for oneself. For accurate detection of affordances for others, preserving relational features between animal and environment in the display of information (e.g., showing both environmental features and the animal within the same display) is particularly crucial (Stoffregen et al., 1999).

In contrast, person perception research examines how perceivers pick up information about the other person, which presumably implies social fit rather than fit of their attributes to the physical world. Such research, for example, demonstrates strong social consensus in the perception of extroversion (Kenny, 1994; Kenny, Horner, Kashy, & Chu, 1992; Levesque & Kenny, 1993) and indicates that such judgments relate to physical features that are plausibly linked to extroversion (Borkenau & Liebler, 1992). For example, judgments of extroversion are associated with an actor's frequency of smiling, loudness of voice, and dynamic and rapid body movements (Borkenau & Liebler, 1992, 1995; Kenny et al., 1992) as well as head nods and gestures (Gifford, 1994). Evidence also supports the possibility of direct perception of some traits. Namely, perceptions of traits such as extroversion can occur rapidly with minimal cognitive resources and no significant social interaction (Ambady, Hallahan, & Rosenthal, 1995; Ambady & Rosenthal, 1992, 1993;

D. T. Gilbert & Krull, 1988; Kenny, 1994; Kenny et al., 1992; Levesque & Kenny, 1993; McLeod & Rosenthal, 1983). Making rather immediate assessments without analytic, cognitive processes indicates that perception is not mediated by thought-intensive processes, but of course it cannot rule out that perception is mediated by automatically evoked cognitive heuristics. Additional suggestive evidence indicates that there is surprisingly little variability in skill at "reading" other people (Buck, 1988); perhaps some social "invariants" exist that are detectable by all, much as physical invariants of objects (e.g., an object's unchanging form), from an ecological perspective, are available for pickup by all members of a species. In general, direct pickup of information is most plausible for traits that are highly relational, such as extroversion, power, and dominance (Dovidio, Brown, Heltman, & Ellyson, 1988; Dovidio & Ellyson, 1982; Ellyson, Dovidio, Corson, & Vinicur, 1980; Exline, Ellyson, & Long, 1975), or ones essential to species survival, such as sexual availability (Gangestad, Simpson, DiGeronimo, & Biek, 1992). However, even for attributes that research suggests are the most promising candidates for direct perception (e.g., extroversion), it is impossible to verify that the features picked up are equivalent to the features that are in fact regulating behavior.

In contrast, research does indicate that facial features that specify aging are picked up by perceivers. Because gravity is a universal and dynamic constraint that operates on growing organisms, it creates a cardiodial strain transformation for craniofacial features such that aging is veridically specified by individuals who see faces that have been transformed (Mark et al., 1988). Adult faces that show the least cardiodial strain (prominent forehead, diminutive face relative to cranium, large, low-set eyes) are perceived as "babyfaced," which Zebrowitz and her colleagues have shown has important consequences for perceivers' judgments of innocence and honesty (Berry & McArthur, 1988; Zebrowitz, Tenenbaum, & Goldstein, 1991). Moreover other research on facial attributes indicates that facial attributes that are associated with physical attractiveness are correlated with perceived health and intelligence (Kalick, Zebrowitz, Langlois, & Johnson, 1998; Rhodes et al., 2001; Zebrowitz, Hall, Murphy, & Rhodes, 2002).

Using the individual-level approach to examine how a cooperative social unit emerges would require a technique that captures dynamic information rather than simple static features, however. This has been achieved using Johansson's (1977) point light technique, which involves filming individuals in motion such that only reflective points at the individual's joints are visible, obscuring surface features that convey identity and gender (hair style, facial features, attire). Participants' perceptions of these point-light videos have been used to demonstrate the principle of *kinematic specification of dynamics* (KSD; Runeson & Frykholm, 1983), which states that the kinematics of movement style veridically specify the lawful constraints that determine attributes that a perceiver picks up. Such attributes include gender and identity of a walker, and activities such as dancing and moving heavy versus light objects (Baron & Misovich, 1993a; Berry & Misovich, 1994; Cutting & Kozlowski, 1977; Johansson, 1977; Richardson & Johnston, 2005; Runeson &

Frykholm, 1983; Shiffrar, Lichtey, & Chatterjee, 1997; Stevenage, Nixon, & Vince, 1999). The KSD research that is most relevant to understanding the emergence of a collective looks at relational attributes conveyed in an individual's movement. For example, kinematic features of female walkers lead them to vary in how "muggable" they appear (Gunns, Johnston, & Hudson, 2002; Johnston, Hudson, Richardson, Gunns, & Garner, 2004). Being perceived as muggable presumably makes one more vulnerable to being pulled into the orbit of another, albeit an unwanted, predatory interaction rather than a voluntary, positive one.

Although KSD studies cannot eliminate the possibility that judgments of perceivers in these studies are mediated by inferences rather than reflecting direct perception processes, at least two important conclusions can be drawn. First, the studies indicate the importance of dynamic information in yielding such judgments, and second, they rule out that other obvious inference cues that convey features such as gender or muggability (e.g., wearing attire such as high heels) are the sole basis for judgments. However, even research that focuses on features most relevant to formation of a social unit (e.g., predatory if not cooperative) lack mutuality—bidirectionality of perception and action.

One way that an individual-focused approach can look at mutuality in a social interaction is to focus on how the target of one's perceptions has apparently been changed by interaction with another. For instance, Van Acker and Valenti (1989) found that perceivers could accurately detect whether a (nonhandicapped) child was being approached by an (off-camera) handicapped child solely by picking up something in his behavior that specified reluctance to play with the (undepicted) child.

A more recent study looks directly at how mutuality in social interaction yields kinematic information that specifies cooperative action (Kean, 2000). Kean filmed two actors cooperating (folding a sheet together) or competing (trying to tug a sheet away from the other person) using point-light methods and found that observers were able to pick up cooperativeness versus competitiveness from the kinematics of the interactions. Although this research is mute on the perception-action processes involved in the emergence of a social unity of action, it makes the important point that kinematic information can be sufficient for specifying cooperation.

In general, research on the pickup of information pertaining to affordances is embodied, that is, it does examine external behavioral features. Moreover, although some of the research is kinematic in that it looks at variables changing over time (KSD research, perceptions of aging research), it does not draw from more general principles derived from modern dynamical systems theory (e.g., Turvey, 1990). The strongest limitation of the individual-difference approach to information pickup, however, is that it does not involve mutuality. The emergence of a social unity of action is typically not examined, for instance. One considerable challenge, however, is that information in such a situation would be "subject to constant transformation" (Valenti & Good, 1991, p. 83) because of the circular

causality involved, with the information emitted about one individual changing as he or she responds to the information emitted from the other person, and vice versa. Individual-level research, however, has not had to address this problem because it focuses on the individual's relatively passive perceptions of specific attributes rather than mutuality of an individual's perceptions and actions with information uncovered through exploration (e.g., social interaction). We detail research on the effects of others on social action (e.g., mimicry) in the subsequent section.

Social Action

Researchers concerned with action influences investigate more inherently relational phenomena such as mirroring, mimicry, and interactional synchrony; such research, however, is not motivated by an ecological perspective. As Figure 1 indicates, in the individual-level perspective the effects of one individual's actions on another are studied without reference to the information pickup processes integral to these. Research shows that perceiving another's mannerisms or gestures can lead a perceiver to mimic the behavior unconsciously (Bargh, Chen, & Burrows, 1996; Chartrand & Bargh, 1999; Dijksterhuis & Bargh, 2001; Johnston, 2002; Kawakami, Young, & Dovidio, 2002; Sanchez Burks, 2002; Wheeler & Petty, 2001). Young babies tend to imitate the facial expressions of caregivers (Anisfield, 1979; Field, Woodson, Greenberg, & Cohen, 1982; Meltzoff & Moore, 1989, 1997). Similarly, adults imitate the facial movements or expressions of others, including yawning (Provine, 1986), pain (Bavelas, 1986; Bavelas, Black, Lemery, & Mullett, 1987), sadness (Bavelas, 1986; Bavelas et al., 1987; Strack, Martin, & Stepper, 1988), smiling, and frowning (McHugo, Lanzetta, Sullivan, Masters, & Englis, 1985). Chartrand and Bargh (1999) found that interacting individuals mimicked even more salient types of gestures such as nose rubbing and foot shaking. In addition, by having confederates mimic the body posture of participants, Chartrand and Bargh found that mimicry leads to increased liking of an interaction partner (for reviews of this research, see Chartrand & Jefferis, 2003; Dijksterhuis & Bargh, 2001). Research has also demonstrated temporally coordinated similarity in movement, posture, and gesture (i.e., "interactional synchrony"), in which individuals who are interacting show a higher degree of synchrony than noninteracting individuals (Bernieri, 1988; Bernieri, Reznick, & Rosenthal, 1988; Condon & Ogston, 1967; Kendon, 1970; LaFrance, 1979, 1982; LaFrance & Ickes, 1981). Synchrony has been associated with rapport and liking as well as healthy relationships (Bernieri & Rosenthal, 1991; Charney, 1966; Chartrand & Bargh, 1999; Julien, Brault, Chartrand, & Begin, 2000; LaFrance, 1982; LaFrance & Broadbent, 1976; Lakin & Chartrand, 2003).

Critique of Individual-Level Approaches

Although the underlying assumption of the individual-level approach is concerned with how one individual's behavior affects another, it inherently views each indi-

vidual as a *discrete* unit rather than analyzing the mutual relations between interacting individuals. Although the language of synchrony research often emphasizes interactional dynamics (likening temporally coordinated behavior to a "dance," for instance), the methods are only applied at the level of the individual—not at the level of the relation between members of the social unit. For instance, mimicry is explained as priming a cognitive representation for the action that then leads to the perceiver emitting similar behavior—in much the same way as an action can be primed by cognitive means (e.g., an unaware participant walking more slowly after an "elderly" stereotype is activated, Bargh et al., 1996). This approach is rather ineffective in explaining coordinated actions, despite researchers' suggestion that it should (Dijksterhuis & Bargh, 2001). How two or more people tightly coordinate their movements temporally within a soccer game, or while walking, or during moving an object together is poorly described by such perspectives, in part because the notion of self-organization of coordinated action is not a part of a representational explanation of physically cooperative movement. Thus, such a perspective requires untenable assumptions about temporally mimicking the other person's previous motions, namely, being able to simultaneously project the others' movements in time to make one's own body synchronize or coordinate appropriately.

Despite many important exceptions (e.g., Berry, Misovich, Kean, & Baron, 1992; Zebrowitz, 1997), some researchers examining perceptual processes similarly emphasize mediating representational processes to explain social interaction. Despite its limitations (Zebrowitz & Collins, 1997), a Brunswikian lens analysis is typically used to examine how individuals pick up and interpret clues regarding another person's attributes (Gifford, 1994). Nonverbal communication researchers similarly emphasize the separateness of two individuals, viewing the interaction as a process of one person "sending" an emotional message and the other individual "receiving" it. Such a perspective, in which each isolated unit tries to signal another person and decipher the emissions of another, does not offer a means by which the *act* of communication is the message, the unit of analysis is the joint action of communication (e.g., Clark, 1996).

Not only does the individual-level approach explain relational phenomena by decomposing a social unit into two or more discrete elements, but it also approaches the perception and action of two or more interacting individuals with similar fractionation. With the exception of research on the direct perception of relational processes (e.g., Kean, 2000; Van Acker & Valenti, 1989), research examining person perception processes—the pickup of information about another's physical, social, and dispositional attributes—is isolated from research that studies the influence of another's physical movement on one's own (e.g., mimicry). In general, the individual-level perspective does not use mutuality in explaining internal properties (person perception) or external properties (effects of action—e.g., mimicry research). Moreover, although some of the research involves the pickup of information over time (e.g., point-light studies of action), this approach does not address general principles of dynamical systems to explain how social interaction is

structured. On the other hand, the individual-level approach was a dramatic improvement over previous social psychological research in that it investigated embodied meaning using the concept of social affordance.

COGNITIVE DYNAMICS APPROACH

The second way that some researchers in social psychology have attempted to dramatically break tradition with the current top-down, representation-driven social cognitive perspective is to use the language of dynamical systems to describe and simulate social psychological processes (Arrow, McGrath, & Berdahl, 2000; Baron et al., 1994; Nowak & Vallacher, 1998; Vallacher & Nowak, 1994; Vallacher, Read, & Nowak, 2002). In contrast to the individual-level perspective, this approach looks at dynamic interactions of variables and examines emergent mutuality of a social unit as unfolding over time rather than focusing on individual-level processes. Although this approach abandons the strong assumption of representation-driven processes, it acknowledges that many social cognitive processes involve self-organizing mental dynamics evoked in response to one's social environment. Much of this research involves computer simulations (Vallacher et al., 2002), which reveal the unfolding of system-level phenomena over long time spans and how social structure emerges from self-organizing dynamics—a process difficult to examine using more traditional measurement techniques. As Figure 3 indicates, however, the emphasis is on describing the dynamics of one's mental processes, not the dynamics involved with perception-action processes between two or more individuals.

Whereas the individual-level approach to cooperation was mute on the nature of the emergence, as well as on the time-scaled processes central to cooperative activity, this second perspective approaches the problem of cooperation by describing its emergence as a dynamical system. In particular, this approach describes how initial conditions (e.g., payoff matrix, individual level of commitment to a relationship) and external constraints (e.g., amount of situational pressure) lead to the emergence of a qualitatively new state (e.g., cooperation) out of less organized interaction.

To date, these approaches have been restricted primarily to modeling social cognitive, affective, and attitudinal processes that are self-organized over time through interactions among more microlevel elements. Thus this approach focuses primarily on internal (mental) properties rather than external properties of social, dynamic systems. More specifically, researchers adopting this approach identify how the properties of complex dynamical systems (Kelso, 1995; Turvey, 1990) such as sensitivity to initial conditions, phase transitions, bifurcations, critical slowing down, critical fluctuations, hysteresis, time dependence, and nonlinear equations can be used to characterize the psychological processes that occur during cooperative interaction.

The importance of this approach is that it demonstrates how "organized patterns of social thinking can emerge without the need for a higher-level cognitive mechanism" (Vallacher et al., 2002, p. 267). Computer simulations using cellular automata and neural networks to describe dynamic patterns have simulated a variety of phenomena. In computer simulations, certain rules are programmed based on relevant psychological research; the system is then given a set of initial conditions (e.g., each cell set to have positive content or negative content) and is run repeatedly through a number of sequences examining the unfolding dynamics and resulting structure over time. For example, one cell might represent an individual with a particular opinion. This individual's opinion is hypothesized to be more strongly influenced by neighboring cells (immediate neighbors in one's community) than by distant cells or neighbors. Thus the total number of cells of individuals who come to hold the same opinion, as well as the initial weights (opinion values) and distribution of who has those opinions, has an effect on the final stable state of the system. Through such processes phenomena such as attitude polarization and pockets of minority opinions emerge (Latané & Bourgeois, 2001; Latané & Nowak, 1994; Nowak, Szamrej, & Latané, 1990; Vallacher & Nowak, 1997). Other approaches have also addressed the problem of how attitude change processes might be described by dynamical and ecological approaches (Baron & Misovich, 1993b; Kaplowitz & Fink, 1992). Interpersonal processes involving social influence and development of romantic relationships have also been modeled. For instance, audiotapes of Milgram's obedience to authority experiments were used as the basis of modeling obedience and resistance reactions (F. Rochat, Maggioni, & Modigliani, 2000). Catastrophe theory and similar models have been used to model how external pressure operating against a relationship might describe the course of romantic relationships, leading to substantial leaps in intimacy with certain trajectories (Tesser, 1980; Tesser & Achée, 1994). In addition, predicted dynamical characteristics such as hysteresis were tested in experiments using hypothetical relationship scenarios (Nowak & Vallacher, 1998).

With respect to the emergence of a cooperative social unity of action, a cognitive dynamics approach has been used to examine cooperation in game theory type tasks. In such tasks, a matrix of interdependent outcomes depends on what choice each individual makes. Dilemmas arise from the conflict between what is the best personal outcome for an individual versus the best joint outcome and also from the uncertainty of having to make one's own choice not knowing what the other individual's choice will be (Axelrod, Riolo, & Cohen, 2002). Computer simulations model a system in which each actor interacts with four neighbors. Each actor is first assigned a strategy specifying whether they cooperate on their first of four moves as well as their probability of cooperating contingent on their partner's previous choice. After each simulated actor plays with four others, actors adjust their strategies to imitate the most successful strategy of its four neighbors. Using such a simulation, Axelrod et al. examined cooperation in systems with a correlated structure—much like a geographical neighborhood with overlapping influences in who

influences whom (because neighbors of oneself are also neighbors to each other). They discovered that regardless of whether the system has a correlated structure or a random structure (nonoverlapping interactions, where one's neighbors' neighbors are not one's own neighbors), cooperation spontaneously emerges. If, however, the random structure is reshuffled at periodic intervals so that there is no historical consistency as to who an individual interacts with, no "learning" of the advantage of cooperation occurs. In sum, such approaches richly describe how group- or community-level cooperative processes unfold over time and examine mutuality in terms of interdependent outcomes—but not in terms of an emergent collective that has its own reality apart from the individual members. Moreover, the processes studied are wholly unembodied. (By embodiment we mean, as discussed earlier, that actual movement is involved rather than only internal processes.)

Another example demonstrates the usefulness of a dynamic approach for describing emergence and change in dyadic-level cooperative exchanges (e.g., intimate relationships; Baron et al., 1994). From their perspective, close relationships can be described as emerging from a pull toward engaging in cooperative behavior (a magnet effect) in competition with a pull toward maintaining one's own behavior (a maintenance tendency). Baron et al. (1994) used theorizing about close relationships (Levinger, 1980) and group socialization (Moreland & Levine, 1982) as a basis for illustrating how psychological factors (affective intensity, stress, perceived contribution of group to one's satisfaction of needs) can serve as "control" parameters that serve to trigger qualitative shifts in relationships—for example, from a stable relationship to one that deteriorates and ends. Shifts in group socialization are affected by similar shifts, for instance, from being a prospective member to a full member or ex-member of a group. The underlying variable that summarizes degree of organization or order in a relationship or group (i.e., the "order parameter") is described as degree of commitment to the group or degree of exclusivity of the relationship (Baron et al., 1994). Other notable qualities of dynamical systems are also illustrated by examination of cooperative relationships. Baron et al. discuss the asymmetry in an evolving relationship such that changes in one direction (e.g., from intimacy to relationship dissolution) are not reversible—a situation in which the history or past trajectory affects subsequent possibilities (i.e., "hysteresis"). Cooperative relationships can progress from committed to dissolved, but ended relationships rarely traverse the same developmental path backward from dissolved to committed—or at least, such reversal requires substantially different levels of the control parameter. Moreover, research supports that developing roles in a group, and developing intimate relationships, do not reflect gradual, linear shifts but are better described as dramatic reorganizations in degree of commitment and roles (phase transitions), occurring at critical values in the control parameters (Baron et al., 1994).

In general, however, one can argue that the cognitive dynamics approach either simply redescribes social psychological concepts using the language of nonlinear

dynamics (Arrow et al., 2000) or runs computer simulations to examine whether certain mathematical models, input values, and rules result in predicted dynamic patterns. In addition, the majority of experimental research conducted by researchers adopting this approach has employed a narrow range of methodologies for collecting data. For instance, Nowak and Vallacher (1998) have extensively used an experimental procedure that assesses the intrinsic dynamics of social judgment. They use a continuous measure of the distance an individual moves a computer mouse over time (e.g., between a symbol that represents self and one that represents positive feelings), as well as variance, speed, and acceleration of movement. This measure has not been used to examine cooperative action or the emergence of a collective but has focused on describing dynamics of internal psychological states. However, researchers have hypothesized about the dynamics of individuals' behavior over time. Its invariant features, the researchers report, are hypothesized to be described by one of three basic forms. Some behavioral patterns are hypothesized to reflect a fixed-point attractor—attempts to converge on a single goal or state of affairs; whereas others should display periodicity—fluctuating, for instance, between two extremes (e.g., attraction versus repulsion); whereas still other fluctuations in behavior will presumably appear unpredictable and chaotic (Nowak & Vallacher, 1998).

The primary emphasis of this approach is to demonstrate that social cognitive phenomena are dynamic and self-organized, showing characteristic patterns of change over time that therefore require nonlinear dynamical systems to explain the data. This perspective offers substantial advances over heavily representational models of social psychological processes, abandoning the view that internal processes must be understood as determined by an internal cognitive structure—an associative network model with spreading activation as the primary "dynamic" principle. The challenge for this approach is to demonstrate that this description of social psychological phenomena can yield novel predictions that can be then tested experimentally—especially to model actual interpersonal behavior, and not just internal psychological processes. That is, this approach remains at the abstract level of description and has not yet yielded empirical behavioral data for making predictions regarding emergent behavior that occurs at the local, dyadic, or small group level in actual interaction with others. In sum, this perspective is vigorously dynamic and often (but not always) involves mutuality. For example, game theoretic approaches involve mutuality in terms of individuals' outcomes being interdependent. However, the research does not focus on an emergent collective that is non-equivalent to the summation of individuals' responses. Moreover, all of the approaches described under the cognitive dynamics approach are wholly deficient in the embodiment criteria. They look solely at mental dynamics rather than the physical dynamics of movement in an emergent cooperative social entity.

In sum, no attempt has been made to describe the dynamics of actions such as in our primary example of moving a log together and whether such actions show similar conformity to the dynamic principles that they use to describe cognition. It is

difficult to see how simple cellular automata approaches (flip to state A vs. B in response to neighbors, or choose one strategy vs. another in response to neighbors) could explain the coordinated actions on a sports team, because it requires something more than mere mimicry of neighboring teammates' physical state. The same is true of our other paradigmatic examples. However, simple cellular automata approaches seem better adapted to gross movements of a group of organisms moving as a body (e.g., a flock of birds moving in sync in response merely to the motion of neighboring birds). Moreover, approaches that describe cognitive dynamics in the language of dynamical systems might similarly be used to try to describe the emergent physical movements of interacting individuals. Thus, from our perspective, the next step is to use such dynamic principles to model external qualities that involve dynamics of action and perception rather than focusing on describing and simulating dynamics of internal, disembodied cognitive processes. The most promising emerging approaches, which may well allow this to occur, include perspectives on multiagent systems (Macy & Willer, 2002; Walker & Wooldridge, 1995) and methods that allow actors to engage in joint action such as simulating fighting and dancing (e.g., by controlling "bugs" on a computer display) while simultaneously generating information that veridically specifies the actions to perceivers (Blythe, Todd, & Miller, 1999).

SOCIAL SYNERGY PERSPECTIVE

An alternative to the individual-level and cognitive dynamics approaches is our attempt to understand and measure the influence of one person on another at the relational level of a collective. Such an approach recognizes that individuals perceiving and acting together are a synergy (Rosen, 2000, p. 308), an implausibly coherent organism that is composed of diverse individual parts. The emergent social synergy is a wholly new perception-action system that cannot be understood merely from understanding the individuals from which the system emerged. Consequently, rather than simply asking whether there is information that another individual displays that lawfully specifies his or her attributes (veridically specifies personality traits), this approach asks the following: What are the emergent properties for action that are self-organized by means of another individual or individual's actions (both psychologically and behaviorally)? What are the physical task constraints that bind a situation, as well as the goals (both dyadic and individual) that can integrate a social unit? What are the aspects of the environment (the social situation—including others present) that lawfully specify the affordances for creating a social synergy? And what kinds of situation- or context-dependent information (social affordances) are social agents sensitive to? In addition, rather than just focusing attention on dyadic relations, which essentially equate a dyad to an individual + individual, the concept and experience of "we" is also addressed (Baron, 2002a, 2002b). A social synergy, we argue, can never be understood from

the mere summation or synthesis of each individual's influence on the other nor from the decomposition or analysis of "we" into its linear parts.

Asch's (1952) example described earlier, for instance, captures the problem of cooperation at the level of the relation between two individuals. Out of the simple physical action of two boys carrying a log we can understand the essence of the emergent social coordination. Out of two solo perception-action systems, a joint perception-action system emerges. Such a synergy emerges through the internal circular causality of each individual's impact on the other (Campbell, 1990) in combination with the actions of the system being influenced by previous (Caporael & Baron, 1997) and future and final (Rosen, 1991, 2000) states of the system. In other words, just as perception and action are mutually and causally coupled to behavioral aims at the individual level—by the detection of information to constrain action and by the control of action to order perception (Kugler & Turvey, 1987; Shaw & Kinsella Shaw, 1988)—the perception and action capabilities of the social unit are mutually constrained, ordered, and dynamically coupled in the satisfaction of an emergent (dyadic) experiential (Csikszentmihalyi & Nakamura, 1999) goal—Asch's (1952) "mutually shared social field." Each individual's perception is coupled to his or her partner's action as it is to his or her own, and each individual's action alters their partner's perception just as it alters his or her own. A social unit or a joint perception-action system should thus be recognized as a "new individual with an identity ... and behaviors ... of its own" (Rosen, 2000, p. 308) in which the relation of perceiving and acting is truly understood at the scale of the living system (one not constrained to biologically integrated or physically connected matter), and the perceiving and acting of those individuals within the social unit are causally entailed to form a distinct and irreducible system motivated by a mutually perceived goal.

This notion that cooperation involves the emergence of a higher-level social unit is supported by research on interpersonal conflict, social-cognitive development, and intergroup conflict. For instance, in the classic "Robber's Cave" study, Sherif and his colleagues (Sherif, Harvey, White, Hood, & Sherif, 1961), in an effort to understand how to overcome conflict, created conflict between two camps of boys. The researchers were unable to find a way to overcome the induced conflict until the situation forced the boys to cooperate, when a truck got "accidentally" stuck and required the efforts of both groups of boys to pull it out. Only when the situational constraints required that they become a higher-level acting unit did cooperation occur. Another illustration comes out of understanding an embodied cognitive account of how children develop skills overcoming perseverative reaching for hidden but moved objects (Thelen, Schoener, Scheier, & Smith, 2001). Valenti and Stoffregen (2001) suggested that the skill development does not necessarily require embodiment in an individual's neural system, but that the behavior that is learned could be based in the information dynamics occurring in a parent-child system of coordination. A third example is of Aronson's "jigsaw classroom" manipulation for removing interpersonal and achievement barriers between

children of different ethnicities, which creates a situation in which producing a final project is impossible without the contribution of individuals who have unshared pieces of information necessary for the task (Aronson, Blaney, Stepin, Sikes, & Snapp, 1978). Such research emphasizes the need for interdependence, essentially creating a higher-level social unit, a synergistic "we," before cooperative action can be observed.

An important supposition we make is that emergence of a higher-level unit, and likewise cooperation, is self-organized out of basic physical principles and simple motives (e.g., to remove an obstacle). From this perspective, the primary questions regarding perceiving and acting in the presence of another become more salient: How is the nature of "doing" changed by the presence of another person? How does a "we" emerge out of a simple situation involving two individual "I"s? What is the nature of that emergence—by what social affordance information (visual, auditory) and under what environmental demands (e.g., goal and task constraints) is it self-organized? Such issues have received some attention in analyzing formation of large-scale units: how civilizations formed in the earth's earlier history (Iberall & Wilkinson, 1993). Our interest, however, is at a more modest level of formation of social units than a civilization—how a social bond is temporarily created and then broken in the brief-lived structure of a social interaction, as well how more stable formation of structure (relationships) occurs over time.

An additional assumption of such social structuring is that once the individual-level interactions (local dynamics) lead to the emergence of some collective perception-action system, the collective emergent property exerts downward causation (Campbell, 1990) such that the behavior of the individual components that gave rise to the collective is changed top-down (Baron, 2002a; Caporael & Baron, 1997). Thus, not only does the emergent collective have unique properties distinct from the properties of the individuals involved, but also, individuals are in some sense changed by the experience of being part of a collective.³ New possibilities for an individual to act are created, and others are destroyed.

Analyzing the cooperative level requires methods and measurement that differ from those generally used in social psychology, which has used individual-level measures; it requires procedures and behavioral measures that are inherently relational. Newtonson (1993, 1994), for instance, developed measures for assessing the combined amount of behavioral activity in a dyad by using measures taken on each individual (number of joint angle changes between subsequent frames in a film of behavior). He found that an individual's stream of movement complexity has a periodic nature, with fluctuations in amplitude of position change that reflect a slow

³This point is essential to Baron's (2002b) notion of social complexity as being a situation in which there is balance between the tensions of individual orientation (sense of "I") and sense of groupness ("we"). Such complexity involves periodic cycling between individual-level and group-level behavior, within a context in which the interface between one's individual and group identities has boundaries, albeit permeable ones.

"behavior" wave (Newtson, Hairfield, Bloomingdale, & Cutino, 1987). His theorizing and primary analyses, however, are at the level of the social unit. For instance, conceptualizing interaction as a coupling of behavior waves, he used detailed analyses of filmed sequences of interactions as well as computer simulations to demonstrate behavioral waves (Newtson, 1993, 1994). A cooperative interaction (two people moving boxes) displayed different patterns of coupled behavior waves than did a competitive interaction (two people playing basketball; Newtson et al., 1987). In Newtson's view, interaction is hypothesized to be regulated by the relative amplitude or magnitude of information flow (e.g., log of amplitude of summed position change and vocal intensity) between pairs of participants' behavior waves (Newtson, 1998). That is, he speculated that people strive to maintain a certain level of relative information flow in an interaction by changing posture or changing vocal amplitude. From his perspective, nonverbal variables (amount of movement) and paralinguistic variables (e.g., loudness of speech) are substitutable for each other. Thus people can regulate the feeling of complexity in an interaction (e.g., when trying to understand difficult conversational content) by decreasing the amount of some movement—resulting also in a damping of the other's activity in response (Newtson, 1994). Apart from demonstrating that filmed interactions can be analyzed and simulated in terms of behavior waves, his remaining hypotheses have not been tested.

From the synergistic perspective, a social unit must emerge "lawfully" in the sense of being self-organized by animal–animal/animal–environment interactions, whereby social agents are, or become, attuned to information that specifies both potentials for action and constraints on action. The focus is thus not merely on information at an individual-level, but on information that specifies animal–animal/animal–environment relations—social affordances—and does so without requiring effortful, error-based, inferential processes. Thus, the methods and measures employed must be truly dynamic, because information about emergence of a higher social unit is likely to be carried by change over time—shifts in movement—path, speed, changes in speed, variability, and instability by which one gets from one state to another. In sum, this approach is dynamic and interpersonal rather than static or focused on individual-level attributes emitted from one individual and detected by another. What is not required is knowledge of an individual's inferences. Rather, possible mechanisms are grounded on lawful principles that generate a flow of information between animal-and-environment and animal-and-animal and that lawfully constrain social behavior.

For example, when a researcher offers a mechanism to explain the complicated task of behaviorally coordinating one's movement, an appeal is typically made to representational processes: "Perceiving an action activates the mental representation of this action, which in turn leads to the performance of the action" (Dijksterhuis & Bargh, 2001, p. 8). If such an approach is taken seriously, such a mechanism is ultimately untenable for temporal interpersonal coordination. Participants in an interaction would have to gauge the others' changing body positions

in space-time, project that into the future, and then move their own limbs and body in a similar fashion. Rather, it seems more plausible that stable macroscopic patterns of movement between people emerge as a function of the dynamic balancing of individual (microscopic) components of the system. Kugler and Turvey (1987) provide a relevant example of social coordination in their discussion of how termites coordinate their behavior to construct complicated nest structures by means of pheromone gradient fields. What is so remarkable about this kind of social behavior is that the whole nest-building process results from the termites following two local principles operating at the individual level: (a) move in the direction of the strongest pheromone concentration and (b) deposit building materials at the strongest point of concentration. Essentially, the control constraints that organize the coordinated building activity emerge from the link between the low-energy pheromone field and the behavior of the individual insects. The linkage forms a circular act-perceive-act information loop that brings about symmetry-breaking instabilities (attractors, saddle nodes, etc), which in turn facilitates further cooperative nest building. In other words, the cooperative behavior of nest building is the result of the pheromone field on the microscopic level, which by means of a direct information coupling results in the emergence of cooperative behavior at the macrolevel. In essence, this is a purely dynamic and self-organizing phenomenon with no calls to stage-based cognitive abilities.

This, then, offers a more plausible account (than a cognitive representation approach) of how movement coordination is achieved at a social level by assuming that the information (optical, verbal) available to people actively interacting with their environment (including other people) directs motion by maximizing certain meaningful patterns of information flow (Bernstein, 1967; Gibson, 1966, 1979/1986; Kugler & Turvey, 1987; Turvey, 1990; Turvey & Carello, 1986). Thus the act of catching a ball (the "outfielder problem") is extremely onerous if we assume that outfielders using mental procedures must calculate the trajectory and timing of the ball and predict its ultimate location. Alternatively, the task can be explained as one of merely moving backward and forward so as to keep the optical expansion and/or the optical acceleration of the ball at a steady rate (McBeath, Shaffer, & Kaiser, 1995; Michaels & Oudejans, 1992). No prediction is required as to where the ball will land, nor must the catcher calculate the rate of movement needed to get to the required location. Rather, a higher-order informational property of environments acts as a constraint for achieving a goal.

In a similar way, recent research (Richardson, Marsh, & Schmidt, 2005; Shockley, Santana, & Fowler, 2003) suggested that interpersonal coordination can be guided by simple mechanisms that involve online animal-animal information couplings emerging from the ongoing flow of perceptual information between interacting individuals rather than based on calculations or inferences about their future motion. We speculate that such information would be both specific to the behavioral control and coordination of individuals within the social unit as well as the patterns of coordinated behavior of the social unit as a whole—a circular pro-

cess of causality operating between the micro (individual) and macro levels of the social perception–action system (Baron, 2002a). Correspondingly, we speculate that other individuals, as well as the social unit as a whole, may provide frames of reference not only for psychological states of mind (as traditional social psychological research shows, others are a source of *informational influence*, Deutsch & Gerard, 1955, providing a frame for assessing the truth of our views), but also in terms of orienting individuals physically and perceptually in a social, physical environment. If so, certain patterns of interpersonal and social coordination (e.g., the notion of being in sync) may prove to be a stable result of appropriately maximizing the patterns of information flow required for a successful social encounter. Movement from the other may provide a mooring for their own unconstrained degrees of freedom, affecting the phasing of their own movements. When two or more social agents are put into matching frames of reference, similar ways of viewing information in a situation (see Kugler, 2004), such as when walking together in a synchronous manner (a matching inertial frame of reference), then information specific to the environment and the other individual(s) can be exchanged or picked up with minimum uncertainty. Indeed, it is hard to imagine how two people could hold a conversation successfully with one individual walking at a different pace than the other. Similarly, Newtonson (1998) speculated that if an individual is striving to maintain a certain amplitude of behavioral/vocal activity relative to another, synchronizing of movement might make assessing relative amplitude easier.

This alternative perspective to the local, physical (individual-level), or abstract and macroscopic (cognitive dynamics) perspectives previously discussed takes as a starting point what is known about the laws that govern solo perception–action systems and uses that as a starting point to conceptualize how joint-perception–action systems might be similar when two or more individuals are co-acting or are co-operating. To date, little research has explored the implications of an ecological, perception–action perspective for joint perception–action systems using this approach. However, several recent avenues of theorizing and research that we are conducting provide an appropriate starting place for examining the similitude of collective perception–action processes, and determining how the added complexity of social interaction reveals novel findings.

Affordances in Social Interaction

We suggest that one important issue from a social synergistic perspective is that there are new possibilities for action that can be realized—affordances—that exist only in the synergy. Research on how action possibilities are perceived, acted on, and how they can be assessed from the relationship between animal and environment (Carello, 1989; Fitzpatrick, Carello, Schmidt, & Corey, 1994; Heft, 1993, 2003; Mark et al., 1997; Warren, 1984) provides an approach to understanding how the presence of another person changes the affordance structure. Each individual brings to a situation certain effectivities (action capabilities), and thus when one moves

from solo action to having another person present, there are new possibilities for action that can be realized—affordances at the level of the new synergy. In part, this approach builds on the logic that transitions in solo actions are predicted by a body-scaled parameter, a “pi-number” (which, like pi, is dimensionless) that reflects a measurement of the environment *taken with respect* to the individual’s physical abilities. For instance, for gripping objects, a pi-number that captures the relationship between hand span and object length (Cesari & Newell, 1999; Newell, Scully, Tenenbaum, & Hardiman, 1989; van der Kamp, Savelsbergh, & Davis, 1998) could be used with two people. To the extent to which another person extends an individual’s action capabilities (i.e., effectivities) quantitatively, allowing the individual, for instance, to pick up larger objects, shifts in behavior from solo to joint action should also be predicted by a similar animal–animal–environment relational variable. Thus, just as the pi-number determines shifts between how one picks up an object individually (e.g., with one hand vs. two), so might there be a pi-number at the interaction level that determines a shift from solo to joint action. We find that the basis of this pi-number is the relationship between pair’s arm spans (e.g., matched or mismatched in height) and their arm spans relative to object length (Isenhower, Marsh, Carello, Baron, & Richardson, 2005; Richardson, Marsh, & Baron, 2005). In this research then, we successfully use what is known about how affordances at the solo level for moving objects (shifts between different modes of lifting: one hand or two hands) are dictated by a relational variable to predict how shifts between solo and joint action are similarly dictated by a relational variable.

For the synergy of an interpersonal perception–action system, however, we believe that a social pi-number will also require an accompanying quantification of interpersonal coupling—the degree of connectedness or degree of “teamness”—to capture a unit’s unique social effectivities. Such a quality might be analogous to the stiffness or elasticity of a movement system, or coupling strength among systems—high effectivities in teamness would mean high awareness of the other’s movements, easy anticipation, and responsiveness to the other, much as teammates on a well honed basketball team can show immediate awareness of the motions of teammates, and quick ability to respond to their moves. For the task of plank-lifting, degree of connectedness could be based in something as simple as whether the pairs are strangers or know each another.

For some contexts, the presence of another individual should lead not merely to quantitatively extending effectivities but to the emergence of qualitatively new possibilities for action. In addition, environmental demands and deficiency states may increase the press for unity of action. Just as inadequacies in food sources force chemical changes in an individual amoeba such that it moves to become joined with others to create a slime mold capable of finding new food (Garfinkel, 1987; Goodwin, 1994) and hunter–gatherers experiencing environmental pressures begin to coalesce in civilizations (Iberall & Wilkinson, 1993), so are humans motivated by unmet needs (e.g., an obstacle that cannot be removed alone) to become a social unit.

Taking as a starting point a methodology for which we can make explicit and precise predictions about the scaling relationship and intrinsic dynamics of affordances at the individual level, we can determine how dual perception–action systems are similar to and differ from those of individuals. For example, recent research suggests that joint action systems can be understood in a way comparable to individual perception–action systems: as a function of qualities of the environment, taken with respect to both those individuals considered jointly. In a series of experiments examining how pairs of individuals shift from solo to joint action in a task involving carrying a series of planks of increasing or decreasing length, we found that the transitions beyond unaided solo action were determined by a body-scaled, dimensionless pi-number (Richardson, Marsh, & Baron, 2005) much as grip transitions (e.g., 1 hand to 2 hand) were predicted by a pi-number (hand length relative to plank length).

One additional assumption of the synergistic approach is that the dynamics of a collective perception–action system will display characteristic features of nonlinear dynamical systems. Thus, the history of a pair's immediately prior sequence of actions should affect the subsequent trajectory and the point at which they show transitions in action (hysteresis). With a different prior action sequence, the trajectory of joint action and transition points (e.g., from solo to joint action or vice versa) will be different. In fact, recent research examining the shift from solo action to joint action in pairs moving planks of increasing or decreasing size finds evidence for such effects. Hysteresis was found in transitions for experiments involving action, whereas enhanced contrast was found in perception experiments (Richardson, Marsh, & Baron, 2005). For instance, when plank lengths gradually decreased in size over trials, participants more quickly shifted to perceiving possibilities for solo action than when plank length increased in size, whereas when actively lifting the planks, participants delayed shifting to solo action in descending-size conditions relative to the ascending-size conditions. Other characteristics of nonlinear dynamical systems can be discovered through use of such methodology, for instance, the sudden emergence of new possibilities for action when someone else is present, and the operation of "control parameter" induced shifts in states of the interaction. This research suggests that the same perception–action coupling that informationally constrains individual action also operates at the interpersonal level and provides a compelling case for approaching embodied cooperation as a self-organizing phenomenon that displays properties of dynamical systems.

Between-Person Movement Coordination

A methodology that assesses the influence of one individual's movement on another in a temporally coordinated way, but at the interactional social unity level, draws from research in human movement science and coupled oscillator theory employing measurement technologies that continuously assess each individual's movement over time. The first assumption from this perspective is that, as scien-

tists from biology, biomechanics, and psychology have argued, the basis of much of biological movement is oscillatory. That is, movement is often periodic—as is the case, for instance, for walking, breathing, imperceptible swaying during standing still, beating of heart muscles, and swinging of arms in walking (Ariaratnam & Strogatz, 2001; Haken, Kelso, & Bunz, 1985; Kelso, 1995; Kugler & Turvey, 1987; Mirollo & Strogatz, 1990; Rosen, 1991; Schmidt & Turvey, 1994; Strogatz & Stewart, 1993; Turvey, 1990; von Holst, 1973; Winfree, 1967; Yeung & Strogatz, 1999). Prior research leads to the suggestion that interpersonal movement coordination can be explained by the pickup of information about the overt (Goodman, Isenhour, Marsh, Schmidt, & Richardson, 2005; Richardson, Marsh, & Schmidt, 2005; Schmidt, O'Brien, & Sysko, 1999) or subtle (Shockley et al., 2003) phasing of others' movements. In a sense, this information that individuals acquire may provide a mooring for their own unconstrained degrees of freedom, affecting the phasing of their own movements. Human movement may be lawfully constrained by other people's movement the way other animals have been found to be constrained by conspecifics. For instance, fireflies have their own individual rate of blinking, but a coupling principle from statistical dynamics (hypothesizing perhaps, that seeing the blink of another has an energy impact on the firefly) means that a firefly's own rate of blinking is pulled in the direction of other fireflies around, resulting—when there are sufficient numbers of fireflies—in pulsing masses of fireflies blinking in synchrony (Strogatz, 2003; Strogatz & Stewart, 1993).

Research testing coupled oscillator theory for the coordination of simple rhythmic movements (e.g., pendulum swinging at the wrist joints or rocking in rocking chairs) for pairs of individuals has revealed that individuals who are instructed to coordinate their rhythmic movements intentionally are harnessing a coupled oscillator dynamic. For example, participant pairs who were instructed to coordinate their movements 180° out of phase (antiphase) and were forced to increase their speed of movement showed a breakdown and shift into in-phase swinging, an outcome that is generically found in coupled rhythmic systems throughout nature (Schmidt, Bienvenu, Fitzpatrick, & Amazeen, 1998; Schmidt et al., 1990). In addition, Schmidt and his colleagues have demonstrated that this same coupled-oscillatory dynamic underlies unintentional synchronization between individuals. Pairs of individuals even become unintentionally phase-entrained when attempting to maintain their own individual tempo in swinging pendulums (Schmidt & O'Brien, 1997). Moreover, coupling dynamics between individuals follow other predictions consistent with coupled oscillator theory such as when two movements are phase locked but have unequal inherent (uncoupled) frequencies, then the inherently faster oscillator leads within the cycle (Schmidt & Turvey, 1994). In addition, transitions from out-of-phase to in-phase modes naturally occur with increased values of the control parameter, that is, with forced increased frequency of movement (Schmidt et al., 1990). Measures that capture more subtle and global behavior (postural sway) similarly show that an informational coupling of individuals (e.g., through conversation) leads to increased behavioral coordina-

tion, as assessed by cross-recurrence quantification—the amount of overlap in the reconstructed phase space of individuals' postural time series (Shockley et al., 2003). In addition, recent research suggests that conversation may be an important medium for informational coupling of physical movement. Shockley et al. found that even when individuals could not see each other, greater coordination of postural sway occurred between individuals who were conversing than between nonconversing individuals.

The important aspect of this research is that it uses truly dynamic measures rather than eliciting judges' subjective judgments of synchrony or coding static features at multiple points or providing more nearly continuous but extremely time-consuming coding of objective features (e.g., limb positions of two individuals; Newton et al., 1987). More important, it uses measures that are not of each individual considered separately and then correlated in some way, but the key measurement is of the relation—for instance, whether the pairs are in-phase or antiphase, or how much shared activity there is in the postural time series of the individuals' movements. Recent studies have found that such movement methodologies hold considerable promise for understanding the dynamics of emergent social psychological processes such as those involved in cooperative versus competitive tasks (Johnston, Richardson, Schmidt, Marsh, & Miles, 2005).

We believe that the logic of emergent phenomena of coordinated movement at the dyadic level should also hold for larger groups of individuals. Moreover, looking at larger groups of individuals will allow us to examine multipurpose approaches for explaining collective group movement. Predictions regarding larger groups of individuals require references to research on group movements of organisms such as schools of fish and flocks of birds using mean field theory (Toner & Tu, 1998; Wong, 2000). The organized movements of these collectives can be understood as being a consequence of direct information about the movement of one's immediate neighbors. This provides a force that operates on the direction of a fish's own movement and that of the school as a whole. Coordinated social interactions might similarly be self-organizing systems founded on such laws. More recently, Neda and colleagues used a similar approach (Neda, Ravasz, Brechet, Vicsek, & Barabasi, 2000) in an examination of synchronized clapping. More specifically, they were interested in how an applauding audience often starts out clapping in a highly unsynchronized way and then after some period of time suddenly makes the transition to synchronized clapping. Of particular interest was how a clapping beat spontaneously emerges, disappears, and reemerges despite the fact that every member of the audience has a preferred clapping tempo and there is no external beat being brought to bear on the audience. The results indicated that the mean noise intensity brought about the changes in synchrony, with the clappers making spontaneous transitions from clapping in an asynchronous manner to achieve higher noise intensity and a synchronous manner that requires less effort. Furthermore, the common tempo of synchronous clapping emerged as a result of each clapper affecting the other, locally as well as globally.

STUDYING THE STRUCTURING OF SOCIAL BEHAVIOR

In sum, we believe that the synergistic approach provides a unique way of ascertaining the essential social nature of interaction as involving mutuality of influence in which novel qualities emerge in a new unit: the synergy of an interpersonal perception-action system. This perspective, we believe, best considers all three features that are essential aspects of social interaction: the structuring of social behavior through mutuality of influence; a concern with embodied (rather than merely mental) properties of interaction; and a reliance on universal laws of biological, dynamical systems. Just as the presence of another individual provides unique possibilities for action, so does it create new physical and psychological constraints on perception-action systems. Such a system has social effectivities that emerge because of unique properties of the involved individuals, and yet the social effectivities that emerge cannot be decomposed into the effectivities of the individual actors. Moreover, we believe that such a perspective will illustrate that dynamical principles that operate in an interpersonal perception-action system have qualities that are universal to complex dynamical systems.

One final issue bears mentioning. The advantages of the individual-level and cognitive dynamics approaches are that they involve less radical reconceptualization of what interpersonal behaviors and social psychological phenomena are appropriate behaviors of study, and they offer an immediate focus on familiar phenomena (personality traits, social cognitive processes). The synergistic approach alternatively uses more unusual methods such as having people swing pendulums together and move objects together—procedures that are rather distant from the immediate measures of psychological attributes and processes commonly measured in social psychological experiments. Thus a reader might reasonably question whether the procedures we are advocating have any ultimate bearing on understanding “truly” social phenomena such as judgments, emotions, attitudes, and relationships.

We believe so. Despite the fact that the topic has been relatively neglected in interpersonal interaction, the basic issues these tasks examine, such as the emergence of a basic social unit, are at the very essence of what it means to be social: to be changed from merely being an individual to being something qualitatively different. Moreover, the procedures may allow us to make rather novel predictions about rather precise points at which psychological experiences will shift. For instance, feelings of uncertainty and bifurcation points at which an interaction can shift into one that feels much more intimate or much more distant will occur at those very points at which the animal-animal-environment relation predicts that shifts in action will emerge.

Moreover, we can make relatively precise predictions about the nature of patterned movement we expect. Social psychologists also concerned with similar phenomena can make only broad predictions, such as the fact that mirroring behavior

(termed the "chameleon effect" by Chartrand and Bargh, 1999) will somehow occur, whereas we strive to make law-driven predictions about the nature of and constraints on such coordinated action. The approach we introduce yields much more precise predictions about behavior, grounded in knowledge of the animal–animal–environment mutuality and understanding of the interplay between the information available to an actor and the actions that result. Whereas current social psychological approaches focus on the *artifice* of an individual, who, like a chameleon changing color, changes behavior in response to others and fails to remain individualistic in the context of others behaving differently, our approach sees the mutuality of chameleons interacting with each other and their environment as the very essence of being a socially "authentic" being. Viewed this way the focus is not on the artifice of the solo individual responding to a force in the environment to which it passively responds. Rather, we see sociality as a process within which the chameleon, by moving off the lonely rock into an environment with other creatures, participates in creating colorful new possibilities for a social quilt that is more than a collection of individual patches.

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REFERENCES

- Ambady, N., Hallahan, M., & Rosenthal, R. (1995). On judging and being judged accurately in zero-acquaintance situations. *Journal of Personality and Social Psychology*, 69, 518–529.
- Ambady, N., & Rosenthal, R. (1992). Thin slices of expressive behavior as predictors of interpersonal consequences: A meta-analysis. *Psychological Bulletin*, 111, 256–274.
- Ambady, N., & Rosenthal, R. (1993). Half a minute: Predicting teacher evaluations from thin slices of nonverbal behavior and physical attractiveness. *Journal of Personality and Social Psychology*, 64, 431–441.
- Anderson, P. W., & Stein, D. L. (1987). Broken symmetry, emergent properties, dissipative structures, life. In F. E. Yates (Ed.), *Self-organizing systems: The emergence of order* (pp. 445–457). New York: Plenum.
- Anisfield, M. (1979). Response to Meltzoff and Moore (1977). *Science*, 205, 214.
- Ariaratnam, J. T., & Strogatz, S. H. (2001). Phase diagram for the Winfree model of coupled nonlinear oscillators. *Physical Review Letters*, 86, 4278–4281.
- Aronson, E., Blaney, N., Stephin, C., Sikes, J., & Snapp, M. (1978). *The jigsaw classroom*. Beverly Hills, CA: Sage.

- Arrow, H., McGrath, J. E., & Berdahl, J. L. (2000). *Small groups as complex systems: Formation, coordination, development, and adaptation*. Thousand Oaks, CA: Sage.
- Asch, S. (1952). *Social psychology*. Englewood Cliffs, NJ: Prentice Hall.
- Axelrod, R., Riolo, R. L., & Cohen, M. D. (2002). Beyond geography: Cooperation with persistent links in the absence of clustered neighborhoods. *Personality and Social Psychology Review*, 6, 341–346.
- Bargh, J. A., Chen, M., & Burrows, L. (1996). Automaticity of social behavior: Direct effects of trait construct and stereotype activation on action. *Journal of Personality and Social Psychology*, 71, 230–244.
- Baron, R. M. (1980). Contrasting approaches to social knowing: An ecological perspective. *Personality and Social Psychology Bulletin*, 6, 591–600.
- Baron, R. M. (1981). Social knowing from an ecological-event perspective: A consideration of the relative domains of power for cognitive and perceptual modes of knowing. In J. Harvey (Ed.), *Cognition, social behavior, and the environment*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Baron, R. M. (2002a, October). *A dynamical systems perspective on individual-group relations: Theoretical and applied considerations*. Paper presented at the meeting of the Society for Experimental Social Psychology, Columbus, OH.
- Baron, R. M. (2002b). Exchange and development: A dynamical, complex systems perspective. In B. Laursen & W. G. Graziano (Eds.), *Social exchange in development. New directions for child and adolescent development* (pp. 53–71). San Francisco, CA: Jossey-Bass/Pfeiffer.
- Baron, R. M., Amazeen, P. G., & Beek, P. J. (1994). Local and global dynamics of social relations. In R. R. Vallacher (Ed.), *Dynamical systems in social psychology* (pp. 111–138). San Diego, CA: Academic.
- Baron, R. M., & Misovich, S. J. (1993a). Dispositional knowing from an ecological perspective. *Personality and Social Psychology Bulletin*, 19, 541–552.
- Baron, R. M., & Misovich, S. J. (1993b). An integration of Gibsonian and Vygotskian perspectives on changing attitudes in group contexts. *British Journal of Social Psychology*, 32, 53–70.
- Barsalou, L. W., Niedenthal, P. M., Barbey, A. K., & Ruppert, J. A. (2003). Social embodiment. In B. H. Ross (Ed.), *The psychology of learning and motivation* (Vol. 43, pp. 43–92). Boston: Academic.
- Bavelas, J. B. (1986). "I show how you feel": Motor mimicry as a communicative act. *Journal of Personality and Social Psychology*, 50, 322–329.
- Bavelas, J. B., Black, A., Lemery, C. R., & Mullett, J. (1987). Motor mimicry as primitive empathy. In N. Eisenberg & J. Strayer (Eds.), *Empathy and its development* (pp. 317–338). New York: Cambridge University Press.
- Bernieri, F. J. (1988). Coordinated movement and rapport in teacher–student interactions. *Journal of Nonverbal Behavior*, 12, 120–138.
- Bernieri, F. J., Reznick, J. S., & Rosenthal, R. (1988). Synchrony, pseudosynchrony, and dissynchrony: Measuring the entrainment process in mother–infant interactions. *Journal of Personality and Social Psychology*, 54, 243–253.
- Bernieri, F. J., & Rosenthal, R. (1991). Interpersonal coordination: Behavioural matching and interactional synchrony. In R. S. Feldman & B. Rime (Eds.), *Fundamentals of nonverbal behavior* (pp. 401–432). Cambridge, England: Cambridge University Press.
- Bernstein, N. A. (1967). *The control and regulation of movements*. London: Pergamon.
- Berry, D. S., & McArthur, L. Z. (1988). What's in a face? Facial maturity and the attribution of legal responsibility. *Personality and Social Psychology Bulletin*, 14, 23–33.
- Berry, D. S., & Misovich, S. J. (1994). Methodological approaches to the study of social event perception. *Personality and Social Psychology Bulletin*, 20, 139–152.
- Berry, D. S., Misovich, S. J., Kean, K. J., & Baron, R. M. (1992). Effects of disruption of structure and motion on perceptions of social causality. *Personality and Social Psychology Bulletin*, 18, 237–244.
- Blythe, P. W., Todd, P. M., & Miller, G. F. (1999). How motion reveals intention: Categorizing social interactions. In G. Gigerenzer & P. M. Todd (Eds.), *Simple heuristics that make us smart. Evolution and cognition* (pp. 257–285). London: Oxford University Press.

- Boker, S. M., & Rotondo, J. L. (2003). Symmetry building and symmetry breaking in synchronized movement. In M. Stamenov & V. Gallese (Eds.), *Mirror neurons and the evolution of brain and language* (pp. 163–171). Amsterdam: John Benjamins.
- Borkenau, P., & Liebler, A. (1992). The cross-modal consistency of personality: Inferring strangers' traits from visual or acoustic information. *Journal of Research in Personality*, 26, 183–204.
- Borkenau, P., & Liebler, A. (1995). Observable attributes as manifestations and cues of personality and intelligence. *Journal of Personality*, 63, 1–25.
- Buck, R. (1988). The perception of facial expression: Individual regulation and social coordination. In T. R. Alley (Ed.), *Social and applied aspects of perceiving faces. Resources for ecological psychology* (pp. 141–165). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Campbell, D. T. (1990). Levels of organization, downward causation, and the selection-theory approach to evolutionary epistemology. In G. Greenberg & E. Tobach (Eds.), *Theories of the evolution of knowing. The T. C. Schneirla Conference series, Vol. 4* (pp. 1–17). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Caporael, L. R., & Baron, R. M. (1997). Groups as the mind's natural environment. In J. A. Simpson (Ed.), *Evolutionary social psychology* (pp. 317–344). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Carello, C. (1989). Visually perceiving what is reachable. *Ecological Psychology*, 1, 27–54.
- Cesari, P., & Newell, K. M. (1999). The scaling of human grip configurations. *Journal of Experimental Psychology: Human Perception and Performance*, 25, 927–935.
- Charney, E. J. (1966). Psychosomatic manifestation of rapport in psychotherapy. *Psychosomatic Medicine*, 28, 305–315.
- Chartrand, T. L., & Bargh, J. A. (1999). The chameleon effect: The perception-behavior link and social interaction. *Journal of Personality and Social Psychology*, 76, 893–910.
- Chartrand, T. L., & Jefferis, V. E. (2003). Consequences of automatic goal pursuit and the case of nonconscious mimicry. In J. P. Forgas (Ed.), *Social judgments: Implicit and explicit processes* (pp. 290–305). New York: Cambridge University Press.
- Clark, H. H. (1996). *Using language*. New York: Cambridge University Press.
- Condon, W. S., & Ogston, W. D. (1967). A segmentation of behavior. *Journal of Psychiatric Research*, 5, 221–235.
- Csikszentmihalyi, M., & Nakamura, J. (1999). Emerging goals and the self-regulation of behavior. In R. S. Wyer (Ed.), *Perspectives on behavioral self-regulation* (Vol. 12, pp. 107–118). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
- Cutting, J. E., & Kozlowski, L. T. (1977). Recognizing friends by their walk: Gait perception without familiarity cues. *Bulletin of the Psychonomic Society*, 9, 353–356.
- Deutsch, M., & Gerard, H. B. (1955). A study of normative and informational social influences upon individual judgment. *Journal of Abnormal and Social Psychology*, 51, 629–636.
- Dijksterhuis, A., & Bargh, J. A. (2001). The perception-behavior expressway: Automatic effects of social perception on social behavior. In M. P. Zanna (Ed.), *Advances in experimental social psychology* (Vol. 33, pp. 1–40). San Diego, CA: Academic.
- Dovidio, J. F., Brown, C. E., Heltman, K., & Ellyson, S. L. (1988). Power displays between women and men in discussions of gender-linked tasks: A multichannel study. *Journal of Personality and Social Psychology*, 55, 580–587.
- Dovidio, J. F., & Ellyson, S. L. (1982). Decoding visual dominance: Attributions of power based on relative percentages of looking while speaking and looking while listening. *Social Psychology Quarterly*, 45, 106–113.
- Ellyson, S. L., Dovidio, J. F., Corson, R. L., & Vinicur, D. L. (1980). Visual dominance behavior in female dyads: Situational and personality factors. *Social Psychology Quarterly*, 43, 328–336.
- Exline, R. V., Ellyson, S. L., & Long, B. (1975). Visual behavior as an aspect of power role relationships. In P. Pliner, L. Krames, & T. Alloway (Eds.), *Nonverbal communication of aggression* (pp. 21–52). New York: Plenum.
- Feldman Barrett, L., Niedenthal, P. M., & Winkielman, P. (Eds.). (2005). *Emotion and consciousness*. New York: Guilford.

- Field, T. M., Woodson, R., Greenberg, R., & Cohen, D. (1982). Discrimination and imitation of facial expressions by neonates. *Science*, 218, 179-181.
- Fitch, H. L., Tuller, B., & Turvey, M. T. (Eds.). (1982). *The Bernstein perspective III: Tuning of coordinative structures with special reference to perception*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Fitzpatrick, P., Carello, C., Schmidt, R. C., & Corey, D. (1994). Haptic and visual perception of an affordance for upright posture. *Ecological Psychology*, 6, 265-287.
- Gangestad, S. W., Simpson, J. A., DiGeronimo, K., & Biek, M. (1992). Differential accuracy in person perception across traits: Examination of a functional hypothesis. *Journal of Personality and Social Psychology*, 62, 688-698.
- Garfinkel, A. (1987). The slime mold *Dictyostelium* as a model of self-organization in social systems. In E. E. Yates (Ed.), *Self-organizing systems: The emergence of order* (pp. 181-212). New York: Plenum.
- Gibson, J. J. (1966). *The senses considered as perceptual systems*. Boston: Houghton Mifflin.
- Gibson, J. J. (1986). *The ecological approach to visual perception*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc. (Original work published 1979)
- Gifford, R. (1994). A lens-mapping framework for understanding the encoding and decoding of interpersonal dispositions in nonverbal behavior. *Journal of Personality and Social Psychology*, 66, 398-412.
- Gilbert, D. T., & Krull, D. S. (1988). Seeing less and knowing more: The benefits of perceptual ignorance. *Journal of Personality and Social Psychology*, 54, 193-202.
- Gilbert, M. (1996). *Living together : Rationality, sociality, and obligation*. Lanham, MD: Rowman & Littlefield.
- Gilbert, M. (2000). *Sociality and responsibility: New essays in plural subject theory*. Lanham, MD: Rowman & Littlefield.
- Goodman, J. R. L., Isenhower, R. W., Marsh, K. L., Schmidt, R. C., & Richardson, M. J. (2005). The interpersonal phase entrainment of rocking chair movements. In H. Heft & K. L. Marsh (Eds.), *Studies in perception and action VIII: Thirteenth International Conference on Perception and Action* (pp. 49-53). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
- Goodwin, B. (1994). *How the leopard changed its spots: The evolution of complexity*. New York: Scribner.
- Gunns, R. E., Johnston, L., & Hudson, S. M. (2002). Victim selection and kinematics: A point-light investigation of vulnerability to attack. *Journal of Nonverbal Behavior*, 26, 129-158.
- Haken, H., Kelso, J. A. S., & Bunz, H. (1985). A theoretical model of phase transitions in human hand movements. *Biological Cybernetics*, 51, 347-356.
- Heft, H. (1993). A methodological note on overestimates of reaching distance: Distinguishing between perceptual and analytical judgments. *Ecological Psychology*, 5, 255-271.
- Heft, H. (2003). Affordances, dynamic experience, and the challenge of reification. *Ecological Psychology*, 15, 149-180.
- Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.
- Iberall, A. S. (1987). A physics for study of civilizations. In E. E. Yates (Ed.), *Self-organizing systems: The emergence of order* (pp. 521-540). New York: Plenum.
- Iberall, A. S., & Soodak, H. (1987). A physics for complex systems. In E. E. Yates (Ed.), *Self-organizing systems: The emergence of order* (pp. 499-520). New York: Plenum.
- Iberall, A. S., & Wilkinson, D. (1993). Essay VI: Some basic aspects of a social physics: Locating political spectroscopy; characterizing its history. In A. S. Iberall, D. Wilkinson, & D. White (Eds.), *Foundations for social and biological evolution, progress toward a physical theory of civilization and of speciation* (pp. 129-160). Laguna Hills, CA: Cri-de-Coeur.
- Isenhower, R. W., Marsh, K. L., Carello, C., Baron, R. M., & Richardson, M. J. (2005). The specificity of intrapersonal and interpersonal affordance boundaries: Intrinsic vs. extrinsic metrics. In H. Heft & K. L. Marsh (Eds.), *Studies in perception and action VIII: Thirteenth International Conference on Perception and Action* (pp. 54-58). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
- Johansson, G. (1977). Studies on visual perception of locomotion. *Perception*, 6, 365-376.
- Johnston, L. (2002). Behavioral mimicry and stigmatization. *Social Cognition*, 20, 18-35.

- Johnston, L., Hudson, S. M., Richardson, M. J., Gunns, R. E., & Garner, M. (2004). Changing kinematics as a means of reducing vulnerability to attack. *Journal of Applied Social Psychology*, 34, 514-537.
- Johnston, L., Richardson, M. J., Schmidt, R. C., Marsh, K. L., & Miles, L. (2005, July). Focusing on the action in social interaction. In K. L. Marsh & M. J. Richardson (Chairs), *Formation of social perception-action units*. Symposium conducted at the 13th International Conference on Perception and Action, Monterey, CA.
- Jordet, G. (2005). Applied cognitive sport psychology (ACSP) in team ball sports: An ecological approach. In R. Stelter & K. K. Roessler (Eds.), *New approaches to sport and exercise psychology*. (pp. 147-174). Aachen, Germany: Meyer & Meyer.
- Julien, D., Brault, M., Chartrand, E., & Begin, J. (2000). Immediacy behaviours and synchrony in satisfied and dissatisfied couples. *Canadian Journal of Behavioural Science*, 32, 84-90.
- Kalick, S. M., Zebrowitz, L. A., Langlois, J. H., & Johnson, R. M. (1998). Does human facial attractiveness honestly advertise health? Longitudinal data on an evolutionary question. *Psychological Science*, 9, 8-13.
- Kaplowitz, S. A., & Fink, E. L. (1992). Dynamics of attitude change. In R. L. Levine & H. E. Fitzgerald (Eds.), *Analysis of dynamic psychological systems* (Vol. 2, pp. 341-369). New York: Plenum.
- Kawakami, K., Young, H., & Dovidio, J. F. (2002). Automatic stereotyping: Category, trait, and behavioral activations. *Personality and Social Psychology Bulletin*, 28, 3-15.
- Kean, K. J. (2000). An investigation into the interpersonal kinematics of cooperation and competition. *Dissertation Abstracts International*, 60, 4965B. (Proquest No. 73019318i)
- Kelso, J. A. S. (1995). *Dynamic patterns*. Cambridge, MA: MIT Press.
- Kendon, A. (1970). Movement coordination in social interaction: Some examples described. *Acta Psychologica*, 32, 101-125.
- Kenny, D. A. (1994). *Interpersonal perception: A social relations analysis*. New York: Guilford.
- Kenny, D. A., Horner, C., Kashy, D. A., & Chu, L. C. (1992). Consensus at zero acquaintance: Replication, behavioral cues, and stability. *Journal of Personality and Social Psychology*, 62, 88-97.
- Kugler, P. N. (2004, June). *Stalking the engine of science*. Paper presented at Symmetry and Duality: Principles for an Ecological Psychology. A Festschrift in Honor of Robert E. Shaw, University of Connecticut, Storrs.
- Kugler, P. N., Kelso, J. A. S., & Turvey, M. T. (1980). On the concept of coordinative structures as dissipative structures: I. Theoretical lines of convergence. In G. E. Stelmach & J. Requin (Eds.), *Tutorials in motor behavior* (pp. 3-45). Amsterdam: North-Holland.
- Kugler, P. N., & Turvey, M. T. (1987). *Information, natural law, and the self-assembly of rhythmic movement*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- LaFrance, M. (1979). Nonverbal synchrony and rapport: Analysis by the cross-lag panel technique. *Social Psychology Quarterly*, 42, 66-70.
- LaFrance, M. (1982). Posture mirroring and rapport. In M. Davis (Ed.), *Interaction rhythm: Periodicity in communicative behavior* (pp. 279-298). New York: Human Sciences.
- LaFrance, M., & Broadbent, M. (1976). Group rapport: Posture sharing as a nonverbal indicator. *Group and Organization Studies*, 1, 328-333.
- LaFrance, M., & Ickes, W. (1981). Nonverbal synchrony and interactional involvement: Sex and sex typing effects. *Journal of Nonverbal Behavior*, 5, 139-154.
- Lakin, J. L., & Chartrand, T. L. (2003). Using nonconscious behavioral mimicry to create affiliation and rapport. *Psychological Science*, 14, 334-339.
- Latané, B., & Bourgeois, M. J. (2001). Successfully simulating dynamic social impact: Three levels of prediction. In J. P. Forgas (Ed.), *Social influence: Direct and indirect processes. The Sydney Symposium of Social Psychology* (pp. 61-76). Philadelphia: Psychology Press.
- Latané, B., & Nowak, A. (1994). Attitudes as catastrophes: From dimensions to categories with increasing involvement. In A. Nowak (Ed.), *Dynamical systems in social psychology* (pp. 219-249). San Diego, CA: Academic.

- Levesque, M. J., & Kenny, D. A. (1993). Accuracy of behavioral predictions at zero acquaintance: A social relations analysis. *Journal of Personality and Social Psychology*, 65, 1178-1187.
- Levinger, G. (1980). Toward the analysis of close relationships. *Journal of Experimental Social Psychology*, 16, 510-544.
- Macy, M. W., & Willer, R. (2002). From factors to actors: Computational sociology and agent-based modeling. *Annual Review of Sociology*, 28, 143-166.
- Mark, L. S., Nemeth, K., Gardner, D., Dainoff, M. J., Paasche, J., Duffy, M., et al. (1997). Postural dynamics and the preferred critical boundary for visually guided reaching. *Journal of Experimental Psychology: Human Perception and Performance*, 23, 1365-1379.
- Mark, L. S., Shaw, R. E., & Pittenger, J. B. (1988). Natural constraints, scales of analysis, and information for the perception of growing faces. In T. R. Alley (Ed.), *Social and applied aspects of perceiving faces: Resources for ecological psychology* (pp. 11-49). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- McArthur, L. Z., & Baron, R. M. (1983). Toward an ecological theory of social perception. *Psychological Review*, 90, 215-238.
- McBeath, M. K., Shaffer, D. M., & Kaiser, M. K. (1995). How baseball outfielders determine where to run to catch fly balls. *Science*, 268, 569-573.
- McHugo, G. J., Lanzetta, J. T., Sullivan, D. G., Masters, R. D., & Englis, B. G. (1985). Emotional reactions to a political leader's expressive displays. *Journal of Personality and Social Psychology*, 49, 1513-1529.
- McLeod, P. L., & Rosenthal, R. (1983). Micromomentary movement and the decoding of face and body cues. *Journal of Nonverbal Behavior*, 8, 83-90.
- Meltzoff, A. N., & Moore, M. K. (1989). Imitation in newborn infants: Exploring the range of gestures imitated and the underlying mechanisms. *Developmental Psychology*, 25, 954-962.
- Meltzoff, A. N., & Moore, M. K. (1997). Explaining facial imitation: A theoretical model. *Early Development & Parenting*, 6, 179-192.
- Michaels, C. F., & Oudejans, R. R. (1992). The optics and actions of catching fly balls: Zeroing out optical acceleration. *Ecological Psychology*, 4, 199-222.
- Mirollo, R. E., & Strogatz, S. H. (1990). Synchronization of pulse-coupled biological oscillators. *Journal of Applied Mathematics*, 50, 1645-1662.
- Moreland, R. L., & Levine, J. M. (1982). Socialization in small groups: Temporal changes in individual-group relations. In L. Berkowitz (Ed.), *Advances in experimental social psychology* (Vol. 15, pp. 137-192). New York: Academic.
- Neda, Z., Ravasz, E., Brechet, Y., Vicsek, T., & Barabasi, A. L. (2000). The sound of many hands clapping: Tumultuous applause can transform itself into waves of synchronized clapping. *Nature*, 403, 849-850.
- Newell, K. M., Scully, D. M., Tenenbaum, F., & Hardiman, S. (1989). Body scale and the development of prehension. *Developmental Psychobiology*, 22, 1-13.
- Newton, D. (1980). An interactionist perspective on social knowing. *Personality and Social Psychology Bulletin*, 6, 520-531.
- Newton, D. (1993). The dynamics of action and interaction. In L. B. Smith & E. Thelen (Eds.), *A dynamic systems approach to development: Applications* (pp. 241-264). Cambridge, MA: MIT Press.
- Newton, D. (1994). The perception and coupling of behavior waves. In R. R. Vallacher & A. Nowak (Eds.), *Dynamical systems in social psychology* (pp. 139-167). New York: Academic.
- Newton, D. (1998). Dynamical systems and the structure of behavior. In K. M. Newell (Ed.), *Applications of nonlinear dynamics to developmental process modeling* (pp. 199-220). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
- Newton, D., Hairfield, J., Bloomingdale, J., & Cutino, S. (1987). The structure of action and interaction. *Social Cognition*, 5, 191-237.
- Nowak, A., Szamrej, J., & Latané, B. (1990). From private attitude to public opinion: A dynamic theory of social impact. *Psychological Review*, 97, 362-376.
- Nowak, A., & Vallacher, R. R. (Eds.). (1998). *Dynamical social psychology*. New York: Guilford.

- Provine, R. R. (1986). Yawning as a stereotyped action pattern and releasing stimulus. *Ethology* 72, 109-122.
- Ramenzoni, V. C., Riley, M. A., Davis, T., & Snyder, J. (2005). Perceiving whether or not another person can use a step to reach an object. In H. Heft & K. L. Marsh (Eds.), *Studies in perception and action VIII: Thirteenth International Conference on Perception and Action* (pp. 15-18). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
- Resnick, M. (1994). *Turtles, termites, and traffic jams: Explorations in massively parallel microworlds*. Cambridge, MA: MIT Press.
- Rhodes, G., Zebrowitz, L. A., Clark, A., Kalick, S. M., Hightower, A., & McKay, R. (2001). Do facial averageness and symmetry signal health? *Evolution and Human Behavior*, 22, 31-46.
- Richardson, M. J., & Johnston, L. (2005). Person recognition from dynamic events: The kinematic specification of individual identity in walking style. *Journal of Nonverbal Behavior*, 29, 25-44.
- Richardson, M. J., Marsh, K. L., & Baron, R. M. (2005). *Judging and actualizing intrapersonal and interpersonal affordances*. Manuscript submitted for publication, University of Connecticut.
- Richardson, M. J., Marsh, K. L., & Schmidt, R. C. (2005). Effects of visual and verbal couplings on unintentional interpersonal coordination. *Journal of Experimental Psychology: Human Perception and Performance*, 31, 62-79.
- Rochat, F., Maggioni, O., & Modigliani, A. (2000). The dynamics of obeying and opposing authority: A mathematical model. In T. Blass (Ed.), *Obedience to authority: Current perspectives on the Milgram paradigm* (pp. 161-192). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
- Rochat, P. (1995). Perceived reachability for self and for others by 3- to 5-year-old children and adults. *Journal of Experimental Child Psychology*, 59, 317-333.
- Rosen, R. (1991). *Life itself*. New York: Columbia University Press.
- Rosen, R. (2000). *Essays on life itself*. New York: Columbia University Press.
- Runeson, S., & Frykholm, G. (1983). Kinematic specification of dynamics as an informational basis for person-and-action perception: Expectation, gender recognition, and deceptive intention. *Journal of Experimental Psychology: General*, 112, 585-615.
- Sanchez Burks, J. (2002). Protestant relational ideology and (in)attention to relational cues in work settings. *Journal of Personality and Social Psychology*, 83, 919-929.
- Schmidt, R. C., Bienvenu, M., Fitzpatrick, P. A., & Amazeen, P. G. (1998). A comparison of intra- and interpersonal interlimb coordination: Coordination breakdowns and coupling strength. *Journal of Experimental Psychology: Human Perception and Performance*, 24, 884-900.
- Schmidt, R. C., Carello, C., & Turvey, M. T. (1990). Phase transitions and critical fluctuations in the visual coordination of rhythmic movements between people. *Journal of Experimental Psychology: Human Perception and Performance*, 16, 227-247.
- Schmidt, R. C., & O'Brien, B. (1997). Evaluating the dynamics of unintended interpersonal coordination. *Ecological Psychology*, 9, 189-206.
- Schmidt, R. C., O'Brien, B., & Sysko, R. (1999). Self-organization of between-persons cooperative tasks and possible application to sport. *International Journal of Sport Psychology*, 30, 558-579.
- Schmidt, R. C., & Turvey, M. T. (1994). Phase-entrainment dynamics of visually coupled rhythmic movements. *Biological Cybernetics*, 70, 369-376.
- Shaw, R. E., & Kinsella Shaw, J. (1988). Ecological mechanics: A physical geometry for intentional constraints. *Human Movement Science*, 7, 155-200.
- Shaw, R. E., Mace, W. M., & Turvey, M. T. (2001). Foreword: Resources for ecological psychology. In H. Heft, *Ecological psychology in context: James Gibson, Roger Barker, and the legacy of William James's radical empiricism*. Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
- Sherif, M., Harvey, O. J., White, B. J., Hood, W. R., & Sherif, C. W. (1961). *Intergroup cooperation and competition: The Robbers Cave experiment*. Norman, OK: University Book Exchange.
- Shiffrar, M., Lichtey, L., & Chatterjee, S. H. (1997). The perception of biological motion across apertures. *Perception & Psychophysics*, 59, 51-59.

- Shockley, K., Santana, M. V., & Fowler, C. A. (2003). Mutual interpersonal postural constraints are involved in cooperative conversation. *Journal of Experimental Psychology: Human Perception and Performance*, 29, 326-332.
- Soodak, H., & Iberall, A. (1987). Thermodynamics and complex systems. In F. E. Yates (Ed.), *Self-organizing systems: The emergence of order* (pp. 460-469). New York: Plenum.
- Stevenage, S. V., Nixon, M. S., & Vince, K. (1999). Visual analysis of gait as a cue to identity. *Applied Cognitive Psychology*, 13, 513-526.
- Stoffregen, T. A., Gorday, K. M., Sheng, Y.-Y., & Flynn, S. B. (1999). Perceiving affordances for another person's actions. *Journal of Experimental Psychology: Human Perception and Performance*, 25, 120-136.
- Strack, F., Martin, L. L., & Stepper, S. (1988). Inhibiting and facilitating conditions of the human smile: A nonobtrusive test of the facial feedback hypothesis. *Journal of Personality and Social Psychology*, 54, 768-777.
- Strogatz, S. H. (2003). *Sync: The emerging science of spontaneous order*. New York: Hyperion.
- Strogatz, S. H., & Stewart, I. (1993). Coupled oscillators and biological synchronization. *Scientific American*, 269, 102-109.
- Tesser, A. (1980). When individual dispositions and social pressure conflict: A catastrophe. *Human Relations*, 33, 393-407.
- Tesser, A., & Achée, J. (1994). Aggression, love, conformity, and other social psychological catastrophes. In R. R. Vallacher (Ed.), *Dynamical systems in social psychology* (pp. 95-109). San Diego, CA: Academic.
- Thelen, E., Schoener, G., Scheier, C., & Smith, L. B. (2001). The dynamics of embodiment: A field theory of infant perseverative reaching. *Behavioral and Brain Sciences*, 24, 1-86.
- Toner, J., & Tu, Y. (1998). Flocks herds and schools: A quantitative theory of flocking. *Physical Review Letters*, 58, 4828-4858.
- Tuller, B., Turvey, M. T., & Fitch, H. L. (1982). The Bernstein perspective: II. The concept of muscle linkage or coordinative structure. In J. A. S. Kelso (Ed.), *Human motor behavior: An introduction* (pp. 253-270). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Turvey, M. T. (1990). Coordination. *American Psychologist*, 45, 938-953.
- Turvey, M. T., & Carello, C. (1986). The ecological approach to perceiving-acting: A pictorial essay. *Acta Psychologica*, 63, 133-155.
- Valenti, S. S., & Good, J. M. (1991). Social affordances and interaction: I. Introduction. *Ecological Psychology*, 3, 77-98.
- Valenti, S. S., & Stoffregen, T. A. (2001). The social dynamics of embodied cognition. *Behavioral and Brain Sciences*, 24, 67-68.
- Vallacher, R. R., & Nowak, A. (1994). The stream of social judgment. In R. P. Vallacher & A. Nowak (Eds.), *Dynamical systems in social psychology*. New York: Academic.
- Vallacher, R. R., & Nowak, A. (1997). The emergence of dynamical social psychology. *Psychological Inquiry*, 8, 73-99.
- Vallacher, R. R., Read, S. J., & Nowak, A. (2002). The dynamical perspective in personality and social psychology. *Personality and Social Psychology Review*, 6, 264-273.
- Van Acker, R., & Valenti, S. S. (1989). Perception of social affordances by children with mild handicapping conditions: Implications for social skills research and training. *Ecological Psychology*, 1, 383-405.
- van der Kamp, J., Savelsbergh, G. J. P., & Davis, W. E. (1998). Body-scaled ratio as a control parameter for prehension in 5- to 9-year-old children. *Developmental Psychobiology*, 33, 351-361.
- von Holst, E. (1973). *The collected papers of Eric von Holst, Vol. 1: The behavioral physiology of animal and man*. (R. Martin, Ed.). Coral Gables, FL: University of Miami Press.
- Walker, A., & Wooldridge, M. (1995). Understanding the emergence of conventions in multi-agent systems. In V. Lesser (Ed.), *ICMAS-95* (pp. 384-389). Cambridge, MA: MIT Press.
- Warren, W. H. (1984). Perceiving affordances: Visual guidance of stair climbing. *Journal of Experimental Psychology: Human Perception and Performance*, 10, 683-703.

- Wheeler, S. C., & Petty, R. E. (2001). The effects of stereotype activation on behavior: A review of possible mechanisms. *Psychological Bulletin*, 127, 797-826.
- Winfrey, A. T. (1967). Biological rhythms and the behavior of populations of coupled oscillators. *Journal of Theoretical Biology*, 16, 15-42.
- Wong, K. Y. (2000). Mean-field theory of learning: From dynamics to statics. *Condensed Matter*, 6251, 1-15.
- Yeung, M. K., & Strogatz, S. H. (1999). Time delay in the Kuramoto model of coupled oscillators. *Physical Review Letters*, 82, 648-651.
- Zajonc, R. B. (1980). Feeling and thinking: Preferences need no inferences. *American Psychologist*, 35, 151-175.
- Zebrowitz, L. A. (1997). *Reading faces: Window to the soul?* Boulder, CO: Westview.
- Zebrowitz, L. A., & Collins, M. A. (1997). Accurate social perception at zero acquaintance: The affordances of a Gibsonian approach. *Personality and Social Psychology Review*, 1, 204-223.
- Zebrowitz, L. A., Hall, J. A., Murphy, N. A., & Rhodes, G. (2002). Looking smart and looking good: Facial cues to intelligence and their origins. *Personality and Social Psychology Bulletin*, 28, 238-249.
- Zebrowitz, L. A., Tenenbaum, D. R., & Goldstein, L. H. (1991). The impact of job applicants' facial maturity, gender, and academic achievement on hiring recommendations. *Journal of Applied Social Psychology*, 21, 525-548.

In Defense of Mechanism

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In *Life Itself* and in *Essays on Life Itself*, Robert Rosen (1991, 2000) argued that machines were, in principle, incapable of modeling the defining feature of living systems, which he claimed to be the existence of closed causal loops. Rosen's argument has been used to support critiques of computational models in ecological psychology. This article shows that Rosen's attack on mechanism is fundamentally misconceived. It is, in fact, of the essence of a mechanical system that it contains closed causal loops. Moreover, Rosen's epistemology is based on a strong form of indirect realism and his arguments, if correct, would call into question some of the fundamental principles of ecological psychology.

The pregnant question "What is life?" has received many different types of answers derived from a variety of different research strategies. One strategy is to examine the denizens of the world and to look for a common element or condition possessed by all living things and by nothing else. That common element, once identified, can then be proclaimed as the answer to the question. There are many difficulties with this strategy. One is that it is circular. It presupposes that living things can be identified in order that the essence of life can be extracted from them. A second difficulty is the essentialist assumption that there is a common thread binding all living things together. The forms of life may simply be too varied and disparate for this to be true.

Another strategy is to proceed by a process of elimination. By becoming clear about what life is not, one hopes to become clearer about what it is. The biophysicist Robert Rosen (1991) adopted essentially this strategy in his book *Life Itself*. Rosen's principal target was the idea that living things were biological machines. In his note to the reader at the start of the book, he said

It has turned out that, in order to be in a position to say what life is, we must spend a great deal of time in understanding what life is *not*. Thus, I will be spending a great

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deal of time with mechanisms and machines, ultimately to reject them, and replace them with something else. (p. xv)¹

Rosen's (1991) central argument reached the conclusion that "*there can be no closed path of efficient causation in a mechanism*" (p. 241). By contrast, in his view, organisms are characterized precisely by the presence of such paths: "*A material system is an organism if, and only if, it is closed to efficient causation*" (p. 244). The centrality of the argument based on causal loops can be gauged from the fact that it is repeatedly reasserted in *Essays on Life Itself* (Rosen, 2000) and is also a key part of Rosen's description of *Life Itself* in a short paper called *Autobiographical Reminiscences*, which can be found on the Internet (Rosen, n.d.). The statement there is clear and trenchant:

I argue that the external, public, material world is full of closed causal loops, just as the internal, mathematical world is full of closed inferential ones (impredicativities). The "world" of the mechanism, or machine (or, as I call it, the simple systems), and which I believe is an artificial human limitation on reality, does not allow such loops. Accordingly, as a class, these simple systems are extremely poor, or limited, in entailment and hence extremely nongeneric.

Rosen (1991) described the idea that science is essentially mechanistic as a prejudice and argued that it had "disastrous consequences" (p. xvi). In particular he claimed that the assumption of mechanism made it impossible to answer the question "What is life?" This was not just dramatization for emphasis: That the charge was intended seriously is clear from the context.

The initial presupposition that we are dealing with mechanism already excludes most of what we need to arrive at an answer. No amount of refinement or subtlety within the world of mechanism can avail; once we are in that world, what we need is already gone. (p. xvi)

It is not immediately clear why the assumption of mechanism should be so damaging to the attempt to understand the essential characteristics of organisms. Theories are always wrong in some respects but rarely make it impossible to answer core questions. The explanation for the strength of Rosen's antimechanism is to be found in his conception of science and his view of the relation between minds and the external world.

¹Quotations throughout from *Life Itself: A Comprehensive Inquiry Into the Nature, Origin, and Fabrication of Life*, by R. Rosen, 1991, New York: Columbia University Press. Copyright 1991 by Columbia University Press. Reprinted with permission.

Rosen's critique of mechanistic ideas in biology has been endorsed by leading ecological psychologists, including Michael Turvey and Robert Shaw (cf. Shaw, 2003; Turvey, 2004; Turvey & Shaw, 1995). If the critique is correct it applies, among other things, to computational models of psychological processes because they are machine models. It thus becomes apparent that the critique is very wide ranging in its scope. It would show, if it were true, that the mainstream approach to cognitive science must be mistaken in its foundational assumption that the mind can be understood in computational terms. It would also show that proposals to deploy computational thinking in ecological psychology, for example, the modeling of affordances as the configurations of Turing machines by Wells (2002), must be flawed or, at best, radically incomplete. Fortunately, for those who value machine models in psychology, Rosen's critique is not correct. It is, in fact, fundamentally misconceived because it is of the essence of a machine that it contains precisely the closed causal loops that Rosen claims cannot be realized in machines.

This article defends machine models and the mechanist philosophy against Rosen's attack. The simplest, and most obvious, way to rebut Rosen's (1991, 2000) critique is by displaying machines that exhibit closed loops. Several such machines are described and discussed. These machines provide conclusive counterexamples to Rosen's central argument. A rebuttal along these lines alone, however, does not address the question of how Rosen came to reach his conclusions nor does it tackle the details of his arguments. These are valuable supporting exercises. This article begins, therefore, with an overview of *Life Itself* (Rosen 1991). It then summarizes and offers a critique of Rosen's central argument. This is followed by discussion of some subsidiary arguments that appear principally in *Essays on Life Itself* (Rosen, 2000). Turing machines are then introduced and are readily seen to exhibit closed causal loops. In the final section of the paper some aspects of Rosen's philosophy and methodology are compared with some of the principles and methods of ecological psychology.

OVERVIEW

One of the curious features of *Life Itself*, which Rosen (1991) described as a book about biology, is that there is rather little in it that most people would recognize as biology and a great deal that looks like mathematics. Category theory, set theory, and recursive function theory all feature in the development of the argument. The reason for this is that Rosen understood science in terms of a specific conception of Natural Law and in terms of an epistemology that laid fundamental emphasis on modeling relations between natural systems and the accounts that we give of them in both natural and formal languages. The first task for a student of Rosen should, therefore, be to understand his epistemology and philosophy of science.

Science, Rosen (1991) said, is built on dualities, and he suggested that "the most fundamental dualism" is that between the self and everything else. Section 3B

of *Life Itself* describes this dualism in Cartesian terms. According to Rosen, the self encompasses or contains "our perceptions, our thoughts, our ideas, our imaginings, our will, and the actions that spring from them. This is the *inner world*. Everything else is *outside*" (pp. 40–41). That which is other than the self Rosen called the "ambience," and he thought of science as a kind of relation between the self and the ambience. Science, he said,

requires an external, objective world of phenomena, and the internal, subjective world of the self, which perceives, organizes, acts, and understands. Indeed, science itself is a way (perhaps not the only way) of bringing the ambience *inside*, in an important sense, a way of importing the external world of phenomena into the internal, subjective world that we apprehend so directly. (p. 41)

It is, I think, of great importance for ecological psychologists to understand, as this quotation shows, that Rosen's epistemology is based on a strong form of indirect realism. It is a key part of the context needed to understand his attack on mechanism and it suggests, rather obviously, that Rosen's philosophy is much less compatible with ecological psychology than some of his apologists may like to think.

A "second basic dualism" (p. 41), as Rosen (1991) described it, concerns how we take the ambience to be partitioned into systems and their environments. The way that Rosen characterized this second dualism reinforces the point just made about his indirect realism. Talking about how we manage our perceptions of the external world, he said,

At this level, we have no universal principles to guide us, nothing *given* to us, like the distinction between the inner world of the self and the outer world, what we called the ambience. It rests rather on a consensus *imputed* to the ambience, rather than on some objective and directly perceptible property of the ambience. (p. 41)

The idea that there is a consensus that imputes or ascribes properties and meanings to the external world suggests the view that everyday reality is, in part, a social construction. Notice the striking contrast here with Gibson's (1979/1986) view of the external world as the locus of ecological reality:

The world of physical reality does not consist of meaningful things. The world of ecological reality, as I have been trying to describe it, does. If what we perceived were the entities of physics and mathematics, meanings would have to be imposed on them. But if what we perceive are the entities of environmental science, their meanings can be *discovered*. (p. 33)

The significance of the partition of the ambience into systems and their environments lies, said Rosen (1991), in the fact that it leads us to treat the components in fundamentally different ways. Systems are described in terms of states, and envi-

ronments are described in terms of their effects on systems. This, Rosen said, is a source of fundamental trouble, but it is of less concern for this article than the first basic dualism between the self and the ambience. Rosen took perception of the external world to be mediated by the inner self. In section 3D of *Life Itself* he said that language plays "an essential role as an intermediary between the self and its ambience" (p. 43), but he did not say clearly in that section what the essential role of language is. Instead he described the differences between natural and formal languages and between syntax and semantics and introduced what will become a key idea, namely the fact that the syntactic production rules of languages, both natural and formal, are vehicles for inferential entailment. Further discussion of inferential entailment in section 3E included a brief discussion of Aristotle's four categories of causation, a topic that is treated further in due course. A key point to note about inferential entailment is that it can be understood in terms of causal relations between syntactic elements. For example, given the rules of elementary arithmetic, the string of symbols $2 + 2 = ?$ entails, or can be said to cause, the symbol 4, whereas the string $2 - 2 = ?$ entails the symbol 0. In section 3G Rosen discussed entailment in the external world. The key question he asked is the following: "Is there, in this external world, any kind of *entailment*, analogous to the inferential entailment we have seen between propositions in a language or formalism?" (p.55).

The discussion that follows further confirms his view of perception as indirect. Rosen (1991) said, with explicit reference to Kant, that things in themselves are "inherently unknowable" except through the perceptions they elicit in us and acknowledges that this is a potent source for skepticism. He concluded, nonetheless, that it is reasonable to posit relations of entailment between phenomena in the external world because natural language "imputes hordes of entailments to the ambience" (p. 56) without leading us seriously astray. These entailments are taken to be causal. Notice the second use of the term *impute*.

To summarize the discussion so far, Rosen (1991) had, before the end of chapter 3 of *Life Itself*, made the following points: There is a fundamental distinction between the internal world of the self, which, in Cartesian fashion, is known directly and indubitably, and the external world, which is known only indirectly. The internal world contains a variety of languages that instantiate systems of inferential entailment. Semantic projections from these inferential systems outward onto the external world are generally reliable and support the assumption that the external world contains entities that are systematically related to one another by causal entailments.

Building on this foundation, Rosen (1991) discussed natural law and modeling relations in section 3H. The point of this section is to discuss whether, and if so, how, inferential entailment in the inner world can be related to causal entailment in the external world. Rosen argued that they can be related by the establishment of a modeling relation between them. According to his view modeling relations are possible by virtue of Natural Law, which provides the explicit underpinning for science. Natural Law, in Rosen's formulation of it, rests on two fundamental asser-

tions: first, that events in the external world are ordered and exhibit systematic causal relations; second, that these orderly causal relations can be grasped by the human mind.

The causal relations manifested by a natural system provide the orderliness required of the ambience. Inferential entailment in a formal system is a way of providing the orderliness required of the self. The art of bringing the two into correspondence, through the establishment of a definite modeling relation between them, is the articulation of the former within the latter; it is in effect science itself. (p. 59)

A modeling relation is thus a form of congruence between entailment structures. Causal entailment in the external world is mapped onto inferential entailment in the inner world. If the mapping captures the essential features of the causal system, it will be possible to use the inferential structure of the formal system to make predictions about events in the external world. The discovery of the planet Pluto is a well known example. Prior to its discovery, astronomers had modeled the orbits of the known planets in a mathematical model of the solar system. The mathematical model was a system of inferential entailment, in Rosen's terms, whereas the actual orbits of the planets constitute a system of causal entailment. Calculations based on the model allowed the astronomers to predict the future positions of the planets. Observations showed that the model was faulty because the planets did not behave as the model predicted. Further mathematical reasoning, which can be described as the tracing of possible paths of entailment in a revised model, showed that the positional discrepancies of the known planets could be accounted for by the postulation of another planet beyond Uranus. The revised model was used to predict the position of this planet, and telescopic search subsequently led to the discovery of Pluto.

Two points of particular importance should be noted about the modeling relation. First, models are essential because they provide the means whereby we obtain knowledge about the external world and its future behavior. Second, there are two-way relations between natural systems of causal entailment (*N*) and formal systems of inferential entailment (*F*). Rosen (1991) described the situation thus:

The modeling process compares causal entailment in *N* with inferential entailment in *F*; if we are successful in establishing such a relation, then *F* is the model; *N* is a *realization* of that model. But it is essential to note that the roles of *N* and *F* can be interchanged. That is, instead of starting with a natural system *N*, and looking in effect for a formalism *F* that models it, we could start with a formal system *F* and ask for a natural system *N* whose causal entailment provides a model for inferential entailment in *F*. (p. 61)

Here, I think, we have reached the foundation of Rosen's objections to machine models in biology and the basis for his belief that such models make it impossible to

discover the causal principles governing organisms. The core problem, in his view, is that mechanistic philosophy starts with a formal machine model in the inner world and projects this onto the outer world. It assumes, that is, that organisms are machines and will be found to exhibit causal entailments that are congruent to the inferential entailments found in machines. This is a double mistake in Rosen's view: It is wrong because, as a matter of fact, organisms exhibit patterns of causal entailment that are not, and cannot be, captured by the patterns of inferential entailment available in machines, and it is wrong because the strategy prevents us from understanding the patterns of causal entailment that do exist in organisms. Formal models are our windows on the external world, and the machine model is a window that makes it impossible to understand how organisms work. It is this, in Rosen's view, that makes mechanism such a pernicious philosophy of biology.

From this standpoint there are two major issues for Rosen to tackle. First, machine models must be characterized and shown to be inadequate; second, an analysis of the kind of modeling strategy needed to provide the theoretical foundation for biology has to be given. Notice that it is not enough for Rosen simply to reject mechanism. In his view, models are an essential part of the process of theory construction and development. A critique of mechanism leaves a gap that has to be filled by formal models of some kind. Chapters 4 to 10 of *Life Itself* are concerned with these issues and the final chapter outlines Rosen's (1991) proposal that biology should be based on relational models and compares the proposed relational biology with existing theories and models.

THE ANTIMECHANIST ARGUMENT OF *LIFE ITSELF*

Rosen's (1991) antimechanist argument is complex and multifaceted. It is also obscure in places. Even his most ardent supporters would hardly claim that Rosen's exposition is always clear. I think, however, that the following list of propositions is a fair summary of the principal points of the argument and, roughly, of its sequence. I have indicated in parentheses the primary places in *Life Itself* in which the points of the argument are presented and/or elaborated. It should also be noted that some points depend on earlier chapters of the book. Points 5–7, for example, draw on the material of chapter 6, and the argument in chapters 9 and 10 draws on the ideas about relational modeling developed in chapter 5.

1. A system, natural or formal, is a machine if it simulates, or can simulate, something else. Simulation is what machines do. (7B, 7D, 7E)
2. Simulation involves a fundamental distinction between hardware and software. (7D, 9A, 9B, 9D)
3. A natural system, *N*, is a mechanism if and only if all of its models are simulable. (8B)

4. A natural system, N , is a machine if and only if it is a mechanism such that at least one of its models is already a mathematical machine. (8B)
5. If N is a mechanism, it has a unique largest model. (8C)
6. If N is a mechanism, it has a finite set of minimal models. (8D)
7. The largest model of a mechanism is the direct sum of its minimal models and is therefore synthetic. (8E)
8. In mathematical machines efficient causality and material causality are segregated into disjoint structures; hardware is the embodiment of efficient cause, whereas material cause is embodied in software. (9A, 9B)
9. Hardware entails the flow of software states from input to output, but software cannot entail hardware. (9B, 9D)
10. A hardware component can be entailed only by another hardware component. (9E)
11. A system S_1 , in which a previously unentailed hardware component is entailed, must have more states than S_0 , the system in which the component was unentailed. (9E)
12. The larger system S_1 will itself have at least one unentailed hardware component. (9F)
13. Only in the limit as n approaches infinity will every component in a system S_n be entailed. (9F)
14. Such a system cannot be a mechanism because a mechanism has a finite largest model. (9F)
15. Hardware cannot be entailed by adding further constraints to existing components because this involves splitting states into direct summands and leads to an infinite regress of fractionation. Such a regress contradicts the fact that a machine has a finite set of minimal models. (9F)
16. The argument of Points 1 to 15 shows that there can be no closed path of efficient causation in a mechanism. (9G)
17. Organisms exhibit closed paths of efficient causation. (10A, 10C)
18. Organisms are not machines. (10B)

The argument is vulnerable to a range of criticisms and fails to establish the central claim made in Point 16. I shall discuss its principal weaknesses but it will be useful, before doing this, to consider briefly the distinction between efficient and material causes that is mentioned in Points 8 and 16.

The distinction stems from Aristotle's classification of "causes" into four types: material, efficient, formal, and final. There is a consensus among contemporary scholars that the Greek word " $\alpha\iota\tau\iota\omicron\nu$," which has traditionally been translated as "cause," should, in fact, be translated as "because" (Hocutt, 1974; Moravcsik, 1974). The four-fold distinction made by Aristotle is, therefore, best thought of as a classification of different types of explanation, not different types of causes. The only type that would be considered causal in modern terminology is the category of efficient cause. Rosen (1991) uses Aristotle's terminology primarily to distinguish

causal relations among the hardware components of a system—which he describes as instances of efficient causation—from causal relations in software, which he describes as instances of material causation (cf. *Life Itself*, sections 5H, 9D). Part of the reason why Rosen uses Aristotle's terminology stems, I think, from the fact that he wants to compare entailment in material systems with entailment in formal systems and is able to do this by using Aristotle's analysis to distinguish the different types of cause in both cases. The discussion in section 3G of *Life Itself* (p. 57) seems to me to support this understanding. However, given the fact that material causes in the Aristotelian scheme of things are not causes as we would understand them, the distinction obscures more than it clarifies. It is, in any event, not a significant aspect of the argument. What is significant is Rosen's claim that the causal relations between hardware components of a system are distinct from the causal relations embodied in software. It should, of course, be remembered that in any real machine to which the hardware/software distinction applies, software components are just as real and material as hardware and, therefore, just as much subject to causal influence. The distinction that Rosen marks by the use of the terms *efficient* and *material* is, therefore, a distinction of causal role, not causal type. Provided, then, it is understood that the central claim in Point 16 of Rosen's argument refers to causal relations among the hardware components of machines, and provided also that the causal roles of hardware and software are distinguished where necessary, nothing is lost by ignoring or eliding the distinction between so-called efficient and material causes.

Turning now to the status of the argument itself, Point 1, which takes simulation to be the key criterion for distinguishing machines from other systems, is simply wrong. Most machines do not simulate. Think of the functions of the everyday machines that surround us: refrigerators cool things, cars transport us from place to place, scissors cut things, pianos produce music, and so forth. None of these machines is a simulator. Machines that do simulate, of which computers are the most obvious examples, are a special, highly organized class. Rosen's (1991) definition of a machine is, therefore, far too narrow. However, even if it were correct, the definition does not establish what he wishes to establish. Part of his reason for focusing on simulation as the key activity of machines is his belief that there is a fundamental divide between simulation and modeling. He claims that whereas a model lays bare the entailment structure of the system it models, a simulation hides it. "In causal terms, simulation involves the conversion of efficient cause, the hardware of that being simulated, into material cause in the simulator. In essence, this means that one can learn nothing about entailment by looking at a simulation" (Rosen, 1991, p. 193).

This is an extraordinary claim that, once again, is simply wrong. If it were true, there would be absolutely no point in the many computer simulations, for example, of airflows over aircraft wings and the development of weather patterns, which are used to study causal relations in complex systems. Far from hiding the details of causal interactions in the systems that are modeled, simulations enable them to be

studied in great detail and at a variety of time scales. A simulation is rather like a high speed film of the impact of a bullet on a particular material in which time can be slowed down on playback precisely to enable the investigator to understand better the extremely rapid succession of causal interactions between the bullet and the material on which it impacts. A simulation should, if anything, be described as a kind of "supermodel."

It is worth pursuing this point a little further because Rosen's (1991) claim about simulation is couched in terms of the unhelpful distinction between efficient and material causes, which is a source of confusion rather than clarification. Suppose we were to construct a simulation of the impact of a bullet on a sheet of glass. To do this we would need, *inter alia*, to construct a simulation of the bullet, a simulation of the sheet of glass, and a simulation of the dynamic relations between them. One obvious way to do this would be by constructing symbolic representations of the terms of the simulation in a computer program. Thus the bullet might be represented as an array of quantities that collectively simulate its shape, mass, density, velocity, and so forth, and the glass might be represented as a lattice or similar regular structure. It is this process of translating into software the causally active components of the hardware system represented in the simulation that Rosen refers to as the conversion of efficient cause into material cause. It should immediately be clear that whether or not one can learn anything about entailment in such a simulation depends not on the process of conversion but on whether one has chosen the correct aspects of the system to represent. A simulation that includes only the name of the maker in the representation of the bullet and the reflection of the external environment in the representation of the glass would not be informative about the impact of the bullet on the glass, but a simulation that includes detailed representations of the salient characteristics of the bullet and the glass and that models the changing dynamics of the relationship between them at a microsecond time scale might be extremely informative. The quality of a simulation depends on the quality of the modeling on which it is based. It is simply incorrect to claim that the conversion of terms that a simulation requires hides the entailment structures of the system simulated.

Point 2 of the argument is correct. There is a fundamental distinction between hardware and software, at least in computers that simulate. However, the distinction does not support the argument in the way that Rosen (1991) wishes to develop it in Points 8 and 9.

Points 3 and 4 of the argument inherit the deficiencies of Point 1. They are also rather strangely worded. One does not normally think of calling a system a machine if and only if its models are of a particular kind. Rosen explains this curious usage in terms of Natural Law: "This peculiarity stems only from my expression of these concepts in terms of the models of *N*, rather than try to talk directly about *N* itself. This is all that Natural Law entitles us to do" (Rosen, 1991, p. 203).

The point is interesting, not so much for what it tells us about the argument but for the fact that it is a further indication of the indirect realism that provides the

foundation for Rosen's (1991) epistemology. In his view we have to discuss natural systems in terms of their models because these are all that is directly available to us.

Points 5, 6, and 7 are lemmas to the main argument. They are used to support Points 14 and 15. There are both general and specific comments to be made. The important general comment is that the arguments of Points 5 to 7 rest on the discussion of models in chapter 6. I do not propose to go into the material of chapter 6 in great detail but I think it is clear that it does not establish the fundamental claims about models that Rosen wants to make. The distinction between analytic and synthetic models that Rosen develops in chapter 6 is based on equivalence relations over sets. Analytic models are constructed in terms of Cartesian products and synthetic models in terms of direct sums of disjoint subsets. Rosen takes the analytic/synthetic distinction to be applicable to models of any kind, but it is not clear that the concept of an equivalence relation is a suitable tool for developing a generally applicable typology of models or for exhibiting the relation between a model and the system, natural or formal, of which it is a model. In order for an equivalence relation to be specified, the elements of the set on which it is defined have to be known, and it is precisely this that is not generally known when a model of a natural system is being developed. Rosen himself acknowledged this obvious disanalogy in his discussion of the equivalence relations over a set S that he called "observables":

I cannot emphasize too strongly that, in the formal world, S is already a determinate entity (in this case, a set), so that in general, looking at S as imaged in the spectrum $f(S)$ of an observable inevitably "loses information" about S . In the case of a natural system, on the other hand, the counterpart of S is initially *unknown*, veiled completely in its noumenal and phenomenal shrouds. The whole purpose of measurement in this case is to *provide information* about it. (p. 157)

It is hard to understand, given this, why Rosen persists in using equivalence relations over sets as the basis for his definition of types of models of natural systems. He suggested on the page following the quotation just given that set theory provides "a formidable battery of inferential structure" (p. 158) to study a given set S , but the various operations on a set, which include the generation of further sets, tell us about the structure of the set, not about the system that the set represents. Consider a simple example to make the point clear. The Cartesian product of a set with itself, a structure about which Rosen says a great deal, is the set of ordered pairs of its elements. Suppose, as a result of observation, we have developed a simple model of a car in terms of the set $CAR = \{\text{body, wheels, engine, transmission}\}$. This is a very simple model, but it is a start. The Cartesian product of the model, $CAR \times CAR$ is the set of ordered pairs $\{(\text{body, wheels}), (\text{body, engine}), (\text{body, transmission}), (\text{wheels, engine}), (\text{wheels, transmission}), (\text{engine, transmission})\}$. Does the Cartesian product tell us anything we didn't already know about the car? Rather clearly, the answer is no. The Cartesian product tells us something about

the structure of the set but not about the system of which the set is a model. The difficulty with Rosen's view is that he assumes that the structures of sets like Cartesian products are somehow necessarily informative about the models represented by the original sets. In general that is not the case. To improve the model we need to make further observations of the car, not engage in an analysis of the set that constitutes the original model.

The more specific points to be made concern the status of the argument that purports to establish Point 5, the claim that every machine has a unique largest model. The argument in section 8C of *Life Itself* is faulty. It takes the form of a reductio ad absurdum. Starting from the assumption that N is a mechanism, but that the category of all its models $C(N)$ contains no largest model, Rosen claims that we can find an infinite sequence of increasingly refined models. Because N is a mechanism, all its models must be simulable and each of them must have a program of finite length. We can then form the intersection of all the models and, by hypothesis, this is also a model. Unless the sequence of models terminates after a finite number of iterations, the model formed from the intersection is larger than any of the other models. Because it is simulable, it must also have a program. The conclusion of the argument, according to Rosen, is the following: "We thus end up with a countable family of distinct programs, each of which is a distinct word of finite length on a finite alphabet. This is clearly impossible" (p. 205).

In fact it is perfectly possible. Thus even if the premises of the argument were correct, which is questionable, the conclusion would not follow. The decimal representations of the integers, for example, are the elements of a countably infinite set of distinct words of finite length on a finite alphabet and integers are commonly used to represent programs. It is also always possible to extend a program without altering its functionality by adding new instructions that do nothing (cf. Rogers, 1967, p. 22, Theorem III). This possibility contradicts the assertion that a machine must have a unique largest model. Given the failure of the argument for a largest model, the argument for a finite family of smallest models is of less interest because Rosen's (1991) argument requires both Points 5 and 6. It is, however, pertinent to ask what is meant by a *minimal* model. Various possibilities exist, but it is hard to form a clear idea of what Rosen intended.

Points 8, 9, and 10 constitute the heart of the argument because they purport to show that the distinction between hardware and software in machines entails the segregation of causal factors that, ultimately, is the basis for the claim that machines cannot contain closed loops of "efficient" causation. There are two principal flaws in the argument. The first is the fact that, contrary to Rosen's view, machines can and do have causal entailments flowing from software to hardware. There is no incompatibility between this fact and the fact that hardware and software are distinct parts of a machine. In consequence, there can be closed loops of entailment in machines involving both hardware and software. Rosen was unable to see this because he thought of the partition between hardware and software as "absolute" (cf. section 9D, p. 228). The second flaw in Rosen's argument is that it simply fails to

recognize the possibility that there can be direct causal links between the hardware components of a machine, as well as links via software, and there is no reason why these links cannot form loops. Indeed, as I show in the discussion of Turing machines, it is of the essence of a Turing machine that there are such closed loops. I think the explanation for Rosen's failure to see this is reasonably straightforward. In the argument presented in chapter 9 of *Life Itself*, Rosen treats hardware as whatever it is that executes a mapping from inputs to outputs. Given a simple function $f: A \rightarrow B$, which Rosen takes to represent a component of a machine, f constitutes the hardware that, as Rosen puts it, induces the software flow from the input set A to the output set B . He is at pains to point out, in section 9B (p. 222) that the hardware and the flows it induces are different things and that the essence of hardware is to generate flows (p. 224). As a result of this way of looking at things, when he comes to consider a system with more than one component (cf. Figure 9C.2, p. 224), he assumes that all components are of the same type and that the only function of the hardware is to induce flows on software. He simply misses the possibility that there can be direct links between the different hardware components representing other types of causal interaction than the generation of software flows. The kind of causal interaction needed can be described as a "component-component" interaction. There is no argument in *Life Itself* to say that such interactions cannot exist in machines, and in fact they both can and do exist. The combined effect of the two flaws is to make Rosen's picture of what can be done with machines irretrievably narrow and limited.

Points 11 to 18 of the argument (Rosen, 1991) depend entirely on the earlier points. They contribute nothing extra. Because the earlier points do not in fact support the claims made, the argument as a whole fails. The failure of the argument shows that machine models of organisms are perfectly possible, but it also shows that Rosen's criterion, which claims that a material system is an organism if and only if it is closed to efficient causation, is invalid. Both organisms and machines can be closed to efficient causation, but such closure does not turn a machine into an organism.

It remains possible that Rosen's (1991) positive proposal, based on the concept of an (M,R)-system, provides a different criterion for distinguishing organisms from machines. However, the description of an (M,R)-system in *Life Itself* is muddled and inconsistent and has been criticized by Landauer and Bellman (2002). In any case, the crucial concept of self-replication was shown to be consistent with mechanistic hypotheses by John von Neumann as early as 1948 (c.f. Aspray & Burks, 1987, chapter 10). The entailment of replication by the functions of metabolism and repair is, therefore, unlikely to distinguish organisms from machines. Rosen (1991) claimed that von Neumann's construction rests on an equivocation between software and hardware (p. 234), but that is not correct. Von Neumann's discussion of the logic of self-reproduction made clear and consistent use of the distinction between hardware and software. He showed that a machine can, in principle, reproduce itself if it has access to a store of elementary parts (hardware) and contains a set of instructions (software) for its own construction that can be copied and passed to its clones.

ROSEN'S CONTRADICTIONARY ACCOUNTS OF OPEN SYSTEMS

The argument of *Life Itself* (Rosen, 1991) is the major, but not the only, source of Rosen's antimechanism. In *Essays on Life Itself* (Rosen, 2000), a collection of papers written mainly after *Life Itself* was published and brought to press by Rosen's daughter after his death, other related arguments can be found. One such type of argument concerns a distinction between simple and complex systems that Rosen used to argue for the fundamental separation of organisms from machines. The argument is different in form from the central argument of *Life Itself* and is worth separate comment. It centers on the concept of an open system and tackles the question of how open systems can be made amenable to analytical study. Different versions of the argument appear in two chapters of *Essays on Life Itself*. They come to contradictory conclusions.

In chapter 1 of *Essays on Life Itself*, Rosen (2000) discussed open systems in the context of Schrödinger's (1944) famous essay *What Is Life?* In the section of chapter 1 entitled "The Forcing of Open Systems," Rosen defined an open system as follows: "A system that is open in *any* sense is one whose behaviors depend on something outside the system itself, whereas in a closed system, there is no outside"² (Rosen, 2000, p. 21). Rosen says that physics has typically had trouble in modeling open systems and that one way to deal with them is to try to internalize the external influences so as to get a bigger system that is closed and to deal with that. However, he says, this strategy does not generally work:

Indeed, what we end up with in this fashion is generally a bigger open system, which is in some sense even more open than the one we started with. ... What one typically ends up with after carrying out such a strategy is the entire universe, which is not very helpful. (pp. 21—22)

After some further discussion of other possibilities for augmenting open systems, Rosen concluded that the resulting models are still not generally stable and that further expansions of the model to include more of the external forces acting on the system are needed. At this point, he says, "we have a glimpse of an incipient infinite regress establishing itself" (p. 24). The regress can be avoided, Rosen says, if the forces internalized at stage N of an expansion process have already arisen at earlier stages.

A source for such an N th-stage internalized forcer is a mechanism for its replication, expressed in terms of the preceding $N - 1$ stages, and not requiring a new $N + 1$ stage.

²Quotations throughout from *Essays on Life Itself*, by R. Rosen, 2000, New York: Columbia University Press. Copyright 2000 by Columbia University Press. Reprinted with permission.

Thus replication is not just a formal means of breaking off a devastating infinite regress, but it serves to stabilize the open system we arrived at in the *Nth* stage. (p. 24)

At this point the crux of the argument has been reached. Rosen claims that the price to be paid for escaping the infinite regress is that the systems thus arrived at are complex, noncomputable, and contain closed loops.

Breaking off such an infinite regress does not come for free. For it to happen, the graphs to which we have drawn attention, and which arise in successively more complicated forms at each step of the process, must fold back on each other in unprecedented ways. In the process, we create (among other things) closed loops of efficient causation. Systems of this type cannot be simulated by finite-state machines (e.g., Turing machines); hence they themselves are not machines or mechanisms. In formal terms, they manifest impredicative loops. I call these systems *complex*. (p. 24)

The particular point to notice is the claim that it is the process of breaking off the infinite regress of system expansions that generates complex systems.

The argument in chapter 1 (Rosen, 2000) contradicts and is contradicted by another of Rosen's arguments in chapter 20 of *Essays on Life Itself*. In chapter 20 Rosen discusses the differences between therapeutic interventions in medicine and control engineering. His target is the idea that an organism is a biological machine. If this were so, he says, we would expect therapies to have few or no side effects, whereas in practice side effects are the rule. To explain why this is the case, Rosen constructs an argument that uses temperature control as an example. A room without temperature control is an instance of an open system. If the room is large the temperature may appear to be constant, but it will eventually change "because the room is open to ambient influences we do not see directly" (p. 299). A first level of control over the room temperature can be achieved by installing a thermostat. However, to close the room to the effects of changes in the ambient temperature in this way, the system as a whole has had to be enlarged.

The thermostat itself is new material structure, which we have had to bring into the system to control the effects of unpredictable temperature fluctuations. The thermostat closes the room off to ambient temperature, but it itself is now open to other interactions—i.e., to new sources of noise. For instance, parts of it may corrode because of humidity and oxygen in the air in our room. ... We may indeed end up with more noise than we had originally. (pp. 300–301)

Notice the strong parallel here with the first example. In each case, the effect of internalizing a source of noise or openness is to produce, potentially, a more open or noisier system. Rosen again explores the possibility of further expansions of the sys-

tem to bring the new sources of noise under control and again the possibility of an infinite regress is noted:

Even in this simple example, we see an incipient and deadly infinite regress yawning before us. ... The real question arising here is whether, and if so, when, this potential infinite regress can be broken off. (p. 301)

As with the first example, Rosen says that the regress can be broken off if the system can be turned back on itself.

It is conceivable that such a potential infinite regress actually breaks off. It will do so if, and only if, we can arrange matters so that the noise arising at the Nth step of this sequence produces consequences that are subject to controls instituted at earlier stages. In such a case, the sequence breaks off at the Nth stage. (p. 303)

Rosen notes that the example of the thermostatically controlled room is characterized by a single state variable but says that the analysis can be generalized to deal with any finite number of state variables. "The analysis, of course, grows increasingly complicated, but, in effect, we now have a much larger family of cascading control loops, each of which creates the potentiality for infinite regress" (p. 303). The crux of the argument has again been reached. In the earlier example Rosen claimed that the price to be paid for breaking off the infinite regress was that the resulting systems were complex. In the latter example, however, he reaches the opposite conclusion:

If every such cascade breaks off after a finite number of steps, then the system itself, and its environment, *must both be simple*. Conversely, if a system (or its environment) is not simple, then there must be at least one cascade of simple controls that does not break off ... A system that is not simple in this sense (i.e., is not a mechanism) I call *complex*. (p. 304)

To drive home the point, a little later in the chapter Rosen argues that "there is a sense in which complex systems are infinitely open" (p. 307) and it is for this reason, he claims, that side effects are the norm rather than the exception in medical interventions.

The contradictory nature of the two arguments cited is perfectly clear. In one case Rosen argues that the existence of a break point that prevents an infinite regress of system openings leads to complex systems, in the other he argues that the break point leads to simple systems. In one case he argues that complexity is the result of system closure, in the other that complex systems are "infinitely open." The core problem is that the distinctions he wants to insist on, between organisms and machines and between simple and complex systems, are not to be had on his terms. Both organisms and machines are systems with closed causal loops and the distinc-

tion between complex and simple systems, if there is one, does not demarcate organisms from other machines.

ROSEN'S SUBORDINATE ARGUMENTS

Life Itself (Rosen, 1991) and *Essays on Life Itself* (Rosen, 2000) also contain subordinate arguments that deserve mention. An argument that is largely implicit in *Life Itself* but which is given greater prominence in *Essays on Life Itself* claims that machines cannot contain closed causal loops because such loops are "impredicative" and are forbidden in formal systems such as Turing's. One instance of this argument, from Rosen's autobiographical sketch, was mentioned in the introduction. Here is another:

Impredicativity ... was identified as the culprit in the paradoxes springing up in Set Theory. Something was impredicative ... if it could be defined only in terms of a totality to which it itself had to belong. ... Formalizations are simple systems (in my sense) and, in particular, cannot manifest impredicativities or self-references or "vicious circles." This is precisely why such a simple world seemed to provide a mathematical Eden, inherently free from paradox and inconsistency. Alas, as Gödel showed, it was also free of most of mathematics. We cannot dispense with impredicativity without simultaneously losing most of what we want to preserve. (Rosen, 2000, pp.293–294)

There are several flaws in this argument. One is the implicit claim that all closed loops are impredicative. They are not: The closed loops in the finite state control automata of Turing machines are not necessarily defined impredicatively, although they may be. Thus, closed causal loops could be found in machines even if impredicative loops were forbidden. Another is the claim that formalizations cannot manifest self-references. They both can and do. The recursive definitions that Turing used in the construction of his universal machine are frequently self-referential. Third, it is misleading to suggest that impredicativity was identified as *the* culprit in the paradoxes identified in set theory. It is true that Bertrand Russell thought it to be the source of the problem, at least with respect to the paradox that he devised (cf. Whitehead & Russell, 1925), but it has been clear since the analysis of Gödel (1944) that impredicative properties are troublesome only under very special circumstances. The idea, therefore, that abstract machines such as Turing machines cannot exhibit closed causal loops because these are always impredicative and hence forbidden is mistaken.

A second argument, related to the first, is the claim that machines are, as Rosen (2000) put it, *nongeneric*, exceptionally rare, and feeble in their entailment structures. The point is hinted at in the preceding quote with the idea that formalization loses most of what is needed from mathematics and that formalizations cannot "manifest" impredicative loops. In another passage from *Essays on Life Itself* Rosen

sums up his view of the attempts at formalization that he attributes to Hilbert's program:

The status of all these formalizations is informative. They turn out to be infinitely feeble compared with the original mathematical systems they attempted to objectivize. Indeed, these attempts to secure mathematics from paradox by invoking constructibility, or formalizability, end up by losing most of it. This is one of the upshots of Gödel's celebrated Incompleteness Theorem (Gödel, 1931), which showed precisely that "self-referential" statements (e.g., "this proposition is unprovable in a given formalization"), which are perfectly acceptable in the context of ordinary Number Theory, fall outside that formalization. (p. 92)

One claim that Rosen seems to be making in this quotation is that self-referential statements cannot be constructed, and hence are not expressible, in formal systems. That appears to be the force of the suggestion that they "fall outside" a formalization. This shows a misunderstanding of what Gödel achieved. The point that Gödel (1931) made was not that you cannot express or construct a self-referential statement in a formal system. It was precisely the opposite. Gödel showed that you *could* construct a self-referential statement as a well formed formula of any formal system powerful enough to contain arithmetic. In the sketch of his proof at the start of the famous 1931 paper, having explained how formulas of Russell and Whitehead's system *Principia Mathematica* (PM) could be used to express metamathematical notions (cf. Whitehead & Russell, 1925), Gödel went on to explain that the proof rested on the construction of a specific proposition using the formalism of PM: "We now construct an undecidable proposition of the system PM, that is, a proposition A for which neither A nor *not-A* is provable" (Gödel, 1931, p. 147). The crucial point was that the undecidable proposition was both syntactically well formed and asserted its own unprovability. From this Gödel showed that if the formal system containing the proposition was consistent, the proposition had to be true and hence unreachable by a finite sequence of inferences from the axioms. Thus the formal system was incomplete. The proof rests on a fundamental distinction between constructibility and provability that Rosen seems not to have fully grasped. A short but telling passage from *Life Itself* (Rosen, 1991) supports this suggestion:

Given any finite set of axioms for Number Theory, there are always propositions that are in some sense theorems but are unprovable from those axioms (unless, of course, the axioms are inconsistent to begin with—in which case everything is a theorem). (p. 35)

The crucial point, which Rosen explicitly fudges, is that unprovable propositions are not theorems in any sense. They are syntactically well formed formulas, but they cannot be reached by finite sets of inferences from the axioms. It is precisely this point that distinguishes constructible, but unprovable, propositions from theo-

rems of the system. To say, therefore, that unprovable propositions are "in some sense" theorems clouds exactly the distinction that needs to be kept clear. The distinction between constructibility and provability undermines the claim that closed or impredicative loops cannot be expressed in formal systems.

A second point that Rosen (2000) makes is that formalizations are in some sense "infinitely feeble." Rosen repeatedly asserts that mechanisms are a vanishingly small proportion of mathematical systems. The assertion rests, I think, on the distinction between countable and uncountable infinities. This distinction was originally made by the mathematician Georg Cantor in the late 19th century (Cantor, 1891). Cantor showed, using the technique of diagonalization, that, in a strictly definable sense, there are infinitely many more real numbers than natural numbers even though there are infinitely many of these. The natural numbers are countably infinite, but the real numbers are uncountably infinite. Turing machines can be paired one for one with the natural numbers and this shows that there are countably, infinitely many of them. In comparison with the uncountably infinite number of real numbers, the Turing machines can be said to be a vanishingly small proportion of mathematical systems.

It is very hard, however, to know what to make of the distinction between countable and uncountable infinities because the sizes, even of countably infinite collections, violate our everyday intuitions about collections of things. If one thinks, for example, about natural numbers, it seems to common sense that the totality of them can be divided into two halves, the odd numbers and the even ones. For any finite totality that is divisible into two halves, each half clearly has half as many members as the totality. If I have five green apples and five red ones I have ten apples in total with the green apples forming half the totality and the red ones the other half. By the same token, because there are n odd numbers and n even numbers, there should be $2n$ natural numbers in total. But it isn't so. Infinite totalities don't work like that. There are exactly as many odd numbers as there are natural numbers and exactly as many even ones. Countably infinite totalities are all of the same size although they appear to common sense to have different numbers of elements. Given this, it is very hard to know what follows from the fact that countable infinities are infinitely small compared with uncountable ones although there is a clear mathematical sense in which this is so. What Rosen (2000) is suggesting seems to rely on combining this point with the supposed exclusion of closed loops from the world of machines. Look, he says, the collection of machines is infinitely small by comparison with the collection of real numbers. Moreover, there are no closed loops in the collection of machines. Thus this collection must be infinitely feeble in the properties it can express. If it really were the case that there were no closed loops in machines, the argument might have some force. As it is, we have infinitely many machines with as many closed loops as we care to define. That is a perfectly satisfactory foundation on which to construct a mathematical account of biological, and for that matter psychological, systems.

CAUSAL LOOPS IN TURING MACHINES

The principal line of defense to Rosen's (1991) antimechanist claim does not depend on the fact that Rosen's arguments about open systems are contradictory or that the central argument of *Life Itself* is unsound. The principal defense of mechanism rests on the demonstration that Turing machines, which underpin mathematical and computational thinking about mechanisms, contain closed causal loops. This demonstration falsifies Rosen's fundamental claim. A Turing machine is an abstract entity but one that could perfectly well be built. In this section I provide a very brief introduction to Turing machines focused on the issue of closed loops. A full account of Turing's work and its place in psychology can be found in Wells (2006). Readers are also encouraged to study Turing (1936), the seminal paper in which Turing set out his theory.

A Turing machine is a model of a human agent engaged in a paper-and-pencil calculation. This simple fact is not often mentioned in psychological discussions of computational models, but it is of great significance and bears consideration by ecological psychologists. I shall take a few moments to comment on it in the light of Rosen's epistemology that constitutes the framework for his objections to machine models. Rosen (1991) said, as reported in the overview, that the primary feature of natural law is to bring systems of causal entailment in the external world into correspondence with systems of inferential entailment in the inner world of the self. He also made the important point that one could start from either side. Starting from the external world, the primary entity is a natural system whose causal entailments one attempts to discover and model in formal terms. Starting from the internal side, the primary entity is a formal system for whose inferential entailments one attempts to find a matching natural system. One of Rosen's principal objections to the machine metaphor, particularly in the form in which it was inherited from Descartes, was precisely that it started from a formal model and attempted to force the phenomena of life to fit that model. Even worse, the Cartesian machine metaphor was incompletely specified. Near the beginning of *Life Itself*, in a discussion of Descartes, Rosen says of him:

What he had observed was simply that automata, under appropriate conditions, can sometimes appear lifelike. What he concluded was, rather, that *life itself was automaton-like*. Thus was born the machine metaphor, perhaps the major conceptual force in biology, even today. Descartes took this fateful step with only the haziest notion of what a mechanism or automaton was (Newton was still a generation away), and an even dimmer notion of what an organism was. (p. 20)

It appears from what Rosen says later in the book that, at the time of writing it, he felt there was still no canonical machine model on which to base his assessment. At the start of chapter 7, for example, he refers to "the vague concept of machine" (p.182) and although he refers to Turing in that chapter, he does so in a way that

suggests he was unaware of the derivation of Turing's machine model from the example of a human calculating with paper and pencil. Had he been aware of this derivation he would hardly have claimed as he did (p. 185) that Turing machines are the formal counterparts of clockwork, that is, the machinery that drives the hands of a clock, and he would also hardly have claimed that his quasi-Newtonian definition of an algorithm in section 7C of *Life Itself* "is essentially a Turing machine" (p. 189). Neither of these claims is accurate. It is a great pity that Rosen was unaware of the origins of Turing's modeling enterprise because Turing machines are exactly the kinds of models that Rosen proposes are needed to embody natural law. Turing began by observing the natural system of causal relations that is involved in a paper-and-pencil computation. From this he abstracted what he felt were the essential components and used these to construct his formal model. He was then able to use the model in the way Rosen says that models should be used, to reflect on and reason about causal relations in the natural system modeled. One important result was the construction of the universal machine, which is a simulator par excellence. What the universal machine shows is not, as Rosen asserts, that simulation hides the details of the modeled system from the observer. Quite the contrary: a simulation makes available in an explicit symbolic format the details of the entailment structures that the model expresses. Turing's universal machine also demonstrates why symbolic notations are so important for almost all systematic human activities. Among other important characteristics, they make available, in forms that do not have to be remembered, structures of inferential entailment that model causal relations in the external world that we find useful or pleasing or both.

The Turing machine has two primary components, a finite control automaton, which is a model of the mind of the human, and a one-dimensional tape, which is a model of the paper on which a human writes out a calculation. For present purposes, the structure of the finite control automaton is of particular importance. Closed causal loops are most evident there, although they are also found in the dynamic relation between the automaton and the tape. Turing machines were originally devised to explore the issue of effectiveness in calculation, and the numbers they can compute, which are called the computable numbers, are a subset of the real numbers and include irrational numbers like π , which have infinite decimal expansions. The opening sentence of Turing's (1936) paper makes a point that is of fundamental importance in this context. He said, "The 'computable' numbers may be described briefly as the real numbers whose expressions as a decimal are calculable by finite means" (p. 230). The point to note is that computable numbers like π , which have indefinitely long decimal expansions, are nevertheless said to be calculable by "finite means." What this means is that a finite structure or set of resources, the control automaton, that is defined in advance of the calculation is sufficient to produce the endless sequence of digits representing a number like π . The way this is done, and has to be done, is to build the finite control structure with components connected in loops whose processing can be iterated as many times as necessary. It is thus of the essence of a Turing machine that its fixed processing re-

sources are structured as one or more closed loops. It is precisely because this is so that infinite sequences can be produced by finite means. Let us consider three examples briefly. Much more extensive discussion can be found in Wells (2006).

The first example is one of the simplest Turing machines imaginable. It was defined by Turing in his 1936 paper and outputs the endless sequence 010101 I shall call the machine TM1. The finite control automaton of TM1 has four internal states, which we can call q_1 , q_2 , q_3 , and q_4 . These, collectively, can be described as a set $Q = \{q_1, q_2, q_3, q_4\}$. Internal states describe the causal relations among the parts of a Turing machine in an abstract way. The concept of state, as it is defined and used in Turing machine theory, is very different from the concept of state used by Rosen (1991) in *Life Itself*. In Turing machine theory states are relational entities, the sorts of things that Rosen calls "components" in chapter 5 of *Life Itself*. The operations of TM1 are described by two functions, each of which takes the "configurations" of TM1 as its arguments. A configuration is an ordered pair consisting of an internal state and an input. One function determines the next state of TM1, the other its output. The next state function is more important for present purposes. This function is a map from Q to Q and is implemented as a closed loop of entailments. The starting state of the machine is q_1 : q_1 entails q_2 , q_2 entails q_3 , q_3 entails q_4 , and q_4 entails q_1 . Once started, the machine cycles endlessly through this processing loop. It is precisely because the four internal states of its control automaton are structured as a closed loop that the fixed, finite machine TM1 can output the infinitely long sequence 010101 TM1 provides a definitive and conclusive rebuttal of Rosen's lengthy and complex argument in *Life Itself*. TM1 is a machine and it has a closed causal loop of the kind that Rosen says machines cannot have. The causal relations between the states that implement the loop are of the type that I described as component-component interactions in the discussion of Points 8 to 10 of Rosen's argument from *Life Itself*.

TM1, by itself, is quite sufficient to rebut Rosen's (1991) argument but it is worth considering briefly two more examples. The first is a machine used to illustrate the argument made by Wells (2002) that the configurations of Turing machines provide natural and informative models of Gibsonian affordances. The machine is called HP and is described in detail in Wells (2002, pp. 163–167). Like TM1, HP has four internal states, but whereas TM1 has a single closed loop connecting its states, HP has six closed loops. In addition, it also makes use of closed loops connecting its internal states with symbol structures on its tape, which is its environment. This is not a feature of TM1. Most Turing machines are like HP in this respect, however, and it is partly because these machines have causal loops connecting their internal states to their environments that they are potentially of such interest and importance to ecological psychology.

Finally, it is worth remarking that universal Turing machines, the abstract ancestors of contemporary digital computers, exhibit complex patterns of closed loops to implement their processing. It is not possible to construct a universal machine that does not have such loops and they involve both hardware and software.

Thus it is of the essence of Turing machines, in general, that they contain closed causal loops.

ROSEN AND ECOLOGICAL PSYCHOLOGY

Rosen's principal concern in *Life Itself* (1991) and in *Essays on Life Itself* (2000) was fundamental theory in biology, and he says relatively little that is specific to psychology. The general thrust of his theorizing, however, appears to be antithetical to the interests and motivations of ecological psychology. His epistemology, as the overview shows, assumes a strong form of indirect realism. He also used the (untenable) distinction between simple and complex systems to rule out at least some of the methods that have been discussed favorably in the ecological psychology literature, and his emphasis on the importance of closed loops of causation *within* the organism downplays the significance of the environment.

Organisms and Environments

Rosen's (1991) epistemology is concerned with the sources of answers to "why" questions about systems of various kinds. He perceives a spectrum of possibilities. At one extreme are systems with components about which "why" questions can be answered only by reference to the environment within which the system is embedded. According to his view, mechanisms are systems of this kind:

Most of the "why?" questions we can ask about such a system are unanswerable within the system, and therefore, must be referred to its environment. Put another way: most elements of an abstract block diagram arising from a mechanism are *unentailed*. (pp. 248–249)

Rosen's view is that organisms lie at the other end of the spectrum. It is generally, he claims, possible to answer "why" questions about organisms from within the organism without the need to make reference to the environment:

My claim is that organisms lie at the other extreme as far as entailment is concerned. Their abstract block diagrams manifest *maximal entailment*; in particular, if *f* denotes a component of such a system, the question "why *f*?" has an answer, in terms of efficient causation, *within the system*. (p. 249)

Setting aside for the sake of the discussion the fact that the distinction between mechanisms and organisms does not hold for the reasons discussed earlier, it is curious, given Rosen's view of organisms as essentially self-contained systems, that ecological psychologists should view his work favorably. As the quotations show, Rosen's view implies that organisms can be understood as largely independent of

their environments, whereas it is a fundamental principle of ecological psychology that organisms and their environments exist in relationships of mutuality and reciprocity and that each has to be understood in terms of the other. This has always been a clear feature of Gibson's (1979/1986) work:

The fact is worth remembering because it is so often neglected that the words *animal* and *environment* make an inseparable pair. Each term implies the other. No animal could exist without an environment surrounding it. Equally, although not so obvious, an environment implies an animal (or at least an organism) to be surrounded. (p. 8)

The reciprocity of animals and environments implies that perception involves causal loops connecting the animal to the environment. Gibson was very clear about this when he developed the concept of a perceptual system:

Instead of looking to the brain alone for an explanation of constant perception, it should be sought in the neural loops of an active perceptual system that includes the adjustments of the perceptual organ. Instead of supposing that the brain constructs or computes the objective information from a kaleidoscopic inflow of sensations, we may suppose that the orienting of the organs of perception is governed by the brain so that the whole system of input and output resonates to the external information. (p. 5)

Rosen (1991), by contrast, viewed the relation between organism and environment in the classical representationalist sense that ecological psychologists reject. He also, as reported earlier, specifically endorses the traditional view of perception as indirect:

As philosophers have pointed out for millennia, all we perceive directly are our selves, together with sensations and impressions that we normally interpret as coming from "outside" (i.e., from the ambience), and that we merely *impute*, as properties and predicates, to things in that ambience. The things in themselves, the *noumena*, as Kant calls them, are inherently unknowable except through the perceptions they elicit in us; what we observe are *phenomena*, which are to an equally unknowable extent corrupted by our perceptual apparatus itself (which of course also sits partly in the ambience). (p. 56)

One further corollary of Rosen's emphasis on the organism as an essentially self-explanatory system, all of whose "why" questions have intrasystemic answers, is a denial of the value of evolutionary explanation.

To me, it is easy to conceive of life, and hence biology, without evolution. But not of evolution without life. Thus, evolution is a corollary of the living, the consequence of specialized somatic activities, and not the other way around. ... Biology is wrapped up

with soma and how it operates; thus we cannot invoke evolution as an explanatory or causal principle for these purposes. (p. 255)

Once again the contrast with Gibson's (1966) views is striking. The facts of evolution came to play a central part in the development of his ecological theory of visual perception.

The fact of information in the light falling upon an organism, is the situation to which animals have adapted in the evolution of ocular systems. The visual organs of the spider, the bee, the octopus, the rabbit, and man are so different from one another that it is a question whether they should all be called *eyes*, but they share in common the ability to perceive certain features of the surrounding world when it is illuminated. The realization that eyes have evolved to permit perception, not to induce sensations, is the clue to a new understanding of human vision itself. (p. 155)

Methodological Issues

One of the consequences of Rosen's (1991) mistaken supposition that machines cannot exhibit closed causal loops was the distinction between what he called *simple* and *complex* systems. All mechanisms and all systems that could be simulated on computers were said to be simple. A system was complex if, and only if, it had noncomputable models. This claim, alone, has a consequence that ought to make ecological psychologists wary of Rosen's work. The consequence is that dynamical systems theory is an inadequate theoretical basis for the study of living systems. The reason for this is that it is based on computable equations. Rosen (2000) was quite clear about its insufficiency:

To assert that organisms, or human systems, are thus complex, is a radical thing to do. For one thing, it says that differential equations, and systems of differential equations (i.e. dynamical systems), which are inherently simulable, miss most of the reality of a complex system ... just as any attempt to formalize, for example, Number Theory misses most of its theorems. (p.325)

Many ecological psychologists believe that dynamical systems theory offers a particularly useful set of tools for studying the complex interplay of organismic and environmental variables that characterizes human situated activity. If Rosen were correct, this belief would be erroneous. I should perhaps add that the claim made by some proponents of dynamical systems theory, for example Port and van Gelder (1995), that dynamical systems approaches are an alternative to computational ones is also a mistake. Rosen was right about that.

CONCLUSION

The antimechanist arguments of Robert Rosen have been used by some ecological psychologists to support an attack on computational methods and mechanist thinking generally. Close examination of Rosen's views shows that his epistemology assumes a strong form of indirect realism and his arguments, if valid, would constitute a denial of some of the fundamental principles on which ecological psychology is based. However, his arguments are not valid and do not show that organisms have properties that cannot be captured by machine models. For me this is important because I believe that antimechanist thinking in contemporary ecological psychology is based on a restricted view of the possible types of computational models and is acting as a barrier to the development of a genuinely ecological form of computational psychology. Computational thinking in psychology need not, and should not, be tied to models derived from stored-program serial digital computers. A genuine alternative, which is distinctively ecological, can be built on the foundations laid by Turing in his groundbreaking paper of 1936. In recognition of the striking parallels between Turing's work and Gibson's (1979/1986) ecological approach, I have suggested that the alternative approach should be called *ecological functionalism* (Wells, 2006). Had Rosen been aware of the possibilities that open up when one combines Turing's (1936) account of inferential entailment in the world of machines with Gibson's (1979/1986) account of causal entailment in the ecological world, I think he might have reconsidered his antimechanism.

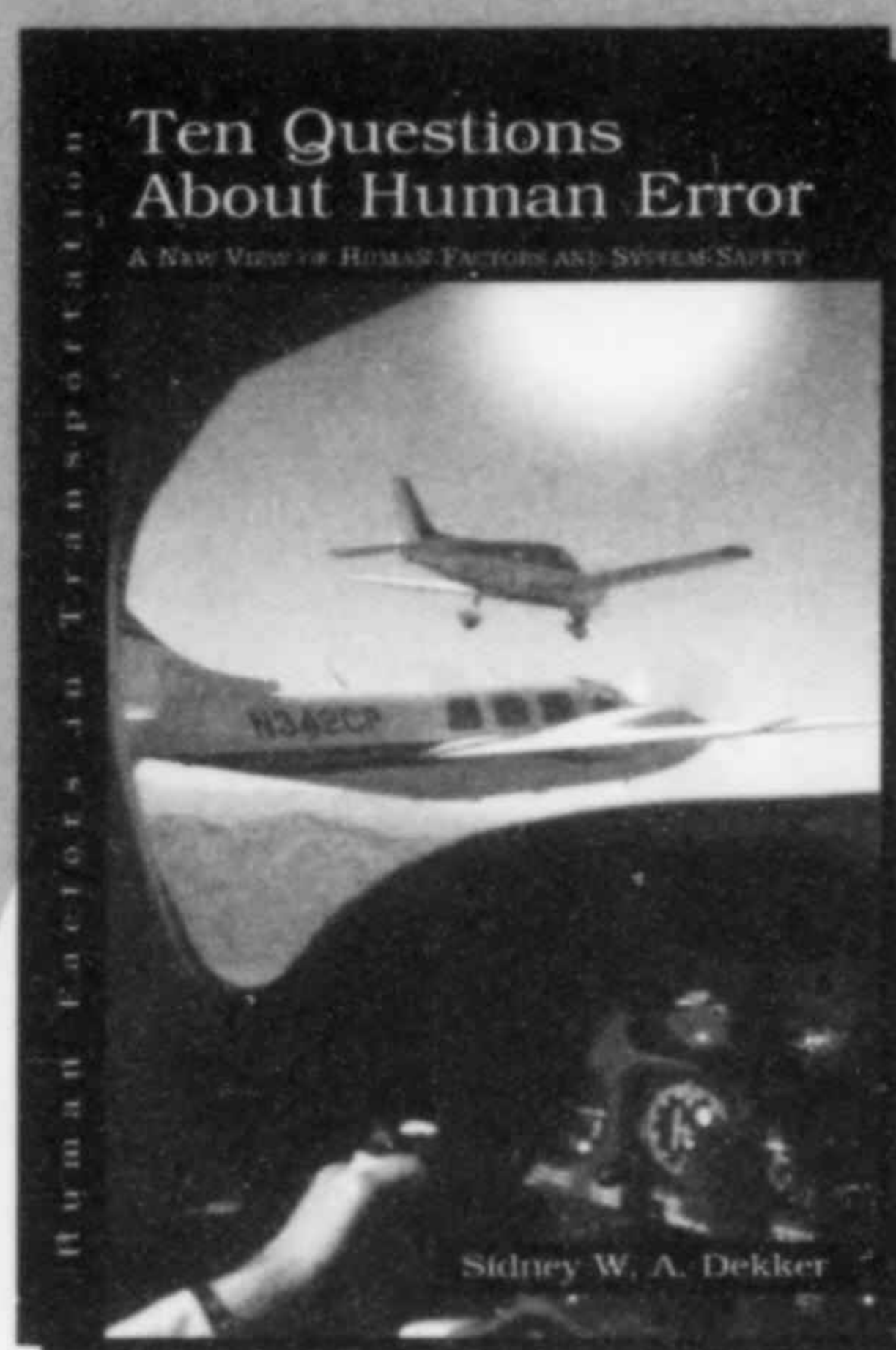
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REFERENCES

- Aspray, W., & Burks, A., (Eds.). (1987). *Papers of John von Neumann on computing and computer theory*. Cambridge, MA: MIT Press.
- Cantor, G. (1891). Über eine elementare Frage der Mannigfaltigkeitslehre. *Jahresbericht der Deutschen Mathematiker-Vereinigung* 1, 75–78.
- Gibson, J. J. (1966). *The senses considered as perceptual systems*. Boston, MA: Houghton Mifflin.
- Gibson, J. J. (1986). *The ecological approach to visual perception*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc. (Original work published 1979).
- Gödel, K. (1931). On formally undecidable propositions of *Principia Mathematica* and related systems I. In Kurt Gödel. *Collected Works, Vol. 1: Publications 1929–1936* (pp. 144–195). Oxford, England: Oxford University Press.

- Gödel, K. (1944). Russell's mathematical logic. In *Kurt Gödel. Collected Works, Vol. 2: Publications 1938–1974* (pp. 119–141). Oxford, England: Oxford University Press.
- Hocutt, M. (1974). Aristotle's four becauses. *Philosophy*, 49, 385–399.
- Landauer, C., & Bellman, K. L. (2002). Theoretical biology: Organisms and mechanisms. *American Institute of Physics Conference Proceedings*, 627, 59–70.
- Moravcsik, J. M. E. (1974). Aristotle on adequate explanations. *Synthese*, 28, 3–17.
- Port, R. F., & van Gelder, T. (1995). *Mind as motion. Explorations in the dynamics of cognition*. Cambridge, MA: MIT Press.
- Rogers, H., Jr. (1967). *Theory of recursive functions and effective computability*. Cambridge, MA: MIT Press.
- Rosen, R. (1991). *Life itself. A comprehensive inquiry into the nature, origin, and fabrication of life*. New York: Columbia University Press.
- Rosen, R. (2000). *Essays on life itself*. New York: Columbia University Press.
- Rosen, R. (n.d.) *Autobiographical reminiscences*. Retrieved April 18, 2005, from <http://www.rosen-enterprises.com/RobertRosen/RRosenautobio.html>
- Schrödinger, E. (1944). *What is life?* Cambridge, England: Cambridge University Press.
- Shaw, R. E. (2003). The agent-environment interface: Simon's indirect or Gibson's direct coupling? *Ecological Psychology*, 15, 37–106.
- Turing, A. M. (1936). On computable numbers with an application to the Entscheidungsproblem. *Proceedings of the London Mathematical Society, Series 2*, 42, 230–265.
- Turvey, M. T. (2004). Impredicativity, dynamics, and the perception-action divide. In V. K. Jirsa & J. A. S. Kelso (Eds.), *Coordination dynamics: Issues and trends, Vol. 1: Applied complex systems* (pp. 1–20). New York: Springer Verlag.
- Turvey, M. T., & Shaw, R. E. (1995). Toward an ecological physics and a physical psychology. In R. L. Solso & D. W. Massaro (Eds.), *The science of the mind: 2001 and beyond*. New York: Oxford University Press.
- Wells, A. J. (2002). Gibson's affordances and Turing's theory of computation. *Ecological Psychology*, 14, 141–180.
- Wells, A. J. (2006). *Rethinking cognitive computation. Turing and the science of the mind*. Basingstoke, UK: Palgrave Macmillan.
- Whitehead, A. N., & Russell, B. (1925). *Principia mathematica* (2nd ed.). Cambridge, England: Cambridge University Press.



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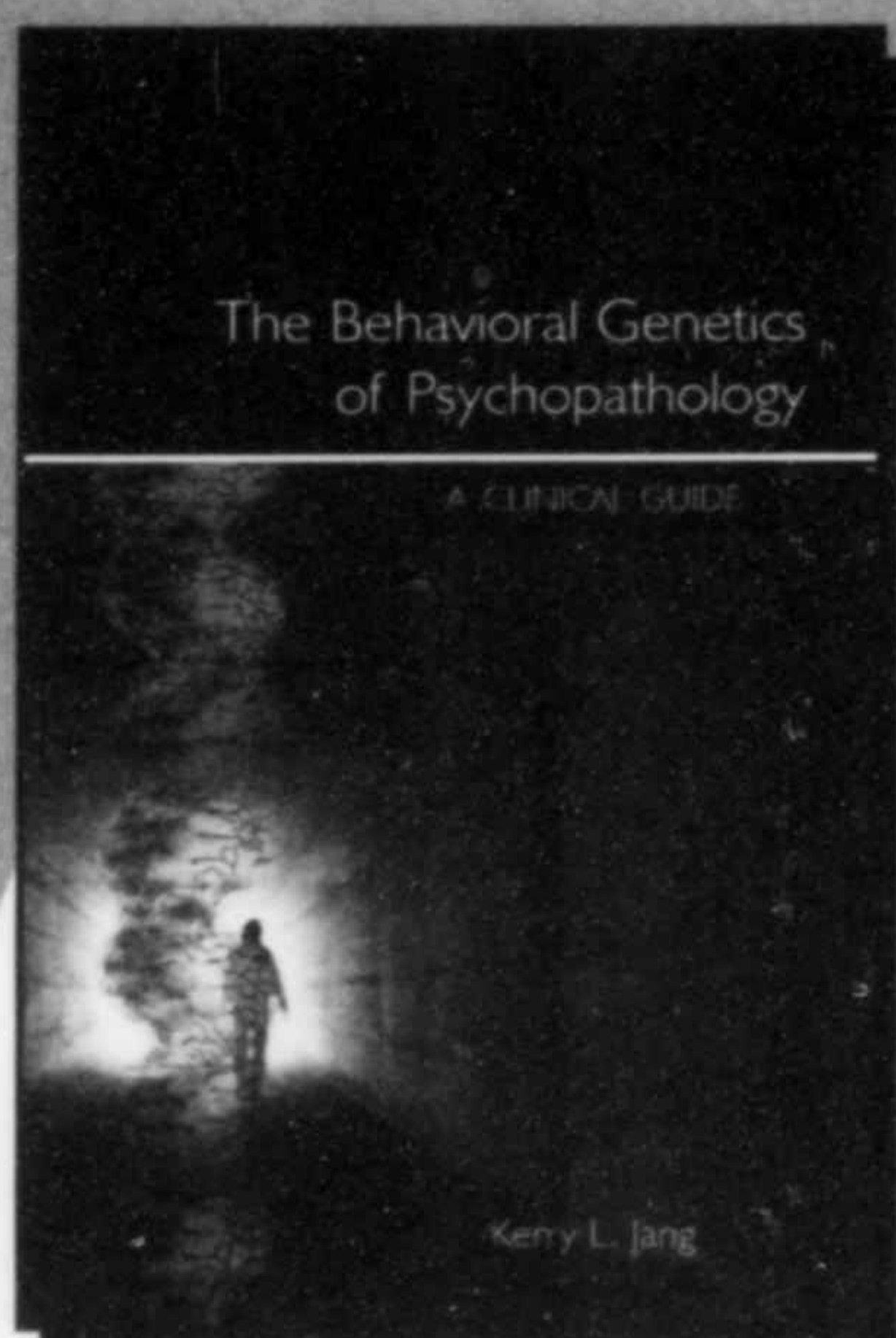
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THE BEHAVIORAL GENETICS OF PSYCHOPATHOLOGY

A Clinical Guide

KERRY L. JANG, *University of British Columbia, Canada*

New discoveries about the genetic underpinnings of many kinds of human experience are now constantly being made. This book explores the impact of these discoveries on the ways in which the common mental disorders are best conceptualized and treated.

Most people think of research in genetics as the search for genes. This is only one focus of effort, and even with the reliable identification of susceptibility genes, the clinical applications of their discovery, such as gene therapies and new drug development, are a long way off. For the present, the impact of genetic research on

our understanding of mental illness is tied to our ability to estimate the effect of *all* genes by means of family, twin, and adoption studies. The results of these studies challenge some deeply cherished ideas and theories, and support others.

Of course, the effect of genes is only half the equation. The role of experience, environment, and living conditions accounts for as much, often considerably more, of the variability in psychopathology. In this book, Kerry Jang attempts not to answer questions about what is "genetic" and what is not, but about what a knowledge of the relative influence of genes versus environment means at a *psychological level of analysis*—to show how it changes common assumptions about classification, etiology, diagnosis, and intervention.

He first offers an overview of contemporary behavioral genetics, dispels common misconceptions, responds to the criticisms that have been leveled at this new field, and describes in basic terms how genetic and environmental effects are estimated and how susceptibility genes are pinpointed. He then points to new directions in which standard nosological systems are likely to evolve as new information about vulnerabilities and covariances emerges. Finally, he synthesizes and evaluates the consistency of the last decade's findings for the most common categories of psychopathology that have been studied by behavior geneticists: mood, personality, and anxiety disorders, substance abuse; and schizophrenia and the psychotic disorders.

Clinicians and researchers alike need to understand the genetic influences on the feelings and behaviors they are seeking to change or study if they are to be effective in their work. *The Behavioral Genetics of Psychopathology: A Clinical Guide* empowers them with this understanding.

Contents: Preface. **Part I:** *Behavioral Genetic Basics.* Introduction. The ABCs of Behavioral Genetics. Classification and Diagnosis. **Part II:** *The Behavioral Genetics of the Common Mental Disorders.* The Mood Disorders. The Personality Disorders. The Anxiety Disorders. Substance Use Problems. Schizophrenia and the Psychotic Disorders. Recapitulation.

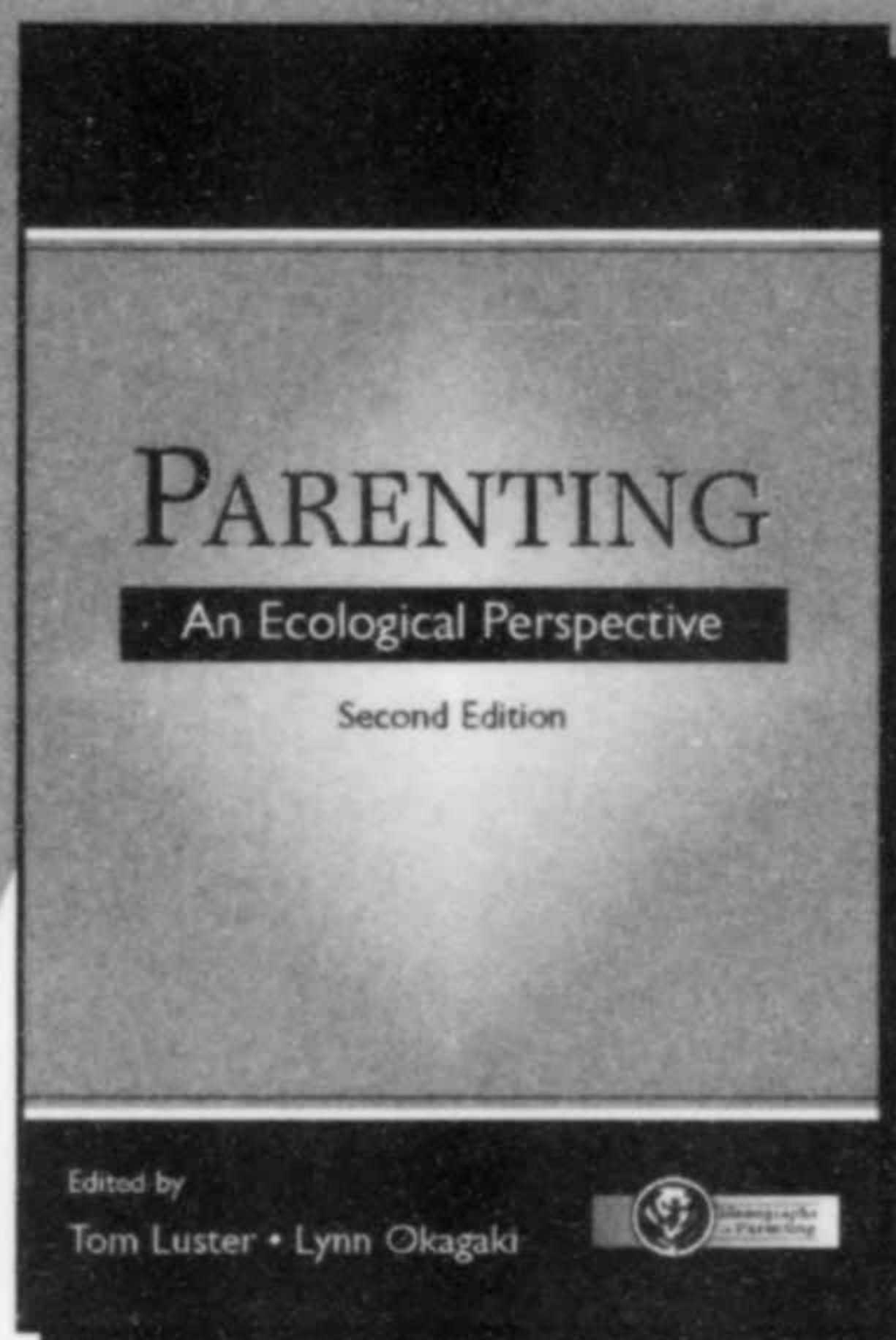
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PARENTING

An Ecological Perspective, Second Edition

Edited by

TOM LUSTER, *Michigan State University*

LYNN OKAGAKI, *Purdue University*

MONOGRAPHS IN PARENTING SERIES

Parenting: An Ecological Perspective was originally created in 1993 to answer questions such as: Why do parents differ markedly in the ways in which they care for their children? What factors contribute to individual differences in parenting behavior? The framework used for addressing these questions is the ecological perspective developed by Urie Bronfenbrenner, who recognized that children's development is influenced by the inter-

actions that they have over time with the people, objects, and symbols in their immediate environment.

Luster and Okagaki have updated the original text focusing on parental behavior and also included 6 new chapters covering topics such as:

- › Fathers/gender of parent;
- › Children with special needs;
- › Ethnicity and socioeconomic status; and
- › Parent education.

The text summarizes the latest research on factors that influence parenting, with each chapter providing a look at one important influence and the linkages among these various factors. An ecological perspective draws attention to the fact that the lives of parents and children are intertwined, and that understanding factors that influence parents is important for understanding the experiences of children.

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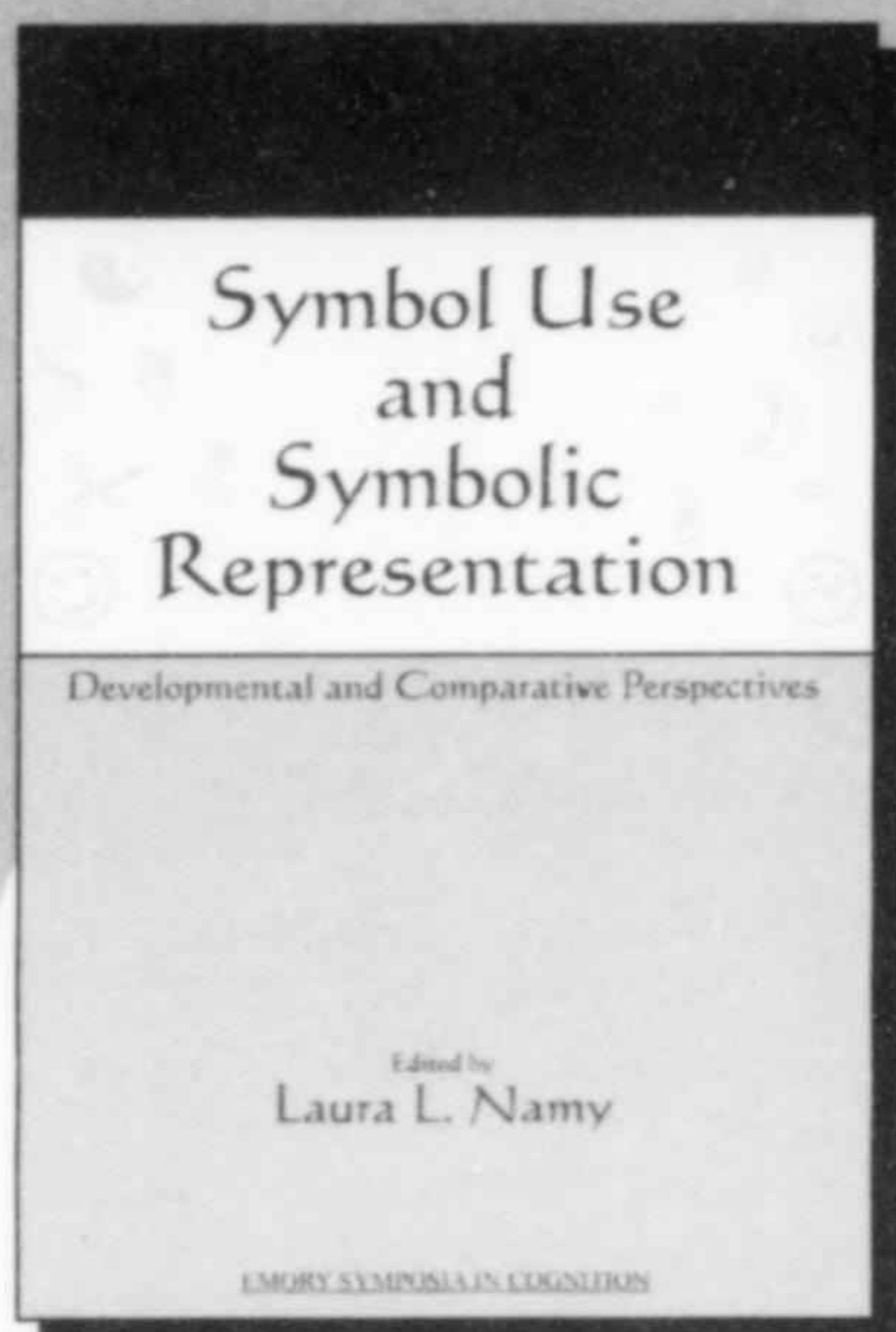
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SYMBOL USE AND SYMBOLIC REPRESENTATION

Developmental and Comparative
Perspectives

Edited by

LAURA L. NAMY, Emory University

EMORY COGNITION PROJECT SERIES

Symbol Use and Symbolic Representation: Developmental and Comparative Perspectives is the proceedings of a workshop held at Emory University in 2002 to discuss the difficult and age-old issue of what makes a symbol symbolic. The issue shifts towards exploring the relation between apparent symbolic behavior and actual symbolic insight on the part of the user or recipient.

The workshop discussed the pitfalls of inferring symbolic understanding from apparently symbolic behaviors and possible criteria that would enable us to ascertain when a symbol is being employed in an intentional, communicative, representational manner. Broken down into three parts, this volume:

- › focuses on the factors that influence the emergence of symbolic behavior in young, typically developing children;
- › turns to an examination of individual and population differences in symbolic development and the ways variability in symbol use can inform the cognitive mechanisms underlying symbolic insight; and
- › explores symbolic understanding in non-human animals.

The text ends with a synthesis of recurring themes, questions, concerns, and conclusions, and offers a new perspective on the process of understanding the relation between symbol use and symbolic insight.

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