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## Coalitions as models for Ecosystems: A Realist Perspective on Perceptual Organization

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### ABSTRACT

Gestalt theory essentially claims that perceptual organization is dictated by the organization of the central nervous system (Wertheimer's principle of isomorphism). This is shown to be a phenomenalist's account of knowing, where the objects of perception are treated as distinct from the objects of the environment. Such a view encounters many logical and empirical difficulties that are avoided by an alternative style of scientific inquiry based on pragmatic realism offered by the American pragmatists Peirce, Dewey, and Bentley. In the realist's view, the objects of perceptual knowing are functionally ascribed directly to objects in the knower's environment. The realist's account offered by the pragmatists derives from the observation that successful scientific theories (e.g., Einstein's) necessarily go beyond explanations in terms of (causal) *interactions* to explanations in terms of (acausal) *transactions*, defined as a reciprocity of mutual constraint existing between phenomena and their contexts. Although the transactional approach is an improvement over traditional interactional ones, it nevertheless fails to avoid "run on" explanations that regress toward ever-more-encompassing contexts of hidden constraint. Still a further improvement is the ecological style of scientific inquiry originally proposed by J. J. Gibson and extended by the authors; although in many ways consonant with the transactional approach, it

avoids the context regress problem by introduction of the concept of "coalition" to model the organization of perceptual systems. A *coalition* is a superordinate system (relational structure) consisting of eight pairs of subsystems (with 1024 states) nested at four exclusive "grains" of analysis (bases, relations, orders, values) and closed at each grain under a (duality) operation that specifies how the two complementary subsystems act as reciprocal context of mutual constraint. Finally, a coalitional model is applied informally to express the symmetry of constraints in an (epistemic) ecosystem that necessarily exists between animals and their environments. In this formulation, the organization that perception takes co-implicates the organization that action takes and is not defined at the scale of animals (i.e., is not an achievement of the nervous system) but only at the scale of ecosystems.

## INTRODUCTION

Can the objects of perception and the manner of their organization be identified with objects and an organization that exists when no perceiving is going on? From the point of view of a commitment to realism, the answer must be that they can; in general, however, and almost without exception, students of perception over the centuries have made certain assumptions and pursued particular forms of argument that have led to the negative answer—precisely, that what is perceived and how it is organized is, by and large, a product of mental or neural processes. But to answer the foregoing question thusly, in the negative, is more than a little curious; it is surely not in the best interests of science to distinguish ontologically between the subject matter of inquiries into perception and the subject matter of other inquiries into nature.

In several recent papers we have sought a clarification of the conceptual barriers to perceptual realism and an identification of the reconceptualization needed to dismantle them (Shaw & Bransford, 1977; Shaw, Turvey, & Mace, 1981; Turvey, 1977; Turvey & Shaw, 1979; Turvey, Shaw, & Mace, 1978). The contribution of the present chapter to a realist program is that nonrealist (phenomenalist) theories of perception are nurtured by styles of scientific inquiry that are too narrow in their conception of the logical and causal support for perception. We motivate and describe a style of inquiry—referred to as coalitional—in which the focus is the animal-environment system described in full. This style of inquiry was anticipated to a degree by American pragmatists and inheres in the ecological approach to knowing that has been championed by Gibson (e.g., Gibson, 1966). Gestalt psychology claimed that perceptual organization is an achievement of the nervous system; we claim that perceptual organization is an activity of the ecosystem—of which the animal and its environment comprise dually complementing parts.

## GESTALT THEORY AS A PHENOMENALISM

## Phenomenalism and Subjective Idealism

The attempt to resolve epistemological puzzles in the half century from 1690 to 1740 was both vigorous and creative, but the predicaments it gave rise to were settled in a most unsatisfactory manner from the point of view of a committed realist. Locke had sought to found an epistemology on the dictum that "there is nothing in the intellect which was not previously in the senses." He was compelled to distinguish among (1) the physical object, (2) the simple ideas or sense data that the physical object gave rise to, and (3) the complex of ideas that constituted the object of experience. Locke's perspective was that of a dualist, distinguishing as he did between two kinds of objects: the physical or real object to which perception was indirectly in reference, and the mental object—or representation—of which perception was directly an experience. Locke, in brief, accepted the Cartesian approach to the problem of perception by assuming the doctrine of representative ideas.

The doctrine invited (and continues to invite) skepticism about perception as a means of knowing reality. On Locke's theory, the perceiver is not in direct epistemic contact with the existence of physical objects; and the sense data from which the object of experience is manufactured could have arisen from sources other than external physical things (e.g., from perceivers themselves or, as some argued, from God). Ideas or impressions (i.e., putative representations) may correspond to reality, but one has no way of knowing that to be so if all that one knows directly are ideas or impressions.

Berkeley's response to the predicament of Locke's theory was to deny the assumption that sense data or the ideas derived from them were a representation of any reality. In short, Berkeley retained mind and its ideas but dispensed with external objects and thus the notion of ideas as representation. (Indeed, insofar as Locke had already proposed that the specific sense qualities represent nothing external, the representative doctrine had been undercut.) The subjective idealism implicit in Locke was made explicit in Berkeley; and where Locke had looked to the regularity of orderliness of the environment as the reason for the regularity and orderliness of ideas, Berkeley looked to God.

But Berkeley's appeal to God was not appealing to Hume, whose focus, in the long run, was more disturbing; it was, straightforwardly, the skepticism implicit in Locke—a skepticism regarding the possibility of certainty in one's knowledge of the natural world. The world erected within Hume's skeptical framework begins and ends with impressions and ideas linked in accordance with the laws of association. For Hume, experience is of phenomena only, and as to what exists other than phenomena, no one can say. In Hume's scheme of things, orderliness of experience is due neither to the external world nor to God but to the laws of association of ideas.

The contrasting perspectives of Locke, Berkeley, and Hume have left a deep impress on the development of perceptual theory but fundamentally through that aspect that is common to all three—namely, phenomenism. By way of a brief overview, and skipping over variations on the theme, phenomenism holds that direct knowledge of one's environment is not possible and that that which is known is constituted solely by the fact that it *is* known. Taken to its extreme, phenomenism is skeptical about one's awareness of the environment; all that is directly knowable are phenomena—impressions, sense data, or, more generally, mental states. Some forms of phenomenism recognize that mental states are in reference to external objects. With regard to these forms of phenomenism, an external reality independent of mental states is assumed, and to mental states are ascribed the role of providing indirect knowledge of external reality or, at least, a basis for constructing a theory of external reality. These forms of phenomenism that assume a reality and, therefore, might be referred to as indirect realisms are susceptible to two problems: The problem of reference—that is, how the object of experience, or the intentional object as it is often called, and the object of reference, the physical object in the environment, are coordinated; and the problem of intentionality—that is, how the intentional object should be described (see Shaw, Turvey, & Mace, 1981).

A profoundly influential perceptual theory from the last century is that of Helmholtz, and its phenomenism is manifestly plain. In accepting Johannes Müller's theory of specific nerve energies, Helmholtz assumed that the percipient was aware of a phenomenon or representation as contrasted with the physical reference object that was the source of stimulation. And we are reminded that the phenomenal object of experience was, for Helmholtz, rarely the bare-bones sensory impression, distinguished by the term *Perzeption*, but rather those impressions elaborated by memories, a totality distinguished by the term *Anschauung*.

In the two sections that follow, we consider a profoundly influential perceptual theory from the present century—namely, the Gestalt theory that is of special concern to the present volume. The thrust of our consideration is the continuity (rather than the contrast) between the Gestalt orientation to knowing and the orientation handed down over the centuries and already given brief overview here: The continuity lies, of course, with the fact that Gestalt theory is a phenomenist theory.

### Why Do Things Look as They Do?

This question was raised and discussed most eloquently by Koffka (1935) in his celebrated *Principles of Gestalt Psychology*. He gave three answers: (1) Distal objects look as they do because they are what they are; (2) distal objects look as they do because the proximal stimuli are what they are; (3) distal objects look as they do because of the field organization of the brain to which the proximal

stimulus gives rise. In rejecting the first two answers and defending the third, Koffka firmly identified Gestalt theory as a phenomenalist theory. To reject the first two answers is a clear repulse of realism, for to reject them is to introduce unbridgeable gaps between the perceiver and the world. And to promote the third answer is to focus attention on brain processes to account for perceptual organization. That is to say, given the question: Why is perception organized as it is? Koffka replied, essentially: Because the processes of the brain are organized as they are. This appeal to brain processes serves the same function as Berkeley's appeal to God and Hume's appeal to the laws of association in lieu of a reality—an animal's environment (or more precisely, as we argue, the ecosystem of which the animal is a part)—to account for the organization of an animal's perceptual experience.

Let us consider Koffka's reasons for rejecting Answers 1 and 2. Our focus is the first answer, because our rejoinder to Koffka's reasons for rejecting it generalizes to the second. One reason for rejecting the first answer rests with being able to show that for a particular perceptual experience (as distinct, presumably, for a hallucination or a dream) of type  $x$ , the existence of a physical object of type  $x$  is neither necessary nor sufficient. For example, Koffka (1935) argues that if it were necessary, then for a particular experience of type  $x$ , there ought to be a physical object of the same type to which the experience corresponds. A typical illustration of the nonnecessity of a physical object of type  $x$  is provided through a consideration of Fig. 11.1.

Koffka (1935, p. 79) and Köhler (1947) would claim that Fig. 11.1 appears to an observer as a single unit, a cross, whereas *in reality* it is nothing but a number of points in a certain arrangement. The reference object is not of the same type as the experienced object because in the absence of a line connecting the points, the points do not collectively define a single physical, crosslike unit—or so runs the argument. But it would seem that the latter contains an arbitrary definition of

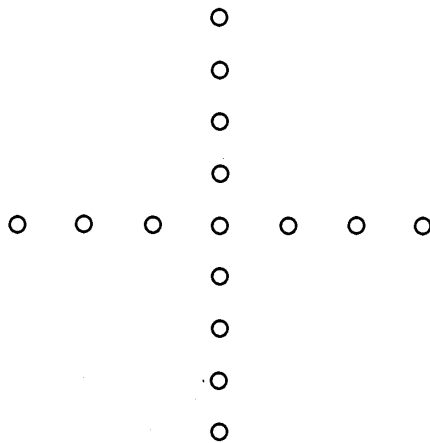


FIG. 11.1. A cross of points.

figural unity, an arbitrary choice of a geometrical language for describing environmental objects. One could just as easily and arbitrarily conclude that the points *do*, in fact, comprise a single unit because some relation among the points does not change under a number of spatial transformations—for example, moving or rotating the page. At all events, the argument for a nonnecessary relation between the type of the object of reference and the type of the object of experience rests with there being an incompatibility between the descriptors of the two objects. It would follow that if one were committed to realism and adverse to phenomenalism, then one would seek a language in which to describe the object of reference and the object of experience so that they were one and the same. The tolerance for, or unquestioning acceptance of, inequitable or incommensurate descriptors marks the path to phenomenalism, and it is no more evident than in Koffka's second reason for denying that things look as they do because they are what they are.

The second reason is the one that is more commonly touted and has to do with the relation said to hold between the distal stimulus and the proximal stimulus. To quote Koffka (1935): "for each distant stimulus there exists a practically infinite number of proximal stimuli; thus the 'same stimulus' in the distant sense may not be the same stimulus in the proximal sense; as a matter of fact it seldom is [p. 80]." And to quote Köhler (1974):

Thus in the reflected light no trace is left of the units which actually exist in the physical world. . . . Thus in countless instances sensory organization means a reconstruction of such aspects of physical situations as are lost in the wave messages which impinge upon the retina [pp. 161, 163].

We see, in short, that the function that maps distal stimuli into proximal stimuli is construed as one-to-many and destructive: The proximal stimulus equivocates on the object of reference (the distal stimulus) and fails to preserve its properties. Therefore, in reference to Answer 1 earlier, things *cannot* look as they do just because they are what they are; the means by which we visually "contact" distal objects—the light at the eye—is not specific to their structure. Elsewhere, we have referred to this time-honored understanding of the distal/proximal relation as the doctrine of intractable nonspecificity (Shaw et al., 1981; Turvey & Shaw, 1979).

The acceptance of this doctrine gives rise to a paradox, as Koffka (1935) noted:

And that raises at once the problem: how the enormous richness and variety of our visual behavioral environment can be aroused by such a mere mosaic of light and shade and color. I think, when formulated in these terms, the problem must appear thrilling by the very paradox which it seems to involve. How can such rich effects arise out of such poor causes, for clearly the "dimensions" of our environmental field are far more numerous than those of the mosaic of the stimulation [p. 75]?

We have quoted this passage primarily because it underscores the inequity or incommensurability of descriptors theme: The descriptors of the light at the eye and the descriptors of the environment are assumed to be different numerically, in grain size, in degree of variety, and in type. And it is perhaps now evident why this assumed and received inequity of descriptors poses such an insurmountable barrier to realism and mandates phenomenalism. As scientists drawn to evolutionary theory as an account of species, we speak of the evolution of an adaptive relation holding between animal and environment. Less generally, we would say of a seeing creature that an adaptive relation holds between the animal's visual system and its environment. Here, of course, we must mean that an adaptive relation holds between the animal's visual system and the light reflected from the environment of the animal, because it is by means of the reflected light that the environment is seen. But if the descriptors of the light to an animal's visual system are not commensurate with the descriptors of the environment—as Koffka and most other perceptual theorists have long assumed—then an adaptive relation holding between visual systems and reflected light is not an adaptive relation holding between visual systems and environments. Insofar as consistency demands that the same story of intractable nonspecificity holds for the energy media of all senses (see Koffka, 1935, p. 75), we should be skeptical about the possibility of an adaptive relation evolving between an animal's perceptual capabilities and the reality with respect to which it lives its hours, days, or years. We might continue to speak of the evolution of such relations, but we cannot with any confidence assume that reality is one of the terms in such relations. On this line of reasoning, realism is denied, and phenomenalism is ascendant.

We have earmarked the inequity or incommensurability of descriptors theme (see Fowler & Turvey, *in press*) as a barrier to realism and we have pinpointed its role in determining the phenomenalist tenor of Gestalt theory. It is one of several barriers to realism (see Shaw et al., *in press*), but it has received special emphasis in the present section because it was, ironically, a theme to which Gestalt psychology was passionately sensitive. In the section that follows, we try to show that Gestalt theory was acutely, though myopically, aware of the scientific conundra that are heir to an inequity of descriptors.

Let us conclude the present section by noting what a commitment to realism would advocate with respect to the relation between distal and proximal stimuli: It would advocate that a description of proximal stimuli be sought such that its descriptors were commensurate numerically, in grain size, in degree of variety, and in type with the descriptors of the environment at the scale of ecology. The phenomenalist's doctrine of intractable nonspecificity is opposed by the realist's doctrine of necessary specificity—precisely, that the properties of a structured energy medium are specific (within the modulatable limits of the medium) to environmental properties (Turvey & Shaw, 1979). The latter doctrine spawns a scientific endeavor that would be referred to as ecological optics with regard to light, as ecological acoustics with regard to sound, and as ecological physics with regard to environmentally structured energy in general (Gibson, 1961, 1966).

### The Issue of Geographical and Behavioral Environments

Behavior, Koffka (1935) argued, takes as its framework the behavioral (or phenomenal) environment rather than the geographical (or noumenal) environment. That is, behavior takes as its reference the environment as it appears to an observer rather than the environment as it would be described by physics. It is of course true that behavior takes place in the geographical environment and that the laws of physics cannot be compromised. Koffka's (1935) point is that the behavioral, or phenomenal, environment mediates the geographical environment and behavior. Thus we may conceive of two distinct stages: In one there is a transition from the geographical environment to the behavioral environment and in the other, a transition from the behavioral environment to behavior. It is a relatively straightforward matter to recognize, but significant nevertheless, that the first of these two stages entails a shift from a physical description of the environment, which is animal-neutral and meaningless, to a mental description, which is animal-referential and meaningful. The objects and types under the latter description are qualitatively different from the objects and types under the former description. Thus the distinction that is drawn by Koffka expresses not only Gestalt psychology's phenomenalism but also its dualism; for whatever else we might mean by dualism, it is, on the bottom line, an argument for speaking about the objects of reference and of experience in separate and irreducible languages.

Curiously, however, the feature of Gestalt theory that we wish to underscore in this section derives from the theory's *distaste* for dualism. We proceed to consider the conceptual steps taken by Gestalt psychology to avoid dualism and how and why these steps failed.

As is well known, Wertheimer, Koffka, and Köhler were adamant in their goal to work out the facts of psychology so that these facts would be continuous with those of physics and biology. Why, then, should a concept such as "behavioral environment," which would seem to introduce descriptors that have no parallel in physics, find a place in their theorizing? To Koffka (1935) and Köhler (1947), the stimulus-response analysis of behavior circa the 1930s and 1940s was unpalatable. They were adverse to the idea that the variety in molar behavior could be encompassed by combinations of a single type of molecular behavior—the stimulus-response link. They saw as unbridgeable the distinction between molar behavior that takes place in an environment and molecular behavior that takes place within an organism. But most of all, they were disturbed by the fact that meaning and significance, intrinsic as they are to molar behavior, have no place in the fine-grained stimulus-response description of behavior. For Gestalt psychology, theory building had to take *molar*, rather than molecular, behavior as its point of departure. It follows that the environment in which such behavior occurs must similarly be molar; that is, its descriptors have to be coarse grained. But more than that, the descriptors of the behaviorally relevant environment must be animal-referential; behavior is meaningful and significant because it is per-

formed in reference to objects and events that have meaning and significance for the animal. Thus runs the rationalization for the concept of behavioral environment.

Nevertheless, Koffka (1935) argued that the behavioral environment could not be advanced as a basic category of explanation, for in order to do so, the behavioral environment would have to be ascribed special ontological status. Such ascription would be a capitulation to dualism, a denial of a single mode or universe of discourse for natural events. In a similar vein, Koffka (1935) noted that the behavioral environment must be related to the geographical environment, but if the two environments identify separate modes of discourse, then the relationship between them cannot be causal, because causal laws hold only *within* a mode of discourse; a failure to recognize this fact is to make what Ryle (1949) called a categorical error.

A simple resolution to these problems, problems bespeaking separate realms of existence, would be—as Koffka (1935) duly noted—to substitute the physical reality of the animal's physiology for the concept of behavioral environment. But if the descriptive language of physiology is continuous with the descriptive language of physics and the latter is presumed to be fine grained, then the molar descriptors captured in the concept of behavioral environment, and held to be so important to the account of behavior, would be irretrievably lost. How, then, might a theorist preserve a single universe of discourse for describing natural events, on one hand, and molar descriptors on the other? The solution, Gestalt psychology opined, lay in discarding the claim that the descriptors of physics and, therefore, of physiology are merely fine grained. To assume that they are fine grained leads any proponent of a single universe of discourse to a fine-grained, molecular description of behavior and consciousness that, Gestalt psychology argued, was contrary to fact; or it leads to the claim for no relation, or a completely mysterious relation, between physiological processes and behavioral or conscious processes. In the light of these remarks (Koffka, 1935) lies both the motivation for and the significance of Wertheimer's isomorphism principle:

Let us think of the physiological process not as molecular, but as molar phenomena. If we do that, all the difficulties of the old theory disappear. For if they are molar, their molar properties will be the same as those of the conscious processes which they are supposed to underlie. And if that is so, our two realms, instead of being separated by an impassable gulf, are brought as closely together as possible with the consequence that we can use our observations of the behavioral environment and of behavior as data for the concrete elaboration of physiological hypotheses. Then, instead of having one kind of such processes only, we must deal with as many as there are different psychological processes, the variety of the two classes must be the same [p. 56].

Let us pause at this juncture to assess what the foregoing strategy achieved. Noting that the descriptors of physics, contrary to a more popular interpretation, were fundamentally coarse grained (Gestalt psychology, we are reminded, high-

lighted the role of field concepts in physics) made possible the claim that the descriptors of physiology were more aptly construed as molar rather than as molecular. Thus, Gestalt theory was able to avoid a marked discontinuity in the grain size of descriptors across the domains of physics, biology, and psychology; for it was self-evident that the descriptors of the behavioral environment were coarse grained or, at least, that they had to be if psychology were to be of any value to, say, the historians and artists with their interests in molar behavior (Koffka, 1935).

But is it the case that the discontinuity-in-descriptors problem is resolved by demonstrating a common and coarse grain size of descriptors? In the sentence of the foregoing quote that reads: "For if they are molar, their molar properties will be the same as those of the conscious processes which they are supposed to underlie," Koffka seems to answer yes. But this affirmation is illusory; for although the steps taken to demonstrate coarse-grained or molar descriptors across the different domains *may*, in principle, relate to the issue of why the experienced object has the structural appearance that it has, they do not, in principle, relate to the issue of why the experienced object has the meaning that it has.

Gestalt theory sought a thoroughgoing physicalism, but its thrust, we argue, was not epistemological problems—the problems of animals as knowing agents—as much as it was a desire to preserve a uniformity in mode of discourse across the *disciplines* of physics, biology, and psychology construed as the investigations of three different phases of matter. Consider how Gestalt theory chose to explain the characteristics of objects to which behavior is referenced, characteristics that Koffka (1935) said invited or demanded behavior. Seeing an object is to know what can be done with it or about it; and the immediacy of his knowing impressed Gestalt theorists. But what is the status of these characteristics that invite specific behaviors? At odds with its thoroughgoing physicalism, Gestalt theory ascribed to them phenomenal, rather than real, status. These characteristics that invite behavior are not ordinary physical characteristics, for they owe their very existence to a perceiver in the sense that they are inexistent outside of perception. Thus, it is argued, the mailbox has the characteristic of inviting letter posting only where one has the need to mail a letter (Koffka, 1935). In like vein, it would be argued that a particular arrangement of surfaces is a place to hide for an animal only when the animal needs to hide; another arrangement of surfaces is a brink in the terrain that demands leaping over only when the animal has a need to leap, and so on. In sum, by this kind of analysis, physical (*qua real*) dimensions are ordinarily neutral with respect to an animal and its capacity for activity; thus those dimensions or characteristics of the world that the animal-referential and activity-relevant must be extraordinary, nonphysical (*qua nonreal*) dimensions.

We see, in short, that the dualistic distinction with which we began this section—that of the geographical environment with its animal-neutral, meaning-

less descriptors and the behavioral environment with its animal-referential, meaningful descriptors—remains unscathed by the effort of Gestalt theory to establish a single mode of discourse. How did this perplexing state of affairs arise? The answer, we believe (and as intimated earlier), is that Gestalt psychologists were concerned with keeping the descriptors commensurate at that scale of discourse that is *talk about mechanical or causal contact* between different phases of matter, but they were not concerned with keeping the descriptors commensurate at that scale of discourse that is *talk about epistemic contact* between an animal and its environment. In this section we have seen how the objects of reference (the geographical environment) and the objects experienced and known (the behavioral environment) were construed as logically separate and their descriptors, as incommensurate. In the preceding section we saw the acceptance as doctrine of a pronounced discontinuity between the descriptors of the energy media at receptor surfaces and the descriptors of the geographical environment. To summarize, Gestalt psychology sought to dispel unbridgeable gaps in the causal process defined over different phases of matter but *created* unbridgeable gaps in the epistemic act defined over the animal and its environment.

#### THE CLAIM THAT PERCEPTUAL ORGANIZATION IS AN ACHIEVEMENT OF THE NERVOUS SYSTEM: COUNTERPOINTS FROM A COMMITMENT TO REALISM

We have considered the historical perspective of phenomenalism that is the backdrop for a good deal of perceptual analysis. *Phenomenalism*, as we have used the term here (see Mundle, 1971, for a more discriminating account), holds that direct knowledge of one's environment is not possible and that what is known is constituted by the fact that it *is* known. The examination of Gestalt theory in the first section of this chapter underscored the theory's allegiance to phenomenalism and dualism—that is to say, the theory's continuity with epistemological positions that are contrary to perceptual realism.

Let us now proceed to identify more fully the set of interlocking themes that underly the central claim of Gestalt psychology—the claim that perceptual organization is an achievement of the nervous system. Our preceding analysis of Gestalt psychology was intended to set the stage for this discussion. First and foremost, we observe that these themes are not independent; indeed, they may be viewed as various instantiations of one of them—precisely, animal–environment dualism (Fitch & Turvey, 1978; Turvey & Shaw, 1979). Nevertheless, for purposes of argument, it is to our advantage to identify them separately even though independent discussion of them is strained.

Not unexpectedly, we treat these themes from the perspective of a commitment to realism. Gestalt psychology (see Köhler, 1947) warned against the *experience error*—that is, attributing the organization of perceptual experience to

the proximal stimuli when in fact it should be attributed, they argued, to the organizing tendencies of the nervous system. Taking a leaf from Gestalt psychology but in the spirit of a commitment to realism, we label each of the to-be-identified themes as an *error*. We do so because each theme leads to attributing perceptual organization to the animal, more accurately, to its nervous system—a position consonant with phenomenism; when in fact it should be attributed to a larger system, the (epistemic) ecosystem, of which the animal is a part—a position consonant (so we argue) with realism.

### An Inventory of Errors

The major theses—or errors as we call them—may be identified as follows:

1. The error of choosing descriptors, or predicates, for the animal term, the environment term, and the energy-medium term of a statement about perception so as to introduce discontinuities or incompatibilities among the three terms.
2. The error of restricting to “inside the skin” the argument against reducing the predicates of psychology to those of a (putative) reducing science (say, physics or even physiology) but accepting, even promoting, reductionism “outside the skin.”
3. The error of taking conventional physical descriptors as the most fundamental *or* the error of assigning to the basic variables of physics primary reality status.
4. The error of slipping between scales of discourse in the phrasing of explanation.
5. The error of confusing the causal support for perception with the epistemic act of perceiving.
6. The error of taking the Newtonian space and time as standard and attempting to force the facts of perception into their form.
7. The error of attributing to a part of a system responsibility for the properties of the system as a whole.
8. The error of holding animal and environment as logically independent.

Let us give due consideration to these errors, respecting the earlier caveat that they are not independent.

### Metaphors for the Nervous System

In Gestalt theory a discontinuity of descriptors is expressed between the geographical environment and the energy media (proximal stimuli); the energy media and the behavioral environment (what the animal is conscious of); and the

behavioral environment and the geographical environment. We cannot doubt that the inequity of descriptors theme places the burden of perceptual organization on the animal. For example, in identifying the proximal stimulus and the percept as end points of the perceptual process and in ascribing to these end points inequitable or incompatible description, Gestalt psychology equated the question of the mechanism of perception with the question of how the terminal description (the percept) is derived from, or arises from, the initial description (the proximal stimulus). That is to say, the question of mechanism was the question of how the activity of the nervous system converts from the vocabulary of stimulation, with its *impoverished* organizational predicates, to the vocabulary of perception, with its *rich* organizational predicates.

Let us be clear on why it is that the first thesis is an error from the perspective of a commitment to perceptual realism. In the first section we remarked on the phenomenalist consequence of inequitable descriptors, and we took note of a contrast between the traditional doctrine of intractable nonspecificity and the doctrine advocated by perceptual realism, a doctrine of necessary specificity. What requires highlighting at this juncture is the following understanding: A way of talking about the surrounding layout of surfaces and substances, the light as structured by that layout, and the layout as perceived and acted upon, such that the languages in all three cases were commensurate (with no queer discontinuity in descriptor type, number, grain, and variety) and would permit the (realist) claim that direct knowing of one's environment is possible and that what is known is constituted by the fact that it *exists*.

By the foregoing understanding, and presuming that it is defensible (see Shaw et al., 1981), the equation cannot be drawn between the question of the mechanism of perception and the question of how the nervous system converts, or translates, from one description to another, because the latter is a false question. With regard to the nervous system, the understanding just aired promotes a radically different and, to most, a curious interpretation of its role in perception. Clearly, terms such as *translation*, *conversion*, *organization* are ruled out as labels for what a nervous system can be said to do when an organism is said to perceive, or for what a nervous system can be said to evolve or acquire the capability of doing when a species of organism or an individual is said to become a more proficient perceiver. If X is a fact of an organism's reality and is perceived as such, then we should say that the tissue medium (the organism's nervous system), like the energy medium in which the organism is immersed (say light), is *functionally transparent* to those properties of the world upon which the organism's successful survival depends (Shaw & Bransford, 1977). We offer the tentative thesis that from the perspective of perceptual realism, the (selective, functional) transparency metaphor connotes the principle to be pursued in discerning the nature of neuroanatomical mechanisms supporting perception and the content to be ascribed to the neural events concomitant to perception.

## Reductionism and Fundamentality in the Context of Animal-Environment Dualism

What determines the promotion of incompatible descriptors? The answer, we believe, rests specifically with the second and third errors already detailed but most fundamentally with the last error, that of animal-environment dualism. Let us elaborate on the second error and then show how Gestalt theory committed a variant of it. Psychology, it can be said, is a special science. It involves predicates of a special order, ones that differ in type from the predicates of what might be referred to as the reducing sciences, physics and (perhaps) physiology. A reasonable belief in the unity of science has led many to advocate that the descriptive predicates of psychology be reduced to the descriptive predicates of physics. Others, to the contrary, have felt that although a unitary science may be a reasonable goal, it is nevertheless unreasonable to reconceptualize the predicates of psychology (and of other unreduced sciences such as economics) in terms of the predicates of physics. To do so would be a denial of the very usefulness of the predicates that gave rise to the unreduced science and promoted interest in its study as a separate discipline.

Psychology, however, can and does receive a curiously unscientific treatment in the hands of those eager to establish its independence. The domain of the predicates of the science of psychology is conceived of as "inside" the body and separated from the rest of the universe by the skin (cf. Bentley, 1954). Hence, when arguments are made to counter or, at least, to hold at arm's length the reducing of psychology to physics, those arguments are solely *intradermal* in focus; *extradermally*, the predicates of physics reign unquestioned (e.g., Fodor, 1975). In short, implicit in opposition to reductionism is the claim that with regard to perceiving (or knowing), the perceiver (or knower) resides inside the skin and constitutes the object of psychological investigation with its special predicates, whereas that which is perceived (or known) lies outside the skin and is quite properly the domain of physical inquiry and reduced predicates. The assumed dualism of knower and known, of animal and environment, is obvious.

Consider now Gestalt theory. As we have taken care to point out, Gestalt theory saw that the predicates and laws of psychology in general and those of perception in particular were molar. They resisted, therefore, the reduction of psychological predicates, or descriptors, to the most molecular physical predicates. In order not to abandon the utility of the molar predicates of psychology—for as Koffka (1935) claimed, psychology should have something useful to say to the historian and the artist whose interests lie with molar behavior—Gestalt theory committed itself to molar physical, and hence molar physiological, predicates.

Recall the Gestalt argument that if the predicates of physiology are molar, then their molar properties will be identical to the conscious processes that they putatively underly (see, particularly, Köhler, 1947, pp. 37–40). But this concern

of Gestalt psychology for molar predicates was bounded by the skin: It promoted a theoretical language of molar predicates inside the skin and denied such a language outside the skin. The predicates of the light to the eye were, after all, molecular (see quotes in first section). To be consistent, Gestalt theory should have argued that the physical medium of the light, no less than the physical medium of the nervous system, is describable by molar predicates, a subset of the molar properties of which are consonant with the predicates of perceptual experience. This commendable consistency, however, was denied Gestalt psychology by its rigid adherence to an entrenched dualism that detaches at the skin perceiver from world, knower from known—animal from environment.

What is at issue when one opposes reducing the predicates of a so-called special science to those of physics is the very notion of fundamentality and the imputed primacy of physics as such. There is an emerging orthodoxy (e.g., Fodor, 1975; Pattee, 1972; Putnam, 1973) that holds that it is legitimate to speak of alternative, autonomous grains or scales (or *levels*—but this is a misleading term) of description and that fundamentality, perhaps, is a functional matter.<sup>1</sup>

The third error detailed earlier dovetails with the second as follows: It is to assume that *extradermally*, the conventional descriptors of physics have a monopoly on describing what is real. To reiterate, whereas a theorist may be inclined to question the primacy and sufficiency of conventional physical descriptors “inside the skin,” he or she would be less inclined to question their primacy and sufficiency “outside the skin.” For observations that are relevant to physics, energy emitted by a source is an appropriate reality, and the descriptors, or predicates, of energy as such are the apposite descriptors of what is real. But to make a similar assumption for observations that are relevant to psychology is—from the perspective of a commitment to realism and, less generally, from the perspective of the emerging orthodoxy already voiced—an error. To ascribe primary reality status to the conventional physical description of an energy medium (or of the surrounding surfaces and substances) is to do two things: It is to assume that any other description must be, in some sense, unreal, and it is to assume that intradermal processes must register these basic descriptors logically prior to anything else they may happen to do (cf. Runeson, 1977). Consider, for instance, a conventional physical description of the light to an eye. A molecular description in terms of photons or, relatedly, in terms of rays of light that may vary in intensity and wavelength is a description of a complex aggregate—more

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<sup>1</sup>Particularly important grist for the mill of the emerging orthodoxy is being provided by: (a) Bunge's arguments for a pluralism of distinct scales and a “moderate” reductionism that pursues an explanation in depth without a denial of novelty (Bunge, 1967; 1977); and (b) the arguments of Iberall and his colleagues for analyzing all systems, whatever their scale, in terms of *physical principles that are scale independent*—that is to say, a reduction to *physics* rather than the reduction traditionally sought, which is to *structures* such as molecules (Iberall, 1977; Yates, Marsh, & Iberall, 1972).

precisely, a complex *chaotic* aggregate when one takes animals into consideration, as Koffka (1935) and Köhler (1947) most vigorously underlined. The point is that whereas a fine-grained scale of description may be exhaustive in terms of the laws of particle physics, there is nothing at that scale of description that *explains* how the light is information about the animal's environment and the animal's relation to it (Fitch & Turvey, 1978; Turvey & Shaw, 1979). Echoing the evolutionary concern voiced in the first section, if adaptive relations evolve between the molecular scale of description and visual systems, then there would be no accounting for the variety of visual capabilities exhibited across species. For there is nothing in the molecular scale of description that accounts for why any visual beast should limit itself to a restricted subset of the visual experiences made possible by the terrestrial and aquatic configurations of surfaces and substances. In sum, with respect to light, there are reasonable grounds as well as a commitment (to realism) for rejecting the fundamentality of a molecular scale of description. The alternative, which a committed realist should abide, is that there is an autonomous scale of description—a scale that is neither redundant nor inconsistent with more molecular scales—the predicates of which are both animal—referential and environment-referential (Fitch & Turvey, 1978; Gibson, 1977; Lee, 1974, 1976; Shaw et al., 1981).

What of the other feature of the third error currently under discussion—that an animal must register the so-called fundamental predicates of physics *logically prior* to registering anything else? If it can be agreed that what is basic to physics need not be construed as monopolizing what is real, then there is no reason to adhere to the claim that what is basic to physics has logical priority in perception. Nevertheless, the student of perception who is drawn toward its supportive neurophysiology may find this conclusion hard to swallow. For surely, is it not a fact that the first intradermal step registers and represents the most molecular physical predicates, with successive steps (or a single step, as the case probably is for Gestalt psychology) yielding and representing the predicates of a higher order?

The putative fact in question bears blatantly the stamp of animal–environment dualism. It presupposes that a major task of the nervous system is to get the world that is exterior to the skin (or some facsimile of it) represented *inside* the skin—more specifically, *inside* the head. The following quote expresses this presupposition with its phenomenalist consequences for neurophysiology (Attneave, 1974b):

All of it [experiencing of the world], to the best of our knowledge, is mediated by receptor activity and is relayed to the brain in the form of Morse code signals, as it were, so that what we experience as the "real world," and locate outside ourselves cannot possibly be anything better than a *representation* of the external world [p. 493]

The buying of this presupposition blinds one to an important distinction between the content of a neural signal to a neural device and the content that one assigns to the signal as an outside observer when one describes the signal and the devices that it goes between (Dennett, 1969). Thus, for example, with regard to the popular conception of feature detector, the scientist so blinded proclaims that a signal from a cell identified as such a detector to a cell with which it is linked is synonymous to the statement: "There is a line of orientation such-and-such (say, 60° on some coordinate system) at a location of such-and-such (say, 30° NE of some origin in the coordinate system)." The highly questionable belief is that the cell receiving the signal understands and uses information of the kind couched in the statement. To the contrary, and even here we are guilty of overpresumption: "What it gets in the way of data are at best reports with uninterpreted predicates ('it is intensely F at location L again') and out of this it must confirm its own dummy hypotheses" (Dennett, 1977, p. 274). The latter statement is overly presumptuous precisely because, like the statement it supplants, it presumes the format of neural signals and the nature of the neural tasks. Unfortunately, thorough examination of token signals will prescribe neither vocabulary nor task for us. As Dennett (1977) puts it: "In fact is either way of talking appropriate? The vocabulary of the signals is not something that is to be settled by an examination of tokens . . . and when we turn to indirect evidence of 'psychological reality' any evidence we turn up will perforce be neutral between interpreted and uninterpreted predicates [p. 274]."

We would like to argue that there are two cognate points that follow from this line of reasoning. One is that neurophysiological "facts" *qua* statements about perception are suspect; they are what they are by virtue of the phenomenalist/dualist tradition guiding their perpetration. The other point is that any claim about what a given piece of the nervous system tells another piece should not be read as a claim about what a given piece of the nervous system tells the animal. Put succinctly, what the frog's eye tells the frog's brain is not the same as what the frog's eye tells the frog—if there is any telling to be done at all.

### Newtonian Space and Time and Causal Interconnection as Allied to Animal–Environment Dualism

Let us proceed to make more precise how it is that animal–environment dualism taints the conventional interpretation of the nervous system's role in perception. In so doing, we will bring together the errors discussed so far and those merely noted in the inventory. In addition we will lay the groundwork for establishing a perspective in which to reevaluate the status of basic physical variables in a theory of perception. Ideally, the perspective sought and the reevaluation given will be consonant with perceptual realism.

In accord with animal/environment dualism is the assumed appropriateness of Newtonian space and time for matters of psychology and the causal-chain theory of perception. Given this dualism, which in its mind-body subtheme distinguishes the object of reference from the object of experience, and given the unchallenged authority (until this century) of the Newtonian formulation, it would have been a historical oddity if no attempt were made to fit the terms espoused by the one tradition to the terms of the other. The fit, however, was never technically secure. Although adherents to the Cartesian-Newtonian scheme of things felt that the reference object could be located with some conviction in Cartesian coordinates, the intentional object (or object of experience), being phenomenal rather than noumenal, could only be given a quasi location—a location that was “not definitely but indefinitely, ‘in’ or ‘at’ an organism” (Bentley, 1954), p. 215). The eventual fit, therefore, took the following form: The reference object located extradermally was separated by a distance in Newtonian space from a representation of it, the object of experience, which was located (roughly) intradermally. How, then, might the aforementioned distance be bridged and the two object kinds coordinated? The answer was looked for in Newtonian mechanics and given as thus: A causal sequence of energy propagations and neural signals covers the distance from the loci of the reference object to the loci of its representation. According to this causal analysis of perception, the reference object is the initial cause, and the representation, or intentional object, the final effect.

Consider two humans—one speaking, the other listening. We can presume that the speaker intends to say something meaningful to the listener. What we wish to note is that a causal chain analysis of this situation, which will unavoidably introduce discontinuities in descriptors—much like the descriptor discontinuity manifest in the analysis of vision by Gestalt psychology—raises two perplexing puzzles: how meaning is lost in transmission and how meaning is recovered. There is a familiar story (see MacKay, 1969) that tells how the speaker’s intent, the speaker’s speech plan (which is the reference object in this particular case), is meaningful but how the mechanical embodiment of the message, first by the efferent neural activity of the speaker’s motor system and then by the acoustic signal generated by the speaker’s vocal activity, is devoid of meaning. “Discussion at this level proceeds in exactly the same terms whether the air is handling the outpourings of a genius or the jabber of a monkey” (MacKay, 1969, p. 20). Thus the first puzzlement: How did something meaningful become meaningless? What is being assumed, of course, is that the proper theoretical language for describing the speaker’s utterance-as-planned will contain predicates sufficiently rich to capture the utterance’s meaning, but the proper theoretical language for describing the speaker’s utterance-as-executed can contain no such predicates.

Because the listener experiences the message and not the properties of the media that mechanically embody it, it must be claimed that the afferent activity

caused in the listener's nervous system by the speaker-produced sounds, although without meaning initially, acquires meaning eventually, at some later point in brain processing. Here lies the second puzzlement: How does a thing that is meaningless become meaningful, and where does it become so?

This story of human communication vividly expresses the errors discussed: a discontinuity in descriptors, the intradermal location of the special predicates of psychology (meaning is inside the head), and an acceptance of the physicist's description of an energy medium as the only and proper description. In addition the foregoing story gives due expression to the following. It provides a spurious causal analysis of speech perception by means of slipping between modes of discourse, or causally interconnecting distinct scales of description as if they were logically alike (cf. Fowler & Turvey, 1978). One mode of discourse in which the story is conducted is talk about communicating; the other mode of discourse is talk about the properties of media that mechanically support but are not identical with the act of communicating. We can appreciate that sound pressure-waves mechanically stimulate the eardrum. We can also appreciate that this stimulation is conveyed by a further mechanical process, that of nerve activity. And although the stages that follow may prove exceedingly more abstruse in their details, they remain, nevertheless, mechanical stages. Thus MacKay's (1969, p. 21) question: "Where to draw the line?"

The point is that talk about the energy states of a system is not talk about the information states of a system,<sup>2</sup> and to confuse or causally blend the two is to invite muddled thinking and misleading questions—such as inquiring of the stage at which the meaning of a message is acquired. A considerably more general point is the paramount importance of holding epistemic acts distinct from their causal support.

The muddled story of human communication that we have been considering was spawned primarily, so it can be argued, by the allied biases of animal-environment dualism, the Newtonian framework, and the causal-chain theory. What follows is a critical evaluation of each.

### Scales of Description as a Temporal Sequence

Is it legitimate to assume that distinct scales of description can be temporally concatenated? Imagine a state of affairs such as a book sitting on a desk. At one scale of description, the book is describable in the molecular terms of quantum

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<sup>2</sup>This requires some qualification. Given a more enlightened interpretation of dynamics (e.g., Glandsdorff & Prigogine, 1971; Iberall, 1977) and explicit recognition of an animal and its environment as logically dependent components of a single system, we might expect the notion of energy states of the system to approximate more closely the notion of information states of the system. Notable in this regard is Thom's (1975) description of information as form—as the geometric parameterization of a stationary regime of local dynamics—and the meaning of a "message" as the topological relation between the form of the message and the eigenforms of the receptor.

mechanics; at another and coarser scale of description, the descriptors are the dimensions of Newtonian mechanics; and at yet another scale of description, the terms are those depicting the properties of the object—the book—taken with reference to human activity. Without embroiling ourselves in debate on whether the different scales identify separate realities or, less ambitiously, distinct realms of inquiry, we can appreciate, by the preceding example, that a state of affairs may succumb to several analyses involving distinctively different scales of predicates, yielding distinctively different understandings. We can appreciate, further, that it would be nonsense to argue that the most fine grained scale of description temporally prefaces scales of a coarser grain. In short, there is no manner of talking that permits us to claim that events captured in the finest scale of description occur first, with the events captured in the language of the other scales occurring thereafter—as so many tumbling dominoes. There is a manner of talking, however, that permits us to say that the scales of description are coordinated; for we may presume that scales of description are alternative descriptions that, although not redundant, are also not inconsistent with one another (Pattee, 1973).

### The Newtonian Framework as Standard

Is there any compelling reason why perceptual theory should assume the Newtonian formulation of space and time as *the* framework for its facts? The answer to this question is, we believe, a tart “no!” (see Gibson, 1966; Shaw & Pittenger, 1977, 1978). Newton’s space for classical physics was absolute; it was a locus in which objects could be placed. Einstein, however, in pursuing an explanation for the facts of physics, followed Riemann’s suggestion and rejected the Newtonian absolute space in favor of a conception of space as relative. On this latter conception, space itself has structure—a structure that is owing to, or induced by, the material that comprises it. In the Riemannian conception of space, there is, strictly speaking, a *single* object—precisely, the space structure as a whole—as a *single* system. The individual objects *in* the Newtonian space are local aspects *of* the structure in the Reimannian space.

We should not suppose that the success of Einstein’s conception of space (and time) and of relativity physics requires the perceptual theorist to shift from a Newtonian view to an Einsteinian view. Rather, the import of Einstein’s work is that psychological theory should not feel compelled (or seduced) to press its facts into the mold of Newtonian space and time. The lesson to be learned is that if physical theory could construct a space and time befitting the facts of research in physics, perceptual theory should pursue the construction of a space and time befitting the facts of research in perception. An argument of like kind was made by Bentley (1954). It was summarized by him as follows:

1. Psychology has always concerned itself with facts which do not tolerate technical description in technical Newtonian space and time.

2. These facts, nevertheless, have their own manifest extensions and durations.
3. Psychology is now at last free to describe them as it finds and observes them.
4. Such observation and description becomes practicable with the frame of a full naturalism for organic and environmental facts [p. 479].

## The Dualism of Animal and Environment

Is it logical to treat the concepts of animal and environment as independent? It is readily agreed that no animal has been observed in the state of animal-alone or animal-by-itself. It can also be agreed—although it will take some argument to engender agreement—that no environment exists in the state of environment-alone or environment-by-itself. The very term *environment* implicates a thing environed, a thing surrounded; without a thing that is environed, the term *environment* makes no sense. If we take that which is environed to be living things—that is, life in general—then the term *environment* can reasonably be equated with the solids, liquids, and gases that compose life's terrestrial and aquatic support. This equation is useful to a point; but it is far too general—far too homogeneous a depiction of environment—for most purposes. In order that we can talk sensibly about adaptation, we must guarantee that *the definition of environment expresses approximately the same order of variety as the definition of species*. An increase in variety is obtained by recognizing that geographical distinctions represent different partitionings on the solids, liquids, and gases that make up the planet. Geographical distinctions stand in correspondence to distinctions among species in terms of *where* they live—their habitats. But the order of variety so gained is insufficient, as evidenced by the observation that many species can occupy the same geographical region; habitats are shared. What is needed is a further refinement in the conception of environment, a refinement that introduces distinctions that stand in correspondence to distinctions among species in terms of *how* they live (Gibson, 1977).

In other words, what is needed is a way of describing the substances and surfaces comprising the terrestrial or aquatic surroundings of an animal that is in reference to that animal's body, in reference to the kinds of activities in which it engages. A predicate or descriptor of this type has been referred to by Gibson (1977) as an *affordance* (see also Shaw et al., in press; Turvey & Shaw, 1979): a combination of surface and substance properties that is uniquely suited to a given animal—to its nutritive system or to its action system. Given this animal-referential descriptor, we can proceed to equate the environment for a given species with a set of affordances—or affordance structure—and to recognize the necessary reciprocity between animal and environment: An environment defined as an affordance structure implies a certain kind of animal, an animal that exhibits a particular set of capabilities, or effectivities, as we have called them (Shaw et al., 1981; Turvey & Shaw, 1979; Turvey et al., 1978); and an animal defined as an effectivity structure implies a certain kind of environment.

### Affordance and the Geographical Environment–Behavioral Environment Distinction

This is an especially good place at which to return the discussion's focus to Gestalt theory, particularly the predicament of the first section of this chapter—the distinction between geographical and behavioral environment. We can do so by considering why a notion such as affordance is necessary and unavoidable from the perspective of a commitment to realism.

The assumed dualism of animal and environment encourages the perceptual theorist to distinguish between what a thing *is* and what a thing *means*; a thing that simply *is* inhabits the physical domain, whereas a thing that *means* inhabits the mental domain. In this vein, as observed earlier, Koffka (1935) distinguished between the geographical world (noumena) and the behavioral world (phenomena) and proposed the latter as the framework for behavior. Thus, Koffka (1935) would say that a handle “invites” or “demands” grasping. But a physical description of the surface and substance properties that constitute the material nature of a handle contains no animal-referential or activity-relevant terms; the physical dimensions used to describe the handle are animal-indifferent. So what is the status of the characteristics of surfaces and substances that behavior is in reference to? As they are not characteristics or dimensions of the geographical or physical environment, they must be dimensions of the behavioral or phenomenal environment. The claim that Koffka was making is that the dimensions of surfaces and substances that behavior is in reference to *are not ordinary physical dimensions* and, therefore, *are not real dimensions*. These dimensions that invite behavior owe their very existence, in Koffka's (1935) reasoning, to an animal's needs. Here we have what has been referred to elsewhere (Shaw et al., 1981) as the incommensurability of natural kinds: The reference object, the mailbox as an object described in physical terms, is logically distinct from the intentional object, the mailbox as an object that invites a particular behavior. And whereas the reference object may have (for a phenomenalism of Koffka's kind) an existence independent of perception, the intentional object cannot.

From the perspective of a commitment to realism, the foregoing conclusions are anathema. They can be avoided, however, by taking the following as a fundamental precept for realism: The dimensions of configurations of surfaces and substances that behavior is with respect to may not be ordinary physical dimensions, in that conventional physical language fails to describe them; but they are, none the less, real dimensions. It would seem that conclusions opposed to realism arise from describing the reference object in a physical language that is committed to a reality but is noncommittal or neutral with regard to animals as epistemic agents, and describing the intentional object in a phenomenal language that is noncommittal on reality but *is* agent oriented. These distinct and irreducible languages are in the spirit of animal–environment dualism. What is needed is

a *single* theoretical language—in the spirit of animal–environment synergy (Fitch & Turvey, 1978; Turvey & Shaw, 1979)—that manages to incorporate both the objectivity of the physical language and the agent orientation of the phenomenal language.

We see, in short, that a concept such as affordance is not optional; rather, it is mandated by a commitment to realism. That commitment also mandates that the affordance of a given thing is always there to be perceived. An affordance exists, we argue (and see Gibson, 1977), as *a real property of the ecosystem* and not by virtue of its being perceived. Defining environment as an affordance structure is to remove the problems that Koffka (1935) addressed and to obviate the distinction (geographical versus behavioral) that he felt compelled to make.

The steps we took toward a conception of environment that exhibits variety consonant with that of species may be characterized as a shift from a conception of environment relating to animals as physical and biological entities to a conception of environment that relates to animals as knowing agents; and, relatedly, a shift from seeking a definition of environment in absolute terms (along the lines of a Newtonian conception of space and time) to an attempt to define environment in relative and functional terms. In sum, the shift in definition is from an absolute and species-indifferent emphasis to a relative and species-specific emphasis.

One should not suppose that a relativistic account of environment, given here in terms of affordances, is just so much heterodoxy; on the contrary, it would seem to approximate the kind of definition that students of evolution are reaching for (see Lewontin, 1978). Waddington (1961) remarks: “The situation is that existing modes of behavior . . . combine with external circumstances to determine the nature of the effective environment [p. 91].” And moreover, one should not suppose that the claim for a synergy (as opposed to a dualism) of animal and environment with their respective definitions reciprocally linked is not without predecessors in biology. Comte (see Jacob, 1976), Needham, and Haldane (see Haraway, 1976) can be counted among those who often gave lip service, and sometimes more, to the critique of conceptually dissociating animal and environment.

### From a Self-Actional to a Transactional Observation Base

We would do well at this juncture to collect our thoughts. Our intention in this section has been to identify those themes, which we take to be conceptual errors, that inspired Gestalt theory to an organocentric view of perceptual organization. In the process of identifying and discussing these errors, we have painted in broad strokes a partial view of the realist backdrop for perceptual theory. Central to that view—to which we have alluded here and argued elsewhere (Shaw et al., in press; Turvey & Shaw, 1979)—is the synergy of animal and environment, and

it has received a brief hearing in the immediately preceding pages. By emphasizing the synergy, or reciprocity, of animal and environment, we intend to rule out other, historically more popular ways of viewing their relation. In the synergy perspective, an animal and its environment are not, in any act of knowing, rigidly separable but, rather, complementary constituents of a system—an (epistemic) ecosystem (Turvey & Shaw, 1979). It may prove convenient and profitable for certain inquiries (those of physics and, perhaps, of physiology) to detach animal and environment. But we would agree with Dewey and Bentley (1949) that: “The student of the processes of knowings and knowns lacks this convenience. He can not successfully make such a separation at any time [p. 151].” And we can enjoy accord with Dewey and Bentley (1949) on further points—specifically, with regard to their analysis of styles of inquiry as they bear on the relation of animal and environment.

These authors identify two traditional forms of inquiry that would be consistent with animal–environment dualism. In one form, *self-action*, things are viewed as acting under their own powers. In earlier times it was commonplace to assign to gods or spirits sole responsibility for physical phenomena; in more recent times it has become commonplace to assign to mental or neural entities responsibility for behaviors and perceptions. Thus, for example, “mind” and a mental constituent such as a “faculty for music” are charged, respectively, with responsibility for behavior in the full and behavior of a restricted kind. Similarly, “brain” and a neural component such as “limbic system” are charged, respectively, with responsibility for behavior most generally and behavior more specifically. This custom has a long history—of regarding behavior and the like as initiated by the animal or, more precisely, by some actorlike entity resident in or at the animal.

Although not explicitly mentioned by Dewey and Bentley, there is a converse form of inquiry to the self-actional—what might be called the *other-actional*. In this view, the control of the behavior of a natural system is seen as lying in something beyond itself, such as in a deity that expresses its volition through animals or people. This view of the actions of a given system being based in an outside agent, shorn of its theistic trappings, is but a small step from the strict behaviorism of the 20th century, which attempted to locate the control of behavior in rewards, reinforcements, incentives, or triggering stimuli seated in the environment.

The second traditional style of inquiry identified by Dewey and Bentley is *interactional*. Here, rigidly separate things—that is, things that one assumes can be described as indifferent to any joint operation—are isolated and held to relate through causal interaction. This form of inquiry—essentially the model of scientific analysis handed down to us by Galileo and Newton—is manifest in the causal-chain theory of perception as depicted earlier. As a substitute for the older self-action form of inquiry, interaction—purely interpreted—would not suppose that perceiving is the responsibility of an animal-localized entity but rather results

from the causal interconnection of animal and environment. Of course, in practice, the older (self-action of other-action) and newer (inter-action) styles of inquiry rarely occur in a pure form. More often than not in interaction analysis, the animal is given the spotlight, ascribed special powers (self-actional entities), and held superior over and against the environment to which it is causally interconnected; but not uncommonly, and as a backlash, some scholars adopt the other-actional stance by assigning to the environment superior reality status, with the animal being just a pawn to the environment's regularities and variations. Where the self- or other-actional scheme requires descriptors for monadic or single-variable states, the interactional form of inquiry requires descriptors that can handle dyadic, or two- variable, relations. In the two-place relationship most cited, the two terms stand to each another as cause to effect or stimulus to response.

There has been a most noticeable change in styles of scientific inquiry or observation bases, as Bentley (1954) and Dewey and Bentley (1949) point out: Physics, the oldest science, has transformed its observation base from one of initiating powers or forces—through one of things *solus*, organized by causal interconnection—to one where the focus is *system*, described in full. This contemporary trend in scientific inquiry is referred to as *transaction*.<sup>3</sup> In a transactional inquiry, it is impossible to study one component of a system as an element in isolation; rather, components necessarily co-implicate their complementary aspects. The transactional form of inquiry eschews the enterprise of decomposing whole systems into separate and distinct substructures that are then treated as if their isolated functions are simply linearly additive to express the functional capabilities of the whole. Dewey and Bentley (1949) oppose the "analytic" fallacy of attributing to any part of a system the responsibility for the whole system's properties (Turvey & Shaw, 1979); moreover, they intend that the concept of transaction, unlike self-action or interaction, should preserve the sense of reciprocity among complementary components that is essential to the integrity of any system. Clearly, the transactional form of inquiry is consistent with animal-environment synergy. The following quote from Dewey and Bentley (1949) expresses this consistency and may be taken as an appropriate summary of the present section and a departure point for the next.

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<sup>3</sup>Dewey and Bentley's term *transaction* was made popular by the Ames group, who labeled their brand of psychology "transactionalism" or "transactional psychology" (Ittelson, 1952; Kilpatrick, 1961). It would be a mistake, however, to assume that the usage of the term by the Ames group was consistent with that intended by Dewey and Bentley. "Transactional psychology" was (is?) a phenomenalism in which the Helmholtzian concept of unconscious inference is taken to the extreme. Although Dewey and Bentley, on initial encounter, expressed enthusiasm for the work of the Ames group and sanctioned the labeling of it as "transactional," they were to become increasingly disturbed by the way in which the group misinterpreted and misused the concept. (See the correspondence between Dewey and Bentley in Dewey & Bentley [1964].)

Our position is simply that since man as an organism has evolved among other organisms in an evolution called "natural," we are willing under hypothesis to treat all his behaviors, including his most advanced knowings, as activities not of himself alone, nor even as primarily his, but as processes of the full situation of organism-environment; and to take this full situation as one which is before us within the knowings, as well as being the situation in which the knowings themselves arise [p. 104].

### ECOLOGICAL THEORY AS A PRAGMATIC REALISM

Let us return to a persuasive Lockean theme: Knowing in all its forms (perceiving, remembering, and so on) requires the interfacing of the knower to the objects and events known. Therefore, there must exist somewhere a medium of "between-things" (ideas, percepts, meanings, organizing principles, propositions, models, and the like) that carry the burden of the interaction of the agent with its world. Locke, in short, posited three ontological realms, and we may recognize that Hume's skepticism and Berkeley's subjective idealism were attempts to rid epistemology, and hence psychology, of the necessity of a third realm of mediating epistemic constructs. But Locke prevailed. Consequently, it has been commonplace for past and present perceptual theory to accept as an explanatory paradigm a three-realm relation, or "semantic triad": Hence, the so-called semantic triad of communication situations: sender → message → receiver; of logical theory world facts (or states of affairs: → proposition → statement (e.g., sentence or utterance); of abstract machine theory (computer science): data → program → output; and, of course, of various mediational accounts of stimulus-response theory: S → O → R. Each generation of psychological theory manages to rediscover this notion; and although the triad is clothed in new terms, no fundamental change in theory occurs.

The crux of the argument we wish to pursue in the present part of the chapter is that the transactional form of inquiry provides a means of avoiding the semantic triad, presumed by nearly all forms of scientific inquiry into matters pertaining to perception. Most pointedly, we attempt to show that the transactional style of inquiry, like its descendant, the ecological style of inquiry, circumvents the need for a third realm of entities interceding between animal and environment-knower and known.

Our hand, however, must not be overplayed in these matters. Let it be clearly understood that we recognize that many of the constructs used by us and our peers are meant to have no reality status beyond analytic or methodological usefulness: Their value is pragmatic rather than ontologic. On the other hand, where analytic concepts are involved in the perception literature, confusion often arises about whether the constructs are real. Such confusion presumably, in more cases than not, betrays real confusion in the minds of the investigators themselves. Such constructs are discussed as if they belong to a causal chain of events that begin with physical activities in the world and are conveyed by biological pro-

cesses to a “sensorium” from which eventually psychological species are extracted and, perhaps, abstracted. Nowhere is there an admission or implied qualification that the causal chain supporting perception may not be wholly real or unbroken. Clearly, such an admission that some link was unsubstantial—say, the final one—would make a mockery of the argument. *Herein lies the uncritical acceptance of the Lockean metaphysics.* Its limitations and inconsistencies were recognized by both Berkeley and Hume. Time has in no way healed these defects of Locke’s thesis but has, perhaps, allowed them to recede into the background, so that incautious theorists no longer see them and, therefore, countenance the thesis unwarily.

Given agreement with respect to the origins of the problems that bedevil current theorizing about perception, the question naturally arises as to an alternative approach that might avoid them: The transactional form of inquiry, updated to accommodate ecological concerns, offers one such alternative. As already intimated, the concept of animal–environment synergy is at least transactional.

### Semantic Triads

It is difficult to grasp fully what is philosophically troublesome and scientifically misleading about too easy an acceptance of three-realm approaches. In a nutshell, however, it is the uncritical treatment of epistemic mediators (psychological constructs) as real objects rather than as analytic categories with no more than pragmatic convenience for scientific inquiry.

Ironically, the need for positing a third realm of existent entities so as to account for meaning is no better seen than in the attempt of traditional logicians to characterize one of the primary conceptual building blocks for logic—the proposition. The traditional conception of a logical proposition—in its rawest, most commonsense form—is any overt act, usually a spoken or written sentence, by which some state of affairs is affirmed or denied. What makes the issue of what really constitutes a proposition problematic is the notion that it might be an implicit rather than an overt act of affirmation or denial. More precisely, the problem reads: Is a proposition identical to the overt act or merely associated with it (say, as the idea that it expresses or entails)?

But such a move lands the issue in the semantic quagmire, a quandary regarding how one can have a theory of entailment logically prior to a theory of propositions, because propositions as formal objects, strictly speaking, may only formally entail other propositions. Hence to base the notion of a proposition on an intuitive conception of entailment—say, that the idea behind the act is somehow entailed by the act itself—is already to prejudge the nature of entailment and to remove it, as it were, from the realm of formal logic to that conceptually more vague realm of meanings hidden from the public eye. Similarly, any attempt to define a proposition as a judgment rather than an overt act pushes the foundations of logic into the psychology of judgments—a most unlikely place in which to find clarity or lucidity.

Dewey and Bentley, among others, have been justifiably unhappy with this turn of events, for one important ramification of the view that propositions are “mental” rather than “behavioral” in nature is to place a realm of mediating entities between thinking animals and their world; unlike overt actions that are, at the same time, animal-based as well as activities in the public domain of the environment, “mental” propositions become reified as a third realm of objects that mediate the epistemic relation holding between a knowing animal and a knowable environment. Dewey and Bentley’s (1949) criticism of this traditional propinquity to confuse ontological status of a concept with its pragmatic value as an analytic category of inquiry was directed at many of the most noted philosophers of their day: Lewis (1943), Cohen and Nagel (1934), Ogden and Richards (1930), Carnap (1942), and Russell (1925). Dewey and Bentley (1949) assert: “[One must avoid treating] . . . a use, a function, and service rendered in conduct of inquiry as if it had ontological reference apart from inquiry [p. 320].”

The things typically given the status of existents by such traditional philosophers were (1) agents or actors, (2) things, and (3) an intervening interpretative activity, product, or medium—linguistic, symbolic, mental, rational, logical, or other (such as language, sign, sentence, proposition, meaning, truth, or thought). For instance, Ogden and Richards’ (1930) semantic triangle included at its vertices “thought or reference,” “symbol,” and “referent or object [p. 14].” Similarly, in Cohen and Nagel (1934), we have the claim that “it seems impossible that there should be any confusion between a physical object, our ‘idea’ or image of it, and the word that denotes it [p. 16].” Carnap (1942) defines the meaning situation as comprising “the speaker, the expression uttered, and the designatum of the expression,” or alternatively as “the speaker, the expression, and what is referred to [pp. 8–9],” where “what is referred to” is also spoken of as that to which the speaker “intends” to refer.

There can be little doubt about the fairness of Dewey’s criticism of semantic theory in the first half of the 20th century; the philosophers identified earlier, like Brentano (1874–1925) early in his career (but he later repudiated the point), all tacitly agreed to reify a realm of immanently or intentionally specified objects—variously termed *ideas*, *propositions*, *concepts*, *images*, or whatnot—as the ghostly entities that mediate our perceivings, remembering, acting, and knowing with respect to the world (see Shaw et al., 1981, for a fuller criticism of the role of Brentano’s fallacy in contemporary psychology). And more contemporary theorists are scarcely less guilty of confusing concepts convenient to inquiry with those that denote things possessing some kind of an ephemeral existence.

### Pierce (Mis)Interpreted as Advocating a Semantic Triad

Nowhere is this traditional attitude more elegantly stated than by Lewis (1943) in a vain attempt to echo the authority of Peirce (1940–1950) by claiming that “the essentials of the meaning-situation are found wherever there is anything which, for some mind, stands as sign of something else [p. 236].” Indeed, Peirce *can* be

read (although, as we shall see, he should *not* be read) as championing such a view, for in his letters to Lady Welby, Peirce (1940/1950) attempts to explain his difficult concept of *Thirdness*, the name he used to denote his view of meaning as a triadic relation existing between a sign, its object, and the interpreting thought. In a different essay, Peirce (1940/1950) argues that “every genuine triadic relation involves meaning, as meaning is obviously a triadic relation [p. 91].”

Now on casual reading, it surely seems that Peirce would approve the interpretation of his semantic theory given by Lewis, but strong exception is taken to this fact by Dewey and Bentley (1949); their concept of the transactional is essentially a restatement of Peirce’s more subtle and too often misunderstood notion of *Thirdness*. Indeed, as ecological psychologists and students of perception, our concern with this debate between Dewey and Bentley and their peers devolves upon this very important point of disagreement—namely, the question of whether semantics, and hence the meaning of perceptual experiences, necessarily requires a triad of realms among which relationships must hold in any meaning transaction. If so, then it is difficult to see how Gibson and other ecological psychologists can continue to oppose so-called mediational accounts of perception that reflect an *indirect realism*—that is, where propositions, signs, or other forms of symbolic representation are required to stand between a knower and its world.

And if our earlier arguments are valid (e.g., Shaw et al., 1981; Turvey & Shaw, 1979), then it is also difficult to see how we can avoid not just a dualism but a tripartite pluralism where thoughts or experiences may be held as separate from those who think and experience, as are the objects to which they refer.

### Semantic Relations Do Not Involve an Ontological Triad of Realms: Peirce Properly Interpreted

Let us proceed to buttress the claim that Peirce, as Dewey and Bentley (1949) correctly point out, has been misread as endorsing an ontological triad of realms over which semantic situations must be defined. Most pointedly, Dewey and Bentley (1949) were against unnecessarily reifying such things as relations or propositions, as this proves to be more of a hindrance than a help to theory. A telling remark by Dewey is the following (Dewey & Bentley, 1949): “I did not originate the main figures that play their parts in my theory of knowing. I tried the experiment of transferring the old well-known figures from the stage of ontology to the stage of inquiry [p. 328].” Bentley (Dewey & Bentley, 1964) also offers the following observations: “If one takes two ‘things’ and does not permit the use of a transactional view, then one adds a third ‘thing’ namely a ‘relation.’ . . . I have always been rabid against the use of the word ‘relation’ as a thing [p. 534].”

On first blush, the last remark may appear nominalistic, but we believe this is to miss the main point; for given their presumed understanding and endorsement of Peirce over and against traditional semanticists, Dewey and Bentley can hardly be considered as nominalists. No, much more is at stake here. Consider their sharp criticism of Lewis' claim cited earlier that Peirce (1940/1950) meant to endorse the semantic triad when he admitted that "every genuine triadic relation involves meaning, as meaning is obviously a triadic relation [p. 91]." To the contrary, they argue, to view this as an endorsement of the ontologic triad is a spurious reading fostered by taking Peirce's thought out of the context of his whole system. Lewis' mistake was particularly ironic and irksome to them because Peirce's concept of Thirdness, which provided the basis for the transactional form of inquiry, was conceived primarily for the purpose of avoiding such fallacies arising from wantonly ignoring the context dependence of concepts. They express it this way (Dewey & Bentley, 1949): "Such words as Lewis takes from Peirce *do not* mean that minds, signs and things should be established in credal separations sharper than those of levers, fulcrums, and weights; Peirce was probing a linguistic disorder and learning fifty years ago how to avoid the type of chaos Lewis' development shows [p. 7]."

But is not a triad of terms involved in their analogy of levers, fulcrums, and weights? How does this relational complex of three things differ significantly from Lewis' and others' use of a triad of terms to capture the relational complex needed to express semantic situations? After all, one might ponder, is not the essence even of a transactional relationship also a triad consisting of two things plus the relationship that "connects" them—as action and reaction connect the opposite but equal forces of one piece of matter on another? Yet Dewey and Bentley (1949) persist stubbornly to deny that Peirce's Thirdness and their transaction necessarily posit three ontological realms of distinct kinds of objects to be studied by science, as is clearly shown by their view of a communication paradigm—a particular kind of semantic situation: "It [transaction] will treat the talking and talk-products of man (the namings, thinkings, arguings, reasonings, etc.) as the men themselves in action, not as some third type of entity to be inserted between the men and things they deal with. To *this extent* it will be not three-realm but two-realm: men and things [p. 5–6]." They go on to point out that in current logics, probably the commonest third-realm insertion between men and things is "proposition," although among other insertions, "meaning" and "thought" are at times most popular rivals for that position of epistemic mediator.

Our own view as to who is correct in this debate, Dewey and Bentley as Peirce's supporters or their opponents such as Lewis, should be transparent. Dewey and Bentley seem to have not only the more accurate reading of Peirce's intentions but also a more clear-eyed grasp of the fundamentals required for the semantics and the logic of scientific inquiry. If they prevail, then a strong historical continuity of principle will exist between the transactional form of

inquiry sired by American pragmatism and the ecological form of inquiry sired by Gibson and currently under development, study, and evaluation by the present authors and others.

It is now time to focus sharply on defense of the claim that the transactional approach, the concept of Thirdness, and ecological psychology are of two rather than three ontological realms and, therefore, to break sharply with traditional forms of scientific enquiry that assume the semantic triad to be equally *real* in each of its parts. To offer a plausible defense, we must show that there is some way to “de-ontologize” one member of the semantic triad—namely, that usually referred to as the proposition, thought, concept, or idea that is typically reified as a bond behind the symbolic or sign relationship imputed to hold between the object (or event) perceived or known and the agent who perceives or knows that object (or event).

### The Concept of Thirdness as the Basis of Transactions

Let us then return to consider more carefully the quote from Peirce that was spuriously interpreted as support for Lewis and others’ contention that Peirce was a three-realm theorist simply because he recognized a need for a triad of analytic categories. *Our purpose is to show that one might hold to a triad of terms in a language of descriptors for semantic situations, as Peirce did, while at the same time rationally disavowing that they necessarily refer to three ontologic realms.* Such a strategy provides the logical and philosophical foundations for establishing a direct rather than a mediated theory of perception—that is, a theory of perception that a committed realist would endorse.

The reader will recall the earlier quote from Peirce (1940–1950). We now present the quote in full with the passages missing in the earlier version in italics so as to emphasize their importance in establishing the full context of interpretation required to understand Peirce’s intent: “Thirdness is the triadic relation existing between a sign, its object, and the interpreting thought, *itself a sign, considered as constituting the mode of being of a sign.* A sign mediates between the interpretant sign and its object [p. 11].”

The clue we seek is in the phrase asserting that the interpreting thought is “itself a sign, considered as constituting the *mode of being* of a sign.” Two things are now apparent that have typically been overlooked by casual readers of Peirce who were attempting to force his conceptions into the context of traditional semantic theory: First, in the preceding quote, Peirce invokes only two realms of entities—signs and objects; thoughts belong not to a third realm but are themselves signs of some sort. Second, the sort of signs they are has to do with their “mode of being.” Now a *mode* is but another word for *function*; thus, we have a thought or, better, thinking construed as a function of signs, or a sign-function. Clearly, if we agree with Bentley and Dewey, we no more want to reify a function than we would a relation. The trick of avoiding treating thoughts,

propositions, or ideas as real “things” is to understand more about how sign-functions may specify the relationship that must exist between things in the world called signs and things in the world to which they refer. Thoughts, or thinking, will then be a functionally specified activity of people *in the world* rather than a vague entity with some immanent existence outside the world or outside the people who populate that world along with its usual furnishings.

Let us pursue an understanding of Thirdness as an analytic rather than ontological category. To do so and to get the full flavor of Peirce’s argument, we must also understand his concepts of Firstness and Secondness. It is pedagogically useful to recognize that Peirce’s concept of Firstness is the progenitor of the notion of self-action, although the latter is an abomination of the former. Similarly, interaction is akin to Peirce’s notion of Secondness, but as a descendant, it has traits not possessed by the first. And, finally, one rightfully expects transaction to be an heir to both the conceptual richness and subtlety of Thirdness, so long as only a family resemblance is sought. But to understand any one of these concepts, one must place it in the context of an understanding of the others. Because our concern, however, is not to present Peirce’s system completely but to borrow from it what we may use to understand the transactional view better, a few passing remarks must suffice.

Peirce argues that there are three modes of being that can be directly apprehended whenever we apprehend anything—say, as in perceiving, communicating, or carrying out other epistemic activities. Firstness is the mode of being that consists in the quality of something being exactly what it is without reference to anything else. It would be an animal in and of itself, conceptually isolated from its environment of other animals and things and therefore disengaged from all activities. Hence Firstness provides the explanatory basis of self-actional forms of inquiry. But because qualities of things are defined by inquiry through the activities in which they participate, no self-actional theories in science are possible and must remain in the realm of speculative metaphysics.

Secondness is the mode of being that comes about through the action of one thing upon another, such as when an animal behaves in accordance with the forces from its environment that constrain those activities of the animal that make manifest the animal’s intrinsic qualities. Hence Secondness, by connecting a given thing to other things, brings Firsts into relationship with other Firsts. The relationship is one of causal interaction and thereby provides the explanatory basis of the interactional form of inquiry. Finally, Thirdness is the mode of being that brings interaction (a Second) into relationship with a third thing, a context of constraint (a Third). Peirce illustrates these three analytic categories with the example of a gift: John’s giving of a present to Jane exemplifies Thirdness not simply because three things—the giver, the receiver, and the gift, all Firsts—are brought into some definitive relationship to one another, for this would only be Secondness (the relating of Firsts); rather, the giving of a gift exemplifies Thirdness because the interaction of John with Jane *vis à vis* a gift invokes the context

of a rule, principle, or law. To give a gift is to relinquish one's rights to an object such that in future activities, a set of new interactions will now follow according to a predictive rule or constraint; namely, Jane may do whatever she pleases with the object John gave her as a gift without fear of moral or legal repercussions. Conversely, John has no right to interfere if the transaction was truly the giving of a gift. On the other hand, if John merely left the object in the care of Jane, she is constrained to act toward it both morally and, perhaps, legally in ways not permitted if it had been a gift. And of course if Jane takes the object without John's permission, it is called stealing rather than receiving of gifts. So here is the main characteristic of Thirdness, or transactions in general: Thirdness denotes the context of constraint (e.g., rule, principle, or law) that must be used to evaluate the meaning of interactions (e.g., giving and receiving of objects), or Seconds, which in turn define the relationships that are manifest among the objects, or Firsts, involved.

By this view, then, note that Thirdness does not have to do with a triad of realms of "things" (Firsts) with coordinate existences, as traditional theorists are wont to argue. Peirce's concept of Thirdness, as Dewey and Bentley point out, cuts vertically over "grains" of analyses or ordered scales of description, if you will, rather than horizontally over realms of coordinate existences. This point—where the triad of terms needed to capture semantic situations is not equated with a triad of ontological realms—defines a significant commonality between the ecological orientation and the American pragmatism movement. Consequently, it is here—in the full realization that Peirce's concept of Thirdness, Dewey and Bentley's transactional inquiry, and Gibson's ecological approach are philosophically of the same breed—that incisive questions might be usefully raised and significant methodological evaluations made.

### THE CLAIM THAT PERCEPTUAL ORGANIZATION IS AN ACTIVITY OF THE ECOSYSTEM: POINTS IN SUPPORT OF COALITIONAL MODELS FOR PSYCHOLOGY

#### The Problem of Context for Transactional Theories

A major stumbling block in the path of all theory construction, regarding natural systems, the transactional not excluded, is how to treat them as "closed" with respect to the manifold and variety of influences from sources within the universe that are not numbered among the known variables of the system. Such uncontrolled sources of variability on systems under study are usually ascribed to a *context of constraints* in which the system is immersed and by whose influences the system is badgered. In such cases, then, we say the system is "open" rather than closed. An *open* system has the nasty habit of behaving in ways that appear

scientifically capricious from the standpoint of explanation solely in terms of the closed set of variables deemed essential to its characterization. On the other hand, any attempt to expand the characterization of the system so as to explain its behavior better, leads to a regress that only ends when the universe as a whole is made the closed field of inquiry.

Laplace treated the whole universe as a kind of cosmic machine whose behavior was in principle totally explicable in terms of mechanical laws. Einstein, in his early stages of theorizing, based his theory of relativity on the assumption that the universe was a closed, steady-state system whose local behaviors were to be explained by its global space-time structure (although he later repudiated this view under the onslaught of evidence that the universe was expanding). Scarcely thirty years ago, the philosopher of science Phillip Frank (1946), in a highly acclaimed book, defended the need for theory on the grand scale by observations of the following sort (quoted by Dewey & Bentley, 1949): "The path of a light ray, without including the environment of the light ray in the description, is an incomplete expression and has no operational meaning. . . . Speaking exactly, a particle by itself without the description of the whole experimental setup is not a physical reality [p. 113]." And, of course, the *whole* experimental setup includes the local expression of variables of cosmic extension (such as gravity); finally, "The law [of causality] in its whole generality cannot be stated exactly if the state variables by which the world is described are not mentioned specifically [p. 113]."

The penchant for grand-scale theorizing that treats local phenomena as inexplicable unless opened up to the source of uncontrolled variability in its wider-world context is not a trait of physicists alone; biologists, psychologists, and social scientists in general have not shied from such expansive theorizing. Under the influence of Darwin's remarkable achievements in the last century, evolutionary factors have been given an indispensable role in attempts to explain the behavior of all kinds of systems—living ones as well as social and political ones. There is general recognition that no evolutionary system, however terrestrially based it may be, can be seriously entertained in a cosmological vacuum; theoretical presuppositions about the history of the universe are prerequisite for understanding the birth and support of any such evolutionary system. This acceptance of the causal regress is common to so many diverse fields as now to have the status of a metatheoretical truism and, therefore, scarcely needs expanding upon. We mention it only to force recognition of what must seem a much belabored and rather obvious point: The poet Donne observed that no man is an island; neither is any given natural system on which we focus scientific inquiry, for it is afloat in a cosmic sea of constraint.

The triteness of this observation, however, vanishes as soon as one raises the possibility that such grand-scale theorizing, which admits to scientific orthodoxy the regressive causal nexus of events, may be not only troublesome but quite unnecessary as a theory-making convention. Perhaps there is a way to close a

system of inquiry short of including all. The mere presumption of such a possibility is evidence enough in the minds of many theorists to brand its author as naive and uninformed regarding the futility of arbitrarily closing systems at boundaries short of cosmic proportions. Indeed, an unkind (and we think unfair) critic of Dewey and Bentley's conception of transactional theory (and Peirce's seminal concept of Thirdness) might smirk and raise a knowing eyebrow at their failure to recognize that transactional analysis, no less than the interactional analysis they criticize, offers no real help in the matter of setting boundaries on inquiry into the bases for explaining the behavior of a system. The critic might point out that Dewey and Bentley correctly expose the limits on interactional principles of inquiry but chastise them for failing to recognize that the absence of all limits is just as damning a fault—a fault that renders transactional inquiry a methodologically naive and unmitigated failure. Both of the foregoing faults were duly noted by Tarski (1944) in his attempt to provide a semantic theory of truth. If we are permitted to identify methods of inquiry—such as self-actional, interactional, and transactional—with attempts to provide a language of semantic descriptors for phenomena, then Tarski's double-barreled criticism surely seems to apply to arbitrarily closed, self-actional languages and prematurely closed interactional systems, on one hand, and to open transactional languages of scientific description on the other. Briefly, Tarski (1944) gave a proof for a very general form of the incompleteness and inconsistency theorem of formal (semantic) languages, of which Gödel's more famous theorems are a special case. Put simply, Tarski showed that any nontrivial language of descriptors that is arbitrarily closed necessarily is inconsistent, whereas any language that is left open to elaboration so as to handle all context effects will necessarily be incomplete. Consequently, we may ask if transactional languages can avoid the charge of necessary incompleteness and, hence, will fail to account for all aspects of the behavior of systems due to contextual influences. To avoid incompleteness by arbitrary truncation of the context of constraint on the system would not be a possible ploy, either, because it leads to necessary inconsistencies among descriptors.

The question arises, then, as to how a phenomenon can be understood as a closed system independently of its world context without introducing self-actional components to take up the slack left by denial of the contribution of contextual factors. Similarly, a contrasting question arises as to how a system, open to the effects of interaction with its immediate context, can not avoid the regress to ever more remote but equally significant contextual effects.

### The Problem of Perceptual Mechanisms

The narrow 19th-century concept of mechanism was an assembly of moving parts performing a function usually as a part of a larger machine that acted as a linkage. The interactional theorists of the 20th century attempted to apply this

concept of mechanism to perception by viewing perception as a causal biological linkage between the physical world and the psychological experiences or judgments of an animal or human—hence, the notions of sensory channels or receptor systems as a biological interface by which stimulation or sensory information “flowed” freely or, perhaps, was processed into a different form. However, given the earlier arguments, it now seems wiser to replace this interactional account of perceptual mechanism with, at the very least, a transactional one.

Prior to the philosophy of mechanical contrivance born during the industrial revolution, there was a deeper, more abstract conception of mechanism that we might do well to reintroduce—namely, that of mechanism merely as the agency or means by which an effect is produced or a purpose accomplished. Under this view, a perceptual mechanism is one that produces a designated effect, whereas an action mechanism is one that accomplishes a designated purpose. Any system, natural or contrived, that is capable of producing the designated effect would be properly termed a “perceiver,” whereas one that accomplished a designated purpose would be properly termed an “actor.” It is our goal, for the reasons stated earlier and elsewhere (Shaw et al., 1981; Turvey & Shaw, 1979), to avoid a three-realm ontological view that reifies psychological predicates as primitive structural realms—say, as some kind of percept, image, idea, proposition, or other immanent existent. Rather, we pursue a two-realm theory that treats psychological predicates functionally—say, as a functionally specified relationship between some semantic aspect of the perceiver’s world and some purposive aspect of the perceiver’s ability as an actor to accomplish ends in that world.

More specifically, we would argue that perception is the mechanism that functions to inform the actor of the means the environment *affords* for realizing the actor’s goals. Correspondingly, we would argue that action is the mechanism that functions to select the means by which the goals of the actor may be effected.

When the mechanism of action successfully accomplishes its goals, then the mechanism of perception completes its functional cycle by moving from information about means to information about ends; in this way, the effect sought by action merges with the effect produced by perception. In seeing that the coffee cup affords grasping, one acts to grasp it; in grasping the cup, one perceives it grasped. In this way, perception and action merge as congruent functional effects determined by “dual”—that is, complementary—mechanisms.

Thus, an isomorphism is achieved between those aspects of the world acted upon and those perceived, just as an isomorphism is achieved between the states of the animal as actor and its states as perceiver. Isomorphisms of the first type are *affordances*, as defined earlier, whereas isomorphisms of the second type, following our earlier usage (Shaw et al., 1981; Turvey & Shaw, 1979), are called *effectivities*. It is important to note that Type 1 isomorphisms (affordances) are reciprocal to Type 2 isomorphisms (effectivities). Such reciprocal isomorphisms are typically called “dual” isomorphisms, or simply *dualities*,

and are to be distinguished from other types of isomorphisms, such as identities and equalities (see following).

Advisedly, we can now speak of the epistemic transactions animals engage in with their worlds as being reciprocal isomorphisms, or dualities, between designated affordances and effectivities rather than as interactions between physical stimulation and biological states, or between stimuli and responses. More generally, the environment of an animal as perceiver can be considered an *affordance structure* that is reciprocally isomorphic, or dual, to the *effectivity structure* of the animal as an actor upon that environment. And most generally of all, the higher-order relational structure consisting of the dual affordance and effectivity structures, as defined for a specific type of animal, is the ecological system, or *ecosystem*, for the designated type of actor-perceiver. In this way, an environment (i.e., an affordance structure) is functionally defined for an animal as perceiver, and an animal as actor (i.e., an effectivity structure) is functionally defined for the stipulated environment as an *ecotope* for that animal.

It should be clear from the foregoing discussion that an environment is not simply a partition of the physical world, as characterized by physicists, any more than an agent is simply a partition of the world of biological functions, as characterized by biologists. Something more has been added to each concept. Physics provides the necessary support to the functionally defined properties (affordances) of the environment, just as biology provides the necessary support for the functionally defined capabilities (effectivities) of the animal.

In other words, the theoretic language of descriptors provided by physics and biology will necessarily be included in the arsenal of analytic concepts for psychology but will be insufficient to capture all the descriptions required to characterize its mechanisms. For instance, a frown on the face of a parent has perceptual meaning for a child that affords constraining or redirecting its activities—say, the retracting of the hand from the cookie jar. The significance of a facial expression to a perceiver transcends any analysis that might be given solely in terms of physical motions of facial parts, or in terms of the muscle synergisms whose actions in concert determine the epidermal stresses that define the various facial expressions.

With this brief discussion of the “ecological” requirements for perceptual mechanism, let us return to address several important issues. If a perceptual mechanism is one that produces a designated effect, what is the nature of this effect, and how is it produced? In addition to answering these questions, we must show how the mechanism for perception to be described can also be used to characterize action; that is, it must function reciprocally as an action mechanism.

Furthermore, the mechanism should also suggest the categories of descriptors, or semantic concepts, and rules for relating them, such that all the significant aspects of perceptual knowing can be accounted for; namely, the mechanism should exhibit in explicit fashion the transactional character of perception and action at multiple grains of analysis that are closed to the context-regress problem.

And, finally, although perception (and action) must be *at least* transactional in order to avoid reifying a third and quite unnecessary ontological realm—one that ultimately invokes self-actional concepts—it must be something more than merely transactional if it is to avoid a context-regress problem arising from rampant proliferation of higher and higher grains of analysis. Another way of posing this problem is to point out that if transaction is a Third, then there must be the concept of a Fourth by which contexts are logically bound to some finite number; no Fifths, Sixths, or *N*ths grains of analysis should be needed.

### Knowing as a Duality of Constraint Between Animal and Environment

What kind of relationship exists between an agent and its environment when we are willing to say that the agent knows its environment (e.g., perceives it or acts purposively toward it)? The foregoing argument suggests two postulates that an ecological style of inquiry might be founded upon: First, the epistemic act mandates a duality, or reciprocal isomorphism, between an environment as an affordance structure and an animal as an effectivity structure.<sup>4</sup> Our suspicion, as already voiced, is that this reciprocal isomorphism is best captured by a duality (see Turvey & Shaw, 1979; Turvey et al., 1978). Second, this duality is of a special sort; it is a reciprocal relationship of mutual constraint that must exist between an animal and its environment if the environment is to be a source of perceptual information for an animal and the animal is to be capable of acting adaptively with respect to its environment. This mutual “fit” of animal and environment requires that each be a context for constraining variations in the other. Let us call these two postulates of the ecological style of scientific inquiry, respectively, the Postulate of Duality and the Postulate of Reciprocal Contexts.

Our main goal in this section is to offer an intuitive characterization of the mathematical structure that satisfies in a rudimentary way these two postulates. (In the next section, we present a more formal account.) Such mathematical structures are referred to as “coalitions,” and we offer them as possible candidates for modeling the relationships of animal–environment synergies, or what we have termed an (epistemic) *ecosystem*. More importantly, in keeping with the claim that something more than the Thirds recognized by the transactional style of scientific inquiry are required to avoid the context-regress problem, we offer coalitions as *Fourths* upon which to establish the ecological style of scientific inquiry as means of avoiding this problem.

Let us now proceed to attempt to clarify these two postulates before using them to provide a more formal characterization of the concept of coalition in the next section.

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<sup>4</sup>The argument that the conceptions of an animal and its environment are *logical duals* has been made independently by Patten, whose theoretical motivations are different from but not unrelated to ours.

*The Postulate of Duality*

A duality is a type of isomorphism that can be distinguished from an isomorphism such as equality because it lacks the property of transitivity, and from an isomorphism such as identity because it lacks the property of reflexivity. In other words, a duality is an isomorphism that has only one of the three properties needed to characterize an equality—namely, the property of symmetry, where  $x R z = z R x$  (hence, the alternative name of reciprocal isomorphism). However, it is not enough merely to distinguish a duality from other isomorphisms; it must also be sharply distinguished from all the other relations, nonisomorphic ones as well. Table 11.1 summarizes those distinctions.

From inspection of the table, it is apparent that all the isomorphic relations are formally distinguished from the nonisomorphic ones, on one hand, and that all the relations of each type are distinguished from one another. Roughly speaking, a duality relation between two structures  $X$  and  $Z$  is specified by any symmetrical rule, operation, transformation, or “mapping”,  $T$ , where  $T$  applies to map  $X$  onto  $Z$  and  $Z$  onto  $X$ : that is, where  $T(X) \rightarrow Z$  and  $T(Z) \rightarrow X$  such that for any relation  $r_1$  in  $X$ , there exists some relation  $r_2$  in  $Z$  such that  $T : r_1 \rightarrow r_2$  and  $T : r_2 \rightarrow r_1$ ; hence,  $X R Z = Z R X$  under the transformation  $T$ .

Duality relations are very general and occur at various grains of abstraction throughout the diverse categories of mathematics and logic. In the next section of this paper, however, we show why the number of grains of abstraction may be naturally restricted to only four in number—a fact that can be used to avoid the

TABLE 11.1  
Table of Relations

Type of Relation	Properties <sup>a</sup>		
	Reflexive	Symmetrical	Transitive
Resemblance <sup>b</sup>	+	+	0
Similarity <sup>c</sup>	-	-	+
Identity	+	-	-
Equality	+	+	+
Duality	0	+	-

<sup>a</sup> A + marks the properties possessed by the relation in all cases where the relation is nontrivial. An 0 signifies that the property may hold under special cases of the relation. And finally, a - signifies the absence of the property as part of the definition of the relation in all its nontrivial forms.

<sup>b</sup> Resemblance as defined here is a *tolerance* relationship and should not be confused with other meanings the word might have colloquially. Given a mapping  $\phi$  between two sets  $M, L, \phi: M \rightarrow L$  and elements  $x, y \in M$ , then a relation  $x R y$  is said to be a tolerance relation if and only if the images of  $x$  and  $y$  in  $L$  share properties that intersect—that is,  $x R y$  if  $\phi(x) \cap \phi(y) \neq \emptyset$ . If identity refers to the perfect interchangeability of  $x$  with  $y$ , then their resemblance refers to their partial interchangeability (e.g., machine parts tooled to be within certain tolerances are functionally interchangeable).

<sup>c</sup> The geometric relationship that defines an equivalence class of objects having the same shape but not necessarily the same size. For instance, large and small equilateral triangles necessarily have the same shape (are similar) but not congruent.

context-regress problem. Consequently, it will be helpful to survey briefly the role that duality has played in logic and mathematics so as to grasp the power of this extremely abstract concept better. A fundamental aspect of this concept to be illustrated is that dualities may exist not only among the objects and functions within a given category of mathematics but also between alternative axiom systems for a given category (e.g., between projective geometries based on lines versus those based on points). In other words, as a general principle, the concept of duality has import for metamathematics as well as for mathematics. Ultimately, we draw upon this fact to suggest by formal analogy that the concept of duality will have import for metatheory in psychology as well as for specific theories of psychological phenomena (e.g., perception).

A very famous duality in symbolic logic, known as deMorgan's Law, relates two theorems so that proof of one theorem automatically entails proof of the other. It is instructive to examine the nature of the relation between the two theorems:

$$\begin{aligned} \text{Theorem 1: } & (p \vee q)' \rightarrow (p' \& q') \rightarrow (p \vee q)' \\ \text{Theorem 2: } & (p \& q)' \rightarrow (p' \vee q') \rightarrow (p \& q)', \end{aligned}$$

where "v" signifies the disjunction *or*, "→" the conditional *if \_\_\_\_\_ then*, "&" signifies the conjunction *and*, and the prime "'" signifies the negation *not*. The importance of these two theorems is not of interest at this time; rather, it is their duality that is of interest to us. The nature of the duality that relates them is obvious on inspection of their related syntactical forms. This becomes most clear when the two theorems are verbalized: Theorem 1 asserts that "the negation of a disjunction yields the conjunction of negations," whereas "the conjunction of negations yields the negation of a disjunction." Theorem 2 is, if you will, the vice versa of Theorem 1: "The negation of a conjunction yields the disjunction of negations," whereas "the disjunction of negations yields the negation of a conjunction."

The duality that relates these two theorems is the fact that a very simple rule (a duality operation) exists by which one theorem can be translated into the other: If in Theorem 1 we replace the word (or symbol) for *disjunction* by that for *conjunction* throughout, then (with but trivial changes to agree with acceptable grammatical form in English) we obtain Theorem 2, and vice versa. Let us call this simple translation rule T; then T(Theorem 1) → Theorem 2, and T(Theorem 2) → Theorem 1. The relationship between Theorems 1 and 2, as defined by T, clearly satisfies the symmetry property required of dualities.

Consider another example. One of the most beautiful applications of the duality principle is in projective geometry. In projective geometry, as in Euclidean geometry, it is true that any two (nonidentical) coplanar points determine, or lie on, one line. But it is also true that any two intersecting lines determine, or lie on, one point. Again we see that a duality relation holds between these two theorems because it is possible to translate one into the other by merely inter-

changing the words *point* and *line*. Thus we can build up two distinct geometries—one that takes points as primitives and derives lines, and one that takes lines as primitives and derives points. In the former case, more complex geometric forms will be defined as loci of points, whereas in the latter case, they will be defined as envelopes of tangent lines. These two geometries are metamathematically equivalent in the sense that any theorem proven in one has a “dual” theorem provable in the other. Hence a great economy of thought is introduced into geometry by this fact: One need only prove the theorems of one of the two geometries, because those of its “dual” geometry can be got by a simple rule that commutes the appropriate terms.

To see more precisely how the principle of duality applies in geometry, let us consider a famous theorem from projective geometry. At age 16, the precocious French mathematician and philosopher Blaise Pascal proved a major theorem of projective geometry. Pascal asserted that if the opposite sides of any hexagon inscribed in a circle are prolonged, the three points at which the extended pairs of lines meet will lie on a straight line. This theorem can be construed both in the terms of a point-geometry and its dual, a line-geometry (Kline, 1953). The point-dual of the theorem reads:

If we take six points, A, B, C, D, E and F, on the point circle, then the lines which join A and B and E join in a point P; the lines which join B and C and E and F join in a point Q; the lines which join C and D and F and A join in a point R. The three points P, Q and R lie on one line l [p. 116].

The line-dual reads:

If we take six lines, a, b, c, d, e, and f, on the line circle, then the points which join a and b and d and e are joined by the line p; the points which join b and c and e and f are joined by the line q; the points which join c and d and f and a are joined by the line r. The three lines p, q and r lie on one point L [pp. 116–117].

The latter theorem is known as Brianchon’s theorem because it was discovered by Charles Brianchon, who derived it by applying the principle of duality to Pascal’s theorem. Indeed, it is possible to show by a single proof that every rephrasing of a theorem of projective geometry in accordance with the principle of duality must lead to a new theorem (Kline, 1953).

The remarkable thing, however, is that the application of the duality principle to logic and geometry is not an exception, but the rule in that it belies a deep-seated truth of mathematics. For instance, similar dualities can be shown to exist in Boolean algebra between theorems based on addition  $+$  and multiplication  $\times$ ; in set theory between theorems based on union  $\cup$  and intersection  $\cap$  or between disjoint union  $\sqcup$  and Cartesian products  $\times$ ; in geometry between points and lines; in vector theory between bases of different fields; in graph theory between

vertices and arrows; in the theory of formal grammars between generative and categorical grammars; in symmetry group theory between enantiomorphic groups; in topology between open and closed sets; and most probably in all other branches of mathematics as well.

Before proceeding to apply the concept of duality to the problem at hand, let us step back from the specifics of the foregoing examples and abstract the form of the duality principle as a conceptual scheme. This can best be seen when expressed in terms of the mathematically neutral device of a *diagram*. A diagram is "neutral" in the sense that it is a metamathematical scheme of relations and functions over sets of variables that belongs to no particular category of mathematic structure (e.g., group, ring, geometry) but can be applied to describe structures that belong to any such category.

Following MacLane and Birkhoff (1967) a "diagram" is defined informally as a set "of vertices  $p, q, \dots$  together with arrows from one vertex to another, where each vertex  $p$  labeled by a set  $S_p$  and each arrow  $p \rightarrow q$  labeled by a function  $f$  on  $S_p$  to  $S_q$ . A 'path' in a diagram is a succession of arrows  $p \xrightarrow{f} q \xrightarrow{g} r \xrightarrow{h} t$  such that each path determines the corresponding composite function  $h \circ g \circ f$  from  $S_p$  to  $S_t$ . Finally, a diagram is commutative when any two paths from any one vertex  $p$  to another vertex  $s$  in the diagram which yield by composition the same function  $S_p \rightarrow S_s$  [p. 32]." The "dual" of a diagram is simply one obtained by reversing all arrows.

Therefore, a concept defined by means of a diagram necessarily has a dual concept defined in terms of the same diagram if a rule, called a "contravariant functor," exists by which the arrows may be legitimately reversed. (For instance, a pair of dual concepts to be defined and used widely in the next section is that of product  $\times$  and disjoint union  $\cup$ , whose diagrams are  $S \rightarrow S \times T \leftarrow T$  and  $S \leftarrow S \cup T \rightarrow T$ , respectively.)

In short, the concept of duality is so general, pervasive, and profound that we should not be surprised to find its outcroppings in scientific areas whose theoretic languages incorporate any of the foregoing mathematical tools or whose concepts can be formulated in terms of diagrams.

Thus the gist of the preceding observations for science is that the principle of duality may prove as regulatory in guiding theory construction about natural phenomena as it has in guiding theory about mathematical ones. Indeed, if it should deserve the status of a metatheoretical principle in science, then a theory designed to characterize formally some natural phenomenon  $X$  would at the same time yield, free of charge, a theory *mutatis mutandis* for some dual phenomenon  $Z$  (i.e., after the appropriate changes are made in the diagrams for the first theory). This idea is not so speculative nor farfetched as might first be thought, for the search for dualities in physics has revealed a near-perfect symmetry between the so-called classical symmetries of Newtonian theory and the dynamic symmetries of quantum mechanics (Wigner, 1970). Likewise, in chemistry and crystallography, the principle of duality comes into play in the study of steroids

and other enantiomorphic structures—the so-called “colored” symmetries (Shubnikov & Koptsik, 1974). Less heralded is the role the principle has played in computer science by constraining the design of programs and switching circuits through the theorems of duals implicit in formal grammars, automata theory, and Boolean algebra.

In spite of the ubiquitous nature of the duality concept in many branches of science, is there any *prima facie* evidence of it being at work in psychology, especially in perceptual psychology? We believe so and have argued to this effect elsewhere (Shaw & McIntyre, 1974; Shaw et al., 1981; Turvey, 1977; Turvey & Shaw, 1979; Turvey et al., 1978). Briefly, before returning to the use of the duality concept to help characterize perceptual mechanism, we would like to reiterate some of those arguments here.

Many examples of dual structures exist in perceptual psychology. For instance, the global invariants of the optical flow field determined by the locomotion of an observer toward a given object are *dual* with the local invariants of the optical flow field determined if the object should move toward the static observer. It can be shown in general that the *open* set of globally invariant vectors associated with observer movement is *dual* to the *closed* set of locally invariant vectors associated with the inverse motion of objects (e.g., when they are inverse rectilinear motions).

The duality relation between these two sets of velocity vectors as defined by some transformation *T* provides dual forms of perceptual information: Any invariant style of change in vectors in a local region of the perceiver's field of vision specifies that it is the object that is moving in such and such a manner, whereas, reciprocally, any invariant style of change in the velocity vectors defined globally over the perceiver's whole field of vision specifies that it is the perceiver moving in such and such a manner relative to the object fixated rather than the other way around. Similarly, the rotation of an object for a static observer determines perceptual information that is dual to the perceptual information determined by the observer who “orbits” around the fixed object. These examples illustrate how the principle of duality might apply in the area of “event” perception (Johansson, von Hofsten, & Jansson, 1979; Shaw & McIntyre, 1974).

In particular, the former example suggests that a duality relation might exist between information that specifies properties of the world (e.g., object motion) and information that specifies properties of animals as actors in the world (e.g., its locomotions). The information that specifies properties of the world corresponds to *perceptual* information, whereas its dual—information that specifies properties of the active self—corresponds to *action* information.

Most generally, as a regulatory metatheoretical principle, the principle of duality offers the hope that the conceptual economy alluded to earlier might be introduced into psychology by adopting the ecological style of scientific inquiry: Theorems that might be proven about the perception of the environment by an

animal could be reformulated as dual theorems that assert truths about the actions the animal might perform on the environment and vice versa. Thus any degree of success that might be achieved in characterizing perceptual processes would ipso facto apply to derive true dual characterizations of action processes and vice versa at some appropriate level of abstraction.

### *The Postulate of Reciprocal Contexts*

Assuming that a case has now been established for the possible validity and theoretic usefulness of the Postulate of Duality, we would like to argue in favor of the validity and usefulness of the other postulate of the ecological approach identified earlier—the Postulate of Reciprocal Contexts (of constraint). The main point to be made is the following: Not only do we wish to exploit the existence of a formal duality relation holding between animals and their environments but, more importantly, to emphasize that this dependency is a very special sort of duality (one that we have argued elsewhere [Turvey et al., 1978] is of great practical significance for theories of control and coordination). The additional claim that goes beyond that assented to in the first postulate is that perception and action are not only duals in the formal descriptive sense already discussed; rather, each process provides a necessary source of constraint on the other in that they act as dual contexts of mutual constraint. Where the first postulate asserts that a useful constraint on the descriptors used for characterizing animals as actors and perceivers is the descriptors selected for the environment that is perceived and acted upon and vice versa, the second postulate posits acausal constraints between an animal and its environment. To see what this means, consider a duality in the context of a linear functional (i.e., a linear transformation whose codomain is the field of scalars with which we are concerned). The duality to be exposed is that of buying groceries from the perspective of the seller and from the perspective of the buyer.

The customer's shopping list is constructed so as to guarantee a desired balance of carbohydrates, proteins, vitamins, and so forth. Let the shopping list be  $(a, b, c, \dots)$ , and let the price list be  $[A, B, C, \dots]$ , so that the cost of the groceries is given by  $Aa + Bb + Cc \dots$ . The customer sees the problem as that of choosing a shopping list that meets his or her purposes but that, at the same time, is minimal in cost. In short, with reference to dietary needs, the customer seeks a minimal value of  $Aa + Bb + Cc \dots$ . We can identify the customer's vector space as being that in which price lists are functionals and shopping lists are vectors. In contrast, the grocer's vector space identifies the shopping lists as functionals and the price lists as vectors, for the grocer is interested in maximizing profits. So his or her concern is with how the cost of a given shopping list depends on the price list. There is, therefore, a symmetrical relation between the customer's vector space and the grocer's vector space, and the two spaces are referred to as *dual spaces*.

Tentatively, we might regard the relationship between an animal that acts in an environment and an environment that is perceived as duals in formal analogy to the grocer's vector space and the customer's vector space: The actions of the grocer (in buying wholesale goods) are practically constrained by the perception of the changing state of the shelves of the store environment. Dually speaking, the actions of the customer (in buying retail goods) are practically constrained by the perceived availability of the items to be acted upon (i.e., bought) in the context of the store environment. The environment that is perceived by the customer (i.e., stock on the shelves) is grocer-referential and, therefore, constrained by the grocer's acts, whereas the environment that is perceived by the grocer (i.e., shelves to be restocked) is customer-referential and similarly constrained by the customer's acts. By generalization, this reciprocity of the mutually constraining contexts of actions and perceptions is seen to hold in other synergistic relations than the grocer-customer synergy.

The foregoing bilinear functional between dual vector spaces provides one way to model the duality of information made available to an animal about its environment as an affordance structure and to an animal about itself as an effectivity structure. At all events, using the formal concept of duality as expressed in the foregoing examples, it is now possible to make more precise this relationship between affordances specified by perception and the effectivities that specify the actions by which the agent realizes the goal-directed relations potentiated by its environment.

We say a cup  $X$  affords grasping  $Y$  (or, alternatively, has the property of *graspability*) for an agent  $Z$  (e.g., a baby) on the occasion  $O$  (say, on the occasion that  $Z$  is thirsty or playful) if and only if there exists a duality relation between  $X$  and  $Z$  on that occasion (i.e., the baby  $Z$  has matured normally to have both the strength and coordinative capabilities to grasp the cup  $X$  and that the cup is not too large, heavy, or ill shaped to be grasped by  $Z$ ). In other words, somewhat tautologously, we say  $X$  affords  $Y$  for  $Z$  if and only if there exists a duality,  $X \diamond Z$  (to be read as "X and Z are compatible"), or reciprocal isomorphism between the properties of  $X$  and those of  $Z$ . We can represent this formally as the affordance schema (see Shaw et al., in press) whose argument has four variables:  $(X, Z, O | X \diamond Z) = Y$  (to be read as "X, Z, and O, given the compatibility of X and Z, equal Y").

Now if perceptually specified affordances are truly dual concepts of the effectivities for the actions potentiated by the affordances, then there should exist some duality operation  $T$ , a metatheoretic principle, by which the semantic descriptor for an affordance  $Y$  (as already depicted) might be translated into the semantic descriptor for some corresponding effectivity  $Y'$ . In other words,  $T(Y) \rightarrow Y'$  and  $T(Y') \rightarrow Y$  should be possible just as in the analogous case of deMorgan's Law in logic and the Pascal-Brianchon theorems in projective geometry. Indeed, we find this is so.

Let T be the following rule:  $(X,Z)' \rightarrow (Z,X)$  and  $(Z,X)' \rightarrow (X,Z)$ . We apply the first part of this rule to our semantic descriptor for affordances; namely,  $T(Y) = Y' = (X,Z,O|X \diamond Z) = (Z,X,O|Z \diamond X)$ . By inspection, we see then that the schema that defines an affordance,  $(X,Z,O|X \diamond Z)$ , is dual with the schema  $(Z,X,O|Z \diamond X)$  under application of the rule already stipulated. This resulting schema should correspond to an effectivity.

Again, we see most clearly the essence of the duality relation when stated in words: "An object X affords grasping Y by an animal Z if and only if the structure of X is isomorphic with the structure of Z"; and, dually, "An animal Z can effect grasping Y' if and only if the structure of Z is isomorphic with the structure of X."

The general form of this duality of perception and action, vis à vis affordances and effectivities, is by no means trivial; for it provides the basis for our original assumption that perception and action must be closely linked. Furthermore, it also provides a concrete way of interpreting the isomorphism between an animal and its environment that is neither an identity nor an equality.

Our task now is to use this duality relation as the fundamental building block from which to characterize in an abstract fashion the style of inquiry that we believe is needed to accommodate the mechanism of perception and its relation to action.

### Coalitions: Treating Perceptual Mechanism as a Fourth

Recall that a transaction, as expressed in the writings of the American pragmatists, is a relational structure defined over three categories of entities—the so-called Firsts, Seconds, and Thirds. And recall further that once a transactional structure is adopted as the minimal structure for accommodating a natural phenomenon, there arises the unwelcome problem of a regress to further contexts. We want to show in the present section and those that immediately follow that there is a way of conceptualizing a relational structure qua style of inquiry that avoids the regress to further contexts. What follows should be read as a constructive definition—an "existence" proof, as it were—of the desired relational structure.

A coalition will be defined as a structure relating four categories of mathematical entities: B—an *underlying set of bases* consisting of all the disjoint subsets of distinguished variables over which relations might be defined; R—a set of *relations* defined in terms of the pairings of the distinguished disjoint subsets in B; O—a set of *orders* defined in terms of the pairings of distinguished disjoint relations; and finally, V—a set of *values* defined in terms of pairs of distinguished disjoint orders of relations.

Each descriptor category just identified designates a “grain” of analysis.<sup>5</sup> By a *grain of analysis*— $g(\alpha)$ —we mean to designate one of the descriptor categories in  $E = \langle B;R;O;V \rangle$  such that  $\alpha \rightarrow \{B,R,O,V\}$ . Moreover, we will call  $g(V)$  the “value-grain”;  $g(O)$ , the “order-grain”;  $g(R)$ , the “relation-grain”; and  $g(B)$ , the “basis-grain.” A requirement of the relational structure we seek is that each grain  $g(\alpha)$  is ordered with respect to the others, so that  $g(B) > g(R) > g(O) > g(V)$  where the basis-grain is coarser than the relation-grain; the relation-grain coarser than the order-grain; and the order-grain coarser than the value-grain. (Read “finer-than” in reverse order.)

Necessarily, in order to avoid the regress problem in either direction, coarser grains than  $g(B)$  and finer grains than  $g(V)$  must be ruled out. In short, the lattice of grains must be bounded on either end. This requires that beyond  $g(B)$ , there is only the universal set  $U$ —namely,  $U \supseteq B$ ; and below  $g(V)$ , there is only the null set  $\emptyset$ —namely,  $V \supseteq \emptyset$ ; hence  $U > g(B) > g(R) > g(O) > g(V) > \emptyset$ .

A further requirement of the relational structure we seek is that each grain be exhaustively (although not exclusively) characterized as the disjoint union of dual subsets so as to close the whole lattice of grains under duality operations yielding a *closed duality structure*. This means that it must be the case that  $B = X \cup Z$ , such that  $T(X) = Z$  and  $T(Z) = X$ ;  $R = \phi \cup \psi$ , such that  $T(\phi) = \psi$  and  $T(\psi) = \phi$ ;  $O = A \cup E$  such that  $T(A) = E$  and  $T(E) = A$ ; and  $V = S \cup N$  such that  $T(S) = N$  and  $T(N) = S$ . To anticipate, a coalition will be a relational structure  $E = \langle B;X,Z; R; \phi, \psi; O; A,E; V;S,N \rangle$  that is closed under the duality operation  $T$ . And assuming that this relational structure can be captured in table form, we might try to anticipate how many entries are required to characterize even the simplest coalition. Including  $E$ ,  $U$ , and  $\emptyset$ , there will be 15 distinct subsets of  $E$ —namely,  $U, E, B, R, O, V, X, Z, \phi, \psi, A, E, S, N, \emptyset$ . The number of dualities, however, will be considerably greater being the Cartesian product of  $E \times E$ —namely,  $(B \times R \times O \times V) = (2 \times 2^2 \times 2^3 \times 2^4) = 2 \times 4 \times 8 \times 16 = 1024$ . Thus, it will require a  $64 \times 64$  table with 1024 cells to describe any coalition, from the simplest with only two variables to the most complex having many variables. (In the latter case, however, the cells will have multiple entries.)

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<sup>5</sup>The terms *scale*, *level*, and *grain* have appeared at various places in the present chapter. We can now consider them together. Scientific models of natural phenomena can be characterized according to scale, level, and grain. The scale of a model refers to the ordinal position it occupies along some extensive dimension of magnitude—for example, atomic, molecular, cellular, organismic, ecosystemic, terrestrial, and so on. The level (of abstraction) of a model refers to its degree of specificity or generality regarding semantic referent—that is, the degree to which it signifies the properties of the phenomenon modeled. The grain of a model at a given scale and a given level refers to its ordinal position with respect to contexts of constraint—for example, value, order, relations, bases. Scales are typically conceived of linearly; levels are typically conceived of hierarchically; grains, by the arguments presented here, are conceived of coalitionally.

With the foregoing stipulations in mind, let us proceed to construct a simple coalition: Let the universal set  $U$  consist of all the pairs of bases  $U = \{ (b_1, b_1'), (b_2, b_2'), \dots \}$  that define the "polar" concepts of all dimensions of significant variation in nature where each  $(b_i, b_i')$  pair defines a unique dimension where each  $b_i$  is a variable and  $b_i'$  its dual covariate variable. For instance, a dimension of thermal variation might be some  $b_i$ ; then  $b_i'$  would be the covariate dimension of radiant variation as represented in a light bulb; the hotter the filament (thermal increase), the more intense the illumination (radiant increase), and vice versa. The basis of our coalition, therefore, can be defined as  $B = \{X, Z\}$  where  $(b_1, b_2, \dots, b_k) = X$  and  $(b_1', b_2', \dots, b_k') = Z$ . Hence,  $B = X \cup Z$  such that for all  $b_i \in X$  and  $b_i' \in Z$ ,  $T(b_i) \rightarrow b_i'$  and  $T(b_i') \rightarrow b_i$ . Consequently,  $X$  and  $Z$  will be called the *dual* bases of  $E$  (symbolized as  $X \diamond Z$ ) and  $B$ , the underlying set of dimensions of  $E$ . Furthermore, we define this grain of analysis to be  $g(B) = X \times Z$  where  $X$  and  $Z$  are duals. Therefore,  $g(B)$  is *closed* under the duality operation  $T$ ; that is,  $g(B)$  is closed because if some  $b_i \in X$  exists, then so does  $b_i' \in Z$ .

Next we proceed to define the grain of analysis of relations  $g(R)$  so as to be finer in structure than  $g(B)$ . By "finer" in structure, we mean only that  $g(R)$  be defined over  $g(B)$ , making  $g(B)$  more primitive and having fewer coarser-grain elements than  $g(R)$ . We do this by defining the set of relations  $R$  over  $B$  in the usual way by using the Cartesian product:  $R = B \times B = \{X, Z\} \times \{X, Z\}$ . The product produces the set of all possible ordered pairs:  $R = \{ \langle X, X \rangle, \langle X, Z \rangle, \langle Z, X \rangle, \langle Z, Z \rangle \}$  where  $\langle X, Z \rangle \neq \langle Z, X \rangle$ .

For convenience, we designate the disjoint subsets of  $R$  to be  $\phi$  and  $\psi$  where  $\phi = \{ \langle X, X \rangle, \langle X, Z \rangle \}$  and  $\psi = \{ \langle Z, Z \rangle, \langle Z, X \rangle \}$ . Notice that  $R - \phi = \psi$  and  $R - \psi = \phi$ , which implies that  $\psi$  and  $\phi$  are duals under complementation; namely, that  $\phi' = \psi$  and  $\psi' = \phi$  satisfy the dual operation  $T(\phi) \rightarrow \psi$  and  $T(\psi) \rightarrow \phi$ , respectively. We define this new grain of analysis over relations,  $g(R) = \phi \times \psi$ . Because  $\phi$  and  $\psi$  are duals, then  $g(R)$  must be closed under the duality operation. Moreover,  $g(R)$  must be finer grained than  $g(B)$ ; that is,  $g(B) > g(R)$  because  $\phi$  and  $\psi$  are disjoint subsets in  $g(B)$ .

The next finer grain of analysis is defined over the orders of relations  $O$  where  $O = R \times R = \{ \langle X, X \rangle, \langle X, Z \rangle, \langle Z, X \rangle, \langle Z, Z \rangle \} \times \{ \langle X, X \rangle, \langle X, Z \rangle, \langle Z, X \rangle, \langle Z, Z \rangle \} = \{ \langle \langle X, X \rangle, \langle X, X \rangle \rangle, \langle \langle X, X \rangle, \langle X, Z \rangle \rangle, \dots, \langle \langle Z, Z \rangle, \langle Z, Z \rangle \rangle \}$  where  $\langle \langle X, X \rangle, \langle X, Z \rangle \rangle \neq \langle \langle X, Z \rangle, \langle X, X \rangle \rangle$ ;  $\langle \langle X, X \rangle, \langle Z, X \rangle \rangle \neq \langle \langle Z, X \rangle, \langle X, X \rangle \rangle, \dots$ , etc. For convenience, we designate the disjoint subsets of relations whose orders are defined by the relation schema  $\langle \langle X, \rangle, \langle \rangle, \rangle \rangle$  as  $A$ , and those whose orders are defined by the relation schema  $\langle \langle Z, \rangle, \langle \rangle, \rangle \rangle$  as  $E$  (e.g., compare  $\langle \langle X, X \rangle, \langle X, Z \rangle \rangle$  and  $\langle \langle Z, X \rangle, \langle X, X \rangle \rangle$ , respectively). Therefore  $A = \{ \langle \langle X, X \rangle, \langle X, X \rangle \rangle, \dots, \langle \langle X, Z \rangle, \langle Z, Z \rangle \rangle \}$ , whereas  $E = \{ \langle \langle Z, X \rangle, \langle X, X \rangle \rangle, \dots, \langle \langle Z, Z \rangle, \langle Z, Z \rangle \rangle \}$ , and  $O = \{A, E\}$  where  $O - E = A$  and  $O - A = E$ . Consequently, as before, this implies that  $A$  and  $E$  are not only disjoint subsets but are

also complementary, so that  $E' = A$  and  $A' = E$ . This also satisfies the requirements of a duality, operation  $T$ , such that  $T(A) \rightarrow E$  and  $T(E) \rightarrow A$ ; hence, the duality relation  $E \diamond A$  holds. Moreover, the order-grain is defined as  $g(O) = A \diamond E$ . The construction runs as before: Given  $R = B \times B$  and  $O = R \times R$ ,  $g(O)$  is finer grained than  $g(R)$ , so that  $g(B) > g(R) > g(O)$  is now the case, along with the fact that  $g(B)$ ,  $g(R)$ , and  $g(O)$  are all closed under the duality operation of set complementation. It only remains to establish the finest grain of analysis as the value-grain  $g(V)$ .

The value-grain  $g(V)$  is defined over  $V$  where  $V$  is the Cartesian product of  $g(O)$  and a two-valued set  $\{+, -\}$ ; that is,  $V = A \times E \times \{+, -\} = 32 \times 32 = 1024$  items to be cross-compared so as to ascertain the dualities that hold. As already stated, this yields 1024 possible comparisons in the simplest coalition. A *value* is to be thought of as a designation of a relation in a sequence to be *selected* or *ignored*. In other words, within a given sequence of ordered relations, some of the relations may be "active," whereas others are "quiescent" in the use of the sequence to define the actual as opposed to the potential activities performed by the specified mechanism, or subsystem. Clearly, then,  $V$  is a set of relation sequences that are partitioned into two mutually exclusive subsets by the selection criterion: Those sequences in  $O$  that receive a positive selection value (+) versus those identical sequences that receive a negative selection value (-). For convenience, let  $S = O \times \{+\}$  and  $N = O \times \{-\}$  (standing for *selections* and *nonselections*, respectively). This means, of course, that  $N \cup S = V$  and a complementary relation again holds:  $V - S = N$  and  $V - N = S$ , so that as  $S' = N$  and  $N' = S$ , or  $T(S) \rightarrow N$  and  $T(N) \rightarrow S$ , then the duality relation  $N \diamond S$  obtains. Thus  $g(V) = N \times S$  and  $g(V)$  is a grain closed under a duality operation  $T$ . Furthermore, because  $V = O \times \{+, -\}$ , it follows that  $V \subset O$  and  $g(O)$  must be more coarse grained than  $g(V)$ .

Thus, we have constructed a relational structure that meets two of the stipulations identified earlier; First, from the basis-grain  $g(B)$ , through the relation-grain  $g(R)$ , and from the order-grain,  $g(O)$  through the value-grain  $g(V)$ , there is an increasing fineness of analysis such that  $g(B) > g(R) > g(O) > g(V)$  holds. Second, each grain of analysis is a closed Cartesian product of duality relations because each set over which the grain is defined consists of dual subsets (i.e., is the disjoint union of complementary subsets).

To summarize: In descending order of coarseness of grain, or context of constraint, we have the inclusion relation among structures closed under duality operations.

$$g(B) = X \diamond Z$$

$$g(R) = \phi \diamond \psi$$

$$g(O) = A \diamond E$$

$$g(V) = N \diamond S$$

Let us now see whether the relational structure we have constructed meets the remaining stipulation identified earlier—namely, that the four grains of analysis are exclusive in the sense that the lattice of grains is bounded on either end.

Recall that the universe of covariate dimensions  $U$ , postulated as the underlying set for a coalition, contains all dimensions over which relations in  $E$  might be defined—that is,  $U \supseteq B$ . This means that the basis-grain  $g(B)$  is the *least upper bound* for the other grains; but there can be no coarser grain than this. Because  $U$  contains only dual partitions, one can augment any given basis-grain, but it will necessarily remain a closed Cartesian product of dual bases; namely,  $B = (b_1, b_1') \times (b_2, b_2') \times \dots = X \times Z$  where  $X = (b_1, b_2, \dots)$  and  $Z = (b_1', b_2', \dots)$ . Hence the set  $U$  is *open* to the number of pairs of dual subsets (i.e., can be an infinite list of pairs) while still being closed under duality because no member of a pair,  $b_i \in X$ , occurs without its dual,  $b_i' \in Z$ .

Similarly, the finest grain possible is the value-grain  $g(V)$ . As  $V$  constitutes all the members of the set of relations that can be defined over  $B$  by Cartesian products, then  $g(V)$  is the greatest lower bound of the lattice of grains. Recall that each grain finer than  $g(B)$  was defined as the product of disjoint subsets defined at the grain immediately superior to it in coarseness. Hence  $g(B) \cap g(R) \cap g(O) \cap g(V) = \emptyset$ . By adding new variables to the sets in  $B$ , we can increase the number of relations on each of the dual subsets of  $R$ , likewise increasing the number of dual orders in  $O$ , which increases the size of the dual subset in  $V$ . But none of these increments can add another finer grain to  $E$ , for there are no new subsets of  $V$  produced by such additions that may be joined by a product relation. Any attempt to fabricate arbitrary partitions under  $V$ , aside from those dual partitions specified by  $\{+, -\}$ , will fail to be closed under a duality operation. Hence it follows that the ordering of set products  $U > g(B) > g(R) > g(O) > g(V) > \emptyset$  holds as claimed.

To summarize: A *coalition* is a superordinate system (relation structure) consisting of eight pairs of subsystems (with 1024 states) nested at four exclusive “grains” of analysis (bases, relations, orders, values) and *closed* at each grain under a (duality) operation.

It is important to note clearly what the foregoing constructive definition, or “existence” proof, does and does not do: What it does is provide an in principle example of a mathematical structure in which there is, by definition, no place for self-actional explanation; a mathematical structure in which the variety of forms, interactions, and transactions it might assume are duly stipulated; and finally, a mathematical structure that consists of a nesting of grains of reciprocal contexts closed under duality operations and that is thereby formally impervious to the context-regress problem.

On the other hand, this schematic definition of a coalition does not provide a complete specification of all the variables required to describe an actualized (i.e., natural) coalition. Most emphatically, it is not intended to be a dynamic model of natural systems, for these must include, in addition to the structural variables

already stipulated, both time-dependent and energy-dependent processes. Rather, the preceding definition provides a formal description for how many grains of analysis are minimally required and maximally allowed over which variables must be selected (bases), related, ordered, and evaluated if the system under analysis is to qualify as a coalition. Thus there are two modeling senses in which the coalitional schema already described might be used—as an a priori formal “recipe” for guiding and evaluating the construction of artifactual coalitions such as machines, factories, or governments; or as a post hoc “blueprint” for describing existing natural coalitions such as evolving molecular systems, social groups, or ecosystems.

### *The Ecosystem as a Coalition*

Let the coalition  $E = \langle B; R; O; V \rangle$  be an ecosystem where  $B = \{X, Z\}$  is the set of dual bases for the ecosystem. The set  $X$  will be associated with all the environment-based variables (e.g., objects, events, media, energy), whereas the set  $Z$  will be associated with all the animal-based variables (e.g., CNS, events, muscle potentials, body size).

$R = \{\phi, \psi\}$  is defined to be the set of all possible *ecological* relations over  $B$ , where  $\phi$  is the set of relations defining the environment as both perceived and acted upon, and  $\psi$  is the set of relations defining the animal as both perceiver and actor. Hence the environment corresponds to the set  $\phi = \{\langle X, X \rangle, \langle X, Z \rangle\}$ , whereas the animal corresponds to the set  $\psi = \{\langle Z, X \rangle, \langle Z, Z \rangle\}$ . But notice that under this conception, the environment is not merely *physical*, nor the animal merely *biological* (as these terms are conventionally used), for this would entail that each be defined over reflexive relations only; that is, to be purely physical, the environment concept would include only those relations  $\langle X, X \rangle$  based on  $X$ ; and to be purely biological, the animal concept would include only those relations  $\langle Z, Z \rangle$  based on  $Z$ . On the contrary, at this grain of analysis,  $g(R)$ , the environment  $\phi$  and the animal  $\psi$  include *ecological* relations as well—namely,  $\langle X, Z \rangle$  and  $\langle Z, X \rangle$  respectively. This means that  $g(R)$  is an *ecological* grain where the environment concept is defined in reference to some associated animal concept, and conversely, the animal concept is defined in reference to some associated environment concept. Hence  $\phi$  and  $\psi$  constitute dual components of a single ecosystem.

The set of ordered relations  $O = \{A, E\}$  is to be semantically interpreted as the descriptors for the *affordance structure* of the environment,  $A = \{\langle \langle X, X \rangle, \langle X, X \rangle \rangle, \dots, \langle \langle X, Z \rangle, \langle Z, Z \rangle \rangle\}$ , and the descriptors for the *effectivity structure* of the animal,  $E = \{\langle \langle Z, X \rangle, \langle X, X \rangle \rangle, \dots, \langle \langle Z, Z \rangle, \langle Z, Z \rangle \rangle\}$ . In other words, an affordance structure description of an environment consists of all those and only those properties of  $\phi$  that can be related to properties of  $\psi$  (where by properties of  $\phi$  or  $\psi$ , we mean a relation over variables in  $\phi$  to variables in  $\psi$ , and vice versa), whereas an effectivity structure consists of all those and only those properties of  $\psi$  that can be related to properties of  $\phi$ .

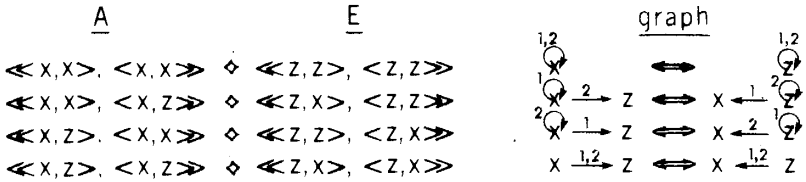
Earlier, we illustrated how an affordance structure might be considered a dual concept of an effectivity structure and proved that the schema for one could be simply translated into the schema for the other—namely, that  $A' = (X, Z, O | X \diamond Z) \diamond (Z, X, O | X \diamond Z) = E$ .<sup>6</sup> The general proof for translations  $T(A) \rightarrow E$  and  $T(E) \rightarrow A$  consists in showing that for each ordered pair of relations in  $A$ , there exists a corresponding ordered pair in  $E$  under some duality specification rule  $T$ , and vice versa. We now show this to be the case: Let  $T$  be the rule whose defining schema is  $T = \langle \langle a, b \rangle, \langle c, d \rangle \rangle' = \langle \langle c, d \rangle', \langle a, b \rangle' \rangle = \langle \langle c', d' \rangle, \langle a', b' \rangle \rangle$  where if  $a, b, c, d$  take values in  $X$  or  $Z$ , then  $a', b', c', d'$  take values in  $X'$  or  $Z'$  where  $X' = Z$  and  $Z' = X$ . For instance,  $\langle \langle X, Z \rangle, \langle Z, Z \rangle \rangle' \rightarrow \langle \langle Z, Z \rangle', \langle X, Z \rangle' \rangle \rightarrow \langle \langle Z', Z' \rangle, \langle X', Z' \rangle \rangle \rightarrow \langle \langle X, X \rangle, \langle Z, X \rangle \rangle$ . Hence  $A \diamond E$ . Table 11.2 gives all of the dualities of the order-grain of analysis  $g(O)$ . This table requires considerable discussion to be fully appreciated. Consequently, only a few of the dualities at this grain of analysis are discussed at this time. A most important aspect of the order-grain are the other duals that relate affordances to effectivities (I, Table 11.2). By a *perception* we mean the specification of the effectivity-dual of an affordance (i.e.,  $T(A) \rightarrow E$ ); by an *action* we mean the specification of the affordance-dual of an effectivity (i.e.,  $T(E) \rightarrow A$ ). (For instance, the perception that the cup *affords* grasping by the hand *versus* the hand *effects* grasping the cup.) In this sense, perceiving and acting can be said to be dual such that theoretical truths about one necessarily imply corresponding theoretical truths about the other. If this is so, then considerable conceptual economy and explanatory power can be introduced into psychology by the stubborn pursuit of the coalitional (ecological) style of scientific inquiry.

A second important aspect is the order-reflexive duals that relate affordances to affordances and effectivities to effectivities (II, Table 11.2). The  $A \diamond A$  duals specify complementary affordance properties of objects, such as the fact that a knife can be sharpened or dulled by stoking its blade with a grinding stone; a brick picked up or dropped; a glass filled or emptied. By contrast, the  $E \diamond E$  duals specify complementary effectivity capabilities of an animal, such as the fact that a hand can be closed to grasp an object or opened to release it; in walking, a leg may be involved at one moment in the support phase and at the next in the transport phase. The self-duals (III, Table 11.2) are those affordances or effectivities that specify themselves as duals. This is the case whenever an event or an act cycles through repetitions, as when a ball bounces or the hands are clapped. One might speculate that self-duals may prove important to understanding persistent patterns of activity often attributed to memorial processes.

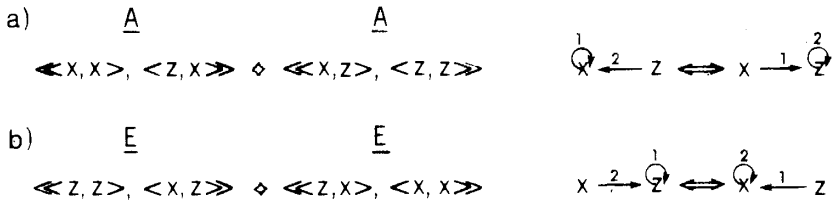
<sup>6</sup>In the dual schemata for affordances  $(X, Z, O | X \diamond Z)$  and effectivities  $(Z, X, O | X \diamond Z)$  defined at the order-grain, the context of constraint or mutual compatibility condition  $[X \diamond Z]$  receives its theoretic motivation and explication from the fact that both the basis-grain and relation grain are realized and elaborated at the order-grain.

TABLE 11.2  
The Dualities at the Order-Grain Where  $0 = \{A,E\}$

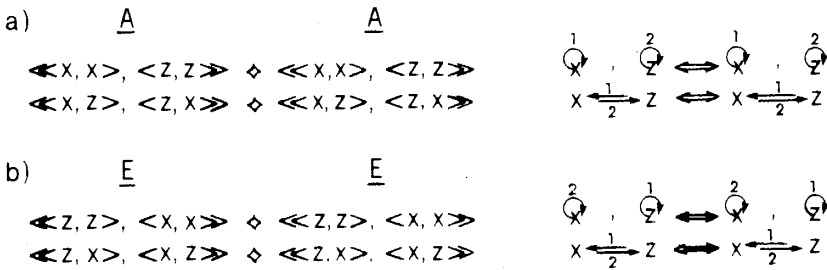
I. OTHER-DUALS: AFFORDANCES  $\longleftrightarrow$  EFFECTIVITIES



II. ORDER-REFLEXIVE DUALS: AFFORDANCES  $\longleftrightarrow$  AFFORDANCES  
EFFECTIVITIES  $\longleftrightarrow$  EFFECTIVITIES



III. SELF-DUALS



The set of values  $V = \{N,S\}$  specifies which affordances among all those composing the affordance structure of a given environment are noticed, S, or ignored, N, on a given occasion or, alternately, which effectivities in the effectivity structure of an animal are active, S, or quiescent, N, on a given occasion. The role of the *occasion* variable defined at the value-grain of analysis  $g(V)$  can be seen in the dual schemata for defining affordances and effectivities discussed earlier—namely,  $A = (X,Z,O|X \diamond Z) \longleftrightarrow (Z,R,O|X \diamond Z) = E$ .

It is interesting to note that the foregoing definitions simultaneously invoke every grain of analysis: X,Z are dual bases at  $g(B)$ ;  $X \diamond Z$  implicates both  $\phi$  and

$\psi$ , which are dual subsets of relations at  $g(R)$ ;  $(X, Z \dots)$  versus  $(Z, X \dots)$  are dual orders of relation at  $g(O)$ ; and the occasion variable  $O$  implicates the value-grain  $g(V)$ .

From the specific evaluation of  $g(R)$  in the context of  $g(B)$ ,  $g(O)$  in the context of  $g(R)$ , and  $g(V)$  in the context of  $g(O)$ , a specific act of perceiving, with a co-implicated effectivity for acting, is not merely potentiated but is actualized. The interdependence of the various grains of analysis is complete: Without bases at  $g(B)$  over which relations might be defined, then no  $g(R)$ ; without relations to be ordered, then no  $g(O)$ ; and without different orders of relations to be evaluated, then no  $g(V)$ . In this way, it is fair to think of a coalition as a structure that carries with it, as an integral part of its conception, all the contexts of constraint on it that can be meaningfully defined.<sup>7</sup> Each coarser grain provides a "ball park" of constraint for the next finer grain, whereas each finer grain provides the evaluation of variables at the next coarser grain. Thus, no regress is possible in either direction.

### The Architectural Capability of Bees

For purposes of illustration, let us consider the beehive within its context of constraints—the honeybee ecosystem. The preservation of the life cycle of a colony of some forty to eighty thousand bees requires exact coordination among the queen, drones, and workers in carrying out their multifarious, intricate activities: The drones fertilize the queen for life, furnishing her with several million sperm cells; the queen lays hundreds of thousands of eggs, fertilizing many of them so as to produce the proper proportion of female workers to male drones; the workers secrete wax, build combs, gather resin (propolis) with which they patch defects in the comb, defend the hive, mummify small intruders with propolis, gather pollen and nectar, produce honey, feed and care for the brood (thirteen hundred meals a day!), clean evacuated cells to receive new larvae, keep the hive warm by fanning their wings, scout for sources of food or new sites to swarm to, dance to inform the other bees of these locations, and then swarm to a new site, where the cycle of life-sustaining work begins all over again.

A complete coalitional account of a honeybee ecosystem should include all such hive activities; however, for our present purposes, it suffices to consider only the architectural behavior of the workers in building combs. It is our intention to show that even such a limited ecosystem activity as comb construction cannot be scientifically explicated at less than all four grains of analysis over which a coalition is defined.

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<sup>7</sup>This is essentially the definition of coalition that we have expressed previously (Turvey & Shaw, 1979; Turvey et al., 1978).

*Details of a Comb's Design.* A comb in a domesticated hive (of the Dadant design) consists of two vertical, back-to-back, parallel sheets of cells, or tessellations, the shapes of each cell being very nearly perfect hexagonal tubes, or prisms, ranging in diameter from 5.2 millimeters for a worker cell to 6.2 millimeters for a drone cell. These tubular hexagonal cells are packed in each sheet in a highly efficient manner, with cells of one row falling neatly between the cells of the rows above and below it—much the same way that hexagonal tiles may be packed to cover a bathroom floor. Furthermore, there is a savings in the wax used in the construction of the comb, because each flat wall of a hexagonal cell is shared by the adjoining cell and has a thickness of around 0.073 millimeter, with a tolerance of no more than 0.002 millimeter in most cases. Moreover, the hexagonal tubes of each opposing sheet are combined inwardly at approximately a 13-degree angle measured downward from the vertical—a slope sufficient to keep the viscous honey liquid from running out until the cell can be capped. An additional savings in wax accrues from the fact that the ends of the cellular tubes in the opposing parallel sheets not only abut but also share adjoining sides: Each end-wall of an opposing cell forms a tetrahedral pyramid consisting of three rhombic plates, each plate forming a common end-wall with a trio of cells in the opposing layer (von Frisch, 1974). Such a tight packing of hexagonal cells has been shown to provide a greater storage capacity than the packing of cells of any other shape.

It has been calculated that it takes approximately 37,000 nectar-gathering flights for a colony to produce just 1 pound of honey (Teale, 1940). However, it takes 5 pounds of honey as nourishment for the bees to secrete the 450,000 wax scales required to produce 1 pound of wax. But from just this 1 pound of wax, the bees can fashion a comb with 35,000 cells that will hold 22 pounds of honey. This means that the top cells of a fully loaded comb must support 1320 times their own weight (Ribbands, 1953).

*How Is This Design Achieved?* There are those, over the years, who have ascribed the design to the intrinsic “intelligence” of the bee. D’Arcy Thompson (1917/1942) tells us how the fourth-century mathematician Pappus of Alexandria remarked on the “geometric forethought” of the bee in selecting hexagonal cells rather than square or triangular cells, which would consume more wax. In the 18th century, Huber (cited in Thompson, 1917/1942, footnote, p. 541) took the manner in which bees fashioned the prismatic shape of the end-walls of the cellular tube, by pulling and pushing the soft wax from opposing sides of the comb, as unmistakable evidence of bee intelligence.

Patently, in the extreme, the latter views exemplify the self-actional approach to scientific explanation. But as we might suppose, the interactional approach has not, over the years, been unrepresented. The 17th-century Danish scholar Erasmus Bartholin was, by Thompson’s (1917/1942) account, among the first to

interpret the comb's design as arising from an appropriate ordering of causal forces. For Bartholin, the shape of the cell was due to the equal application of pressure from *each* bee striving to make circular cells as large as possible.

An approximation to a transactional account can also be noted. If Bartholin was to emphasize bee interactions, D'Arcy Thompson was to underscore the material context in which those interactions take place and by which they are constrained. Thompson drew the parallel between the close packing of soap bubbles and the close packing of hemispherical wax cups manufactured by the bees. In both cases, relatively uniform, spherical bodies contact at their boundaries, and as a general principle, symmetrical tensions of the semifluid films are sufficient to bring the system into an equilibrium state in which potential energy is minimal. That state is one in which surface area is minimal; and surface area is minimal when the closely clustered bodies join at 120-degree angles—in short, when the pattern is hexagonal.

Though terribly elegant, the Thompson account is not without its detractors. Von Frisch (1974), for one, is of the opinion that the hexagonal tessellation does not arise gradually with the increasing tensions and general stresses that accompany the accumulation of cells. Rather, von Frisch (1974) is strongly of the opinion that the hexagonal shape is there *from the very beginning* of the comb. Each cell is constructed from rhomb-shaped modular units starting with the base section. Thus, a phenomenon that Thompson had sought to explain at the relation-grain and Bartholin at the order-grain is returned, by this claim of von Frisch's, to the value-grain. Unfortunately, to relinquish the explanation of an effect to the value-grain is to grant the effect a status sui generis. In the present example, this is tantamount to ascribing the hexagonal shape of the cell to a genetic program. To the question: Why is the comb hexagonally patterned? is given the answer: Because the bee is genetically programmed to build hexagonally shaped cells.

Not surprisingly, we would not consider the latter an acceptable answer. It would be mistaken, however, to assume that our displeasure would be due simply to the fact that a self-actional assumption is involved. The main result of raising an account of a phenomenon to higher grains of analysis is that self-actional assumptions become increasingly attenuated until, by the time the account attains a proper coalitional explication, the degree of reliance on self-actional assumptions, or variables at the value-grain, is no longer scientifically objectionable. (After all, the goal is not to demand that lower grains of analysis be rendered null, but to offer instead a more balanced account that places no disproportionate weight on any grain.)<sup>8</sup>

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<sup>8</sup>This theme is eloquently expressed by Pronko, Ebert, and Greenberg (1966), who promote a style of inquiry in which "all variables share the burden and the organism is freed from its crushing and perplexing job of doing a theoretical solo [p. 77].

One misgiving we have about the von Frisch (1974) claim is that inspection of photographs and scientific illustrations that exhibit combs at various stages of construction suggests that cells befitting the label "hexagonal" do not appear to be available at the earliest stages. Nevertheless, assuming that they were, it is not necessarily the case that this fact enforces the extreme self-actional interpretation. There is a line of reasoning, owing to Darwin (1859/1959), that reduces the weightiness of self-actional assumptions (without eliminating them) by enriching the order-grain of analysis. Darwin (1859/1959) notes that the Mexican bee (which makes a nearly regular comb of cylindrical cells) is intermediate between the bumble bee (which makes very irregular, rounded cells) and the honey- or hive bee (which makes regular hexagons). The thrust of his argument is that only a slight modification in the "not very wonderful [p. 244]" instincts of the Mexican bee—such as turning on a fixed point to hollow out spherelike burrows, laying cells one upon another, standing at a certain distance from her neighbors—would be sufficient to produce a structure "as wonderfully perfect as that of the hive [p. 244]." Darwin's hypothesis is that with regard to comb construction, natural selection selectively tuned the individual action capabilities of the Mexican bee so as to produce the individual action capabilities of the honeybee. In neither case are the action capabilities especially fanciful, but in the latter case, the action capabilities interact to produce hexagonally shaped cells.

Of course, one is wont to ask about the origins of even the crude architectural capabilities of the Mexican bee upon which was forged *ex hypothesis* the honeybee's more stylish development. Origins aside, however, the instinctive capabilities ascribed to the individual bee by Darwin are many steps removed from the conception of a bee-mind containing a complete architectural blueprint of the comb. For Darwin, the exact shape of the cells in the comb derives from the order imposed on the work done by the individual bees.

At all events, the foregoing, though a rough and far from complete overview of theorizing on bee-produced hexagonal patterns, serves to highlight the inadequacy of an account that (1) fixates at a single grain of analysis and (2) fails to appreciate the reciprocity of animal and environment variables at any grain of analysis. Where analysis is at the order-grain, substantial self-actional assumptions must be made to take up the slack. With regard to cone architecture, the self-actional fallacy is not simply that of imparting a motive force to the bee or intentional direction to its behavior, for surely both of these are true. The fallacy inheres to the degree that a theory ignores the valid contribution made by ecosystem constraints that can only be adequately characterized at the higher grains of analysis. A fallacy of like kind inheres in Thompson's approach. Thompson sought an account of cone architecture in terms of a free interplay of forces and mutual interactions among components tending toward equilibrium where the forces and components were almost solely of the bee's *econiche* to the exclusion of the bee. We would say of Thompson's approach that it excludes the bee at the relational-grain of analysis and trivializes the order- and value-grains.

## An Introduction to a Coalitional Analysis of Comb Construction

Let us give a simple sketch of the kinds of questions and the types of resolution that the coalitional style of inquiry would entail. Ideally, this sketch should carry us a little way in the direction of an adequate and satisfactory picture of comb construction; but perhaps the most we should expect of it is that it prepares us for the very much harder things that coalitional inquiry demands.

What are the basic dimensions over which the bee ecosystem is defined? More particularly, what variables are pertinent to the problem of comb construction? A cursory examination reveals five prominent dimensions. (Our "examination" is based in very large part on the details provided by von Frisch, 1974.) Three of these dimensions can be defined simply and precisely. The other two dimensions, however, by their very nature resist concise identification. Nevertheless, they can be intuitively grasped, and if time and space permitted, they could be more properly articulated. Recall that in detailing the basis-grain, the task is to identify covariate dimensions over the animal and environment components of the ecosystem.<sup>9</sup>

Temperature and two forces, gravitational and magnetic, comprise the concisely defined environment-based dimensions. Their covariate animal-based dimensions are proximity to other bees, rotation in the vertical plane, and rotation in the horizontal plane, respectively. Let us elaborate on these three covariate dimensions in turn.

The wax secreted by the worker bee is optimally malleable by legs and mandible at 95 degrees Fahrenheit. Owing to the vagaries of ambient air temperature, the temperature in the hive cannot be expected to remain at the optimal level for wax as a building material. The optimal temperature is preserved by the activity of the bees; at lower ambient air temperatures, the bees are distributed compactly in the hive; at higher temperatures, they cluster more loosely. By varying the manner of their clustering—that is, their proximity to their neighbors—the bees vary the contribution of their body heat to the temperature of the wax. We may suppose that this contribution is "inadvertent" in the sense that the proximity of a bee to its neighbors is probably due to the individual bee moving on a local temperature gradient in response to its individual heat-balance requirements. Importantly, the density of bees in a cluster decreases from the middle outward. There is, in consequence, a temperature gradient or, reciprocally, a gradient in the production and malleability of the wax, so that inner bees, in principle, are able to build more in the same amount of time than their more peripherally located neighbors. Combs exhibit a rate of completion gradient that

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<sup>9</sup>The task of detailing the basis-grain shares much in common with the task of applying dimensional analysis to problems in biology (Günther, 1975; Rosen, 1978; Stahl, 1961). We would expect both the specifics and the spirit of dimensional analysis to be significant to the coalitional style of inquiry.

follows the thermal gradient—inner cells of the comb are completed earlier than more peripheral cells.

Combs are constructed downward—with gravity, rather than against it. Bees orient in the vertical plane with respect to gravity. Curiously, successive combs built by the same bee colony are virtually identical in their horizontal alignment; and their common alignment can be offset by introducing a magnet into a hive in which bees must forge their comb without the benefit of light. Bees orient in the horizontal plane with respect to the earth's magnetic lines of force. (In contemplating the means by which a cluster of thousands of bees work in unison to produce such an intricate architectural structure, much help is provided, as von Frisch [1974] notes, by recognizing the shared orientation of all workers—building downward with gravity and in the magnetic direction of the original comb.)

The dimensions that resist concise identification might be termed chemical and geometric. By the former, we recognize an umbrella label for variables such as concentration, flux, viscosity, energy, and the like as they bear on the materials ingested and excreted and the metabolic processes that mediate them. By the latter, geometric, we recognize the very important fact that *space* precludes very many things and permits very few things, so that *nature* is not free to build any structure it desires in any way it desires (Stevens, 1974; Thom, 1975; Wheeler, 1962). If nature "requires" that the flow of material from a central point traverse the least distance in the most direct fashion, then it has no option but to introduce branching; if nature "wishes" to close pack in order to save space, it must use hexagons. (The significance of hexagonal tessellation for the bee is that the comb contains the maximum volume for storing honey while using the least amount of wax, which in turn requires less honey to be eaten by the workers in order to secrete the required wax; the fewest number of trips to flowers to retrieve nectar; and hence, in general, more honey for the brood to survive on with the least work invested.) If for simplicity (but not for accuracy) we speak of the environmental-based geometric dimensions as structural and the animal-based geometric dimensions as transformational, then we can intuit covariation. Moreover, this manner of speaking gives us a crude way of conceptualizing the geometric dimensions of the basis-grain that is helpful for present purposes: They constrain both the forms that structures can take and the formative processes that can be enacted. Let us focus on dimensions of geometric constraint to illustrate the kind of analysis that the coalitional style of inquiry motivates at the relation-grain.

Recall that the relation-grain  $R = \{\phi, \psi\}$  consists of all possible ecological relations, with the environment  $\phi = \{\langle X, X \rangle, \langle X, Z \rangle\}$  and animal  $\psi = \{\langle Z, Z \rangle, \langle Z, X \rangle\}$  being defined in reference to one another rather than as logically independent systems. The aspects of the ecosystem of the bee that pertain to comb construction consists of all those ways in which the environment  $\phi$  and the animal  $\psi$  mutually constrain one another. A mutual constraint is, by

definition, a bidirectional relationship between two variables that restricts the number of degrees of freedom each might assume to something less than what each might assume if they were unrelated. But in order for constraints to exist between an animal (here, a bee) and some significant aspects of its surroundings (here, flowers, structural supports for combs, and so on), the two systems must be *mutually* compatible; that is, they must reciprocate along shared dimensions. This means they must not only share bases, but they must also be duals of one another. Suppose that one were to assume that bees, working independently of one another, share nothing but an instinctual propinquity to build hexagonal cells; then because of their ability to start building at different sites, under a common support, and to interchange work in the middle of constructing even a single cell, nothing should prevent them from creating a jumble of hexagons. To make such a self-actional thesis plausible, one must assume not only that each bee has a program for building hexagons but also that each must possess the same mental blueprint of the comb-to-be, with constant updating of how far the work has proceeded at each separate locale. This would require either careful, time-consuming, and detailed communication among workers or a strong overseer who sees everything at once and gives simultaneous directions to all personnel. The only plausible self-actional thesis is to assume that each bee has precognition or partakes of a single "mind" of the collective. Is there a more acceptable alternative?

In the long term, a better alternative will follow, we believe, from the assumption that a higher-order set of relations exists between the comb, at various stages of construction, and the anatomy of the bee such that those forms that result do so as a product of ecological constraints—that is, as a product of the ongoing interactions of the bee-collective with certain specific global chemical, thermal, geometrical (and the like) relations that either exist throughout, or gradually unfold during, the dynamic process of comb construction.

Traditionally, dynamics has been concerned with systems that are linear and conservative and, thus, with functions that are continuous. The newer dynamics (Glandsdorff & Prigogine, 1971; Prigogine, 1978), largely inspired by biology, is concerned with systems that are nonlinear, nonconservative, and, thus, with functions that are discontinuous. For nonlinear systems displaced far from equilibrium, fluctuation plays a central role. Fluctuations force the system to leave a given macroscopic state and lead it to a new state that has a different spatiotemporal structure. Prigogine (1976) gives a brief but illuminating application of the theory of "dissipative structures" to the construction of a termite nest. Nest building is initially uncoordinated and characterized by a random depositing of building material. In manipulating the construction material, the termites mix in a chemical attractor that diffuses over time, giving rise to a "scent" gradient. Equations can be written that express the relations among the concentration of insects carrying material, the density of the building material, and the density of the chemical attractor. Where the density of material in each location is low, the

said equation has a stable solution—a uniform distribution of the termites over the region on which they are depositing material. However, when the uncoordinated activity of the termites raises the density of deposited material in a location or number of locations above a particular value, the uniform distribution ceases to be a stable solution. The new stable solution is one in which the termites cluster about the locations of higher density. At these locations, the termites deposit more material, and if two such locations are close, an arch will form; on the other hand, if a location of high density is relatively isolated, then merely a pillar or wall will be formed. In brief, a new spatial structure arises from the dynamics of nest building—or, as Prigogine would express it, order arises from fluctuations. The immediately following shares the spirit but not the details of Prigogine's analysis. It is a first pass at identifying a geometric relation in the bee-ecosystem from which hexagonal tessellation might arise.

1. It can be shown that three-dimensional tessellations of cylindrical cells can be readily transformed into a tessellation of hexagonal prisms by any process that simply removes the excess material between cell walls so that the walls are thinned uniformly. Of course, the walls between cells may be made as thin as the material will allow under prevailing conditions of heat and stress (e.g., wax will allow walls of only 0.073 millimeters thickness, which will support 1320 times its own weight).

2. Bees have been observed to gnaw away excess wax to make curved walls more rectilinear.

3. In order to gnaw down the walls shared by any two cylindrical cells to a minimal thickness, the bee must insert its head into the cell at an angle that will bring its mandibles into contact with the plane of the wall. This means that the main axis of the bee's body must fall on a line that is roughly the perpendicular bisector of the wall section shared by the two cells. (Typically, the opposite side of the wall is being gnawed in a similar manner at the same time by a co-worker.) Moreover, given the size of the worker bee's head, it is impossible for the bee to rotate its mandibles while in the hole of the cell by an angle of less than approximately 120 degrees (i.e., the interior angles of a hexagon).

The preceding constraints are sufficient to guarantee that the bee will ultimately produce combs whose cells are hexagonal prisms to the extent that, at some early stage of construction, the cells assume a cylindrical shape. Let us now try to give a more precise characterization of the geometric constraints that are implicit in the foregoing assumptions and that—for this limited analysis—guarantee closure of the comb construction activity of a bee-ecosystem at the relation-grain.

It is convenient to use what is known as Schläfli notation to represent regular tessellations (Coxeter, 1961). Let  $\{p, q\}$  stand for the tessellation of regular  $p$ -sided polygons with  $q$  of them surrounding each vertex. In this notation, the

symbol for a honeycomb is clearly  $\{6, 3\}$  (see Fig. 11.2). The *dual* of a  $\{p, q\}$  tessellation is that tessellation whose edges are perpendicular bisectors of the edges of  $\{p, q\}$  and that has the Schläfli symbol  $\{q, p\}$ . Thus the dual of the hexagonal comb  $\{6, 3\}$  is a tessellation  $\{3, 6\}$  consisting of a packing of triangles ( $p = 3$ ) in the plane such that exactly six ( $q = 6$ ) meet at any given vertex. (For convenience, the dual tessellations  $\{6, 3\} \diamond \{3, 6\}$  are reproduced in Fig. 11.2 by superimposition.)

The importance of this duality is that it provides a means for explicating the relationship between the bee's activities in producing and reshaping cell walls and the total shape of the honeycombed tessellation that is finally created. Let us assume that the alignment of the bee's body that permits the mandibles to come into play falls on the perpendicular bisectors of the line separating the wall of adjoining cells into two equal halves. The gnawing of the bee that thins the wall to its minimal thickness, or that builds it in the first place, conserves wax to the extent that the cell wall approaches his imaginary line. As the wall does so, it approaches rectilinearity and thereby becomes a shared wall with an adjoining, incipient hexagonal cell. The lines of alignment, noted in Fig. 11.2 as broken lines, constitute a  $\{3, 6\}$ , whereas the comb pattern that results is its dual, a  $\{6, 3\}$ .

We represent this state of affairs at the relation-grain as follows:

$$\phi = \{ \langle c, t \rangle, \langle t, b \rangle \} \text{ and } \psi = \{ \langle b, h \rangle, \langle h, c \rangle \} \text{ for}$$

$c$  = cylindrical walls

$t$  =  $\{3, 6\}$  axes of alignment for bee's body

$b$  = bees

$h$  =  $\{6, 3\}$  tessellation of hexagonal cells

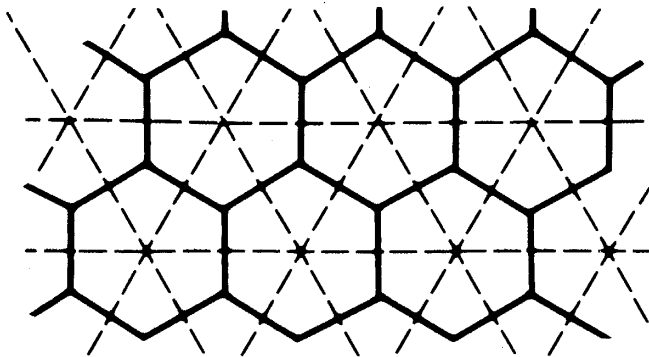


FIG. 11.2. The hexagonal tessellation is a  $\{6, 3\}$ , whereas the triangular tessellation is its dual, a  $\{3, 6\}$ .

That is,  $\phi$  equals the environmental constraints consisting of cylindrical walls to be gnawed by bees and the perpendicular bisectors of the walls that constitute the axes of alignment along which the bees must orient their bodies; and  $\psi$  equals the bee's behavior of gnawing the cylindrical walls of the cells and the hexagons that that behavior produces.<sup>10</sup> The following dualities hold to guarantee closure of the comb production activity of the bee-ecosystem:

$$(1) c' = b \text{ and } b' = c, (2) t' = h \text{ and } h' = t.$$

The duality  $c \diamond b$  holds in the sense that the cylindrical walls are the object acted upon (gnawed) and the bee is the actor, whereas the duality  $t \diamond h = \{3, 6\} \{6, 3\}$  holds for reasons already given. The test of closure is given as follows:

$$\begin{aligned} \phi &= \{ \langle c, t \rangle, \langle t, b \rangle \}' = \{ \langle c, t \rangle', \langle t, b \rangle' \} = \{ \langle c', t' \rangle, \langle t', b' \rangle \} \\ &= \{ \langle b, h \rangle, \langle h, c \rangle \} = \psi. \end{aligned}$$

To articulate the duality schemata of the order-grain will require resolution to such problems as determining the nature of the perceptual information that allows bees to distribute themselves at the appropriate relative distances over the comb work-space; the perceptual information by which they determine exactly how much to excavate in wax foundations for cells; the perceptual information for exactly how high to construct a cell wall before moving on to another site, and so forth.

There is, however, one piece of information reported by von Frisch (1974) that sheds light on the very important perceptual process that guides the bee in determining how thin a wall might be gnawed. Von Frisch (1974) suggests that bees gauge the thickness of a wall by pressing their mandibles against the wall so as to produce a mechanical deflection. Upon removing its mandibles, the bee senses the degree of deflection and recovery through sensitive cells in its antennae. Under the prevailing conditions of consistency of wax and temperature, there is sufficient invariant information for walls of constant thickness to be produced. It is just such a reciprocal coordination of action (deflecting the wall) and perception (measuring its recovery) in the midst of dynamic, ongoing behavior that precludes the need for radical self-actional constructs. One might reasonably assume that the degree of mechanical deflection afforded by the wall is peculiar to the mass and biokinematic links of the bee's anatomy. The antennae might register no more than a simple "stop" or "go" signal for gnawing or, alternatively and perhaps more rarely, for depositing more wax. *The bee's body would*

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<sup>10</sup>Implicit in this analysis is an appreciation of the dynamical nature of ecosystems: What is a Z term in an earlier phase is an X term at a later phase. Thus, in the present illustration, the hexagonal cell is a Z term; it is bee-referential in comparison to the cylindrical cell from which it arises in the same sense that wax is bee-referential in comparison to the nectar from which it is produced. At an even later phase of the ecosystem, where our concern might be the honey-storing activity of the bees, the hexagonal cell would assume the status of an X term.

*itself be the standard for measurement as well as the means for creating the deflection to be measured.* Hence no ‘‘mental’’ copy of the perceptual standard or the actional means need be stored as an ‘‘instinctual’’ program. This account exploits perceptual information and action goals as duals and shows how environmental properties may be defined in reference to body or action coordinates of the agent.

And finally, with respect to the value-grain, we should expect the particular features and specific dimensions of combs to be determined by a convergence of constraint from the other three grains plus adventitious aspects of the materials and site layout encountered. Notice, in particular, that the value-grain under a complete coalitional analysis would not be trivialized, but it would, nevertheless, be excised of *deus ex machina*.

### Coalitions: A Step Beyond Transactional Structures

To end this section of the chapter, we underscore why it is that coalitions are more than transactional. The concept of the transactional is a Third, a law or rule, that relates Seconds or interactions. Interactions, the reader will recall, are defined as relations among Firsts. But what are Firsts? Consider the example of the giving of gifts. In this example, the giver, the receiver, and the gift are all Firsts. A giver or receiver is necessarily a person; a person, however, is able to do many things other than just give or receive and, therefore, is a complex effectivity structure. In order to specify just those aspects of a person involved in giving or receiving, then certain effectivities must be selected and others ignored. Thus, as explained earlier, the value-grain,  $g(V)$ , must be invoked when members of a set are selected, or activated, ignored, or left quiescent. A gift is only an object *qua* object at this grain and can not be ascribed as a role in the gift function.

Similar analysis must be carried out at the grain of order  $g(O)$  where perceptions (of the gift) and actions (realization of the intent to give it) are defined. This is the grain where the displacing of the object (the gift) from one person to another involves an interaction that is an ordered relation (i.e., X gives and Y receives). But the legal aspects of this gift-giving activity, as a voluntary transaction among responsible parties, require additional analysis at the grain of relation  $g(R)$ , for it is here that the lawful aspects and significant meaning of the transaction are revealed. For instance, one’s ability to give gifts is a social effectivity just as the affordance of an object to be a gift requires a social context (e.g., customs, laws, and so forth) of interpretation. In other words, the effectivity pertaining to the giving or receiving of gifts, like the affordance value legitimately ascribed to objects that qualify as gifts, exists not by virtue of the physical interaction alone but also by virtue of the cultural constraints (e.g., laws and customs) that define the social transaction. This requires analysis at the relation-

grain  $g(R)$ , where laws as Thirds can be defined. For these reasons, we see that a transactional analysis ranges over three grains: Firsts are specified at the value-grain (e.g., givers, receivers, gifts as objects); the interactions of Firsts as Seconds are specified at the order-grain (e.g., the activity of giving objects); the laws that constrain and interpret Seconds are Thirds (e.g., laws governing gift giving) and must be specified at the relation-grain. But Thirds or transactions as invoked by Peirce or Dewey and Bentley, respectively, cover only three of the four possible grains of analysis. What of the remaining grain, the basis-grain; what role does it play?

As we have argued, transactions, like interactions, may lead to a regress unless constrained by some higher context. This can be seen in the foregoing example with respect to the social relativity of gift laws: What counts as a binding transaction between people is dependent on the legal basis of the society to which they belong. Consequently, the abstract ground of the analogy holding among instances of gift giving across distinct societies can not reside at the transactional alone but must be defined at a higher, more inclusive level. What is required for a valid comparison to be made over different legal bases is a grain of analysis at which the commensurability of gift giving in different societies is defined. That such an analysis is possible presupposes the existence of minimal mutual compatibilities, or dualities. The concept of dual bases, or basis-grain, is that which constrains the transactional (relation-) grain. But if the transactional is a Third because it constrains an interaction, a Second, then the basis-grain—or what we shall call the coalitional—because it constrains a Third can be properly deemed a Fourth—a concept that transcends anything explicitly introduced by Peirce or Dewey and Bentley. In summary, let us sharpen the analogy between the foregoing example and perception. The analogy is straightforward: Perceiving logically corresponds to the act of giftgiving at the order-grain, whereas the ecosystem, or grain of ecological law, corresponds to the social law of gift giving at the relation-grain. The comparison of perceptual activities of different species depends on the existence of an abstract analogue over the distinct but commensurate (dual) bases of diverse ecosystems to which each species belongs. This of course must proceed at the basis-grain, as do comparisons of gift laws over different societies.

In sum, we have argued that the designated effect of a perceptual mechanism to establish a reciprocal isomorphism, or duality, between animal and environment is a relation that must be considered a Fourth to be coalitional, rather than a Third—transactional. Also we have argued that by treating perception as an activity of an ecosystem (a coalition), all regresses are avoided, and yet sufficient grains of analyses are defined to permit incorporation of all the defensible aspects of interactional and self-actional principles. In the final section of the chapter, we return to consider the contribution of Gestalt psychology in the light of these results.

THE FAILURE OF THE GESTALTIST VIEW  
OF PERCEPTUAL ORGANIZATION

The Gestaltists' formula for perception was predicated on the proposition that distal objects look as they look because the perceptual experience is isomorphic to the field organization of the brain to which the proximal stimulus gives rise. Two factors are supposedly at work here—first, an interactional component by which the distal object interacts with the brain field vis à vis the proximal stimulus; and second, the self-actional component consisting of the autochthonous forces by which the percept is finally organized. Hence the Gestaltist theory offers no new principle of perceptual organization beyond that based on Firsts (self-actional) and Seconds (interactional). Because their view is merely interactional, the laws of perceptual organization that might otherwise have been truly transactional, as Bentley warned, necessarily must be construed as self-actional in order to account for the sources of variability not explicable in terms of interaction with the distal stimulus alone. In other words, the degrees of freedom for explaining perceptual phenomena are greater than the degrees of constraint offered by interactive principles; hence, to take up the slack in their theory, the Gestaltists were forced to postulate a power of “things solus,” the self-acting biotonic forces.

Most theorists, however, have found such an explanation unrevealing and treat the so-called laws of Gestalt psychology as merely descriptive principles that summarize a common set of experiences over a widely diverse class of perceptual displays. Moreover, we can now recognize in Gestalt theory the reification of a relational term and the consequent endorsement of a rather crass semantic triad consisting of the distal stimulus, the experience of the proximal stimulus, and the laws of psychoneural isomorphism—a reification of a complex set of relationships.

The irony of it all is that the Gestaltists who admonished others to be more molar than molecular in explanations were themselves apparently guilty of not being sufficiently molar. Had they understood Peirce's thesis—namely, that a Third is something that brings Firsts (the distal object; the proximal stimulus) into relation to a Second (the brain-field organization)—then they would not have mistakenly interpreted the brain-field forces as being self-actional; rather, they would have looked beyond the brain-field organization to a broader context of constraint lying beyond the perceiver. And, of course, what lies beyond the perceiver as a self-organizational entity is the transactions the perceiver-as-actor has with its environment.

Lest it be claimed that the Gestaltists did indeed mean to interpret the laws of organization as a Third and hence as transactional, consider the following quote from one of their chief spokesmen, Wolfgang Köhler (1958a):

Organization ought not to be interpreted as a mere formation of agglomerates [of Firsts]. In the first place, the characteristics of things are generally affected by their inclusion in larger organizations. In other words, organization involves *interaction*. Such interaction seems to explain colour and brightness contrast, most so-called optical illusions and also, several perceptual constancies. . . . According to the Gestalt psychologists, this constancy of object colour is brought about by *interaction* between the object and its brain-field environment. They claim that, under the circumstances given a case of constancy, this *interaction* operates against the effects of changed local stimulation, and thus exerts a compensating influence [p. 715] [authors' emphases and additions].

There can be little doubt from this authoritative text that the Gestaltists, perhaps unwittingly, were theoretically fixated in their language of descriptors for perception at the grain of interaction (what we called g(O) earlier).

However, to be fair, there is another aspect of Gestalt theory that recognizes the role of contexts of constraint on the interactions that take place within the field of cerebral forces and that must be invoked to explain contrast and constancy effects. There are also those structural properties, called variously Gestalt or Ehrenfel's qualities, that are produced by the dynamic constraints resident in the whole field and that act upon the phenomenal products of perceptual experience. Köhler (1958a) explains it this way in contrast to the first point made in the preceding quote: "In the second place, organization gives its products characteristics of their own, such as Ehrenfel's qualities. . . . Thus, a certain point in an object is a corner only within this larger unit, a line is a boundary only with reference to a segregated area, etc. [p. 715]."

Clearly, they do mean to propose some kind of context of constraints to help explain the perceived structure of objects. However, the shortcomings of their proposal do not lie in their inability to see the *need* for context effects but in their unflinching loyalty to an interactive interpretation of how contexts produce their constraining effects. The somewhat surprising point to be emphasized in this regard, given their otherwise high degree of sophistication in theory construction, is that the Gestalt program of inquiry failed primarily because of its failure to grasp the fundamental notion of context.

For Gestalt psychologists, at least those of them who agreed with Köhler, the principles of organization were the dynamic field properties of the electrical brain potentials. Most contemporary psychologists are willing to recognize such properties as a necessary but insufficient part of the causal nexus of support for perceptual experience but are not willing to impute to such field properties total responsibility as the efficient cause of organization. This amounts to an attempt to explain perception from below rather than from above, because causal support for a phenomenon is a finer grain of analysis than the context that constrains it. In terms of our earlier analysis, it is an attempt to reduce the order-grain g(O)

(interactions) to the properties selected at the value-grain  $g(V)$  (specific causal chains) and ignores the true context of constraints on interactions that are provided from above by the relation-grain  $g(R)$  and the basis-grain  $g(B)$ .

The truth of the matter is that the Gestalt theory, at least as interpreted by Köhler, was fundamentally inconsistent in the use of the concept of organization by which perceptual phenomena might be explained. On some occasions, it is argued that the essence of the Gestalt approach is an analysis "from the top" as opposed to the elementarism of the associationists that proceeded "from the bottom" (Köhler, 1958a).

In contrast, on other occasions, it was argued that the properties of perception were, if you will, induced from the dynamic relations of the supporting medium, the psychoneural basis, that in their own words was itself an "underlying process" (Köhler, 1958a). The Gestalt principle of isomorphism clearly shows that all perceptual organization was coordinate with this underlying causal nexus of relations that support, and from which structural properties are induced onto, the phenomenal field of experience.

To summarize: The Gestaltists' program went astray because, surprisingly, they confused the concept of context of constraint (which by definition must act from above) with the concept of causal support (which by definition must act from below); they confused a Third for a Second, a transaction for an interaction, and hence had to fall even further back to reliance on Firsts, self-actional un-analyzable "laws." This is clearly a reductionistic attempt to explain perception at a finer grain of analysis than can be adequate.

Perhaps they did this in order to avoid what they correctly saw was the ever-present danger of molar approaches to regress to ever-coarser grains of analysis. If so, we now see that like nearly every one of their predecessors, Gestalt theorists fall into a conservative stance of dualism in theorizing that attempts to avoid the dreaded regress by spuriously isolating the animal-as-perceiver from the environment on which the animal acts. But is there anything positive to be gained for future endeavors from this critical examination of Gestalt theory?

Indeed, the ecological approach can be viewed as an attempt to salvage to some extent this *one* aspect of the Gestalt program—namely, the notion that the properties of perceptual experience are not to be explained "from the bottom" alone, nor even "from the top" alone, but must be explained *simultaneously* at all grains of analysis. The four grains proposed should be considered to be a closed set of perspectives on the same underlying reality, rather than as different *levels* of analysis that are somehow in competition. All four grains, no fewer nor less, must be invoked in order to obtain an explanation of perception that avoids incompleteness or regress. This is the essence of the coalition style of inquiry.

In closing, let us venture to speculate where the coalitional or ecological style of inquiry might lead. To see these prospects most clearly, a brief recounting of

the positive features of the ecological program that arose in contrast to the Gestalt program will prove helpful. In spite of our criticism, it should be emphasized that we feel that the Gestalt program may yet prove to have made an important contribution to scientific theory in psychology—that of suggesting a cure to the ills that have plagued perceptual psychology for over 2 millennia. It is with this belief and in great respect that the following concluding remarks were framed.

### The Lesson to Be Learned From Gestalt Psychology

The fundamental insight upon which the ecological approach rests was offered by J. J. Gibson (1966): The language of description required for the object perceived should and can be the same language of description required for the perceptual experience (see Fowler & Turvey, in press). By contrast, the Gestalt program set up incompatible descriptors for the distal object and the proximal object of experience. This makes the avoidance of phenomenalism impossible. The ecological style of inquiry, because of its commitment to realism and rejection of phenomenalism, seeks a language of descriptors that treats the object of experience and the object of reference at the same grain or, better, grains. The treating of perception in terms of the duality structure outlined earlier offers the formal means for fulfilling this criterion.

The ecological approach, as most other approaches, nevertheless agrees with the fundamental Gestaltist claim that some kind of isomorphism exists between whatever is perceived and the perceptual experience. The two approaches differ radically, however, with respect to what counts as the object of experience: For the Gestaltist perceptual experience is isomorphic with the brain field, making the Gestalt theory a form of indirect realism with no clear way of avoiding phenomenalism and its entailed dualism; for the ecological theorist, the experience is of the functionally specified environment itself (not to be confused with the world as defined by conventional physics)—an affordance structure.

Because many contemporary theorists would still prefer the Gestaltist indirect view to the epistemically more direct ecological view, let us reiterate briefly where the two views may lead with respect to a broader perspective on scientific inquiry.

Even if a psychoneural isomorphism as proposed by the Gestaltists did exist, the organization of the field of brain events would require explanation in terms of a context of constraints that transcends an interactional account; otherwise, self-actional elements analogous to Gestalt “laws” would have to be invoked—such self-actional entities as homunculi, executors, egos, “unconscious” inferences, “self-reading representations,” and so on, as were noted as already being in the current literature. These views, to be harshly candid, are no more than species of scientific animism and hold no real interest as sources of scientific explanation for perceptual mechanism for reasons given earlier.

Consequently, even if we admit to some form of brain–experience isomorphism, this is no theory of perceptual mechanism until some explanation is given for the origin of the interactional properties registered on the brain that convey pragmatic information about the environment to the agent who owns the brain. But to what broader context of constraints might appeal be made to explain the ultimate origin of animal–environment isomorphism?

We have already seen that such an appeal can not be simply “causal,” as causal interaction in no way can be identified with informational transactions. Similarly, we have also seen that no rational appeal can be made to evolutionary adaptation, because that same intractable nonspecificity that holds for visual perception must hold likewise for all other perceptual processes as well. If one is inadequate to evolve powers of induction to elaborate inadequate information available from the world, then so are they all equally inadequate. This line of reasoning, therefore, was found to lead ultimately to the *reductio ad absurdum* of the interactional mode of inquiry—namely, that the cerebral system must receive the content and organization from somewhere other than causal interaction. If the causal is the most molar context of constraint, then self-actional entities must be invoked. But by what means, if not interactional, could such self-actional entities have evolved? Such self-organizing principles must be part of the design of the perceptual mechanism but could not have evolved by adaptive means.

Thus, the causal process approach (interactional) leaves the fundamental nature of perceptual mechanism a mystery to be puzzled over, perhaps by speculative metaphysics but in an area quite beyond the purview of science. Clearly, a view that treats the isomorphism of animal experiences with the objects of experience as a miraculous happenstance in the evolutionary design of the central nervous system—one that just happens to coincide with the pragmatic goals of the species in its struggle to sustain life and maintain health—is no theory at all.

The alternative program of inquiry offered by ecological psychology as a legitimate extension of the pragmatist’s program avoids the premature closing of the context of constraints at an interactional grain of analysis. Such a program renders unnecessary the postulation of self-actional entities, or magical contrivances by evolution, to explain the reciprocal isomorphism that naturally exists between the logically distinct but interdependent components of the ecosystem.

The ecological approach, by defining the environment in reference to the animal and the animal in reference to the environment, avoids the troublesome and unnecessary semantic independence of a phenomenal, or behavioral, environment from a geographical environment and, hence, of perceptual experience of an object from the object experienced. It is this spurious semantic independence that renders the interactional approach a source of mystery rather than enlightenment, for there is no way that two semantically independent realms could have coevolved so as to achieve the coordination required to define the reciprocal isomorphism demanded for perceptual knowledge.

The question of the origin of perceptual mechanism, when construed from the standpoint of ecological theory, can be dealt with as a problem rather than a mystery. *The problem framed under an ecological mode of inquiry is not how the animal's biological system evolved so as to explain the organizational properties of perceptual mechanism, but how the affordances and effectivities that define an ecosystem coevolved.* A study of affordances naturally entails the study of effectivities and vice versa for they are dually specified aspects of the same ecosystem: Put even more simply, the evolutionary question for an ecological theory of perceptual mechanism is not *how* the necessary biological support evolved but *what kind* of ecosystem evolved, because it is here that all four grains of analysis are to be found that provide an adequate explanation of perceptual mechanism. In other words, evolution of perceptual mechanism is to be understood as the constrained development of the ecosystem to which it belongs as a dual aspect—the action mechanism being its other coevolved partner.

But what of the still broader context of physical constraints in which ecosystems evolve? Before there were animals, there were necessarily no environments and vice versa, for these are functionally defined terms that co-implicate one another. Environments and animals coevolved, so that there was either no time in cosmological history when ecosystems did not exist, or they must have somehow emerged from a more primitive physical world. Whatever causal support might eventually have been required for explaining how ecosystems arose or how they function (e.g., support perceiving, acting, remembering, and so on) must reside in the descriptors for a primordial physical world. Does this mean, then, that ultimately even the ecological approach must regress to a more general, more primitive context of constraints? And, more pessimistically, does this mean that because all the grains of analysis available are specified within the ecological coalition, the regress to an all-embracing physical context takes us beyond the purview of the ecological style of inquiry?

These are serious questions and can not be lightly dismissed. Therefore, the final issue that must be addressed is the relationship of the physical world to the ecosystems that exist within its context of constraints.

### Ecological Psychology and "Ecological" Physics

The relation existing between the physical world and an ecosystem is most probably a duality of an open set of constraints (termed the universal set earlier) with a relatively closed system (the ecosystem) that can be biased by the former, may even causally interact with it, but transacts no epistemic business with it.

The further speculative question regarding what, if anything, lies behind the scientific description of reality is an open question and can not be addressed by current scientific principles. Scientific views of cosmological development are limited by the singularity from which all matter was promulgated by the "big bang." Similarly, current attempts to grapple with the universe around us are

limited by the fact that "black holes," also singularities, can not be peered into or through so as to discover what, if anything, might be on the "other side." The unanalyzability of such opaque windows to whatever might lie behind the impenetrable wall of mystery surrounding current conceptions of physical reality, a wall assured of its existence by modern physical theory itself, makes it less than reasonable to predicate the future of ecological style of inquiry on the physical style of inquiry. But is there any pragmatic alternative to this metaphysical impasse?

What the existence of these barriers to physical inquiry implicate is an open set of possibilities for ecological science. As the current language of descriptors for physical science changed dramatically in the passage from the Newtonian conception of the world to the Einsteinian conception, and from the view of Laplace to that of Heisenberg, so did our view of the nature of the physical constraints that shaped ecosystems. Science progressed from a view of an observer-free description of nature to an observer-dependent one. Contemporary physical conceptions of events in nature—as Wigner (1970), Wheeler (1974), von Neumann (1966), Schrödinger (1962), and Trimble (1977), among others, point out—co-implicate psychological variables in such a way as to render the equations of physics virtually uninterpretable without them (Shaw & McIntyre, 1974).

Hence the pragmatic rule that seems on the verge of emerging is that there can be no absolute physical conception of nature but only a total ecology for physics that includes the physicist as both perceiver and actor in the experiments run or the observations made. A direct consequence of a change in our conception of the psychological variables implicated in physics would necessarily alter our conceptions of physical reality. Does this tight fit of physics and psychology arise from the coalitional structure of nature? Perhaps there exists a duality between physical theory and ecological theory, a complementation of the physical world as the "environment" with those ecosystems as coarse-grained "organisms" surrounded by it. If so, we should look for this duality at the basis-grain—a grain only partially exploited by the ecological approach to terrestrial systems.

Just as a change in our *Weltanschauung* in psychology was precipitated by Darwin's providing biology with an evolutionary language of description, so might a change in the physicists' *Weltanschauung* be wrought by a successful theory of the evolution of psychological ecosystems. We see this possibility very clearly in the argument offered by the noted physicist Wheeler (1974)—that the fact of the existence of conscious, intelligent forms of life in nature logically (although not teleologically) preconditions our rational reconstruction of the conditions for the cosmological evolution of matter: Whatever primordial properties of matter-energy existed just prior to the "big bang," they must be conceived of as accommodating the ultimate outcome for intelligent life (see Turvey & Shaw, 1979).

Similarly, we see this need to accommodate psychological descriptors in the field of computer science, where physical devices are seriously described in terms borrowed directly from contemporary psychology—terms such as *memory*, *problem solving*, *pattern recognition*, *decision making*. Moreover, to the extent that robots, cyborgs, and bionic mechanisms in the future achieve a wedding of the psychology of natural systems to a psychology of artificial ones, to that extent will physics be forced to accommodate directly psychological descriptors without cushioning the blow by a layer of biological descriptors.

Therefore, it is not unreasonable to suppose that in the years to come, there should arise a scientific ecology that encompasses the science of the living and the nonliving, on one hand, and the intelligent and nonintelligent on the other (where perception and action are included among intelligent functions of matter). Psychologists no longer have the luxury of merely sitting back and letting the physicists and biologists work on the fundamental grains of analysis at which ultimate constraints on ecosystems emerge. Rather, the time may well be upon us when the language of description we develop as psychologists provides constraints on the doing of physics and biology. Thus, we seem to be at that point sometimes referred to as the “mind-matter meld” or, better, we think, the animal-world synergy.

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