

afferent-efferent link and that there is a metamorphosis from meaningless states to meaningful states. To his credit, Sayre aspires to make the representations genuine. He wants them to stand for real things. He wants the transition from meaningless sensory states to meaningful perceptual states to be (mathematically) principled.

From my perspective as a proponent of the ecological approach to perceiving-acting (see Gibson 1979; Turvey, Shaw, Reed & Mace 1981), Sayre's sentiments are right but his premises are wrong. Not surprisingly, I find his treatment of intentionality disappointing. I concur with Sayre's implicit wish for a concerted effort to *naturalize* (my word) intentionality, but my preference is to keep the deliberations very close to natural science and the search for lawful regularities. Sayre is quite right in his assessment that an attempt to devise an explanation of intentionality in the Turing reductionism/token physicalism perspective of cognitive science (which denigrates intentionality to the states of a computational device) does not have a "ghost of a chance" (Carello, Turvey, Kugler & Shaw 1984; Turvey et al. 1981). But he is quite wrong, I believe, in suggesting that pursuing the purer equation of intentionality with representation (relieved of computational procedures) can fare any better.

Intentionality is directedness toward objects. Locomoting terrestrial animals, including humans, direct themselves through openings and around barriers. They direct their limbs in certain ways with respect to a brink in a surface - directing them one way if the brink is where they can step down and another way if it must be negotiated by jumping. Gibson (1966; 1979; Reed & Jones 1972) advocated mutually constraining theories of animals and environments (see Alley in press; Mace 1977; Michaels & Carello 1981) as the basis for an understanding of perceiving-acting that addressed such mundane intentional behavior. (This central thesis of the ecological approach, the duality of animal and environment [Shaw & Turvey 1982], implies that efforts to ground intentionality only in "environmental constraints" will miss the mark. Duality, by the way, is not dualism.) Gibson pursued a perceptual theory that was fundamentally intentional rather than one that is made intentional as an afterthought. With considerable care he identified how an understanding of intentionality of perceiving poses challenges for science on several fronts, and how these challenges might be met. I will describe two of them.

The first challenge is to describe the layout of surfaces with reference to the animal. This move is continuous with the larger lesson of relativity theory: All state descriptions are frame dependent. Reference frames are substantial and are not to be confused with the coordinate systems that abstractly represent them. The properties of an animal to which surface layout must be referred are basically the animal's magnitudes, its morphology, its metabolism. With regard to a brink, the separation of surfaces is in reference to limb magnitudes. Obviously a given brink can be referred to multiple, equally real frames. One frame is the terrestrial frame with distances and durations measured in arbitrary units. This frame is useful to the physicist but it is, by definition, animal-neutral. (In the received view it is mistakenly adopted as the sole objective frame.) Other frames are individual animals. Consequently, the same brink in the terrestrial frame is a place negotiable by leg extension in the frame provided by one (larger) animal not negotiable in this fashion in the frame provided by another (smaller) animal.

A second challenge is to describe how animals can be informed about these frame-dependent environmental properties (affordances) to which their activities are directed. There are two senses in which the term information is used (cf. Turvey & Kugler 1984). In the indicational/injunctional sense information consists of symbol strings identifying states of affairs ("the situation is so-and-so") or things to be done ("do so-and-so now"). Information in this sense is underconstraining, like a stop sign. The other sense is the specificational sense of Gibson (1979). In the case of vision, information is optical structure

Intentionality: A problem of multiple reference frames, specificational information, and extraordinary boundary conditions on natural law

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It is refreshing to see a scholar who is largely sympathetic to the so-called information processing or representational/computational approach to cognitive systems recognizing its fundamental inadequacies. To be blunt, that approach fails to come to terms with either information or intentionality. Sayre's response to these inadequacies, however, keeps close to the received view. He assumes that a biologically and psychologically relevant sense of information can be provided by the mathematical theory of communication; he assumes that intentionality amounts to representation. These assumptions are bolstered by the closely cognate beliefs that intentionality is to be ascribed to some roughly midway-state in the classical

lawfully generated by facts – properties of surface layout, properties of an animal's movements. This structure does not resemble the facts: rather it is *specific* to them. The ecological argument is that information in the specificational sense meets the above challenge. I will give some examples shortly but I wish to preface them by noting what's at issue in the contrast between the two senses of information.

The indicational/injunctional sense, I believe, fits neatly into a tradition that takes the primary perceptual activity to be discriminating among members of a set and the equilibrium thermodynamics of closed systems as the branch of physics to which discussions of information can be meaningfully referred. In such a system the states are enumerable from the outset. To put it very roughly, the information notion only has to address their individual probabilities, thereby providing a basis for discriminating among them. Living things, however, are open systems. The animal–environment system, in which an animal participates as one of the two mutually tailored components, is open. Significantly, the states of an open system need not be fixed at the outset. Given fluctuations in the microstructure and nonlinearities, a scaling up in one or more variables discontinuously decreases an open system's symmetry. More constraints arise. The system becomes more ordered. New states come into existence. Consequently, the order principle and complexions of Boltzman, and the notion of information that they sustain, are of limited applicability to open physical systems (e.g., Prigogine 1980), including animal–environment systems.

Open (evolving, developing) systems motivate a different notion of information from closed systems (Kugler, Kelso & Turvey 1982; Kugler & Turvey, in press). Sayre makes an offhand remark about the information in the genes and in the phenotype. Efforts to apply classical information theoretic notions to the genotype–phenotype link, conceived as a communication channel, have largely been dismissed. In intuitive terms, the dismissal is based upon a feeling that an information metric should recognize the greater complexity of the full-fledged animal (Waddington 1968). Even where the open–closed distinction is sidestepped, as in Pattee's (1973; 1977) thoroughgoing and celebrated efforts to detail the problem of a physical interpretation of "genetic information," the conceptions of the mathematical theory of communication have proven to be of little value.

The specificational sense of information is consistent with the perspective that takes perceiving the persisting and changing properties of a thing as primary. For Gibson (1966; 1979) the fundamental question is how to characterize the information that supports the perceiving of *P*: the question of how to characterize the information that supports distinguishing *P* from *Q*, *R*, and so on is secondary and derivative. Suppose that *P* is the animal itself. In locomoting, a terrestrial animal generates forces that displace it relative to the surroundings. There are obvious mechanical regularities to be noted. They are ordinarily expressed through Newton's laws. But this situation also exhibits nonmechanical regularities expressed by non-Newtonian laws of wide (though not universal) scope. For instance, all the densely nested optical solid angles, whose bases are the faces and facets of surfaces and whose apex is the point of observation, change concurrently. An optical flow field – crudely, a smooth velocity vector field – is generated. The global form of the flow, or optical morphology, is specific to the configuration of locomotory forces and to the displacements of the animal. Rectilinear forward locomotion, for example, lawfully generates a dilating parabolic flow; a dilating parabolic flow specifies rectilinear forward locomotion.

This simple but significant example of information in the specificational sense permits me to make briefly some important points that can be more carefully developed (e.g., Solomon, Carello & Turvey 1984; Turvey & Carello 1985; in press; Turvey et al. 1981). First, optical information in the specificational sense is optical structure whose macroscopic, qualitative prop-

erties are nomically dependent upon and specific to (under natural boundary conditions) properties of the animal–environment system. Second, optical information in the specificational sense does not reduce to neural signals in the visual system (see below). Thinking about optical information as alternative (macroscopic, qualitative) descriptions of the photon light field, structured by the layout of material surfaces and defined relative to locations and paths in the transparent medium (air for terrestrial animals), is useful. It aids an understanding of optical information independent of vision and of the kinds of ocular systems that evolved. Optical information in the specificational sense is tied to laws at the ecological scale, laws that relate optical properties to kinetic properties (of the animal–environment system). The ecological approach argues that these laws were the basis for the evolution of, and are the basis for the everyday realization of, locomotor activity and its directedness and intentionality.

Let's extend the example a little. Dilation of an optical solid angle relative to a point of observation specifies the approach of a substantial surface. The inverse of the relative rate of dilation, τ , specifies when the collision will occur if the current kinetic conditions persist (Lee 1980). And the rate at which τ changes has a critical point property below which it specifies that the upcoming collision will be soft and above which it specifies that the upcoming collision will be hard (Kugler, Turvey, Carello & Shaw 1985; Lee 1980). The foregoing are not so much quantities as they are local flowfield morphologies and their changes. They specify pending states. They make possible the synchronizing of acts with events – the prospective control of basic behavior. They are meaningful in a very pragmatic sense of the word. Speaking in Dennett's (1983) terms, information in the specificational sense has "intentional features." And to echo Gibson's (1966, 1979) longstanding gripe, the "meaningless to meaningful" problem with which Sayre struggles is not a problem. (Coming to terms with the laws at the ecological scale on which the intentionality of perceiving-acting is founded, and figuring out how to formulate and systematize them, now that's a problem!)

Said succinctly, there is a description of optical structure under which its detection guarantees the intentionality of perceiving. There are other descriptions of optical structure under which it must be translated or processed or interpreted or embellished to *make* perceiving intentional. Sayre is playing with one such description. In this respect it is important to note that Gibson (1966, 1979) avidly denied that optical information in the specificational sense was the sort of thing that could be "processed." It is bizarre, therefore, for Sayre to claim that Marr (1982) is on target with his criticism that Gibson underestimated the complexity of visual information processing. There is a clash of metaphors here. Marr and Sayre are operating in the orthodox metaphor of the nervous system as an efficient cause; for example, it produces percepts. Gibson (1966) sees the nervous system as functioning vicariously in perceiving. It is a part (albeit extremely rich) of the supportive basis for the expression of natural cum ecological laws (cf. Ben-Zeev 1984). An understanding of the nervous system's role in vision in the support metaphor will be radically different from the processing/producing understanding subscribed to by Marr and Sayre (Kugler & Turvey, in press). At all events, in the ecological view, optical descriptions that invoke processing to render intentionless inputs into intentional percepts are of the wrong kind. They beg too many questions and they cast intentionality as a derivative rather than a primary phenomenon.

The last sentences, of course, are just another way of saying that intentionality should not be reduced to representation. As I remarked above, Sayre's goal of disengaging intentionality from computational procedures is admirable; his insistence on the intentional–representational equation is not. That equation, as I have been trying to stress, diverts us from addressing intentionality in a way that reveals its position in the natural order of things. Consider the following: What are customarily referred to

as an animal's or person's intentional contents (cf. Dennett 1969; Searle 1983) constitute extraordinary boundary conditions on natural law (especially those laws that are particularly pertinent to the ecological scale). A flying animal aiming to collide gently with a surface will synchronize its deceleration with one value of τ ; an acceleration to produce a timely, violent collision will be generated with respect to another value of τ (e.g., Lee & Reddish 1981; Lee, Young, Reddish, Lough & Clayton 1984; Wagner 1982). In these simple examples the final conditions – the animal's intentional content – specify the initial conditions that a law (relating optical properties to kinetic conditions) must assume. Examples like this abound, and one of them has been investigated quite thoroughly (Kugler & Turvey, in press). They suggest a profound challenge for naturalizing intentionality: understanding the principles by which intentional contents harness natural laws.