PERSPECTIVES ON MEMORY RESEARCH:

Essays in Honor of Uppsala University's 500th Anniversary

EDITED BY

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9 The Primacy of Perceiving: An Ecological Reformulation of Perception for Understanding Memory

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INTRODUCTION

In what way do perception and memory relate? Self-evidently, an answer to this question depends a good deal on how the two terms in the sought-after relation are construed. It is equally self-evident that the two terms, *perception* and *memory*, are so intimately bound that given a definition of one, the interpretation of the other is necessarily constrained.

We present an overview of kernel themes that collectively provide the contemporary orientation to perception. These themes have at their source, or so we claim, an overarching dualism that conceives of the animal and its environment as logically independent. This collection of themes is the perceptual theorist's legacy of (at least) the last 500 years; and given the interdependence of the conceptions of perception and memory, it follows that the understanding of perception induced by this legacy conditions our understanding of memory in the large, and not just its relation to perception. It is our major intent to contrast the traditional themes with themes of a radically different kind that have as their base animal-environment synergy (or reciprocity). Collectively, these themes identify what might be called an ecological orientation to perception. Viewed ecologically, perception takes an unconventional form: It appears to be a property of the ecosystem rather than of the animal as such; its laws seem to require a three-term logic for their expression; and it does not appear to be propositional and mediated—to the contrary, perception is nonpropositional and direct. The ecological reformulation of perception offers a new framework in which to pursue the puzzle of memory.

In keeping with the charge of this conference, we propose that the contrast between animal-environment dualism and animal-environment synergy is that between two departure points—one that has determined the direction of thought on matters of perception and memory for the past five centuries (or more) and one that might provide a new direction of thought on these matters for the future.

THE LEGACY OF THE PAST FIVE CENTURIES

Animal-Environment Dualism

The dualism with which we are most familiar is that drawn by Descartes between mind and body. The hegemony of this separation in philosophy, psychology, and physiology needs no comment. Nevertheless, a case can be made for an even more pervasive and influential dualism of which the Cartesian kind is merely one of several significant manifestations. This overarching dualism is that drawn between the animal and the environment: The animal, as perceiver and as actor, is construed as logically independent of the environment, which it perceives, with respect to which it acts, and together with which it evolved. What is denied is the organizational wholeness of the animal-environment system (cf. Fitch & Turvey, 1978; Lombardo, 1973).

A primary consequence of animal-environment dualism has been the promotion of the animal as the proper unit of analysis for psychology. In its ideal form (cf. Lombardo, 1973), the focus of this methodology is strictly on entities whose locus is either obviously the animal or deemed to be the animal as a matter of convention. In reference to perception, consider the three varieties of psychology in the past half-millennium: physiological, mentalistic, and behavioristic. The brain most obviously is in the animal and so, it necessarily follows, must be the brain's constituents. The mind is less obviously *in* the animal, but it has become a matter of convention to speak as if it were and to regard its constituents—the mental processes—as bounded by the skin. Behavior, though not in the animal as such, is often localized in the animal in the form of surrogate, mediating responses. Whether the analysis be in terms of physiology, mentalism, or behaviorism, questions of perception are read as questions of what the requisite animal-localized entities are and how they relate.

We see, in short, that the ideal methodology has been to examine the perceiver as distinct from the environment—a methodology that is consonant with the following two subthemes. First, it is popular to identify the percept as the terminus of a unidirectional causal chain that begins in the world. In this conventional view, the perceiver and world, the animal and its environment, are causally separate. The causal theory of perception (Russell, 1927) suggests that the *proximal cause* for perceptual experience is not the environment as such but one of the links in the cause-and-effect chain that connects the perceiver to his or her surroundings. In short, and this is the second subtheme, "knowledge by acquaintance" is interpreted not as knowledge of something happening in the environment but as knowledge of something happening *inside* the animal. The animal does not perceive the environment as such, but rather an animal-analogue (more familiarly, a homunculus) perceives a representation of the environment.

If an animal and its environment are logically independent, then one is encouraged to speak about certain epistemic entities as being proprietary to the animal or to the environment and to liken the animal-environment relation to an economic transaction. The problem of the ascription of meaning is commonly pursued in the context of an economic metaphor. The conventional practice is to hold distinct what some environmental arrangement *is* and what that environmental arrangement *means*. The former is said to be in the physical or in the environmental domain and the latter in the mental or in the animal domain. Thus follows the view that neural, or mental, or mediating response processes give meaning to meaningless sense data or, more generally, that the animal gives meaning to the environment. The economics of the situation is that the environment supplies the signs and the animal supplies the significances.

There are many more manifestations of the animal-environment dualism—some of which are fleshed out in the remarks that follow. For the present it would be valuable to shore up the claim that mentalism and behaviorism *both* adhere to the methodological ideal fostered by the dualism. Behaviorism would seem to lay great store by the environment; at least behaviorism's explanations of psychological phenomena are environmentally tinged to the degree that mentalism's explanations are not. Moreoever, logical (Ryle, 1949), methodological and radical behaviorism (cf. Skinner, 1974) reject mind-body dualism; whereas by and large, the various forms of mentalistic psychology have, over the ages, courted Descartes's separation. Indeed, the commonplace understanding is that mentalism and behaviorism are mutually exclusive; and we should argue in consequence that if mentalism endorses the methodological ideal of animal-environment dualism, then behaviorism most surely cannot. A brief deliberation, focused on the concept of environment, is sufficient to disarm such arguments and to lead us to the important conclusion that theories that distinguish on the issue of mind-body dualism may be indistinguishable on the issue of animal-environment dualism—a conclusion that points to the latter dualism's overarching status.

The term *environmentalism* is not uncommon in behavioristic psychology. It is a synonym for past experience with the environment and is meant to do explanatory duty similar to, but distinguishable from, nativistic abilities on one hand and mental processes on the other. But just as appeals to innate capabilities as explanatory principles are often gratuitous, with the nature of the capabilities left largely unanalyzed, so are appeals to environmentalism.

The term *environment* is used interchangeably with the terms *stimuli* and *reinforcement contingencies*. One interpretation of this commutativity of terms is that the environment is an independent variable in relation to the dependent variable that is the animal's behavior. This unidirectional relation is reminiscent of the causal chain theory of perception, and it is congruent with the methodology of animal–environment dualism. A further interpretation of the commutativity of *environment* with *stimuli* and *reinforcement contingencies* is that the environment is conceived of in a very general sense. Let us explain.

Contemporary behaviorism shares with its intellectual predecessors the beliefs that learning is a general capability and that the laws of learning will hold uniformly across all species. It is the case, however, that each species occupies a different niche where species and niche are defined relative to each other. In brief (and anticipating a larger point of this paper), environments are specific to species, and learning as a facultative adaptation (Williams, 1966) ought to be specific to environments. We may well suppose, therefore, that learning is not a general process differing only quantitatively from one species to another; rather, it is a special ability that differs *qualitatively* from species to species, paralleling the qualitative differences in their environments.

There is no recognition of the fundamental species-specific aspect of the concept of environment in behavioristic psychology. For that psychology, in both its past and present forms, the methodological axiom has been to construct surroundings for an animal that can be reliably and easily controlled by an experimenter. The environment has been experimenter-specific rather than species- or animal-specific. And to this methodological axiom are added the selection of a "representative" animal for the investigation of the laws of learning and the selection of a (piece of) behavior for investigation according to the criteria of reliability and ease of measurement (cf. Skinner, 1957). Collectively, these axioms define the behaviorist methodology, and they are clearly in keeping with the ideal method of animal–environment dualism. If one were to summarize current feelings toward the laws of learning, the summary would bespeak a relativistic rather than uniform view: Learning depends in important (coimplicative) ways on the animal doing the learning, the behavior being learned, and the situation in which the learning is occurring (cf. Bolles, 1975). But this, as remarked, is to anticipate our argument. The section that follows is more pedestrian. In it we identify the doctrines that have been the bedrocks of perceptual theory in the present and past centuries.

The Inadequacy of Stimulation and the Need for Epistemic Mediators

The received status of proximal stimulation is that it relates poorly, equivocally, to its distal referent, the environment. The retinal image has long been taken as the apposite optical basis for visual perception; yet it is by traditional definition a bidimensional, inverted, distorted, and temporally frozen image of the environmental layout at which the eye is directed. Moreover, under traditional analysis, the same retinal image can result from an indefinitely large number of distal stimuli, and vice versa. 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]."

Not unrelatedly, the descriptors of light and sound as provided by physics have been taken as the received descriptors for the purpose of perception. Thus, an acceptable description of light is that it is radiant energy in the form of quanta (photons, for visible light) that can vary in mass and energy. From the perspective of the retinal mosiac, light rays are distinguished only by intensity and wave length; and the ageless mystery, then, is how the rich vocabulary of visual perception is induced from the impoverished vocabulary of the light.

In short, the past and current claim is that the energy distributions at the receptor surfaces are insufficient in richness and precision to account for perception. If the energy distributions underdetermine perception, then mechanisms must be proposed to redress the imbalance. Putatively, the animal as perceiver must bring to bear sources of knowledge such as memories and concepts and intellectivelike operations, such as hypothesis testing and inference, in order to achieve an adequate perception of its environment. Perception, in the conventional view, is epistemically mediated (Shaw & Bransford, 1977; Turvey, 1977).

Let us express the fundamental premise guiding theoreticians in the past half-millennium as follows: The relation between proximal stimulation and environmental properties is intractably equivocal or nonspecific. To this doctrine of intractable nonspecificity, should be added the following doctrine: the independence of perception from stimulation. The often-cited evidence is that where proximal stimulation is fixed, perception may vary (e.g., the Necker cube); and where proximal stimulation is varying, perception may be unchanged (e.g., the retinal orientation of an object in the frontal plane varies with head movement, but the perceived orientation does not). In accepting these doctrines as identifying the initial conditions for perception, it follows that insofar as perception is veridical, insofar as the animal and its environment relate adaptively, *the animal as perceiver must* *embody a theory of the environment and a theory of how the environment structures energy distributions.* Whatever epistemic mediators are proposed, if they are to be taken seriously, they must subsume as a minimal requirement *both* theories. Nothing less will suffice as a basis for discerning the meaning of the light at the eyes, of the pressure waves at the ears, of the molecular distributions at the nose, etc.

The thorny issues to which the conventional view is heir have never been resolved satisfactorily. These issues, at their core, are questions of origin. It is well and good, perhaps, to postulate mediational mechanisms that are essentially embodiments of knowledge about the world if one can present a sensible means by which that knowledge is made possible. Echoing Pattee (1970), one cannot divorce the mechanism question of "How does it work?" from the origin question of "How did it arise?" And it can be argued (and is, later) that neither empiricism nor nativism have responded convincingly or even seriously to the latter.

In view of the problems it gives rise to, why have scholars (both past and present) accepted the traditional analysis of the physical basis of perception as sufficient for their purposes? Faced with the erstwhile doctrines, the student of perception has had two options. Figuratively speaking, one option is to pack whatever *epistemic* entities are needed between the proximal stimulus and the percept so as to derive the self-evident perceptual complexity and consistency from the imputed physical simplicity and equivocality. This option, as intimated, has been virtually the universal choice for the past half-millennium. The other option is to assume that the doctrines are false and (pursuing the figure of speech) to pack whatever *physical* entities are needed into the physical basis for perception so that it and perception are of the same order and are compatible. This option has been almost universally ignored. The choice of option, we believe, has been dictated by the implicit acceptance of animal–environment dualism.

The point about the dualism, in this respect, is that it fosters tolerance for discrepancies between animal-related statements and environment-related statements. If animal and environment are thought of as logically independent, then it is not upsetting nor especially surprising to learn that the descriptors of one do not fit the descriptors of the other (as the classical descriptors of the light reflected from the environment do not fit the descriptors of visual experience). If the animal and its environment do not comprise an organizational whole and if the animal is taken as the relevant unit of analysis, then the idea of a nonspecific, orderless medium (e.g., the light) is tolerable and the conferring upon the animal of capabilities for imparting specificity and order is a relatively simple, and natural, theoretical gambit.

With respect to the options noted, then, there is a further but related aspect of animal–environment dualism that would hamper pursuit of the second

option and reinforce choice of the first option. Essentially, it is the issue of reductionism. This issue most commonly focuses on the animal: Can mental processes be reduced to material processes? Can life be reduced to physics? At the heart of the issue is the understanding that there is more than one level at which an animal can be described and that these levels range from very fine-grained descriptors to very coarse-grained descriptors—for example, subatomic particles to the contents of consciousness. It is similarly the case, however, that proximal stimulation and the environment can be addressed at a number of descriptive levels. The issue of reductionism is no less an issue for proximal stimulation and the environment than it is for the animal, but there is a conspicuous asymmetry of concern in favor of the latter. For present purposes, we need only note that given animal–environment dualism, a theorist can deny vigorously a reductionist argument for the animal as a perceiving agent and yet accept unquestioningly a reductionist argument, say, for the optical support of visual perception (see Fodor, 1975, for a contemporary example). More commonly, a theorist can choose one grain size of description—often coarse—for the animal and another grain size of description—often fine—for stimulation. Although a theorist is willing to remark that the light, after all, is nothing but photons (see Boynton, 1975), he or she would presumably be less willing to remark that the animal, after all, is nothing but atoms.

At all events, given the two aforementioned doctrines, let us proceed to assess the classical stances of empiricism and nativism with reference to the origins of the knowledge needed for perceptual efficiency.

The Problem of Origin: The Solution from Empiricism

The difficulty with assessing the empiricist's approach to the origin question is that empiricism is never pure. A rule of thumb says scratch an empiricist and you will find a rationalist. Thus it is more accurate to describe Aristotle as a "less extreme rationalist than Plato" than it is to describe him as an empiricist. Locke refuted innate knowledge in general but allowed the concept of substance and admitted experience-free and question-begging operations such as reflection and judgment. And the great 19th-century empiricist, von Helmholtz, saw fit to propose explicitly a "law of causation" as a law of thinking prefatory to experience and more generally to presume the laws of inference.

Berkeley (1709/1964) devised an enormously influential empiricism with reference to vision. His favored metaphor was that vision was like language in that the variables of light had no more meaning for an experientially naive observer than would a word in Russian have for a non-Russian-speaking person. For Berkeley, the ascription of meaning to the variables of light was achieved by association with the products (ideas) of specific tactile or kinesthetic experience. But Berkeley's solution is a notorious nonsolution to the origin questions and for a number of reasons. Most blatantly, it is a solution that both accepts *and* denies the doctrine of intractable nonspecificity; the doctrine is accepted for vision (hence the ascription of meaning problem in that modality) and denied for haptic perception (hence the rationalizing role imputed to tactile and kinesthetic ideas). The hidden claim is that haptic perception cannot itself be mediated epistemically if it is to epistemically mediate vision in the manner desired (Mace, 1977; Turvey, 1977). Clearly, the fundamental inconsistency of Berkeley's solution makes it undesirable. At the very least, it raises the heretical question, for conventional theory, of why even one modality should not suffer from nonspecificity of stimulation and not require any kind of epistemic mediation. Nevertheless, we should note that the Berkeleyean (non)solution was promoted by scholars in the last century (e.g., Helmholtz, 1911/1925) and continues to be invoked by scholars in the present century (e.g., Gregory, 1969).

Let us press empiricism's solution to the origin question a little further so as to reveal more of its inconsistency. Recall that epistemic mediators must minimally subsume a theory of the environment and a theory of the way in which the environment structures energy distributions. Is it possible that a specific-association mechanism, such as that proposed by Berkeley and championed illustriously by Helmholtz, could achieve in principle this minimal requirement? Helmholtz spoke as if he meant for rules or algorithms to be applied and as if he assumed the internalization of the theories in question; it is true, nevertheless, that he described no mechanism other than specific associations. A blunt result of 20th-century science is that a device constructed in strict accordance with specific associations is inept at rule acquisition and by extension at theory construction. The proof rests with showing that finite state automata, formally equivalent to specific-association mechanisms, are limited to the acceptance of Type 3 languages[1] (Hunt, 1975).

We may justifiably claim that with regard to the origin of minimally sufficient epistemic mediators, a specific-association mechanism will not do. Let us therefore take the liberty of proposing a different acquisition mechanism but one that is continuous with the commonplace empiricist emphasis on perception as a matter of hypothesis testing. Let us propose that the minimally sufficient epistemic mediators are acquired through a process of projecting and confirming hypotheses.

[1] That is to say, one-sided (right or left) linear grammars. Put differently, finite-state automata are incapable of the rules that underly the multiple embeddings of natural-language sentences.

A representative example of the rules or algorithm that Helmholtz had in mind and one that is a popular choice of neo-Helmholtzians (e.g., Epstein, 1973, 1977; Rock, 1975) is the size–distance invariance hypothesis: A given proximal extent determines an invariant ratio of perceived size to perceived distance. The size–distance invariance hypothesis emphasizes covariation of percepts; thus, the perception of size takes into account perceived distance, and the perception of distance takes into account perceived size. This hypothesis can be said to entail knowledge about environmental properties and about how the environment structures proximal stimulation in that it relates to the fact that if the metrical distance of an object from an observer increases, its metrical size must also increse if the metrical size of the retinal image corresponding to the object is to remain unchanged. Let us refer to the size–distance invariance hypothesis as the size–distance invariance *concept*, the reason being that we wish to view acquisition as a process—of projecting and confirming hypotheses—that eventuates in some useful conception of the environment. Can an animal, in principle, acquire the size–distance invariance concept?

Let the animal be in the following conjectural state with respect to the environment: "If an object O projects a proximal extent (visual angle) s and is perceived at a distance d (from me), then O's size is given by: $S = sd$." This hypothesis would be confirmed by the algorithm being consistently correct in an (indefinite) number of instances. Let us worry about consistency and correctness, separately. A minimal assay of the consistency of the algorithm would be given by comparing estimates of S at two distances (d_1 and d_2) and therefore necessarily at two times (t_1 and t_2). The comparison is shown in Fig. 9.1. If $S = s_1d_1 = s_2d_2$, then this constitutes minimal confirmation of the consistency of the hypothesis. However, since we cannot compromise the doctrine of intractable nonspecificity, a number of ancillary assays must be conducted in order to guarantee the legitimacy of the comparison. It is worth pausing at this point to see what is at stake.

When the object goes to d_2, there is a change in the proximal stimulation. In order to conduct the comparison in good faith and to protect iself against false conclusions, the animal needs to know whether the change in the proximal stimulation is due *solely* to displacement. Suppose that the two estimates of S do not agree. Is the disagreement due to the fact that the algorithm is incorrect, or is it due to other undetected changes that accompanied (causally or otherwise) the displacement? According to the

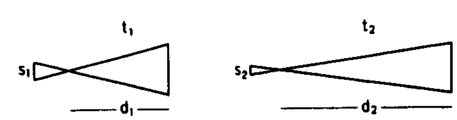

FIG. 9.1

nonspecificity doctrine, the proximal stimulus is ambiguous with reference to the distal object per se and with reference to the *changes* undergone by the distal object. Empiricist theorizing is permitted no *fait accompli*; given intractable nonspecificity, nothing is given.

The point is simply this: To test the consistency of the algorithm, the animal must be assured that only the variables of the algorithm have changed between tests. It must determine, in short, (and much like the scientist) the constancy of the irrelevant variables. To assess the consistency of $S = sd$ entails answers to (at least) the following questions:

1. Has O been preserved over time and displacement? That is, is the O at t_2 (or d_2) the same O as at t_1 (or d_1)? This identifies the problem of *constancy of identity*. If the evidence is that O at t_2 is not the same O at t_1, then the comparison of s_1d_1 and s_2d_2 is invalid.
2. Has O's size been preserved over time and displacement? That is, is the S at t_2 (or d_2) the same S as at t_1 (or d_1)? This identifies the problem of *constancy of size*. If the evidence is that the size has changed, then the comparison is invalid. Unfortunately, the point of acquiring the size–distance invariance concept is to achieve size constancy.
3. Has O's orientation been preserved over time and displacement? That is, is the orientation at t_2 (or d_2) the same orientation as at t_1 (or d_1)? This identifies the problem of *constancy of object orientation*. If the orientation has changed, then the comparison is invalid, because proximal extent is a function of the slant of the object, as Fig. 9.2 demonstrates.
4. Has the animal's orientation to O been preserved over time and displacement? That is, is the orientation of the animal at t_2 (or d_2) the same orientation as at t_1 (or d_1)? This identifies the problem of *constancy of perceiver orientation*. If the animal's orientation has changed, then the comparison is invalid, because proximal extent is a function of the eye's orientation to O.
5. Has O's shape remained the same over time and displacement? That is, has O undergone a nonrigid transformation from t_1 (or d_1) to t_2 (or d_2)? This identifies in part the problem of *constancy of shape*. If O has undergone a nonrigid transformation, then the comparison is invalid, as Fig. 9.3 suggests.

We take the conclusion of this line of reasoning to be that if there is a set A of algorithms to mediate the set C of perceptual constancies, then determining the consistency of any one algorithm, a_i (to mediate the constancy, c_i), requires that the set A be at the disposal of the animal. This conclusion is clearly contradictory to the aims of empiricism.

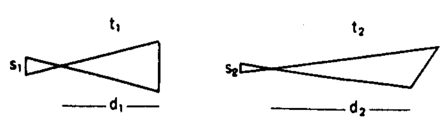

FIG. 9.2

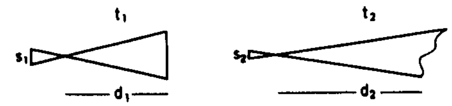

FIG. 9.3

Assuming, nevertheless, that consistency could be established in a manner consistent with empiricism, we ask: Would it be sufficient? If an animal (or a theorist) were content with phenomenal descriptors—that is, descriptors relating solely to how things looked—then consistency might be a sufficient criterion for confirming hypothesized algorithms. It would matter only that for a given distal object or property, the said algorithm would consistently yield the same phenomenal descriptors; on such consistency, stable discriminations could be drawn and category labels reliably ascribed. In the extreme, it is imaginable that a distal object X, by virtue of a given algorithm, would look like Y. That is, X could consistently be given a phenomenal description that is not consonant with the properties of X but with the properties of some other object, Y. Filling in the dummy variables, X could be a saber-toothed tiger and Y a tropical flower. If an animal (or a theorist) were content with phenomenal descriptors, then the physical and behavioral dissonance between tiger and flower would matter little. It would, on the other hand, matter a great deal if the animal (or theorist) were not content with how things looked but needed to know, in terms of activity, how things related to it and how it related to things.

For any activity to be realized, the material design of the animal and the material design of the environment must be consonant. This mutuality in material design is the support for activity; for example, locomotion by ambulation is possible only if the ground surface can supply reactive forces complementary and equivalent to those forces supplied by the animal. This mutuality, of course, is a matter of physics and cannot be compromised. It follows, then, as a reasonable claim, that for the realization of actions, perception in the service of action cannot simply be consistent; it must be correct. At least it must be correct in the following sense: The animal must veridically perceive the physical nature of the environment in reference to its own physical nature if it is to behave adaptively; algorithms that consistently miscalculate or misrepresent distal objects in reference to the animal will invite physically unrealizable activities and behavioral chaos. The point we are guilty of belaboring is an obvious one: A perceptual theory restricted to an account of the *phenomenal* contact between animal and environment is considerably less constrained and more arbitrary than a theory that respectively includes an account of the *physical* contact between animal and environment.

At all events, the preceding suggests that in reference to confirming a projected algorithm, consistency is insufficient. If, in addition to consistency, correctness (as minimally defined) is required, how might it be determined?

Suppose that a visual algorithm a_i consistently miscalculated the environmental property p_i, which is relevant to the control of some activity. Now according to the official doctrines, proximal stimulation is not specific to the distal object and perception is independent of the proximal stimulation. It follows, therefore, from the official doctrines that the percept "p_i" does not correspond to p_i itself but to a surrogate for p_i—namely, the end product of the algorithm. If the animal could determine the degree to which p_i was consistently miscalculated—that is, the degree to which the property and the percept were at odds—then it could, in principle, make compensatory adjustments to ensure an adaptive relation to p_i. This strategy, however, presupposes that the animal can become apprised of the dimensions of p_i through some means that is independent of the algorithm a_i. For reasons cited above, we cannot allow that haptics is this alternative, independent means if it is intended that haptics makes this appraisal directly. We might allow a comparison of the property p_i as calculated by the algorithm a_i with the property as calculated by a haptic algorithm. But the comparison in question would be of two percepts corresponding to two internal representations (namely, the products of the visual and haptic algorithms), and neither can lay a greater claim to legitimacy than the other.

The muddle that arises is owing to a failure to uncover, within the framework of empiricism, any legitimate kind of knowing that is epistemologically unquestionable. It has been suggested (Fodor, 1975), however, that such epistemic incorrigibility is not really needed. All that *is* needed is that some kind of knowing—in the context of the present argument, some algorithmic consequences—be unquestioned rather than unquestionable. But this solution bears the traces of legerdemain; an unquestioned but incorrect algorithm as a bench mark could hardly guarantee that other algorithms will be adjusted in the direction of a truer fit to reality.

Let us summarize to this point. The question was raised of whether an animal could, in principle, acquire the size–distance invariance concept (as exemplary of the concepts that mediate constancy of perception). The answer appears to be "no" even when the animal is assumed to have the remarkable acumen to propose hypotheses that bear closely on the nature of the environment and the relation between the environment and the light it structures. This acumen, of course, expresses more than just a shade of rationalism; moreover, it invokes nativism. Empiricism's solution to the question of origin, the question of how the animal can come to embody the knowledge needed to achieve perception, reduces to an appeal to a priorism.

We soon inquire whether mechanisms for achieving constancy could have evolved. Our immediate concern is to pursue the comparison between empiricism and rationalism, for most fundamentally, rationalism sought to impugn—on logical grounds—the validity of perception as an instrument of knowledge.

The Primacy of Reason Versus the Primacy of Perception

Rationalism rejects the empiricist's claim that all forms of knowledge can be reduced to just one—namely, perceptual knowledge. Moreover it rejects with equal vigor the notion that perception has primacy over other "faculties of mind." Typically, rationalists have so distrusted the senses as a source of knowledge about the world that they have disavowed any knowledge that does not arise either *de novo* by logical inference or by logical induction from the sparse evidence that the senses on occasion may yield about the world.

The skepticism toward empiricism leads rationalism to distinguish the appearances of the perceived world (phenomena) from the reality that lies behind such appearances (noumena), a reality that is knowable only by rational construction or induction that goes beyond any form of experience. Often in this regard, the fruits of theoretical science (e.g., invisible microbes, unobservable particles, or hidden stellar energy sources) are taken as evidence for skepticism regarding the extent to which human experience can, even in principle, reveal nature's hidden face. For instance, the Copernican revolution and the eventual rejection of the flat-world hypothesis are often cited as significant examples of where our senses have misled us into believing something that reason was eventually able to reveal as patently false. The fact from appearance that the sun rises and sets was replaced by the rational conclusion that it is the earth that moves around the sun rather than vice versa. And although the earth appears to be relatively flat, reasonable arguments to the contrary were launched and embraced by the scientific community centuries before astronauts were able to provide corroborating perceptual evidence. In like vein, the objects of the earth such as rocks, tables, metal rods, and crystal balls appear as densely packed, static solids; however, physical theory, in contravention of the senses, informs us that these perceived solids are in reality clouds of swirling particles whose interstices contain more void than mass. On this line of argument, appearance and reality are largely distinct; and where they are at odds, reason is the final arbitrator.

It is therefore no great leap to the conclusion that theoretical (rational) science has dealt a severe, perhaps fatal, blow to the hypothesis that perception is primary and, in so doing, has undercut the foundation of *any* type of empiricism. But the cogency of this implicit argument against the primacy of perception rests with the legitimacy of distinguishing appearance from reality, a conceptual dichotomy that is a variant of animal–environment dualism.

Let us proceed to the arguments often cited by empiricists for a theory of indirect perception. For interestingly (or ironically) enough, the arguments on which empiricists postulated inferred entities to stand between the knower and the knower's world are the very same arguments that invited rationalists to separate appearance and reality.

The Argument from Illusion (or the Argument from Failure of Specification). Taken to its necessary conclusion, the argument from illusion is generally thought to provide the skeptic with an unassailable position from which to chide empiricism. More positively, the argument is used to buttress a belief in phenomenalism (Ayer, 1940) or in subjective idealism (Berkeley, 1713/1964).

The plausibility of the argument from illusion derives from the fact that things sometimes appear different to different people or to the same person under different circumstances. The early empiricists (like Locke) and later ones (like Moore and Russell) concluded from the fact of variant appearances that some sensible qualities (sometimes called "secondary" qualities) such as colors or odors do not really belong to the objects. Rather, objects are to be identified only with their so-called primary qualities such as shape. Therefore, secondary qualities, such as color, because they do not necessarily belong to the object, must belong to some intermediary entity—an epistemic mediator (e.g., a retinal image or brain-state) that intercedes between the perceiver and his or her world. Such mediating epistemic constructs were usually called "sensa" or "sense data." Significantly, in the postulating of intervening sense data, empiricists ally themselves with a realism that is indirect rather than a realism that is direct.

The dogmatic rationalist often argues that this same argument reveals a chink in the perceptual armor of empiricism, because it can just as well be legitimately used to cast plausible doubt upon the veridicality of so-called primary qualities. Just as an object that is green may appear blue under yellow light, so an object that is circular may appear elliptical from a different perspective. Therefore, one must "perceive" sense data (phenomena) in all cases rather than the actual objects (noumena), so that phenomenalism rather than realism is the only possible contribution of perception. In short, there is a failure of referentiality or specificity in that the patch of color fails to index uniquely a distal *object*. Moreover, because *any* properties perceived may be on some occasion "*p*" and on other occasions "not-*p*," it is impossible to trust perception as a true source of knowledge; surely such a logical contradiction can only inhere in appearance and not in reality; no *real* properties would show such inconstancy. For this reason, it can be argued (e.g., Berkeley) that the primary-secondary property distinction is an invalid contrast. One can no more perceive the true shape of things than one can perceive their true color.

Thus, empiricism was and is hoisted on the twin petards of its implicit dualism: On one hand, empiricism is confounded by the dilemma that if it repudiates the notion of secondary qualities and claims that *all* perceived qualities of objects are primary, then it is guilty of naive realism—thereby exposing the theory to serious attack from the skeptic who uses the argument

from illusion. On the other hand, if empiricism seeks to parry this thrust of the skeptic by holding firm to the distinction between primary and secondary qualities, then the argument can be used to infirm not only the usefulness of secondary qualities but that of primary qualities as well. Assuming its validity, the rationalist can wield the argument as weapon, forcing the empiricist to yield up realism to phenomenalism. What begins as a slight retreat of empiricism from naive realism to the apparently more defensible fall-back position of indirect realism ends in a full-fledged route of empirical realism.

The Argument from Incomplete Specification. Assuming it to be valid, the argument from illusion leads inevitably from the somewhat timid admission by empiricists that some perceived qualities may not be real to the terrible confession that *no* perceived qualities may be real. The argument from incomplete specification has equally dire consequences for empiricism as realism. Following Anscombe (1965), the argument can be summarized as follows:

A hunter aims his rifle and fires at a dark brown patch seen through the green foliage of the forest. Later he discovers much to his dismay that he has unintentionally killed his friend rather than a stag. In this example, the brown patch seems to serve two contradictory perceptual functions—one as an *intentional* object (the stag) and one as a *material* (or referential) object (his friend). To avoid this apparent contradictory outcome, which defiles perception by allowing it to be a source of error rather than of knowledge, it seems advisable to give up a theory of direct perception in favor of an indirect one. From the fact that perception can serve either an intentional function or a material function, to avoid contradiction we must conclude that a sense datum (e.g., a dark brown patch) exists as a perceptual mediary that serves simultaneously as a partial specifier for the intentional object (e.g., the stag) and the material object (e.g., the friend). Error arises because imagination (i.e., invalid inference) can sometimes lead to a fallacious perceptual judgment.

The possible role of imagination in perceptual judgment must be assumed by the traditional empiricist so as to leave unbesmirched the reputation of perception per se as a source of knowledge. For if the empiricist assumes that no imagination is ever involved in the process leading to perceptual judgment, then it would follow that no real difference should exist between intentional and material objects of perception. But such an admission would force empiricism into either of two equally untenable positions: Without imagination as a part of the perceptual judgment process, no errors should ever occur from our perception of the world; or, if it is admitted that imagination can sometimes elaborate sense data to construct intentional objects, then how can it be guaranteed that imagination does not do so in every case, so that perception may always be of appearances and never of reality?[2]

The contrast between empiricism and rationalism is most easily drawn with reference to two distinct questions. First, what is the source of an animal's knowledge? And second, what is the backing for it? Empiricism answered both questions in essentially the same way—"observing events." Rationalism on the other hand answered the first question by an appeal to innate capabilities, an answer referred to as "nativism," and answered the second question by an appeal to reason. The argument from illusion and that from incomplete specification appear to contravene the empiricists' claim that observation or perception is a privileged source of knowledge about the environment and a privileged means for justifying what is known. On these arguments the requisite epistemic mediators—knowledge of the environment and how it structures energy—cannot arise a posteriori. Let us, therefore, consider the claim that they are innately given.

The Problem of Origin: The Solution from Nativism

We will be reading the solution from nativism as the solution from evolutionism. At issue is the question of whether or not the knowledge reputedly needed to achieve perception could have evolved, given the boundary conditions defined on perception by the doctrine of intractable nonspecificity and the doctrine that perception is independent of stimulation (or, conversely, that perception is dependent on internal representation).

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[2]As the title of this chapter implies, we are clearly of the belief that *an* empiricism is needed. What the conundra identified here suggest, however, is that the establishment of a tenable empiricism will require a radical reconceptualization of perception (and a most careful assessment of the notion of error) so as to take "perception" out of the propositional domain in which it can be said to be either right or wrong and to relocate it in a nonpropositional domain in which the question of whether perception is right or wrong would be nonsensical. Is it that the proper domain of perception is ontology rather than logic or epistemology? If it were, then perception would be characterized as a state of affairs, and like other states of affairs that constitute the facts of the world (such as galaxies, water, living things, etc.), it would be necessarily true by force of existence rather than possibly true by force of argument.

In addition, and closely related, the conundra identified here suggest that the establishment of a tenable empiricism requires that an understanding of "reality" be sought, which for any given animal dissolves the dichotomy of appearance and reality, or the dichotomy of intentional object and material (or referential) object. In part, this dissolution demands a single vocabulary of terms that are symmetric and reflexive, a vocabulary in which animal-focused descriptions are always in reference to the environment and environment-focused descriptions are always in reference to the animal. These thorny issues for a tenable empiricism, in which perceiving is *the* incontravertible source of knowing what is real, are touched upon in the present chapter and are the subject of a considerably more adventurous treatment elsewhere (Shaw, Turvey, & Mace, in press).

In Neo-Darwinian theory, random variation is affected through mutation defined as change in a chromosomal gene; selection is of those mutants that are most prolific; and what matters is that the gene pool undergoes continuous change.

Let us inquire about the evolution of the size–distance invariance concept. As before, we may take this concept—or algorithm—as representative of the kind of knowledge that would make for stable perception in the face of equivocal and ever-changing stimulation. And the significance of this kind of knowledge to the conventional account of perception should not be underestimated: "The perceptual world without constancies would be a bewildering experience that would make the acquisition of adaptive behavior extremely difficult" (Epstein, 1977, p. 6).

It is not unreasonable to conceive of learning as a speeded-up version of evolution in the sense that learning is a means by which an adaptive relation between animal and environment can be established in a relatively short period of time. When learning intervenes, an animal can be said to know something at a later point in time that it did not know at an earlier point in time. Similarly, it can be said of an evolving species that if one of its members possesses some property at a later point in time (t''), there was an earlier point in time (t') at which an ancestor of the said member did *not* possess that property. Let the property in question be the size–distance invariance algorithm. Now it is necessarily assumed that at t' the ancestor and its environment were *relatively well adapted*. The ancestor at t' was able to multiply in sufficient numbers so as to provide the variability on which natural selection could act to produce the better adaptation at t''. It follows, therefore, that for the adaptive relation to have existed at t', the ancestor must have possessed a goodly number of the constancy algorithms. Without these algorithms, the experiences of the ancestor would have been bewildering and its behavior with reference to its environment essentially chaotic. Consider the following (nonexhaustive) features of the environment that with reference to the control of behavior ought to be perceived as constant despite variations in proximal stimulation: Object and surface properties such as position, size, slant, shape; event properties—more precisely, styles of change that can be participated in by a large variety of different objects such as starts, stops, collisions, touches, breaks, approaches, retreats, falling, rotations, etc.; and relatedly, animal actions such as the behavioral displays that mark aggression and courting. The latter two classes are often ignored as constancy problems, but they are as deserving of consideration as the constancies of object properties. After all, if it is claimed that stimulation is equivocal about object properties such as size and shape, it must also be claimed that stimulation is equivocal about styles of change and the behavior of conspecifics.

Consider now an ancestor at an evolutionary point earlier than t'. Presumably, by the above reasoning, the ancestor did not possess some of the constancy algorithms at t that the later ancestor possessed at t'. But given that natural selection always assumes a reasonably efficient perception–action capability in that it presupposes the means of self-preservation and reproduction, then it must always assume constancy algorithms of some kind at any earlier evolutionary point that we choose. Unfortunately, this last sentence touches upon the issue that makes some scholars (e.g., Bertalanffy, 1969; Moorhead & Kaplan, 1967) skeptical of the theory of evolution in its current form. Natural selection acting by way of differential reproduction presupposes the essential attributes of life (e.g, self-maintenance, reproduction, adaptability), thereby making circular the argument that these attributes are the *effects* of natural selection. While admitting to the inadequacy of natural selection as a directive force in evolution, one should not at the same time construe constancy algorithms as being entities of the same conceptual status as adaptability, reproduction, etc.

A constancy algorithm always *presupposes* sensitivity (however crude) to the surrounding medium. If the surrounding medium is not modulated by the organism's environment in ways that are specific to the environment, then the organism's sensitivity cannot register, and the organism cannot become sensitive to, the specifics of the environment with respect to which adaptation occurs. Consequently, there can never be a perceptual origin for the kind of knowledge that is said to mediate perceptual constancy. We are led to conclude either that some minimal set of constancy algorithms was available a priori—that is, extraevolutionary—or that the problem of the constancies has been ill conceived.[3] The former conclusion is indefensible, and the latter conclusion may draw support from the earlier discussion of what *acquiring* a constancy algorithm would entail.

[3]With respect to the animal as perceiver, there are two logically separable demands put on evolution by the assumption of intractable nonspecificity. One demand is to make the animal sensitive to the basic descriptors of at least one, but generally of several, forms of energy. The other demand is to provide the animal with the kinds of knowledge needed to make correct inferences about (or to project correct hypotheses about, or to construct a correct representation of, etc.) survival-relevant properties of the world from the basic energy descriptors. The latter demand is what we have referred to previously as the problem of origin for traditional perceptual theory; more poignantly, the *mystery* of where the requisite knowledge comes from. But suppose (as we do in the pages that follow) that contrary to traditional understanding, an energy medium as structured by an environment is *specific* to the properties of that environment (such as surfaces of support for locomotion, enclosures, behaviors of conspecifics, etc.). On this supposition, evolution's task with respect to the animal as perceiver is eased and, we believe, made feasible. The *single* task is that of making animals sensitive to the invariant relationships in the structured energy media that are specific to the properties of the world relevant to their survival. Sensitivity to some invariants embodied by structured energy *is* sensitivity to or knowledge of some properties of the world. We submit that the origin of this sensitivity is a tractable scientific problem unlike the origin of knowledge in the traditional theories of perception, which looks like an insoluble mystery.

Indeed, from an evolutionary point of view, the traditional accounts of perception that propose epistemic mediators and the nonprimacy of perception look more than a little curious. First, there seems to have been an implicit assumption that the eye as an organ evolved prior to the means by which the eye's images might be interpreted. It is not an exaggeration to claim that the focus of visual perception theory in the past five centuries has been on the mechanisms that operate on the retinal image and convert it into a meaningful "cerebral image." In evolutionary terms, it is as if visual scholars conceived the adaptation of interest as that between retinal image and cerebral image (or whatever one wished to call the terminal, internal representation) rather than that between animal and environment. Implicitly, the assumption has been that the structure and function of the eye are disassociated in evolution from the structure and function of the mechanisms by which visual perception is achieved.

Second, and in very much the same vein, the ageless point of view that perception proceeds from elementary sensory variables (corresponding to basic physical variables) seems to have peculiar evolutionary implications. Specifically, it might be taken to imply that the earliest life-forms evolved as sense-data devices (sensitive solely to energy *as such*) and only subsequently did relatively higher life-forms emerge possessing the capability to ascribe meaning to the sensory variables. Although this implication cannot be ruled out completely due to the paucity of understanding of prebiotic evolution, there are good reasons for believing it to be unlikely.

At its most primitive, life seems to be deserving of Dennett's (1971) definition of rationality—an optimal design relative to a goal or optimally related collection of goals and a set of constraints. Additionally and cognately, life at its most primitive exhibits *discrimination by significance* (Dennett, 1969); situations are distinguished by the behaviors they do or do not permit the organism to perform. Discrimination by significance is to be contrasted with the kind of discrimination often discussed with reference to pattern recognition where the focus is whether or not some device is capable of providing outputs (whatever they might be) that co-occur with energy kinds or energy distributions at its surface.

Monstera gigantea is an arboreal vine whose seeds germinate on the ground subsequent to falling from the parent plant. Soon after germination, the seedling grows in the direction of the nearest tree, contacts the tree, and ascends, losing its roots in the process. The seedling's adaptive behavior may be characterized as a positive skototropism—that is, a tendency to move toward darkness (Strong & Ray, 1975). In fact, the seedling always grows in the direction of the darkest sector of the horizon.

We may say of the seedling that it detects a climbable object. A climbable object may be defined by certain properties, some of which would be strength, rigidity, and surface texture. In the environment in which the plant has evolved, these properties have been invariant with dark sectors on the horizon. Because of this invariant, the seedling does not and need not detect the individual properties that we, as scientists, would propose as the distinguishing features of a climbable object for a vine. Moreoever, the darkest sector invariably corresponds to that climbable object that can be reached with a minimum of horizontal growth. The plant exhibits discrimination by significance.

The behavior of *Monstera gigantea* is especially illuminating in reference to the traditional emphasis on the distinction between appearance and reality. It is easy to imagine an environment in which the distribution of light does not relate to the locations of trees. Strong and Ray (1975) used the open ends of opaque tubes to produce dark sectors in the seedling's horizon; the seedlings grew (maladaptively one *might* say) into the open ends of the tubes. There are two points to be emphasized. One point is that from an evolutionary point of view, it cannot be said that the plant's sensitivity (perception?) was in error.[4] The individual plant detected and grew toward the dark sector of its horizon; it did that which it had evolved to do. The other and more general point is that from an evolutionary point of view, perception suffices when it reveals sufficient information about an organism's environment to support self-preserving and reproductive behavior.[5] Both points bear significantly on the appearance–reality dichotomy: *It is not clear from an evolutionary stance how presumed differences between the appearance of things and their description as determined by physics and human reason are differences that*

[4]This point is worth belaboring for it bears on our subsequent claim that perception cannot err. The plant's sensitivity is to dark interruptions of an otherwise light horizon. An opaque tube causes such an interruption, and it is detected by the plant. The plant, however, cannot detect those features of the source of this dark sector that are at odds with its upward growing behavior. That is to say, the plant can and does detect that information that specifies support for upward growth, but it cannot detect that information that specifies *non*-support for upward growth. Therefore, it is wrong to say that the plant's sensitivity, its perception, is in error; rather, it should be said that the plant's *lack* of sensitivity, lack of perception, results in its going astray. A similar argument can be made for the complementary case where the inadequacy lies not in the animal or organism's sensitivity but in the information made available. Consider the bird that flies into the plane glass window. Owing to the conditions of illumination and to the absence of irregularities in or on its surface, a window may fail to reflect the light in ways that a substantial surface would normally reflect the light. Because there is no information in the light about the plane glass window, we cannot expect the bird to visually detect the presence of the glass window. The bird perceives the environment that is "broadcast" in the light; its perception is not in error. It flies into the window because of a lack of perception (in regard to the substantial surface) owing to a lack of information.

[5]Which is to say that the description of reality relevant to any given organism or animal is not a description that is true in any absolute or metaphysical sense, but a description that is true in a pragmatic sense as perhaps captured in Plato's concept of *doxa* (see Shaw, Turvey, & Mace, in press).

make a difference in regard to the adaptive relation between animal and environment.

Consider a further primitive life form, the bacterium.[6] The bacterium is a single-cell organism that swims about in a medium consonant with its metabolism through the use of flagella attached to the wall of the cell. The swimming is of two kinds, "runs" and "tumbles" (Adler, 1976); runs are rectilinear motions, and tumbles are random changes in direction. The movement of a bacterium through the medium is essentially a random walk in which the length of the runs is inversely proportional to the frequency of tumbling. When a bacterium is in a gradient of a chemical "attractant," the frequency of tumbling decreases as the bacterium moves up the gradient and increases as it moves down the gradient. The opposite relation holds for a chemical "repellent." The chemical gradient modulates the locomotor styles of the bacterium, guaranteeing (within the environment to which the bacterium is adapted) movement toward nutritious substances and movement away from potentially harmful substances.

A chemical gradient is a "complex" variable in the conventional understanding. Where the stimulation relevant to some behavior is spread over time as well as space, it has been traditional to conceive of the stimulation as being registered in terms of more "basic," discrete variables whose sensory consequences are then preserved in a storage medium for the perusal of inferential mechanisms. On this account, the bacterium's behavior is mediated by a process that computes differences between stored representations of chemical concentrations at successive moments in time.

The logical difficulties with the popular interpretation of temporally extensive, perceptual information have been aired elsewhere (Gibson, 1966a; Humphrey, 1933; Shaw & Pittenger, 1977; Turvey, 1977). Here it is sufficient to make the less formal observation that the bacterium's unicellular material design does not appear to have the complexity needed to support the kinds of processing that have been traditionally implicated. Very much the same argument can be made for *Monstera gigantea*, for the absence of any sense organs rules out a sensation-based account of the plant's discriminative behavior. But if neither bacterium nor *Monstera gigantea* are devices that register the significant properties of their environments through the mediary of the sensory consequences of basic physical variables, then what kind of devices are they? They are, in a simple phrase, "smart" devices (Runeson, 1977a)—that is to say, devices that register complex particulars of adaptive

[6]Our thanks are extended to Tim Johnston for bringing both of these examples to our attention and for giving us the benefits of his perspective on them.

significance in an elegantly simplistic fashion, nonmediated by simple particulars.[7]

The polar planimeter measures directly the area of any regularly or irregularly shaped plane figure, and it provides a delightful example of a smart instrument (Runeson, 1977a). The planimeter consists of two rods, say, *A* and *B*. Rod *A* (the tracer arm) connects an index to a measuring wheel, and Rod *B* (the pole arm) connects Rod *A* (between the index and the wheel) to a fixture on the surface on which the plane figure is to be measured. The index is moved around the boundary of the figure. As the index traces out the profile, the measuring wheel skids and rotates such that the total angle of rotation consequent to a complete circuit of the figure is directly proportional to the area of the figure. The instrument is a simple mechanical expression of rather abstract mathematical principles (see Runeson, 1977a, for more details).

With regard to reputedly more basic variables, the planimeter is not especially efficient; it does not permit the straightforward measurement of, say, lines and angles, and such measurements may prove to be relatively inaccurate. But to be dismayed at the fact that the instrument is unreliable with regard to these supposedly basic variables would be missing the point. The polar planimeter exemplifies smart devices in this sense: It is a special-purpose instrument tailor-made for a particular kind of task and a particular kind of situation. Such being the case, its construction can take full advantage of the special features of the task it is to perform and the circumstances in which it is to operate (cf. Fowler & Turvey, 1978; Gel'fand & Tsetlin, 1962).

Apart from bringing into question the hypostatizing of the basic variables of physics, the preceding examples and arguments are of importance in the following final respect. The suggestion is that the evolution of perceptual systems may be understood as the compiling of special-purpose, smart devices to directly register higher order variables or complex particulars. This would contrast with the understanding that evolution manufactured a few types of basic components, each computing a basic physical variable or simple particular, and achieved the computation of more complex variables through programs defined over the basic components.

We might go further, and further than we have room for here, to delimit and evaluate the conceptual bequest of the preceding five centuries as it bears on the nature of perception. But what has been deliberated to this point must suffice; and in the contrast drawn in the last few paragraphs we have caught a

[7]We believe it prudent to avoid where possible the concrete-abstract distinction, where *concrete* refers to particular things and *abstract* to nonparticular things. In the view that we wish to promote, animals always perceive particulars. Some of these particulars may, as a matter of convenience, be deserving of the label *complex* in comparison with other particulars, but they are, nevertheless, particulars and thus ought not to be conceived of as reducible in the way that abstract amorphous entities might arguably be reduced to concrete particular entities. We thank Ed Reed for introducing us to this conception of *particular*, although our usage is somewhat different from his.

glimpse of a different conceptual basis and one that we now try to develop. As postulated at the outset, the stock concepts of traditional and conventional perceptual theory follow from the assumed dualism of animal and environment. The promissory note to be cashed in is that an assumed synergy of animal and environment yields an orthogonal collection of concepts and in consequence a radically different understanding of perception.

AN ECOLOGICAL REFORMULATION

The Principle of Mutual Compatibility

There is a contemporary understanding with which animal-environment dualism and the doctrine of intractable nonspecificity seem to be graphically at odds. It is that the universe is finely balanced with reference to life (Trimble, 1977; Wheeler, 1974). Characterizable in terms of a relatively small number of properties, it is becoming increasingly evident that the universe's hospitality to life depends on these properties having just the particular values they have, and no others. A fairly minor change in either a fine-grain property or a coarse-grain property of the universe, and life would be impossible. Thus, at the fine grain, a lowering of the electromagnetic force that regulates the structure and interactions of atoms and molecules would release electrons from their bondage to atoms, thereby making chemical reactions impossible; at the coarse grain, a rise in the rate of expansion of the universe would rule out the forming of galaxies and induce a uniform spread of matter (see Trimble, 1977). We recognize, therefore, the fitness of the universe for life. But more than this we will recognize that the universe and life are coimplicative: They have coevolved and they are codesigned. For the 17th-century philosopher, Leibniz, it could not have been otherwise.

Leibniz believed that substances could not interact. That which passes for causal interaction among substances was interpreted by Leibniz as a parallel coordination of state changes; the coordination arising from the inexorable unfolding of natural laws according to symmetry among substances. In his "principle of sufficient reason," Leibniz advocated that only those things may coexist—only those things are possible—that satisfy certain fundamental compatibility relations. By this principle—which we will refer to as the "principle of mutual compatibility"—compatibility relations among logically possible structures is the defining criterion of existence.

We see, in short, that for Leibniz there must be a good or a sufficient reason for anything to exist. Darwin's theory of evolution and other evolutionary theories (e.g., cosmological theories) all begin by assuming the existence of a collection of things that evolve, but they do not address the issue of why *that* collection—or any other, for that matter—should exist at all. Leibniz sought a deeper understanding: Whatever exists does so because it is mutually compatible with more things than something else. Thus he sought to derive the existence of things from a logically more primitive and simpler notion, namely, that of compossibility, or what we have chosen to call *mutual compatibility*. Hence the Leibnizean argument for existence is not circular; it does not derive existence from existence, but from something else.

There is a good deal (of what we take to be necessary future endeavors) foreshadowed in Leibniz's intuitions. Looming large is the necessity to develop a logic of synergistic relations among natural systems—a logic that does not shy away from the image of natural law relentlessly fashioning reality. In what follows we reiterate and embellish a sketch of the desired logic as given by one of us elsewhere (Shaw & McIntyre, 1974).

Adjunctive Logic, and Natural Law

The Stoic philosophers distinguished several kinds of logical propositions: among them the *hypothetical, causal,* and *adjunctive*. The hypothetical or conditional proposition takes the form: "*If* x, then y." This can be contrasted with the causal proposition: "*Because* x, then y"; and the adjunctive proposition: "*Since* x, then y."

The hypothetical proposition is invalid whenever the premise is true and the conclusion is false, and valid otherwise. It can be said to be conditionally true or correct if the opposite of its conclusion contradicts its premise (i.e., by *modus tollens*). However, the opposite of the conclusion (e.g., not y) is not necessarily inconsistent with the premise (e.g., x). For instance, "If this is Monday, I go to work." However, it may indeed be Monday, but I may not go to work simply because it is a holiday. In short, the consequent does not disconfirm the premise.

In general, hypothetical propositions constitute a poor model for natural laws, primarily because there are too many ways in which they can be invalid. Additionally, they fail to provide a necessary relationship between premises and conclusions. The reason why these limitations make the hypothetical proposition an inappropriate model for natural laws becomes apparent as soon as one attempts to fit these laws to this propositional schema.

Let the initial and auxiliary conditions that define the domain of application of the natural law correspond to the premise of the proposition. The valid outcome predicted by the natural law will then correspond to the consequent of the proposition. A principle is considered to be a natural law: (1) if the denial of its prediction or consequent is necessarily inconsistent with the premises; and (2) when its premise can be shown to be true (i.e., when its initial and auxiliary conditions can be shown to be satisfied). In brief, a natural law is a principle that predicts true outcomes whenever it can be shown to validly apply.

It clearly violates what we mean by a natural law to say that the law validly applies but does not predict the outcome. In such a case, either we would not accept the principle in its stated form as being a valid law, or else we would

deny that the conditions for its application had actually been satisfied. In sum, a law cannot validly be applied to any situation where its premises are not true, but a hypothetical proposition is valid, by definition even when its premises are false. It is not difficult to see how attempts to interpret laws as hypothetical propositions lead to paradoxes. In particular, what is conventionally and intuitively accepted as the function of scientific theory evades formal confirmation. Thus, Popper (1959) and others have shown that when stated in hypothetico-deductive form, neither natural laws nor theories are logically verified simply because their predictions are confirmed. Affirming the consequent of a hypothetical proposition does not affirm the premise. Hence, if law x predicts outcome y, given that y is true does not imply that x is true.

Unfortunately, Popper's attempt at an alternative evaluation of scientific laws and theories fails in like fashion. His argument is that even though laws or theories cannot be verified directly they can be evaluated by showing that their predictions do not hold. The falsifiability procedure is based on the time-honored and valid argument schema known as the *modus tollens*: If law x, then outcome y, but not y, therefore, not x.

It is quite unlikely, however, that falsifiability is ever achieved in practice (Lakatos, 1970), because the premises for a law or theory are such a complex of variables that it often proves impossible to determine which one has been falsified. The onus, therefore, falls upon the theorist to decide whether a major or a minor assumption of the theory is at fault. Given the potential arbitrariness of this choice, it would be imprudent to reject a law or the core of a theory that had been developed carefully and arduously.

On learning that Eddington's measurement of light bending around the eclipsed sun agreed with the predictions of his theory, Einstein replied: "But I knew that the theory is correct." When asked how he would have responded if the predictions had not been confirmed, Einstein candidly countered: "Then I would have been sorry for the dear Lord—the theory is correct" (Clark, 1971, p. 369). The point on which argument and vignette converge is this: The validation of theories and laws appear to be logically impossible. Thus it is important to note that it is not that logic makes no difference in theory evaluation (and a law is, of course, just an accepted consequence of a theory), but rather that logic makes so little difference. The fruitfulness of a theory in explaining anomalies and bringing general consistency into science is more important than either logical verification or falsification. In other words, the degree to which a new law applies symmetrically across a wide domain of natural phenomena and relates other laws is the highest criterion of its worth. It is also a realistic measure of the resistance scientists will show in abdicating it.

At all events, we should pursue logical forms other than the hypothetical proposition. What is sought is a logical form that is consonant with the aforementioned facts about theory evaluation. In this perspective, consider the Stoics' conception of causal propositions.

A causal proposition begins with a true premise and ends with a necessary consequence; for example: "Because it is day, then it is light." The causal schema more appropriately expresses the form of laws; by contrast we are reminded that the hypothetical proposition is still valid if its premises are assumed false. For instance, consider the following hypothetical: "If it is night, it is light," then whether night or day, it follows that "it is light"—a valid logical argument but scientifically false.

The causal proposition, however, does not permit such a trick to be performed on our scientific intuition. A causal proposition is incorrect (by definition) if it begins with a false premise or ends with a conclusion that does not follow from it. Thus, unlike hypothetical forms, the causal interpretation demands that the premise and conclusion correspond.

Although the schema for natural laws seems to be satisfied by causal propositions, the intuitive notion of causal relation cannot be effectively captured in formal statements. Moreover, it can be argued that invariance laws (Wigner, 1970), laws that characterize the symmetry relations existing among natural laws, do not seem to fit the schema for causal propositions (see Shaw & McIntyre, 1974).

There seems to be a fit among the varius phases of matter that permits some kind of macro-determinism to hold among their distinct phenomena, but that does not permit (nor does it require) the micro-deterministic relations necessary to the concept of causal interaction (Shaw & McIntyre, 1974). On this point the adjunctive propositional form offered by the Stoics, although essentially ignored by history, seems more promising.

An adjunctive proposition begins with a true premise and ends with a necessary consequence. For example: "Since it is day, then the sun is shining." This proposition is incorrect when it either begins with a false premise or ends with a consequence that need not follow. The adjunctive proposition professes both that the second member follows from the first and that the first member is true. Adjunctive logic requires a commitment to one's premises, and it is this propositional schema that we believe is consonant with the sense of natural laws.[8]

[8]Our experience is that the adjunctive propositional form is not so easily grasped as the more familiar propositional forms. The following example sometimes proves helpful. Mendeleev predicted the existence of elements on the basis of a profound belief in the symmetry of the periodic table of chemical elements. Or, as we might say here, Mendeleev believed that *since* the elements that were known to exist did in fact exist, then elements x, y, z, etc., must also necessarily exist. Clearly, it was not a matter of Mendeleev believing in a hypothetical relation that *if* the elements known to exist did exist, then x, y, z, etc., exist. Nor (and perhaps more significantly) was it a matter of his believing in a cause–effect relationship such as: Those chemical elements known to exist *caused* those not known to exist—say, x, y, z, etc.—to come into existence. The point is that the adjunctive entailment of one thing by another is a manifestation of an underlying principle of symmetry and that the existence of either one of the things in question is inconceivable without the other.

If we analyze the "adjunctive proposition, "Since x, then y," in terms of truth tables, it is the case that in order for the adjunctive relation to hold, both x and y must be true. The adjunctive relation is false otherwise. Now this looks suspiciously like the truth functional definition of a conjunctive relation (e.g., x and y). It differs, however, in one important way: Where conjunctive relations are commutative (i.e., "x and y" is equivalent to "y and x"), adjunctive relations are not; hence, "Since x, then y" does not imply "Since y, then x."

The adjunctive formulation seems to capture the sense that laws of nature apply in an inexorable manner to grind out reality. This is expressed simply as the adjunctive proposition that: "Since the law applies, the observed outcome must follow (necessarily)." If the outcome does not follow invariantly upon correct application of the law, we have grounds for falsifying the whole proposition, because in an adjunctive proposition the truth of the conclusion follows necessarily from the truth of the premises. Thus, in this special sense, the falsifiability criterion is preserved.

The verification criterion, however, does not hold for adjunctive propositions at the level of natural law. The observation (y) that some event (x) occurs as predicted by physical law x does not verify that x is a law. Thus, given y, it is fallacious to affirm x. Although natural laws apply to predict outcomes, no number of observed outcomes can be used logically to verify the law, a fact that is expressed in the noncommutativity of the adjunctive propositional form of natural law.

One might even question the utility of the verification procedure, because natural laws are postulated on more general grounds than observations. The major grounds for accepting or rejecting principles as natural laws is whether or not they fit into the invariance structure of a science, resolving anomalies and relating other principles (cf. Wigner, 1970).

The accuracy with which natural laws predict effects is not so important as the degree to which they contribute to the coherence of explanations for natural phenomena. Because one might predict what one does not understand, prediction alone is an insufficient criterion of the explanatory worth of theories, hypotheses, or laws. Scientific theories or natural laws that help simplify a field will never be abdicated solely on the grounds that they are not predictive. Indeed, they should not be, for the conditional logic of verification does not apply.

Defining Mutual Compatibility in Adjunctive Logic

Let us now return to the notion of mutual compatibility. Compatibility can be defined in the adjunctive propositional form; that is, x is said to be compatible with y if it is the case that since x, then y. Using the symbol "$\succ$" to represent the adjunctive (and, therefore, compatibility) relation, the adjunctive proposition can be written as, $x \succ y$. From this adjunctive schema we define further compatibility relationships through the addition of two symbols: $\diamond$—mutual compatibility—and $\vdash$—unidirectional compatibility.

1. *negation:* $x \succ y$ (x is not compatible with y).
2. *mutual compatibility:* $(x \succ y) \cdot (y \succ x) \equiv (x \diamond y) \equiv (y \diamond x)$. (Read simply as: when x is compatible with y and y is compatible with x, then x and y are mutually compatible.)
3. *mutual incompatibility:* $(x \overline{\succ} y) \cdot (y \overline{\succ} x) \equiv (x \overline{\diamond} y) \equiv (y \overline{\diamond} x)$.
4. *unidirectional compatibility:* $(x \succ y) \cdot (y \overline{\succ} x) \equiv (x \vdash y) \equiv (y \vdash k)$.

We can now proceed to illustrate Leibniz's argument from the principle of sufficient reason or mutual compatibility, in the sense of the following law, a law that we boldly refer to as the *Law of Existence.*[9]

The *Law of Existence* says that comparatively speaking, that object (or event) exists which has the greatest mutual compatibility with other logically possible objects (or events). To illustrate: Assume $a, b, c, d,$ and e, are all logically possible, (i.e., noncontradictory) objects. (Logically impossible objects are those whose conjunction is false; e.g., the conjunction $x \cdot y$ is false when $y = \bar{x}$, because this entails that x and $\bar{x}$—the contradiction of x—are both true.) Now assume that the following compatibility relations either obtain or do not obtain among the logically possible objects postulated above: (1) $a \overline{\diamond} b$; (2) $a \diamond c$; $a \diamond d$, $a \diamond e$; and (3) $b \overline{\diamond} d, b \diamond e, b \diamond$ c. Then by the Law of Existence, it follows that $\exists a \diamond \exists b$ (read as "the existence of a is mutually compatible with the nonexistence of b"). Thus, the conclusion follows immediately as a necessary fact that a can exist in the same possible world, W_1, as c, d, e whereas b can only exist in a possible world, W_2, containing c and e. This means that by the Law of Existence, the possible world $W_1 = (b \cdot c \cdot d \cdot e \cdot x)$ (where $x \neq b$) exists as an a posteriori fact[10] whereas the possible world $W_2 = (b \cdot c \cdot e \cdot y)$ (where $y \neq a$ or d) does not.

To put the matter differently: The logically possible world that is most likely to exist is that which contains the greatest number of mutually compatible objects. The alternative possible (candidate) worlds contain only a subset of the mutually compatible objects in question. Thus, the Law of

[9]Our boldness in this regard is encouraged by the bold charge of this conference—to project an understanding of memory and closely related phenomena (here, perception) in the next half-millennium. The reader's indulgence is requested!

[10]The notion of "a necessary a posteriori fact" is prominent in the remarks that follow. By identifying a fact as necessary, we mean: There is a state of affairs that exists and that coud not have been otherwise. A contingent fact, by contrast, is a true fact but one that *could* have been otherwise. Prefacing a fact by "a priori" means a fact that is true independent of existence. Conversely, prefacing a fact by "a posteriori" means that the fact's truth is manifest in existence. A necessary a posteriori fact, therefore, is a fact that is necessarily true by force of existence.

Existence provides a determinate principle of adjunctive (compatibility) logic by which worlds that are merely logically possible (i.e., noncontradictory) may be actualized as a posteriori facts of existence. This law provides a way of imputing the greatest degree of existential import to that logically possible world scheme, commensurate with other equally logically possible world schemes, that possesses the greatest number of mutually compatible objects.

Let us attempt now to apply the Law of Existence to resolve a classical cosmological problem. It is often claimed by the indeterministic reductionist that life is a chance happening in the physical universe, say, resulting from nothing more than the spontaneous mutation of complex molecular forms. By contrast, the determinist wishes to argue that the laws of nature apply in such a strict manner that life was inevitable, in the sense that these laws applied inexorably to grind out life. Unfortunately, neither view seems cogent: The "chance happening" hypothesis obscures the deeper question of what mitigating circumstances necessarily held sway prior to life to allow chance mutations to occur that *could*, in principle, lead to the complex molecular structures underlying life. Even such chance combinations could only occur under mitigating circumstances that constrained certain combinations over others. Unmitigated chance, or truly spontaneous mutation, would logically permit *any* arbitrary combination whatsoever. But the existence of laws of nature, and the selectivity of their initial conditions, logically entailed life as an actuality and not as a mere logical (chance) possibility. This is a clear confusion of the laws of nature with the laws of logic. Laws of nature are not existentially arbitrary, whereas the laws of logical systems may be, because they need only conform to the principle of noncontradiction—a very weak criterion that excludes fewer possible outcomes than do natural laws constrained by precise initial conditions. Whatever is the case in nature is not only logically possible; it is also naturally potential and existentially instantiated (actual). Therefore, the "chance happening" hypothesis fails, not because it is illogical but because it is *only* logical—permitting other possible worlds than the one we actually live in.

But does the determinists' hypothesis fare any better? It seems not, because the view that natural laws have applied inexorably to grind out whatever is the case (e.g., life) must also assume that the initial conditions to which the laws applied to grind out reality were such as to allow whatever happened to happen. Clearly, this is nothing more than a tautology asserting that given the laws, in order for life to be as it is, the initial conditions for it to be as it is must necessarily have prevailed. This is true but trivial; all it asserts is that the necessary (initial) conditions for life must necessarily have been the initial conditions for life.

The question remaining under either hypothesis is how might such regresses be avoided. A third, but scientifically unpopular hypothesis, that attempts to avoid the regress is the teleological argument that asserts that the production of life was the purpose that the laws of nature and initial conditions were designed to accomplish. But this hypothesis leaves unanswered two important questions: First, what is the design of the laws and the initial conditions that permitted life? And second, by what means was this design cosmologically orchestrated? To regress to a "God" hypothesis is to discharge the argument from the purview of science altogether and thus to render it irrelevant to our purposes.

However, there is an argument, unlike any of these, that avoids the regresses they entail by offering a theory of what initial conditions must necessarily exist, not as necessary a priori facts, but as necessary a posteriori facts. This argument might be called the "unique origins" hypothesis. It goes as follows: What now exists is necessarily *uniquely* consistent with that from which it originated. Unique consistency of one thing with another means that neither of the things in question is conceivable without the other (logically, a biadjunctive relation). The argument, implicit in the foregoing, that the science of life and the science of the physical world must be mutually dependent is by no means novel. For instance, Wheeler (1974) suggests that given that the universe is home for man, then the initial conditions for cosmological evolution must have been attuned a priori to the possibility of life tens of billions of years prior to the occurrence of life of any sort (cf. Blum, 1968). Wigner (1970) has argued that the origins of the self-reproducing unit required for life can not be accounted for by quantum mechanics. And in this regard, Pattee (1971) has made the bold suggestion that the biologist might turn the tables on physics by asking, "Can life explain quantum mechanics?"

Consider the following argument of Dicke (1961). All the mechanisms for life that have ever been conceived require elements that are heavier than hydrogen (Wald, 1963). Such elements depend for their production on thermonuclear combustion, which happens to need several billion years of cooking time in the interior of a star. The theory of general relativity tells us that for a universe to provide several billion years of time, it will have to be several billion light years in size. Hence, Dicke's (1961) conclusion that given life, the size of the universe is what it is. Or, as Trimble (1977) remarks more generally: "It seems, in other words, that the Universe must be more or less the way it is just because we are here [p. 85]."

There is a danger in the views of cosmological theorists such as Wheeler and Trimble—that they might be interpreted as merely a resurgance of the perennial, but philosophically discounted, teleological argument. It will serve us well therefore to consider critically what type of logical proposition is entailed by an assertion such as that of Trimble just quoted. For it is our contention that cosmological theorists like Wheeler and Trimble intend to endorse the "unique origins" argument rather than an obtuse version of teleology. Necessarily, the consideration to follow overlaps with and extends the preceding deliberation on the proposed Law of Existence. Indeed, the Law of Existence can be used to demonstrate how one's endorsement of the

"unique origins" hypothesis not only avoids the problems of the teleological argument but provides a positive principle by which the actual world (that which is existentially the case) can be individuated from among all logically possible worlds (those which are only logically possible).

We may paraphrase the quote from Trimble in three logically distinct ways:

1. *Because* life is what it is, then the universe is what it is.
2. *If* life is what it is, then the universe is what it is.
3. *Since* life is what it is, then the universe is what it is.

With reference to (1), if it is assumed that life arrived late in the course of cosmological evolution, then the nature of the physical universe would be determined by something that appeared later than it—a clear case of the teleological argument. How some effect can be the cause of something earlier is left unexplained.

The conditional reading of Trimble's quote allows for the possibility that:

1. Life might not have been what it is now, and yet the universe could still be what it is.
2. Neither life nor the universe might have been what they are observed to be; that is, (a) "if F, then T" is valid; and (b) "if F, then F" is also valid. The only reading that is excluded is (c) "if T, then F," which is invalid.

But we would not be happy with the proposition that the nature of life and the nature of the universe are so loosely related.

What we wish to capture is the claim that the nature of living organisms fits with the nature of the universe in a tightly constrained system of mutual compatibility relations. Therefore, the most appropriate propositional form is the adjunctive or, more precisely, the biadjunctive, which captures the sense that the universe and organisms living in that universe are bound together by mutual compatibilities. In other words, since life is what it is, then the universe is what it is—namely an environment for life; conversely, since the universe is what it is (and has been), then life has the character that it does. $(U \succ L) \cdot (L \succ U) \equiv U \diamond L$.

Sensitive to the developing argument, we may say that the biadjunctive expresses the animal–environment synergy whereas the conditional form expresses animal–environment dualism and the causal form expresses a logically opaque teleological hypothesis.

The Law of Existence can be used to argue that among all logically possible worlds, only that world scheme that when elaborated proves to provide a home for the most compatible phenomena is to be ascribed to our actual world. If we assume that reductionism is untenable so that physical (ϕ), biological (β), and psychological (ψ) phenomena are logically distinct objects, then the "unique origins" arguments . . . can be shown to follow from the compatibility logic (i.e., the Law of Existence). Assume the logically possible categories of objects ϕ, β, and ψ. By taking these in all possible schemes, a set of distinct but equally possible worlds are indicated: $W_1 = (\phi)$, a purely physical world without life or mind; $W_2 = (\beta)$, a world where all objects consist of living material governed by biotonic law; $W_3 = (\psi)$, a world of subjective idealism; $W_4 = (\phi, \beta)$, a world without "mind;" $W_5 = (\phi, \psi)$, a world where "mind" resides in inanimate stuff; $W_5 = (\phi, \beta)$, a biotonic world composed solely of living, psychological entities; and, finally, $W_6 = (\phi, \beta, \psi)$. Clearly, by the Law of Existence due to the fact that W_6 consists of a larger set of mutually compatible categories than the other possible worlds, it is more likely to exist than they are.

Let us pursue this rough sketch of a logic of synergistic relations among natural systems through a consideration of two other possible laws.

There are naturally potential objects, events, or worlds that—although not known to exist—could in principle exist under the current conception of natural law if only the initial conditions of cosmological evolution had been otherwise. This suggests the need for a second law of compatibility logic to supplement the Law of Existence; we call it the *Law of Potentiality*. In other words, that object, event, or world that is not mutually incompatible with anything that exists is naturally potential (rather than merely logically possible).

For example, assume b is possible, and let $\exists W$ be the actual world of existing objects; then b is potential ($b!$) if the adjunctive proposition, $(b \succ \exists W) \equiv b!$. On the other hand, given some logically possible object c such that $c \not\succ x$ where $x \in \exists W$, then c is not potential (i.e., $\bar{c}!$).

And, finally, there are those naturally potential entities that may exist by virtue of the dependency some existing entity has on them. We call this the *Law of Subordinate Existence:* Given that $a!$, that b, and that $\exists b \in a!$, then it follows that $(\exists b \succ a!) \equiv \exists a$. Intuitively, if a is potential and b, which exists, requires a as a condition of its existence (e.g., an initial condition), then a also must necessarily exist. This means that if $\exists W$ is the actual world scheme embracing b $(b \in \exists W)$, then it embraces a as well $(a \in \exists W)$, i.e., $(b \in \exists W) \diamond (a \in \exists W)$.

Let us summarize this section by identifying its thrust with respect to the parts that follow. We believe the implications of the mutual compatibility of life and universe to be profound and to bear strongly on the perennial puzzle of perception. Perception is most usefully conceived as an adaptive relation between animal and environment, two terms that are readily recognized as scaled-down versions of "life" and "universe," respectively. In the perspective being developed, animal and environment will be said to be mutually compatible in that a given species adjunctively entails its environment and a given environment adjunctively entails its species. But the understanding of this mutual compatibility and its implications rests with several prefatory considerations.

Environment and Econiche

First among them is the ambiguity of the term *environment*. It has been commonplace in the past 100 years to remark that organisms come to fit the environment by natural selection. But the notion of fit implies complementation, rather like the relation among pieces of a jigsaw puzzle; and insofar as there are many species, there must be at least as many environments for which the species are the apropos complementations. It is terribly evident that the term *environment* is asked to do double duty both as a general animal- or organism-neutral term and as a specific, animal- or organism-related term. Let us reserve *Environment* (with an upper-case initial letter) for the solids, liquids and gases, or the substances and media (interfaced by surfaces) that comprise the planet Earth; this will be the animal-neutral usage. The animal-related usage will be captured by the term *environment* (with a lower-case initial letter) or more advisedly by the term *niche* or *econiche*. The second sentence of this paragraph can then be rewritten partially and more accurately as: Life came to fit the Environment, and organisms came to fit econiches, where Life is used in the general sense commensurate with the usage of Environment.

Fitness of the Environment

It will prove helpful to the developing thesis of animal–environment synergy to reverse the commonly ascribed valences of animal and Environment and take the animal term as the independent variable and the Environment term as the dependent variable. Stripping away a greal deal of the variation in the concept of animal, we ask: Given the common properties of living things, what must be the properties of the Environment, so that it might provide a fit to Life? This reiterates Henderson's question of "the fitness of the Environment" (Blum, 1968; Henderson, 1913/1970). If Life and Environment are mutually compatible (just as we have already supposed that Life and Universe are), then it is just as meaningful to ask how Environment came to fit Life as it is to ask how Life came to fit Environment.

An in-depth exploration of the fitness of the Environment is beyond the scope of this paper. It will suffice to limit ourselves to the remarkable thermal properties of water, for they are of great importance to the Life process and they may be taken to illustrate the proposition that Life adjunctively entails Environment.

The properties of water that contribute to its fitness for Life are intimately linked with the properties of the element hydrogen. Examination of the periodic tables indicates the uniqueness of this element: Hydrogen atoms are the lightest and the smallest, permitting hydrogen to enter into more chemical combinations than any other element. Chemical combinations are due in part to the instability of certain electron configurations. In the face of such instability, an atom may host electrons from another atom—in which case we speak of ionic bonding—or two atoms may share a pair of electrons—in which case we speak of covalent bonding. Water is the covalent bonding of three atoms (that is, three nuclei and their attendant electrons), two of hydrogen and one of oxygen. Significantly, the hydrogen atoms are on one side of the water molecule, the oxygen atom on the other. In short, the atoms do not lie in a straight line, and this asymmetry in the structure of the water molecule is of singular importance to the properties of water. The negative charge of the electron clouds opposite the hydrogen atoms attract the hydrogen nucleus of an adjacent water molecule to produce a low-energy, easily formed, easily ruptured bond that is referred to as a *hydrogen bond.* It is the relative ease with which water molecules become hydrogen bonded to form three-dimensional lattices that gives water its special properties. On the average, six water molecules clump together, giving water much higher values for specific heat, latent heat of vaporization, and latent heat of fusion, viscosity, and surface tension than would be the case if the molecules remained separate.

A primary role of water seems to be in preserving a relatively constant temperature for the Earth. Terrestrial and aquatic life as we know it survives in a relatively small range of temperature; water's fitness to Life is manifest in large part by its singularly important contribution to preserving this range.

Consider first water's high specific heat. Compared to other substances, water must gain or lose a large amount of heat before there is an appreciable change in its temperature. This property prevents sharp rises in water temperature that might accompany the night-to-day transition and moderates water temperature extremes that might accompany the seasons. Moreover, with water covering so much of the Earth, its high specific heat prevents sudden shifts in the temperature of the Earth. Equable temperature of the ocean and the moderation of the climate are the principle consequences of water's high specific heat. But there is a third consequence worth noting, and it has to do specifically with the individual organism. Given that water is the principal chemical constituent, a given quantity of heat produces the smallest possible change in the temperature of the body. If some other substance were the principle constituent, the elimination of heat would become considerably more contrived and arduous, and the regulation of temperature during muscular exertion well nigh impossible (Henderson, 1913/1970).

The control of the Earth's temperature is also assisted by water's high latent heat of vaporization. To convert 1 gram of liquid water into water vapor

requires approximately 500–600 calories of heat, which of course must be supplied by the adjacent medium, the air. Similarly, to condense 1 gram of water, the same amount of heat must be withdrawn from the water and taken up by the air. The significance of water's high latent heat of vaporization is that the amount of heat required to produce a given amount of vapor in the air is considerably greater for water than for most other substances. It follows, therefore, that water is close to optimal for prohibiting rapid rises in air temperature (as might accompany sunrise).

Consider the related situation of converting water in the liquid state to ice. At the freezing point, 80 calories must be withdrawn from the water to convert 1 gram of water to ice. This conversion warms the air; moreover, water's high *latent heat of fusion* guarantees that large bodies of water will not significantly exceed the freezing point. Below the ice caps of the poles, life finds a haven. But it is due to a curious feature of the water molecule that ice floats on the surface rather than descends—with putatively disastrous results—to the bottom. In the solid state, water molecules do not crowd together, making water one of the few substances that is less dense in the solid state than in the liquid state. Water's greatest density is reached not at the freezing point but at 4° C; liquid at this temperature, the denser water sinks, forcing the warmer water to the surface and thus insuring that freezing proceeds from the top to the bottom and not vice versa.

The foregoing is not exhaustive of the properties of water that fit Life. Ideally, however, it suffices for our purposes. The reader is referred to Henderson (1913/1970) and to Blum (1968) for a fuller account. Let us conclude this piece by recognizing the nonarbitrariness of the relation between water and the earth.

Hydrogen's low atomic weight makes it a good candidate for escaping earth's gravitationaL field. That a hydrogen egress has not occurred to a debilitating degree is due in part to hydrogen's ability to combine with other elements, yielding molecules of sufficient mass to be retained (Blum, 1968). But it is also due in part to the size and temperature of the Earth; a smaller or a hotter Earth and the availability of hydrogen would have been lessened to a degree possibly prohibitive of Life.

Additionally, we may note that in reference to the fitness of water's high latent heat of vaporization, other hydrogen-bonded molecules exhibit a similar fitness. Thus, theoretically, hydrogen fluoride and ammonia could have provided a fluid medium consonant with life. These substances, however, are ruled out, simply because the temperature of the Earth does not permit them to exist in the liquid state. In appreciation of the web of mutual compatibilities, we are reminded that the Earth's temperature is in large part due to its speed of rotation and to its distance from the sun. In short, liquid water and the Earth are compatible, but liquid hydrogen fluoride and the Earth and liquid ammonia and the Earth are incompatible.

Partial and Total Systems

Let us now consider the concept of *system*, for it is of special significance to an understanding of animal-environment synergy. The following description comes from Weiss (1974): A system "... appears as a complex unit in space and time so constituted that its component subunits, by "systemic cooperation," preserve its integral configuration of structures and behavior and tend to restore it after nondestructive disturbances [p. 44]." In reference to system behavior, Mach (1902) observed that when a symmetrical system is deformed in such a way as to destroy the symmetry, the deformation is complemented by an equal and opposite deformation that tends to restore it.

Any entity that we should choose to label a *system* on the basis of the preceding descriptions will have a distinguishable "inside" and "outside." Where a system is contained within another system (as all systems will be, with the exception of the total universe), we may identify the subsumed system as a partial system (cf. Humphrey, 1933). It must necessarily be the case that a partial system cannot, in all practicality, be disengaged (in the sense of observed in isolation) from the system that includes it; it can of course be disengaged in theory. The decomposing of systems is an unavoidable feature of science. It makes the universe of phenomena potentially manageable. Thus, given an isolable collective of entities, the manner of their interrelating can be studied with planned indifference to the fact that the process or structure under observation is sensitive to its surroundings.

But it is a delicate strategy that disengages a partial system from the system that includes it. Considerable caution must be taken to insure that the decomposition does not go so far as to slip by the system (or unit) that is actually exhibiting the phenomena of interest. In particular, the consequences of overdecomposing are twofold. First, the phenomena may appear to be indeterminate and to refer to no underlying law, when in fact at their proper and coarser grain size of analysis, they are determinate and lawful. There is a principle advocated by Weiss (1969) that anticipates this consequence of overdecomposing—namely, that there may well be *determinacy in the gross despite demonstrable indeterminacy in the small* (see also Bohm, 1957). Second, there is a tendency to ascribe erroneous content or function to the partial system. Where a selected system is at the wrong grain size of analysis for the phenomena of interest, that system must take on properties that putatively could secure the phenomena. In what follows we present examples of these two consequences of overdecomposing.

The first example was used, and for very much the same purpose as intended here, by Humphrey (1933). Suppose that the phenomena of interest are the short-period diurnal and semidiurnal tides and the long-period tides whose periodicities range from 14 days to 19 years. And suppose further that these short- and long-period oscillations in sea level were thought to be phenomena of the Earth-Water system. Then it is not difficult to imagine that from the perspective of this system, the phenomena in question would look capricious and that they might be interpreted as the behavior of different systems at different times. But the lawfulness of the tidal phenomena is soon vindicated when the phenomena are understood as indices of a larger system—precisely, the Sun-Moon-Earth-Water system. The later system embodies the laws of which the tides are necessary consequences; in contrast, the partial Earth-Water system does not embody these laws, and so there is no invariant basis in that system for the changes in sea level.

The second example is from Ashby (1963). The example makes the general point that if the total system (from the perspective of the phenomena of interest) is unobservable, the partial system that can be observed may assume "remarkable, even miraculous properties" (Ashby, 1963, p. 114). The magician's trick provides a paradigm case: It looks miraculous, because not all of the significant variables are observable.

Consider a system composed of two interconnected devices A and B and an input I that affects both. Thus A's inputs are both B and I. The device A shows some characteristic behavior R, only when: (1) I is at state y; *and* (2) B is at state z. And it happens to be the case that B is at state z only *subsequent* to I taking the value x.

There are two observers. Observer 1 sees the total system and is able to conclude that R occurs whenever the total system shows a state with B at z and I at y. Observer 2 cannot see B (or does not take it into account). Consequently, knowing the states of A and I is insufficient to reliably predict the occurrence of R. After all, I is sometimes y and sometimes some other state. Nevertheless, Observer 2, by paying attention to earlier states of I, can make reliable predictions about R. If I passes successively through states x and y, then R will occur and not otherwise. It follows, therefore, that Observer 2 can make reliable predictions by taking into account successive values of I that he or she can in fact observe. But suppose that the two observers now argue about the "system." Observer 1 will claim that R is fully accounted for by the *present* state of the system; Observer 2 will claim that R can only be accounted for by considering the *past* states of the system—that is, only when memory is assumed. The point is, however, that the two observers are arguing about different systems (respectively, $A + B + I$ and $A + I$) and that Observer 2 ascribes "memory" to the system as a substitute for failure to observe (or to take into account) B. As the bottom line to this example, we may write that the possession of some property by a system is not wholly an objective property of the system (cf. Ashby, 1963). Rather, the ascription of content or function depends on the relation between the system and the observer. And obviously, properties will be ascribed to the degree that the total system is unobservable (or ignored).

Consider one further example. Weiss (1969) believes that the acription of powers to the gene, such as "controlling" and "organizing," is misguided. Indeed, he argues controversially that it is logically and factually fallacious, for the very reason that the gene (more accurately, the interaction among genes) is an overly decomposed system for the phenomena of interest—say, the growth and development of an organism. The popular reductionist view (e.g., Shaffner, 1967) with which Weiss takes issue fosters the attitude that the gene imparts order to an orderless and logically separate surrounding milieu. This amounts to the claim that the genes have a monopoly on the control of growth and development. The claim is logically weak on two related grounds: One is that it introduces the phenomena of "control," "organization," etc. as first principles—phyenomena *sui generis*; the other is that terms such as "control," "organize," "coordinate" are intentional terms. And as Dennett (1971) remarks, any theorist who uses intentional terms has taken out a loan of intelligence (or rationality) that must eventually be repaid.

The claim is also weak on factual grounds. As Weiss (1969) takes great pains to point out, the milieu in which the genes are enclosed is highly ordered, perhaps as ordered as the genes are themselves. It is therefore more judicious, Weiss argues, to answer the question of "What controls or coordinates?" with "the whole" rather than "the gene." We are reading this argument of Weiss's as saying that control and coordination of organismic development are necessary consequences of the mutual fit among the various biological pieces. Control, coordination, and the like are not phenomena *sui generis*.

This last example is a point of entry into what we take as the most telling feature of natural system dynamics. Given a total system (that is, one for which the phenomena of interest are virtually determinate by its laws), the partial systems of which it is composed must be so structured that for any single partial system, the remainder of the system provides the requisite context of constraint. By a definition we have sketched elsewhere (Turvey, Shaw, & Mace, in press), systems in which an "operational" component and the context of constraint are wedded together into a relatively closed, single unit are designated as *coalitions*. Simplistically conceived, given two systems X and Z that form a coalition, X constrains the degrees of freedom of Z, and Z constrains the degrees of freedom of X. We say that control or coordination or organization in such a system is the product of the fit between, or *dual complementation* of, the two partial systems (Fitch & Turvey, 1978; Turvey et al., in press). It is significant to note that in the coalitional conception, "control," "coordinate," "organize," etc. are not first principles,

properties *sui generis*. Nor are they properties to be conceived as properties possessed by one or another partial system, as a gene is said to possess the capacity for controlling and for organizing the encompassing milieu (or as an animal is said to possess the capacity to ascribe meaning to the encompassing Environment). On the contrary, such properties are the properties of the coalition, the minimal system identified relative to the phenomena of interest, which carries its own context.

The Mutual Compatibility of Animal and Environment: Affordances and Effectivities

The animal-neutral conception of Environment, at the very finest grain, is matter and energy understood as particles and the laws governing their motion. At a coarser grain, Environment may be described (as earlier) in terms of solids, liquids and gases. On rewording, this latter description reads as "substances and media interfaced by surfaces."

What we now seek is a partitioning on the coarser grained description of the Environment that yields environments or econiches. That is to say, a partitioning that results in animal-specific (more aptly, species-specific) descriptions. The major criterion for this partitioning is that the descriptions that arise are optimal for understanding how the different species of animal relate to their surroundings as knowing-agents and not simply as biological or physical entities (cf. Shaw & Bransford, 1977).

The partitioning problem has been addressed by Gibson (1977) through the concept of *affordance*. As Gibson (1977) remarks: "Subject to revision, I suggest that the affordance of anything is a specific combination of the properties of its substance and its surfaces taken with reference to an animal [p. 67]." By this conception, an econiche or environment is defined as a set of affordances, or an *affordance structure*.

Examplary of an affordance is a place or surface that supports upright locomotion by a human: a surface that is more nearly solid than liquid, more nearly horizontal than vertical, more smooth than wrinkled, and more near the feet than the head. What is evident, therefore, in the concept of affordance is the notion that properties of substance and surface enter into invariant combinations to comprise an animal-relevant, alternative description of the Environment. The Environment is partitioned relevant to an animal's, or more aptly a species of animal's, capacity for activity.

The principle of mutual compatibility, however, invites a further and complementary partitioning—namely, a partitioning of Life with reference to environments or econiches. The term *effectivity* is offered to complement the term *affordance*, and it is defined subject to revision as follows: The effectivity of any living thing is a specific combination of the functions of its tissues and organs taken with reference to an environment. By this conception, an animal is defined as a set of effectivities, or an *effectivity structure*.

We may collect together the two partitionings in this manner: An econiche is an affordance description of Environment in reference to a particular species; a species is an effectivity description of Life in reference to a particular econiche. And we may schematize the affordance and effectivity conceptions in the following way, in general accordance with the compatibility logic:

> An environmental event or situation X affords an activity Y for an animal Z *if and only if* certain mutual compatibility relations between X and Z obtain (i.e., $X \diamond Z$).

> An animal Z can effect an activity Y on an environmental event or situation X *if and only if* certain mutual compatibility relations between X and Z obtain (i.e., $X \diamond Z$).

The Concept of an (Epistemic) Ecosystem

The preceding is by way of arriving at a tentative definition of an ecosystem and, hence, animal–environment synergy. Our conception of an ecosystem will differ from more familiar conceptions, for these conceptions forwarded by biologists and ecologists are intended to capture the relation between an animal *as a biological or physical entity* and its habitat. Our conception, on the other hand, is intended to capture the epistemic relation between the animal *aş a kowing-agent* and the environment that is known. An ecosystem is a coalition comprising an animal plus a mutually compatible environment (or, equivalently, an environment plus a mutually compatible animal). The animal is a closed (but unbounded) set of effectivities, or goal-directed functions, that identify the potential actions of the animal and that complement the affordances. The environment is a closed (but unbounded) set of affordances, or functionally defined goals, that identify the potential perceptions of the animal and that complement the effectivities. Minimally, an ecosystem is a relational structure with three terms corresponding to the following: an effectivity structure, an affordance structure, and a symmetry operation (to be defined later) that relates the two.

The dualism of animal and environment encourages the view that the animal possesses a model of its environment (e.g., Gregory, 1969); this internal representation is the proposed basis for interpreting the environment's signals and for directing and controlling behavior. In the phrases used earlier, this model or representation is—with reference to perception—the conjunct of a theory of the environment and a theory of how the environment structures energy distributions.

Similarly, the dualism encourages the view that perception *represents* the facts of the environment to the perceiver. A shopworn retort is that if this view were true, would it not require a perceiver, an animal analogue, to perceive the representation? And would this not require another smaller scale representation with its own scaled-down perceiver *ad infinitum*, that is, an unequivocal regress? There is a way to avoid this regress—precisely, by defining perception as the *act of representing* rather than as *a process of using a representation*. But in this usage, it is doubtful that the term *representation* is appropriate.

To represent entails three terms: that which is represented, the representation itself, and that for whom the representation is intended. It seems to us a confusion to treat the act of *using* a representation as being logically independent of the process of *making* a representation. For the concept of representation is user dependent; it must be tailored to fit the user's capabilities.

A representation for one class of users may not be a representation for another class of users; part of the meaning of the term *representation* is the rule or rules required to use it for the purpose it was intended. For instance, a data representation in the programming language of one type of computer may not even be compilable on another type of machine. Similarly, a problem stated in Chinese characters is not a representation of the problem for persons who do not read Chinese. If this argument is valid, then it is not at all clear what it would mean to say that perception is the process of making a representation that is not to be used (perceived) by some agent. Thus, the concept of a "userless" representation is muddled (Shaw & McIntyre, 1974).

In any event, internal representation as the proposed operation that epistemically relates animal and environment is plainly asymmetric. Though it is said that the animal represents (via an internal model) its environment, it is rarely if ever said that the environment represents (via *any* model) its animal; indeed, it would be a very odd thing to say.

In contrast, the synergistic perspective implicates a symmetrical operation binding animal and environment (Shaw, McIntyre, & Mace, 1974; Turvey et al., in press). The mathematical concept of duality (not to be confused with dualism) is offered as a likely candidate for this operation.

A simple interpretation of duality is given by considering a concept defined by means of a diagram consisting of vertices that label sets and arrows, from one vertex to another, that label functions on one set to another (MacLane & Birkhoff, 1967). A "dual" of a diagram can be obtained by reversing the arrows—the dual diagram can then be called the "dual" concept. If in one diagram X is the domain of the function f, in the dual diagram X is the codomain of the function f. Crudely speaking, duality in mathematics is a principle by which one true statement can be obtained from another by merely interchanging two words. Thus, as a further example, in the projective geometry of the plane, the words *point* and *line* can be interchanged, giving the dual statements: "Two points determine a line" and "Two lines determine a point." And in set theory, the relations "contained in" and "contains" can be commuted (with the union becoming the intersection and the intersection becoming the union), leaving the original structure unaltered.

Consider an example of duality in the context of a linear functional (a linear transformation whose codomain is the field of scalars with which we are concerned). The circumstance 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, etc. Let the shopping list be $(a, b, c, \ldots)$, and let the price list be $[A, B, C, \ldots]$, so that the cost of the groceries is given by $Aa + Bb + Cc \ldots$ 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 $Aa + Bb + Cc \ldots$ 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 an animal and its environment (or an environment and its animal) as duals, in which case the relation between the descriptors of the animal and the descriptors of the environment is not one of symbolizing but of complementing. The concepts of affordance and effectivity are dual concepts, and a simple metaphor conveys the gist of this idea: An animal and its environment relate as the two pieces of a two-piece jigsaw puzzle (Fowler & Turvey, 1978).

We can now complete our definition of an (epistemic) ecosystem: It consists of an affordance structure, an effectivity structure, and a duality operation that relates the two.

Perception as an Ecosystem Property

Earlier, attention was brought to the problem of identifying *the* system to which a given phenomenon or set of phenomena corresponded. Recall that "meaning" has been traditionally assigned to the system "animal." Symptomatic of this assignment is the convention of treating sensation as meaningless and perception as meaningful; more generally, it is the distinction drawn between what a thing is and what that thing means—the former being physical and objective, the latter being mental and subjective.

Significantly, the concept of affordance differs from past treatments of meaning in that an affordance is *objective*, defined over the components of an ecosystem. A distinct bonus of a description of the Environment that is animal-related is that it obviates the requirement that the individual animal *add* meaning or value to that which is "merely" physical.

The idea that perceiving is a process that involves a transfer from *meaningless* to *meaningful* is consonant, as noted previously, with animal–environment dualism. But it is an ill-conceived idea, as Gibson (1950) has long maintained. In the perspective of animal–environment synergy, "meaningful perception" is adjunctively entailed by the mutual compatibility of the animal and its environment. Meaning is not a kind of thing that an animal can possess, not a kind of thing by which an animal can impart order to an orderless habitat. Nor is meaning a kind of thing that can be imposed on an animal by the Environment. Meaning is a property of the ecosystem, and individually the animal and the environment constitute *partial* systems with reference to meaning and, in general, to the phenomena of perception. In short, perception and its laws are at the level of description of an ecosystem and not at the level of description of an animal.

The What of Perception Re-examined: The Doctrine of Necessary Specificity

We have acknowledged the traditional complicity between the following two beliefs: One belief holds that the theory of physics has a monopoly on the description of reality; another belief holds that the patterning of energy by an environment (however that patterning is defined) is equivocal and inaccurate —the doctrine of intractable nonspecificity. The complicity lies in the fact that the basic variables of physics constitute a fine-grained description of the energy at the eyes, the ears, etc.—a grain size of description that yields a complicated, chaotic aggregate in contrast to the animal's environment and to the phenomena of perceptual experience (objects, surfaces, events, and the like), which at a considerably coarser grain of description, are coherent, orderly, and systemic. This incompatibility of descriptors, as remarked earlier, is tolerable in the context of animal–environment dualism. In that context there is no reason for surprise at a discontinuity in descriptors; indeed, it is virtually demanded by the received dichotomy of appearance and reality.

In sharp contrast we take the following to be a methodological prescription of animal–environment synergy: With respect to the study of a given phenomenon (such as perception), the animal-related statements and the environment-related statements must be equivalent in grain of analysis, and they must be compatible. If the animal-related statements are that the animal perceives obstacles and apertures as it steers its way through a cluttered terrain, then by this prescription, it would be mistaken to describe the environment-reflected light in terms of photons or in terms of a mosaic of rays of various intensities and wave lengths. Although these descriptions of the light are compatible with a grain of animal-related statements that includes references to individual receptor activity and retinal transduction, respectively, they are not compatible with the grain of description that includes references to the actions of the animal *qua* animal.

It has seemed in the past that only a very fine-grained description of the light is legitimate, because only the basic variables of physics have primary reality status (see Runeson, 1977a, 1977b). But though a very fine-grained description may be exhaustive in terms of the laws of particle physics, there is nothing in that description that *explains* how the light can be information about an animal's environment. If the evolution of vision was the induction of adaptive relations between a fine-grained description of the light and visual systems, then it would be difficult, if not impossible to account for the variety of visual capabilities manifest across species. For what reason should any given type of visual system limit itself to a restricted subset of the possible visual experiences made available by the Environment (von Uexküll, 1957)? At base, the problem arises from the doctrine that physics has a monopoly on describing what light really is. We will have to conclude that there are alternative descriptions of light—no one description more or less real than the other. And this conclusion, it should be noted, is congruent with the ecological approach to the definition of environment; an affordance structure is the reality for a given species.

First steps toward a description of the light at an ecological (as opposed to a cosmological or quantal) scale have been taken (e.g., Gibson, 1961, 1966b; Lee, 1974, 1976; Mace, 1977; Runeson, 1977b). Gibson (1961, 1966b) refers to the enterprise as ecological optics. More generally, when all energy forms are under consideration, the enterprise is referred to as ecological physics. The underlying premise is that at the scale of ecology, an energy medium is not completely free varying; but to the contrary, it is regularly patterned or constrained by the environment so as to be specific to the environment. The environment as a source of constraint on radiant light can be said to condense out environment-specific, complex optical particulars from the environment-neutral, simple optical particulars exhibited at a more molecular level of description. These complex particulars have been referred to by Gibson (e.g., 1966b) as invariants; and Lee (1976) provides an elegant case in point: Rate of magnification of a closed optical contour with internal texture uniquely and invariantly specifies time-to-contact between an animal and an object.

Significantly, the description of radiant light as constrained by an environment is neither redundant nor inconsistent with the most molecular description of the light. This is because a constraint is an *alternative description*, as Pattee (1972) has sought to clarify; and in this respect, an illustration of Medewar (1973) is illuminating. Given the order Euclidean, affine, projective, topology, each successive geometry allows larger equivalence classes than its predecessors and embodies fewer constraints. But what is true about a less constrained geometry, say topology, is not contradicted by a more constrained geometry, say Euclidean. Nevertheless, it is the case that topology cannot explain why two squares that differ only metrically are not equivalent in Euclidean geometry. In short, with respect to the least constrained (and putatively more basic) geometry, the most constrained geometry is not redundant; and neither is it inconsistent.

Importantly, the acceptance of alternative descriptions of the light (or any energy medium, for that matter) weakens the strangle hold of the doctrine of intractable nonspecificity. For in principle, there is a way of describing the light so that proximal stimulation and distal objects are not equivocally or imprecisely related; and this, surely, has been Gibson's (1950, 1961, 1966b) guiding intuition. It is notable that while students of perception in the past five centuries have paid lip service to physics' monopoly on describing light, they have at the same time pursued alternative and generally coarser grained descriptors than those distinguished by physics. This pursuit was inevitable, given the improbability and questioned usefulness of translating from the physicist's fine-grained description of the light to the philosopher's or psychologist's coarse-grained description of visual, phenomenal experience. But herein lies a dilemma. A theorist chooses some grain size of description coarser than the finest grain, presumably because the coarser grain facilitates understanding of the phenomenon in question. The phenomenon is more determinate in reference to the coarser grained description than it is in reference to the finer grained description. At issue for the theorist is the criterion by which to decide on the *proper* grain; ideally, the choice of criterion should not be arbitrary.

On this issue, animal–environment synergy is anything but mute. To begin with, it suggests that that description should be sought which is a partitioning of the ambient light in reference to an animal. An affordance-based partitioning would contrast with a partitioning relative to the transformations of Euclidean geometry. The latter is an animal-neutral partitioning and one that has played a significant role in the past half-millennium of perceptual theory. But partitioning the light relative to Euclidean geometry offers little by way of an understanding of perception as an adaptive relation, and its original usage was perhaps more a matter of convenience than of reason, bolstered by the implicit animal–environment dualism.

It follows (informally) from the compatibility analysis proposed earlier that the logically possible world in which the energy distributions are mutually compatible (that is, invariant or symmetrical) with the facts of the environment is more likely to exist than one in which such compatibilties fail to hold. The upshot is that animal–environment synergy advocates a *doctrine* *of necessary specificity*, and in so doing it offers a further guideline for choosing the grain of description—namely, that there must be *specificity in the coarse grain despite demonstrable nonspecificity in the fine grain*. That is to say, there *is* a grain of description at which the patterned energy is specific to the environment. The ecological theorist's charge is unequivocal: Pursue ever coarser grain sizes of description until the specificity is realized.

Patently, the doctrine of necessary specificity is the ecological orientation's counter to the traditional doctrine of intractable nonspecificity. Among the accomplices of the latter doctrine was the assumption that the basic variables of physics identify the primary reality and that the registering of these variables constitutes a necessary initial step in perception. In the ecological reformulation a complicity is observed between the doctrine of necessary specificity and the dehypostatizing of the basic variables of physics. The ecological reformulation postulates that complex particulars *qua* invariants, defined over the patterned energy, constitute information about the reality that is specific to the animal—precisely, the affordance structure that is its environment. As a further postulate, the animal's perceptual systems register these invariants directly, without prior registration of the variables basic to physics and without recourse to epistemic mediators (Gibson, 1966b; Mace, 1974, 1977; Shaw & Bransford, 1977; Shaw & McIntyre, 1974; Turvey, 1977). We pursue this latter postulate in the section that follows; but before doing so, let us consider a further implication of the doctrine of necessary specificity.

The doctrine of necessary specificity relaxes the traditional restrictions on the amounts of space and time over which information for a given environmental property might be expressed and to which a given perception might correspond. According to the doctrine, there is no fixed, context-free quantity of the space-time manifold to which can be ascribed the status of "region of perceptual information," in the sense that the information embraced by this region relates to perception whereas the information outside of the region relates to something else such as, for example, memory. Accordingly, it is ill advised, from the ecological point of view, to distinguish perception from memory along the lines that perception is of adjacent order whereas memory is of successive order, or that perception is of the present whereas memory is of the past. Gibson has often spoken of the detection of invariants over time (e.g., Gibson, 1967, 1973) to emphasize that the Newtonian instantaneous moment is not synonymous with the temporal grain of either perception or of the informational support for perception (cf. Turvey, 1977).

In the classical orientation toward events—that is, changes wrought over an object or complex of objects—the registering of form or static pattern was considered basic, and the perception of change was conceptualized as a deduction from sequences of registered static arrangements. As might be expected, a significantly different reading of events is given in the ecological

orientation. There are two major components of an event—the nature or style of the change (e.g., rotating, growing, bouncing) and the object properties preserved over the change—and it would follow from the doctrine of necessary specifity that there must be two kinds of invariant information corresponding to these two components. These invariants can be labeled, respectively, *transformational* and *structural* (Shaw & Pittenger, 1977). A transformational invariant is that information, specific to a style of change—that is preserved over different structures "supporting" the change. A structural invariant is that information, specific to an object structure, that is preserved over the styles of change in which the object participates. To perceive an event, therefore, is to detect these invariants.

The Postulates of Direct and Indirect Perception

To say of perception that it is direct, rather than indirect, is to say that it necessarily provides information about how things are (in reference to the effectivities of a given animal) and not merely about how they appear. Traditionally, as noted above, variants of the nonspecificity and independence doctrines such as the argument-from-illusion and the argument-from-incomplete-specification have been used to cast doubt on the claim that perception can in any sense be direct. In order that we might better understand the notion of indirect perception, let us formulate what is meant by the assertion that some observer, O, perceives some state of affairs, S (where S is taken logically as that which is the case). Under the indirect perception idiom, the assertion "O perceives S" means one of several possibilities:

"O perceives S as X."
"S appears as X to O."
"S is perceived as X by O."

The middle term X plays the role of an epistemic mediation for O's perception-knowledge of S. Under the indirect idiom, perception is of some surrogate that *contingently* stands for, or represents, but is not *necessarily* identified with S. To identify the contingent mediary X with what is necessarily true about S, requires an additional inferential step; in other words, O perceives X and then infers that X is to be identified with S, given that sufficient additional evidence to do so is forthcoming (say, from memory of previous occasions on which it *seemed* justified to do so or from application of an a priori logical rule for associating X with S that is deemed useful or correct).

Thus, from this characterization, perception provides only contingent, as opposed to necessary, grounds for identifying that which appears to be (namely, X) with that which actually is (namely, S). Several consequences follow from this that are consonant with the presumed import of the two arguments from illusion and incomplete specification:

1. If what is known (X) through perception about the world (S) is necessarily indirect, then perception-knowledge is at best contingent and must be treated always as potentially suspect.
2. If (indirect) perception-knowledge is merely contingent, then evidence from some source other than perception (e.g., inference or memory) is required to evaluate the worth of perceptual information.
3. Given that perception-knowledge can be shown to be a source of either true or false information about that which is the case, S (e.g., the perceiver's environment), then perception-knowledge, because it involves an inferential step, must be considered a proposition-making activity.

Thus, what might be called the *Postulate of Indirect Perception* can be summarized as follows: *Perception-knowledge consists only of contingent propositions about possible states of affairs that may or may not be demonstrated to be either true or false about the perceiver's actual world (e.g., the animal's environment).*

The Postulate of Indirect Perception has been tacitly adopted by students of perception for the past half-millennium and long before; and it is a logical consequence of the doctrines of intractable nonspecificity and perceptual independence from stimulation. But as we have intimated, this postulate renders the perceptual bases of an animal's knowledge about the dangers and pitfalls of its environment so weak and tenuous, that it is difficult to imagine the successful survival of even one generation of animals, much less the continued evolution of their species over countless generations without a break in the chain. The Postulate of Indirect Perception (or indirect realism) runs counter to the understanding that from the beginning of their association, animals and their environments have enjoyed common causal bases that guarantee their original and continued mutual compatibility.

The argument for a contrary postulate, that of *direct perception* (or direct realism), can be outlined as follows: First what justifies the claim that perception is a valid and reliable source of information for an animal or human about its environment is that perception is necessarily incontrovertible by any other form of knowing the environment (e.g., inference). Second, perception is incontrovertible, because it is necessarily a direct apprehension of that which is true *by force of existence* rather than by force of argument. And third, perception may not be contradicted, because only propositions may be true or false and perception is not a proposition-making activity. *Propositions* are assertions regarding states of affairs that either always obtain or never obtain. *Perception*, by contrast, is not an assertion about states of affairs but is a state of affairs and therefore necessarily obtains (a claim that is explored at length in Shaw et al., in press).

Here is the postulate that summarily captures the sense of the foregoing outline: *If some state of affairs,* S *is (directly) perceived to be some state of affairs,* T, *then it is necessarily what it is perceived to be, namely,* T.

This *Postulate of Direct Perception* can be placed in sharp contrast with the Postulate of Indirect Perception by restating the latter in analogous form: *If some state of affairs,* S, *is (indirectly) perceived by virtue of some other state of affairs,* T *(e.g., sense data or memories), then it is not necessarily what it is perceived to be namely,* T.

The former postulate can be interpreted as asserting that perceptual information provides direct, unassailable evidence regarding the identity of what is perceived; whereas the latter postulate claims only that perceptual information provides indirect, questionable evidence regarding the identity of what is perceived. (What is perceived is the environment, which—by the definition of environment or econiche given earlier—is species specific. It would be a mistake therefore to read either postulate as naive realism; from the perspective of evolution and ecology, realism is necessarily critical. (See Shaw & Bransford, 1977.)

The Postulate of Direct Perception can be arrived at by virtue of a further consideration of the compatibility analysis, viz., the Law of Existence. It follows (again, informally) that the logically possible world, in which perception is mutually compatible (that is, invariant or symmetrical) with the energy distribution or proximal stimulation as engendered by an environment, is more likely to exist than one in which such compatibiity fails to hold. That is to say, animal-environment synergy advocates a *doctrine of the symmetry of perception and proximal stimulation* as the counterassumption to the traditional doctrine of independence of perception from proximal stimulation. Thus, given an observation in which perception is stable but proximal stimulation appears to be varying, the traditional independence doctrine would foster the acceptance of the observation at face value; the ecological symmetry doctrine, on the other hand, would encourage a search for an alternative description of the proximal stimulation that was as stable as the perception.

The Postulate of Direct Perception is given by the fit between the two aforementioned ecological doctrines. Since a symmetry (law) between the environment (e) and the energy distributions as modulated by the environment (ϕ) holds, and since a symmetry (law) between ϕ and perception (p) holds, then by transitivity a symmetry (law) between e and p holds. That is, $e \diamond \phi$, $\phi \diamond p$, therefore, $e \diamond p$.

On this point we conclude our discussion of the ecological reformulation of perception. It remains for us to do two things: To draw up an inventory of the major contrasts between the legacy of the past five centuries and the ecological reformulation, and to identify some of the implications of the reformulation of perception for the understanding of memory. The inventory

TABLE 9.1

The Legacy of the Last 500 Years	*The Ecological Reformulation*
Animal–environment dualism	Animal–environment synergy
Conditional or causal logic	Adjunctive logic
Doctrine of intractable nonspecificity	Doctrine of necessary specificity
Doctrine of independence of perception from proximal stimulation	Doctrine of symmetry of perception and proximal stimulation
Experience as constitutive of perception	Experience as preparatory to perception
Postulate of indirect perception (or indirect realism)	Postulate of direct perception (or direct realism)
Events (change) as reconstituted or deduced from static samples	Events as transformational and structural invariants
Operation of representation (a ternary operator or triadic relation)	Operation of specification or duality (a binary operator or dyadic relation)
The theory of perception as independent of the theory of action	Coalitional organization of perceiving (affordance structure) and acting (effectivity structure)
Simple particulars and general-purpose devices	Complex particulars and special-purpose devices

is given in Table 9.1, and the implications for memory are given in the following section.

SOME IMPLICATIONS FOR THE INTERPRETATION OF MEMORY

How might we view memory, given the ecological reformulation of the problem of perception? If it is admitted that the distinction between the two no longer can be considered to reside in the temporaneity of memory experiences as opposed to the contemporaneity of perceptual experiences, then the basis of their distinction must be sought elsewhere. Especially, we are hard pressed to explain the perception of events that stretch over significant periods of time as "memories" of the cumulative effect of experiences of successive parts of the events. We perceive the concert, the duration of the day from dawn to dusk, the drying up of a puddle over a long, hot afternoon, and so forth (Shaw & Pittenger, 1977). Invoking memory as a process to explain how events are experienced begs the important question of what is experienced, simple or complex particulars, and moreover, stands in contradiction to the Postulate of Direct Perception.

Let us remark on the latter contradiction before pursuing the *what* issue. The Postulate of Direct Perception rules out epistemic mediators. Memories, therefore, cannot be the kinds of things that enter, with sense data, into a recipe whose product is a perception. Put another way, experience cannot be

constitutive of perception in the sense that experience traces are conventionally, said to be part and parcel of a perception. Rather, on the ecological reformulation, experience is *preparatory* to perceiving; said succinctly but incompletely, experience attunes or sensitizes perceptual systems to the information that specifies affordances.

Returning to the *what* issue—if memory itself is taken to be the experience of complex particulars (e.g., events), then the concept of memory merges indistinguishably with the concept of perception as reformulated, and no progress is made toward their distinct characterization. The attempt to consider perception of events as merely the stringing together of memory images or representations of successive perceptual experiences runs into perplexing difficulties (besides contradicting the Postulate of Direct Perception).

One such difficulty with the representationalists' (indirect) theory is that the memory images (or repreesntations) of each successive experience must themselves be contemporaneous; they must occur *now*, when we are remembering (Locke, 1971). Thus according to this theory, what we apprehend when we remember is not what has happened (i.e., the successive perceptual experiences) but what is happening now (i.e., the current memory experience). But if that is so, then how can a contemporaneous experience ostensively specify past (noncontemporaneous) experiences? How can a temporal series be rendered manifest in local signs of a spatial series; how can temporaneity be reduced to contemporaneity, or successivities to adjacencies?

The so-called trade-off between time and space is well understood, movies and other such recordings being prime examples. But as Pattee (1971) suggests, the puzzle with natural records, such as genes and memories, is not *how* they are made (for there are abundant causal mechanisms to explain their occurrence); rather, the difficulty is to conceptualize *what* is contained in such records. This is the real puzzle of memory. If we understood what constitutes a memory, then we might begin to work out the details of how what is remembered is remembered. Hence it is imperative, if progress is to be made, to hold fast to the distinction between the causal process that supports memory—the physical, chemical, and biological mechanisms—and the epistemic act of remembering as such. To confuse the two is to miss the heart of the puzzle.

The quest for an ecological reformulation of the problem of memory would begin with this distinction: Memory as a causal process that accomplishes record keeping of experience *versus* remembering as an epistemic act supported by such a mechanism but by no means explained by it. An analogy might make this distinction clearer. That the polar planimeter described earlier measures area is no where given as a manifest sign or obvious aspect of its mechanism. One moves the index arm around the perimeter of the closed line-drawing, and the measuring wheel skids and turns until a final value is arrived at for one complete circuit of the index around the figure. A person untutored in the use of the polar planimeter, even if told how to use it, would not immediately grasp what the significance of the act was; there would be no way of knowing what the numeric symbols on the measuring wheel signified. How could there be?—for the causal mechanism provides only support for the epistemic act of measuring area and is in no sense semantically equivalent to the act.

A similar argument can be made with respect to the causal mechanism of memory. Even the most thorough understanding of how it works would bring us no wit closer to understanding what it is that such a mechanism does nor what it signifies. In both cases, the significance of the epistemic act, whether remembering or measuring area, is not obvious but must be discovered. But how might we discover the significances, unless we already have constraining hypotheses regarding *what* it is we believe the devices in question were evolved or designed to perform?

Hence the puzzle of what mechanisms do must be pushed back to the question of why they originated—why they are needed. The desired ecological reformulation of the problem of memory, like that of the problem of perception, requires an insightful attack on the question of origin; for it is here and only here that the secret significance lies of why memory, perception, or other such processes should exist at all.

At least a stab can be made at what may be contained in memory records. Our hunch is that if the ecological reformulation of perception is in the right direction, then the attempt to reformulate the problem of memory should follow suit. First and foremost, memory—like perception—rather than being merely an organismic process, should be a property of an ecosystem. That is to say that memory like perception should be conceptualized in terms of the mutual compatibility of animals (as effectivity structures) with their econiches (as affordance structures).

The following three postulates represent a first effort to address the boundary conditions on learning, generalization of knowledge, and remembering, respectively. (The first postulate is written fully in both affordance and effectivity terms, but the effectivity portion is omitted in the second and third postulates for simplicity of presentation.) *Postulate I (Learning): An environmental event or situation X affords an activity Y for an animal Z, and an animal Z can effect an activity Y on an environmental event or situation X if and only if X and Z are mutually compatible* $(X \diamond X)$.

Where the first postulate states the boundary condition that must be satisfied if learning is to take place in a given situation, the second postulate states the conditions that must be satisfied if knowledge gained in such situations is to be generalized to analogous situations. *Postulate II (Generalization of Knowledge): An environmental situation X affords an*

activity Y for an animal Z only if another situation W affords the same activity Y for Z where X stands to Y as W stands to Y (i.e., $X/Y{:}\ W/Y$*) if and only if X is mutually compatible with Z in the same way that W is mutually compatible with Z [i.e.,* $(X \diamond Z) \equiv (W \diamond Z)$*].*

This postulate describes the conditions required for the analogical extension of knowledge from one situation to another according to the usual way of analyzing analogies and metaphors (Verbrugge, 1977). Following such an analysis, X/Y is the *topic*. W/Y is the *vehicle*, and $(X \diamond Z) \equiv (W \diamond Z)$ is the *ground* of the analogy. If the analogy is perceptually defined, then the postulate can be used in principle to capture the notion of perceptual invariants as the ground of the analogy. Finally, we identify the postulate that states the boundary conditions that must be satisfied if remembering is to be an ecologically defined epistemic act and memory a property of an ecosystem.

Postulate III (Memory): An environmental situation X affords an activity Y for an animal Z at some later time t_k *only if some situation W affords the same activity Y for Z at some earlier time* t_1 *where* $(X/Y{:}\ W/Y)$ *if and only if* $(X \diamond Z) \equiv (W \diamond Z)$.

This final postulate proposes a view of memory as knowledge that persists by analogical extension (generalization) from earlier to later situations; the second postulate, as already pointed out, can be used *inter alia* to propose a view of generalization by analogical extension over distinct perceptual situations. Hence the second postulate can be said to describe the necessary conditions for perception-knowledge, whereas the third postulate can be said to describe the necessary conditions for memory-knowledge. And in the unpacking and extension of these postulates is defined, in large part, the tack that an ecological orientation would take toward the phenomenon of memory.

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IV

BIOLOGICAL PERSPECTIVES