

A comment on equating information with symbol strings

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TURVEY, M. T., AND PETER N. KUGLER. *A comment on equating information with symbol strings.* *Am. J. Physiol.* 246 (Regulatory Integrative Comp. Physiol. 15): R925-R927, 1984.—Symbol strings are advanced as the informational basis for many biological, physiological, and psychological phenomena. The role ascribed to them is that of indicating or directing states of affairs. Pattee has suggested that nature exploits information in this quasi-linguistic sense sparingly, that symbol strings are limited in detail, and that their relation to dynamics is one of complementation. A different, nonsymbolic view of information that addresses how animals can guide their locomotion in cluttered surroundings has been pursued by Gibson. It has considerable generality: information is low-dimensional qualitative properties of low-energy fields, lawfully generated by properties of systems and surround. It is argued that in the absence of information in Gibson's specificational sense, information in the indicational-injunctional sense is ineffective, and it is suggested that perplexities about the selective content of symbol strings may be resolved by a thoroughgoing understanding of Gibsonian information.

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PHYSICISTS HAVE BEEN INCLINED in the past to regard information as a physical variable similar in kind to energy or matter (e.g., 7, 14). There are objections, however, to carrying this inclination over to the realms of biology, physiology, and psychology. The equating of information with negative entropy or an absolute measure of objective order does not adequately capture the ways in which the term information is used in explanations of the phenomena characteristic of those realms. There is a very general impression that the various explanatory roles ascribed to information in biology, physiology, and psychology are performable by symbols organized by a grammar.

What roles do symbol strings fulfill? Fundamentally they are indicational and injunctional: symbol strings can indicate states of affairs (e.g., "deficiency of metabolite so and so" and "road work ahead"), and they can direct or command states of affairs (e.g., "release hormone so and so!" and "slow down!"). This popular quasi-linguistic view of information—what might be termed the indicational-injunctional sense of information (cf. Ref. 15 and E. Reed, unpublished observations)—is central to the papers of Bellman and Goldberg (1) and Iberall (4a). Our efforts in this brief note are directed at putting this indicational-injunctional sense of information into

perspective. Insofar as the issue of the continuity of linguistic and movement capabilities involves the concept of information, clarifying the different senses of the concept and their relationship will prove helpful. Two rather different sets of arguments are involved—those attributed to Pattee and those attributed to Gibson.

Pattee (9-11) has identified two modes of complex system function: 1) a discrete mode characterized as rate-independent operations on a finite set of symbols and 2) a continuous mode that consists of the rate-dependent interplay of dynamical processes. Given this distinction, one can ask how symbol strings and dynamics coevolve from the cellular level up through the evolutionary scale. Are there universals of symbol string-dynamics interactions that might be appropriate to an understanding of the linguistic and coordinated movement capabilities of living systems? Pattee addresses these questions through the problem of enzyme folding. This consists of two qualitatively different phases: the genetic code synthesizes an amino acid string, which then folds into a functioning enzyme. The translation of the DNA symbols into amino acid strings is a discrete symbolic process, while the folding of the one-dimensional amino acid string into a three-dimensional machine is a continuous dynamical process. The former is a constraint on the latter. To describe the relationship as one of constraint is an important step for Pattee, for it suggests that the system's meaning—its dynamic activity—does not merely reduce to a symbolic representation. The symbolic mode harnesses the forces responsible for the function but is not equated with the function, but neither is the dynamical mode completely autonomous. The folding of the enzyme cannot proceed until the code provides the necessary constraint. In other words, neither mode alone is sufficient for the activity in question.

Of significance is the observation that the discrete symbolic mode—information in the indicational-injunctional sense—is kept to a minimum in natural systems (12). Information construed quasi-linguistically does not provide all the details for a given process; it acts as a constraint, of the nonholonomic type,¹ on natural law, so that the dynamical details take care of themselves. In other words, by Pattee's analysis most of the complex behavior of living systems is essentially self-assembly

¹ *Editor's note:* Nonholonomic constraint is typified by a billiard ball, constrained to roll from one location to another on a table, which can take many paths; a wheel constrained to roll between locations on track is holonomically constrained.

that is "set up" by symbol strings but not explicitly controlled by them. Presumably this should be no less true of the linguistic and movement coordination capabilities of biological systems. For Pattee, complete comprehension cannot be had by appealing to symbol-string processing or to physics alone. Both must be used together, but in a special way. Pattee advises us to use physics cleverly so that symbol strings need be used only sparingly to assure the parsimony of the explanation.

As noted, symbol strings are incomplete—they are limited in detail with respect to the detail of the processes they indicate or direct. A number of perplexities are generated by this incompleteness. For example, on what grounds and by what means is one particular symbol string created rather than another, referring elliptically to one set of properties of the indicated or directed dynamical process rather than another? What determines the detail of the symbol string with respect to the detail of the indicated or directed dynamical process that the symbol string represents? Taken together these two questions require an answer beyond that given by a physics (e.g., Prigogine's dissipative structure theory and Iberall's homeokinetics) that seeks to explain how structure evolves with a consequent loss of dynamical degrees of freedom. What is required is an explanation of how that loss is *special*, yielding a symbol string, an alternative description (9), that is *privileged* with respect to the dynamical process that it indicates or directs (see 1a). There are shades of the problem of induction (4) here—the problem of projectable predicates or properties—which continues to resist solution in conventional philosophy and psychology.

Consider another consequence of incompleteness. Because of its necessarily reduced detail, a symbol string cannot *specify* a process or act; that is, it cannot provide a lawful basis for the process. This is not to say that information in the indicational-injunctional sense cannot be responsible for a process in part, only that it cannot constrain a process in full. Pattee's paradigmatic example is meant to suggest that the known laws of physics complete the picture—filling in what the symbol string leaves out—but we doubt whether all relevant examples succumb to this solution, tout court. It seems to us that in many (if not most) biological settings the dynamical details "take care of themselves" because there is nonsymbolic information that specifies how they should do so. As Iberall and Soodak (5) express it, a cooperativity is a state of affairs of an ensemble that is maintained from below by the activity of the atomisms of the ensemble and from above by the field boundary conditions (equated with nonholonomic constraints qua symbol strings in most biological instances). The intimation of the discussion that follows is that cooperativities involving biological atomisms are predicated in large part on information in a nonsymbolic sense that is made available in the course of atomistic activity.

Gibson's focus (2, 3, 13) has been the control of locomotory activity in natural, cluttered surroundings. His definition of information is explicit and distinct from the orthodox sense of information as indicational and in-

junctional. For Gibson, information in the case of vision is optical structure that is lawfully generated by environmental structure (the layout of surfaces) and by movements of the animal (both movements of the limbs relative to the body and movements of the body relative to the surround). The optical structure does not resemble the facts of the animal-environment system, but it is specific to them in the sense of being lawfully dependent on them. In short, Gibson's sense of information is *specificational*. A simple example illustrates the relation between the two senses of information, Gibson's and the orthodox. Symbol strings on the highway of the type "slow down" and "stop" are intended to direct the dynamics of traffic flow. For atomisms (humans) that can read the symbol strings, complying with these injunctions is possible only if there is continuously available information *specific to* the retarding of forward motion and the time to contact with the place where velocity is to go to zero. A deceleration of *global* optical outflow specifies the slowing down of a moving point of observation relative to the persistent, nonmoving layout of surrounding surfaces. The inverse of the rate of dilation, of the visual solid angle to the point of observation that is created by the approach to the place where motion is to be fully arrested, specifies continuously the time at which the place will be contacted. And the first derivative of the time-to-contact optical property specifies that the forward motion will or will not be arrested in time under the current conditions (forces) of motion (see Refs. 3, 6, and 8 for a detailed discussion of each of these forms of specification). This example suggests that without information in the specificational sense, information in the indicational-injunctional sense is impotent. Further this example suggests that for a given process the degree of detail in a symbol string is inversely related to the availability of information in the specificational sense. At the very least, the information available in the specificational sense determines the lower bound on the detail of information in the indicational-injunctional sense.

Stated in more general terms, Gibsonian information is a physical variable that can be identified with low-dimensional macroscopic properties of low-energy fields lawfully generated by properties of system and surround (6). For a system that has an on-board source of available potential energy (such that it can resist the surround's forces through the generation of forces of its own), information in the Gibsonian specificational sense is the basis of the system's coupling to its surround. Where a convention, abstractly interpreted, leads the system to take a nongeodesic path (route), information in the specificational sense provides the support by which this elected activity is made possible.

In summary, the points we wish to underscore are these: 1) the indicational-injunctional sense of information is not exclusive; 2) information in the indicational-injunctional sense is predicated on information in the specificational sense; and 3) the perplexities surrounding the incompleteness of symbol strings may be dismissed in a principled fashion by a thoroughgoing analysis of information in the specificational sense (cf. 1a, 15).

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