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Clues from an Ecological Theory of Event Perception

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Abstract. Language is reformulated to be an abstract system by which one person's actions (speaking, signing) may constrain another's thinking. Because actions are also events, language phenomena may be given a fresh perspective from the standpoint of abstract event theory. Applied, or ecological, event theory then may apply to language construed as a special class of action-events in which perception plays a necessary role. Communicative events are given an interpretation under ecological physics - a discipline founded by J.J. Gibson in order to avoid some of the perennial problems of more traditional perceptual theory. Some of these are discussed with regard to the ecological framework for event-perception. Finally, an application of this approach to sign language construed as kinematic events is attempted.

INTRODUCTION

Overview: Event-Theory as Ecological Psychology

An overriding theme of 20th century science, as opposed to that of the 17th, 18th, and 19th centuries, is that nature is in process rather than simply in motion. Nature consists of events rather than merely of objects, and it is, at least at limit, observer-dependent rather than observer-independent. With the advent and ascendancy of quantum mechanics and relativity physics, the role of the situation and the state of the observer in the process of observation and measurement can no longer be considered perfectly benign. Both micro- and macro-physics now recognize that the inescapable probabilism of the wave-mechanical equations in the former (i.e., Heisenberg's uncertainty principle) and the inherent observational ambiguities of the Lorentz transformational group in the latter (e.g., the problem of simultaneity) fail to offer a definitive theoretical foundation upon which to build a scientific understanding of the evolution of life and the experiences of living creatures at the level of terrestrial physics (14,20,21).

To supplement contemporary investigation, then, we need something more than a physics of the diminutive and the superlative. We need a new physics of the "middle" ground; that is, the world in which biological systems evolve, over which they move, and to which their experiences refer. Following the perceptional psychologist J.J. Gibson (7,8), this new discipline has been called <u>ecological physics</u>. It focuses on the nature of objects and events, not as limiting or reduced physical constructs, but as goals toward which animals' acts conform and as sources from which perceptual information arises. Thus ecological physics should provide a scale of analysis that captures not only the extensional parameters of stimulation (e.g., distance and duration) - a problem that falls naturally within the purview of traditional physics - but also the intensional parameters of perceptual information upon which animals act, make decisions, and form concepts. For these reasons, the science of ecological physics necessarily involves both physical and psychological variables; it must deal with events both in terms of extensive variables such as geometric relations (distance, order, and proportion), forms of kinematic change (velocities and accelerations) and dynamic forces (mass, friction, elasticity, etc.), and of intensive variables that define categories of meaningful events specific to a class of animals (e.g., humans). In short, ecological science incorporates psychology as a companion endeavor to physics and biology. This is done so that the study of information transactions between an animal, as agent and perceiver, and its econiche may supplement our understanding of the energy exchanges that transpire between it and its environment.

Linguistic Phenomena as Communicative Events

Natural languages are, first and foremost, abstract systems by which one person's actions (speaking, signing) may constrain and direct another person's thinking. The heart of the problem of understanding language is to explain this communicative function, that is, to understand how language creates a class of biologically constrained and psychologically motivated physical events. Such a function is a clear case of extensive physical parameters constrained by extra-physical factors (intents) to give rise to specific intensive effects. From this perspective, it is reasonable to treat speech and sign language as coordinate subclasses under a special class of action events (events which express intentionality) that might be called communicative events.

An analysis of such events requires simultaneous descriptions at several levels of abstraction that cut across many disciplines. The requirements for signing include: a geometrical analysis of (hand-) shapes displaced through a variety of trajectories to a variety of coordinate positions in space (including contact with the body, other hand, or face); a kinematic description of modulated rates of change (velocities and acceleration); the dynamic laws of physics for work and momentum (how easy or hard signs are to make); biological principles to account for how complex muscular synergisms (coordinative structures) focus the work done through their skeletal and elastic linkages and become effectors of sign-events; a psychological analysis of how intents and meanings are to be understood through perceptual and cognitive means; and finally, a social/cultural (e.g., social psychology or linguistics) account of communications between two or more persons.

Methodological Issues

Traditionally, perception has been viewed as a process for detecting and discriminating elementary properties of physical stimulation. Hence, perceptual science has pursued a program of characterizing the causal link between physics and psychological experience. The results of 120 years of psychophysical research, however, have shown that the covariate relationship between simple changes in the extensive parameters of physical stimulation (e.g., amplitude or wavelength) and one's subjective impressions (e.g., loudness/brightness or pitch/color) are neither simple nor exact. Rather, continuous and linear stimulation is often perceived as nonlinear or even abruptly discontinuous. Mach bands and the segmentation of the continuous acoustic stream into the discrete phonemic-based speech code are examples of this.

(a) Degrees of freedom problem

Thus, the "modulation transfer function," by which input-output characteristics of perceptual systems may be mathematically described, reveals that perception typically maps extensive physical variables that are linear and continuous, into intensive psychological variables that are nonlinear and discontinuous. Paradigmatic examples, for instance, are the mapping of extensive variation of the amplitude of sound pressures by the human auditory system into the intensive nonlinear effects of "noise."

Consider, for instance, equiloudness contours for sounds of different frequencies: As we scale up on decibels the intensive effects range from the inaudible, to soft pleasant sounds (rustling of leaves), to louder sounds (an orator, a truck), to sound levels which are felt as tickling in the ear (rock bands) and finally, reaching noxiousness at the pain threshold (roar of jet plane with afterburner). Thus, continuous variation along a linear extensive dimension (decibels) yields discontinuous or nonlinear categorical effects. Similarly, in the visual domain it can be shown that as the zero-gradient of light contrast between a highly reflectant surface and a darker background is linearly increased, subjects report a range of categorical effects beginning with a homogeneous field (Ganzfeld), through cloudy or shadowy objects having insubstantial appearances, to an optically specified bright, impenetrable object with sharp, hard edges (3). These simple cases make apparent the most serious problem faced by perceptual theory: How to account for a modulation transfer "function" that maps continous variation of linear variables into discontinuous variation of nonlinear variables. Such a mapping of extensive (physical) variables into intensive (psychological) effects would seem to be structure-creating; it is a one-to-many map that poses the question of how a modulation transfer function is constrained. Traditionally the answer is that "hidden" variables are implicit to the argument of the function and map a variable space that appears to have fewer parametric dimensions (i.e., degrees of freedom) into a variable space that appears to contain relatively greater parametric dimensions. The incommensurate degrees of freedom between the dimensions of the variable space in the argument of the function and those in its range must be resolvable if the mapping is to constitute a well-defined function, that is, a function that maps one-to-one.

By definition, a mapping which is one-to-many is creative rather than effective. Thus, in a traditional view, a modulation transfer function appears to create structure by mapping extensive physical variables with fewer degrees of freedom onto a space of intensive psychological variables (e.g., perceptual categories) possessing a greater number of degrees of freedom.

But a modulation transfer function relevant to perception, like any function, can only be a structure-preserving mapping or a structure-reducing mapping. It can never be truly a structure-increasing mapping when one's theory of the function is complete: A one-to-many mapping is no function at all. To construct formal models in perceptual psychology consonant with the ideal of natural sciences requires well-formed functions allowing no creation of degrees of freedom by the animal over those given by its relations to its environment. Another way of stating this problem which implies a solution is as follows: The undesirable, creative mapping arises because the variables selected to describe the environment-as-perceived are numerically incommensurate with those selected to describe the animal-as-perceiver. A solution to the incommensurability problem would be to adjust the measurement bases of the environment and animal by selecting a set of variables for each that have the same number of degrees of freedom (dimensions). More will be said about this solution later.

(b) Origins problem
A second problem arises when one recognizes the need for a function that takes extensive physical variables into categories of intensive psychological effects. Not only do nonlinearities and discontinuities arise in the mapping from environmental stimulation into perceptual effects, but such mappings specify the significance that environmental objects and events possess for constraining the actions of the perceiver. Hence, an additional problem for traditional perceptual theory is to explain how sensory stimulation, described in the semantically neutral predicat of physics, might become ecologically significant information, described in the semantically rich predicates of psychology. Hc this occurs can be understood by formal analogy to the phenomena of phase transitions in chemistry (6). Water can be made to pas nonlinearly through various material phases (intensive effects) by continuous variation of an extensive parameter, say, temperature, while holding other relevant extensive parameters such as pressure and volume constant. As temperature is increased, wate in the solid phase (ice) moves through the liquid phase and fina ly, into the vapor phase (steam).

Similarly, perceptual displays can be made to yield nonlinear, intensive effects by the continuous manipulation of appropriate extensive variables. For instance, by altering the angles on th famous Müller-Lyer figures, the comparative length of two identi cal line segments passes nonlinearly through three phases: the first being longer than the second, the two being equal in leng and finally, the first being shorter than the second. Here, as in the case of the phase transitions of water under continuous temperature variation, there is a nonlinear mapping from change in a single extensive variable into three intensive effects (phases) - a 1:3 mapping. Furthermore, the mapping not only ex hibits the degrees of freedom problem but also creates an appar ent incommensurability in the richness of semantic predicates b tween the domain and range of the perceptual mapping. In the H_2O example, a continuous change in temperature, a single semant (intensive) dimension, creates three new semantic dimensions:

solidity, liquidity, and gaseousness. In the case of the Müller-Lyer illusion, continuous variation in the relative size of the angles attached to the two line segments also creates three intensive effects: longer-than, equal-to, and shorter-than.

From a traditional viewpoint similar problems of incommensurability arise with regard to language phenomena: The perceptual mapping from the continuous acoustic stream into phonemic segmentation, or from optically specified hand motions into sign gestures, also seem to be examples of "structure creating" mappings. If there is to be an adequate theory of speech or sign perception, it is imperative that these two problems of incommensurability of descriptors be resolved. The ecological approach to event perception provides one way that this might be done.

Ecological Solution to the Creative Mapping Problem

The foregoing discussion identifies two scientifically obdurate questions that any approach to perception, classical or ecological, must address. First, what is the nature and source of the additional constraints on perception required to render it a well-defined function rather than a structure-creating mapping (the degrees of freedom problem)? Second, what is perceived such that the animal or human, as actor, can be appropriately constrained by (i.e., informed about) its state of affairs in the environment (the origins of ecological information problem)? Neither of these questions has been dealt with adequately by the classical methods of psychophysics or other stimulation-based contemporary psychologies, perhaps, because they misconstrue the nature of perceptual information and how it should be measured. Consequently let us work toward a more adequate account of perceptual information.

Classical psychophysics postulates three continua along which corresponding measurements might be made: a stimulus or physical continuum, an inferred or subjective continuum, and a response or judgment continuum. A psychophysical measure of perceptual information consists of the degree of correlation between variations along the physical and subjective continuum. However, the value of this correlation can only be determined inferentially from variations measured along the response continuum. Psychophysical law, ideally speaking, requires the existence of a pair of significant statistical correlations between values on the three continua. Unfortunately, the mere existence of such correlations in no way guarantees that the bases (intensive dimensions) of the three continua will be commensurate either numerically (equal degrees of freedom) or semantically (shared significance).

An ecological reformulation of the problem of measurement for perceptual information requires, in part, the empirical discovery of a common basis to physical and so-called "subjective" continua This permits the two continua of classical psychophysics, which make reference to the environment and animal, respectively, to be collapsed onto a single ecological continuum - a continuum whose units of measurement (bases) are no more of the perceiver than of that perceived.

To illustrate the explanatory power of the ecological reformulation of the problem of perceptual information measurement, consider the following example: the so-called "geometric" illusions provide cases where extensive variation of physical parameters gives rise to nonlinear, intensive perceptual effects. For instance, as noted earlier, the Müller-Lyer figures consist of two line segments of equal length that appear unequal in the context of attached angles of different degrees. As in the case of other geometric illusions, physical measurements of the forms involved are at odds with perceptually estimated measures. Lines that physical measurements reveal as straight, parallel, or intersecting when placed in the context of other lines, may be seen as curved (Wundt-Hering illusion), non-parallel (Zöllner illusion), or non-intersecting (Poggendorf illusion).

Because of its phenomenalism-bred dualism, traditional perceptual theory not only assumes a distinction between physical and perceptual measurement but invests the former with a more privileged reality status than the latter, hence the reason for placing the blame for any discrepancy arising between the two on the perceptual system by calling it a perceptual "illusion" rather than a physical error. However, from the vantage point of ecological psychology that invests reality in neither an objective, animal-irrelevant physics nor a subjective, environment-irrelevant psychology, there is no "error," only a difference to be explained. The difference to be explained is why the extents of two objects (e.g., lines) that are on some occasions perceived to be equal are on other occasions perceived to be unequal. That equals are perceived as equal of course poses no conundrum, but that they might be perceived as unequal surely does. Any adequate theory of measurement theory, with basis in real number magnitudes, is unable to do so, as witnessed by the fact that the stems of the Müller-Lyer figures always prove to be equal under physical measurement.

An ecologically valid basis to measurement theory should provide an explanation of the above problem. Indeed by defining measurements over a natural number basis rather than a real number basis, it is possible to predict such intensive perceptual effects (differences) that arise as a function of extensive changes in the geometric context of a figure (say as a function of contrasting changes in attached angles on the Müller-Lyer figures). Perception or measurement of extent presupposes the ability to detect "chords," that is, the differences in distance between pairs of points lying on the figure. A geometry which defines figures in terms of such differential lengths is called a <u>chord</u> geometry, say as opposed to a <u>point</u> geometry. Since chords may be ordered in terms of length, natural numbers may be used to index the various lengths. In this way a point geometry is but a special case of a geometry whose chords approach zero length at limit. Hence the natural number based chord geometry can approach at limit the precision of measurement afforded by a real number based point geometry. However, there is one important difference between the two types of geometries: where measurements carried out in point geometry by necessity are infinitesimally precise, those carried out in chord geometry are no more precise than the tolerance provided by their shortest chord.

This feature of chord geometry is very convenient for expressing the limited resolving power of natural measuring devices, the human visual system not excluded. Moreover, this feature also permits a principled continuity to be defined between systems that conduct measurements at micro-levels of precision, say those limited only by quantum uncertainty, and those systems that function at more macro-levels of precision, such as the human visual system, whose tolerances may be set by the dipole functions of the receptor field (12). In a dramatic and convincing demonstration of this point, Moore (13) constructed a pattern recognition device which "sees" illusions such as the Müller-Lyer. His model was designed to recognize two-dimensional line patterns. To do so, inter alia it also had to detect lengths. However, because the "retinal mosaic" of the computer's "eye" had limited acuity, the model arrived at its measurement of lengths by sampling only moderately short chords.

Endpoints of line segments, vertices, and intersections are located by natural number, chord-coordinates as the centers of iso-extent, chord distributions. In asymmetrically dense regions of high geometric complexity, these centers will often be shifted away from the locations given by real number, Euclidean point-coordinates. For instance, the Müller-Lyer figure with angles that open inwardly have chord distributions with centers further in sinc that is the region of greatest geometric complexity. By contrast, the Müller-Lyer figure with angles that open outwardly have chord distributions with centers further out, approximated where the physical vertices are, for the same reason.

It is important to note that chord density information is intrinsic in nature; it is a function of the overall structure of a pattern: A measurement (e.g., perceptual sample) carried out on one region of the structure is dependent upon what measurements might reveal in all other regions. By contrast, physical measurements are extrinsic in nature; they are insensitive to overall structure and depend only on local circumstances. Moreover, the standard measurement in chord geometries is intrinsic, being dictated by the organization of the pattern to be measured (its chord distribution). The standard of measurement in Euclidean based (physical) geometries is extrinsic, being selected for convenience from extraneous sources (the Bureau of Standards).

In conclusion, if perceptual information is taken to be based on intrinsic measures of structure (perhaps, chord geometry) rather than extrinsic (conventional physical) measures, then the two fundamental perplexities of traditional perceptual theory can be resolved: First, perception can sometimes be at odds with physical measures because the two systems of measuring do not share common bases. Second, structures perceived in one context (Müller-Lyer figure with angles open inwardly) may appear different from the same structure perceived in another context (Müller-Lyer figure with angles open outwardly).

The plausibility of the ecological reformulation of the perceptual mapping problem is buttressed by Révész's (17) finding that even baby chicks can be taught to peck to the apparently longer of two figures in the Jastrow illusion. Moreover, the fact that humans, computers, and chicks may all exhibit similar intensive effects as a function in the variations of the extensive parameters of geometric figures ("illusions") argues strongly against the traditional cognitive explanation for such phenomena. By showing that a common basis of measurement exists for both environmental structures and the perceiver of those structures, the problems of incommensurability is resolved, and the perceptual mapping is found to be a structure-preserving function rather than a structure-creating mapping. This means that the information specifying the structure is available to be actively differentiated by the human, animal, or machine perceiver; it need not be enriched. Hence there is no need to postulate mediating cognitive factors. Moreover, the foregoing arguments justify the conclusion that perceptual information must be ecological in nature, in that the mapping over which such information is preserved is defined over bases common to both the environment and the animal.

Several questions regarding the perception of spoken and signed language naturally arise within the context of the ecological reformulation of creative mapping problems traditionally encountered: Can common bases be found which functionally (non-creatively) relate continuous variations of acoustic and optic variables into the perceived intensive effects such as phonemic and segmental boundaries? Surely information for such events must be ecological in the foregoing sense.

Two modulation transfer functions

Classical approaches to perception and behavior tend to separate a pair of modulation transfer functions. One is responsible for the mapping of perceptual information and the other is responsible for mapping action information (i.e., the information by which the muscles and other effector organs of the body are systematically integrated into a bio-kinematic linkage for the acting out of goal-directed behaviors). Ecological physics, by contrast, treats this pair of functions as conditionally related and functionally inseparable. Consider an example: In walking toward an object, optical flow-fields projected to the actor specify first, that the animal's velocity and trajectory are over certain paths toward certain places in the environment and second, the degree to which the surrounding environment is, for example, stable, cluttered, or flat. The focus of expansion in the optical flow-field specifies for the actor whether she is moving on a trajectory to a particular target; the velocity with which objects "flow" from the focus specifies how much off target the trajectory is and, therefore, how to adjust the action pattern.

Hence, there is complementary information available in such locomotive events: Actions determine perceptual information about the location, orientation, trajectories, and rates of an animal as perceiver on the one hand. On the other, these perceptions determine the nature and degree of adjustments to be made to realize an action. Thus in every ecological event, by definition, there is simultaneous, functionally complementary information produced by action that is specific to their planning and execution, as well as information about the environmental situation in which the actions occur and to which they must be accommodated. For this reason, the two modulation transfer functions required for action and perception have a source of complementary constraints. (Mathematically speaking, the two complementary mechanisms can be modeled in terms of a single bilinear function between dual vector spaces.)

The importance of the ecological conception of action and perception as a pair of functionally integral mechanisms that map complementary information is the potential it offers for solving the degrees of freedom problem and the origins of ecological information problem. The relevant insight is simply this: Action provides the requisite variables of constraint to allow perception to be a well-defined function (i.e., a non structure-creating mapping); perception reciprocally provides the constraint to allow action to be a well-defined function.

Why Perceptual Information is not Projective

The basic insight of ecological physics is the following: The semantic descriptors (variables) imposed on the information specifying the environment participated in by the perceiver must be commensurate (i.e., functionally correspond) with the semantic descriptors imposed upon the information used by the actor. Contrast this assumption of commensurability of descriptors with the traditional assumption of incommensurability, which holds that the world of stimulation is impoverished while perceptual experience is rich. This latter view is usually founded upon the uncritical acceptance of projective geometry as the basis for describing perceptual information (8). Such a view is inadequate because it ignores the role of change in the world. Rotating or translating objects in a cluttered environment introduce, by interposition effects, successive discontinuities in optical texture. Such defy description in terms of the linear projections but fail to be even topological (homeomorphic) (B). Since the elements of optical texture to be projectively accounted for "come and go," the perceptual modulation transfer function is often nonlinear and discontinuous, thereby yielding ambiguous results. Thus, under this view, fewer values of independent (extensive) variables sometimes get mapped into more values of the dependent (intensive) variables of perception. (Recall that such structure-creating mappings are not functions.)

On the other hand, if one recognizes that perception cannot be a projective relationship because of the existence of structure-altering changes, then one must seek a different model for perception. In replacing the concept of proximal stimulation as projected information with the concept of distal events as directly perceived, the one-to-many mapping difficulties of classical perceptual theory are avoided. An event, by definition, has an integral, higher order character. To perceive an event is to apprehend the invariance structure of objects undergoing change. To see why this is so and why events might best be abstractly characterized this way, a few words must be said about abstract event theory.

<u>Abstract Event Theory: A Sketch of Its Goals</u>

An abstract theory of events should single out for definition and discussion the essential aspects of events that occur. Real events have both a material aspect (form and substance) and a functional aspect (value and significance). Associated with each level of abstraction are three levels of abstract description: For the material aspect there are geometric, kinematic, and dynamic levels of analysis which articulate the spatiotemporal structure assumed by some mass, while for the functional aspect there are biological, psychological, and sociocultural levels of analysis which explicate the meaning or significance that material events have for agents as perceivers and the value they have for constraining the choice of goals (intents) for agents as actors. Taken separately, form and substance are dual complements of the material aspect - each constrains and is constrained by the other. Similarly, value and significance taken separately (as action and perception) reciprocate as dual complements of the functional aspect. At still a more general level of analysis, the material aspect reciprocates with the functional aspect.

In this way the six levels of abstract analysis constitute a six-dimensional duality structure, or phase space, of events, with material aspects as (extensive) parameters and functional aspects as phases (intensive effects).

Although theoretical implications of this approach are beyond the scope of this sketch, the applied implications are worth noting in passing: The phase space approach to events is analogous to Gibb's phase rule, which has proven of great practical importance for chemistry, thermodynamics, and other areas. The phase rule is a topological rule that allows for the prediction of (a) the intensive effects (phases) a material system might give rise to when (b) certain structurally invariant constituents of the system (components) are (c) varied over a given set of extensive variables (degrees of freedom). Or, more generally, knowledge of any two of the above can be used to predict the value of the third. That is to say, the variance, F, of a system consisting of C components in P phases is $F = C - P + 2$. An example is the prediction of the phases of water (e.g., ice, liquid, and vapor) from extensive variation of certain parameters (pressure, temperature) while holding its components (volume of H_2O molecules) invariant.

If such a phase rule held in event perception theory, it would have powerful implications for determining the universal nature of all events - language events included. Not only might intensive effects, such as perceptually meaningful categories in speech perception and sign language perception, be predicted from manipulation of their acoustic or optic parameters, but their raison d'etre might be explained as well.

Systematic (topological) aspects of the invariance structure of events (communicative and otherwise) must be understood ultimately if an ecological theory of event perception is to succeed Although some progress is in the offing, too few event classes have been studied, and none so extensively as to allow us to go beyond this sketch. However, some preliminary success has been achieved with respect to the study of more elementary properties of the invariance structure of events.

Several important concepts from abstract event theory will prove useful to signed and spoken language and to other communicative events.

(a) Spatial structure versus space

Following Riemann (2), a spatial structure is defined as a set of adjacency relations among co-occuring material parts; hence, the classical conception of space as an empty locus, or receptacle, is superseded.

(b) Temporal order versus time

Traditionally, time has been treated as if it were, on the one hand, a disembodied "flow" and on the other, as merely a fourth spatial dimension. The former view is as abstruse as the latter is inaccurate. Temporality, or temporal order, is defined as a successive-ordering of adjacency structures. A succession, or successive-order, has no parts which co-occur simultaneously. (For clearly if they did, then they would be adjacent and simultaneous.) As examples, constant speeds, hums, buzzes, and ticks are steady-state successions, while accelerations, jerks, and rhythms are modulated successions.

(c) Events and objects

An event entails a change in adjacency structure (spatiality) over successive orderings (temporality). A permanent object is a nonchanging adjacency structure. But the latter is an ideal concept since all real objects have only relative permanence. Properly speaking, objects are events of a certain kind, namely, those characterized by minimal variation in adjacency structure over temporal succession. This fact can be demonstrated by strobing rotating objects. At strobe rates asynchronous with the period of symmetry of the object, the object loses its perceived permanence of identity and becomes a jerky, elastic assemblage of disconnected parts (13). Thus, marked variation in adjacency structure over temporal succession destroys the perceived identity of objects. An important question regarding sign-events, then, is how stable is the identity of signs under various forms of event modulation? Clearly, the successful signer must have action skills constrained to certain forms of nonradical change by the perceptual abilities of the sign recipient. The reciprocal constraints of action and perception are apparent. The naive person in learning to perceive signs must become attuned to the different styles of change (modulation) that are deemed equivalent in contrast to those that change meaning.

(d) Invariance structure of events

Those properties or relations that distinguish one object of a class from other objects are called structural variants. Those that do not distinguish it are called structural invariants. Spatial transformations act on adjacent relations simultaneously while temporal transformations act on adjacent relations successively. A transformational invariant is a class of transformations that define the same "style of change" over adjacent structures, whether successively or simultaneously applied. (Typically, in event theory we will find the concept of temporal transformational invariant most useful. Consequently, unless stated otherwise, transformational invariant refers to a temporal style of change.)

The invariance structure of an event consists of the relatively permanent object and the style of change it undergoes. Or, more simply, an event is the structural invariant plus the transformational invariant (15,16,19). The abstract concept of an event refers only to the class, or type-identity, of the object and ignores its token- or individual identity. The token-identity is what makes each object unique; while object uniqueness might be used to distinguish events, it is useless for developing event classification schemes since it leads to a potentially infinite enumeration. Surprisingly, no such infinite enumeration is possible under the type-identity approach because the concepts of structural and transformational invariants have their abstract model in symmetry group theory and transformational group theory respectively. It is known that for finite dimensions these groups are not only finite but reasonably small in number.

Finally, every event has a temporal period, in the sense that any modulation of its successive style of change has a discrete beginning and end, or a pair of inflection points that mark in the successive order either discontinuities or nonlinearities. This last point suggests a significant insight for the study of the perception of sign events.

(e) Composite events

Complex events may be constructed from simple events by four operations: nesting, coordinating, concatenating, or multiplying styles of change. A nested event is one consisting of subordinate styles of change of relatively short temporal periods being superimposed on styles of change with relatively longer periods. For example, just as plays are nested events inside the game of (American) football, and games are nested within the season, so too are finger movements, hand movements, and arm movements nested in signing. A compound event is one constructed by coordinating two or more relatively independent events as in the case of using the two hands in double-handed signs. A concatenative event is a complex event that strings together events so that their periods follow successively (e.g., donning an undershirt before a shirt and a shirt before a tie). In general, discourse aspects of conversational signing are concatenative. Reversible events (e.g, stacking, unstacking) and repeating events (e.g., faucet dripping) also occur here. A fourth kind of complex event is a product event yielded by taking the (group) product of two or more distinct temporal styles of change (where the product of nondistinct styles of changes is identity). This is exemplified by multiplying a rotation (e.g., the turning of a steering wheel back and forth - a reversible event concatenated) with a translation (e.g., the constant forward motion of the car - a steady-state event) to yield a sinusoidal style of change (e.g., weaving in and out of traffic). Unlike the other three event composition operations, the product operation merges the identity of each old style of change into a new transformational invariant.

Although token-identity of an object might be unspecified, its type-identity (structurally invariant properties) must be if a non-trivial event is to be defined. A form of change that deletes all structure at one moment and replaces it with <u>totally</u> new structure in the next moment is discontinuous. Discontinuous forms of change may define substitutions but such types of change are a limiting, even trivial, kind of event. Non-trivial events require styles of change (transformational invariants) over which some structural invariants are preserved. In sum, not all forms of change create events, and the concept of event is thereby nontrivial. This restriction on event specification was shown to be a real constraint on the perceptual information for events in the case of the strobed, rotating object. Is there equally strong evidence showing that even under complex event compositions information for event specification can be reliably preserved? Apparently so: From the complex relative motions of nonspecific configurations of elements (points of light placed on humans viewed in the dark), observers have little trouble recognizing a human form that is walking, jogging, dancing, sitting, or doing calisthenics (4,5,10). Similar demonstrations show that complex biological styles of change also preserve perceptual information for object identity such as changes in facial expressions (1) and growth changes in craniofacial morphology (15,18,19). Parallel investigations might be run to determine how fragile or robust the perceptual information is for the identification of the structural invariants (handshapes) of complex sign events. A still deeper issue for event perception theory is explaining how people recognize an event as being the same event when transposed over different objects or when composed with other events. These questions are especially pertinent to events that are as elaborately composed as is sign language discourse. Consider a few experimental cases that clearly show that the perceptual information for a style of change is abstract (although not ideal or disembodied). Subjects can recognize easily that a style of change is "growth" even when defined over highly schematic drawings of humans, animals, and inanimate subjects (which of course do not really grow at all) (16). It has similarly been shown that the abstract identities of diverse temporal and spatial transformations are clearly recognizable as visual analogies in movie sequences or cartoon strips even though remarkably different objects are used. For instance, Heider and Simmel (9) showed that an animated movie using geometric forms could depict styles of change reliably identified as complex social events (e.g., hostile, aggressive acts, and fearful retreats). Such studies show that change constancy is as much a psychological reality for event perception as object constancy was shown to be for object perception.

Kinematic Information for Sign Events: Two Examples

Although the kinematic (geometry plus time and its derivatives) level alone is not adequate to describe most events, or even other communicative events, it is very important for sign events. This is because sign events rely heavily on the modulation of rate parameters for the parsing of concatenative sign events and for various forms of inflections, to name but two uses. Modulation or change of rate is velocity. Although the concept of velocity is usually confined to the motions of objects through space, it will be useful to allow it to apply to any change in an extensive dimension. By doing so, it will be possible to show how a large number of intensive effects may be created by extensive variation over a relatively small number of dimensions. Consider two examples.

(a) Kinematic information for parsing sign events

Velocities without acceleration are constant. No object can move from one constant velocity to another velocity without undergoing acceleration. An important velocity value is zero, for it is the one that leaves an object unmoving with respect to its environment; moreover, one can easily recognize objects changing from static positions to dynamic ones (and the reverse). It must then follow that acceleration or its effects are likely candidates for perceptual importance. It seems plausible that acceleration is also important for the parsing of one event from another.

Consider the dynamics of a very simple (but peculiarly constrained) form of sign - the citation form of a separate lexical item. Each sign, which we can properly call a separate event, can be separated from other events by pausing. The pauses are unnaturally long and the arms of the signer are held at the side. The sign begins with the motion of the hands from the side to the front of the signer, followed by the gestures peculiar to that sign, followed by the movement of the hands back to the signer's side ending the event. Notice that the event begins with change - the signer going from a static position to a dynamic one. By the logic above, this involves acceleration. The acceleration is that of the arms (for simplicity's sake, leaving out the head, shoulders, and hands). Arms are relatively massive and subject to particular movement constraints. Next, in the citation form of the sign is the sign gesture itself. Let us say that this sign is one involving the wrists and fingers of both hands. The hands and fingers are smaller masses and, though subject to the same general physical laws of motion as the arms, can move much more rapidly. Superimposed on the movement vector of the arms coming up from the sides is the more rapid acceleration of the hands and fingers. This more rapid acceleration can serve to separate the uninformative beginning of the event (the transition to the sign), from the informative middle (the sign core, or, the sign itself), and as the sign is delivered and finished, from the uninformative end of the event (the transition from the sign). Of course, citation signing does not occur naturally and the flow of a sign conversation should make it clear that this simple beginning needs considerable sophistication when applied to conversational sign. Nevertheless, since successive signs in discourse also seem to be separated by different rates of acceleration, this crude beginning is not likely to be off mark.

(b) Kinematic information for aspectual modulation of sign events

According to Klima and Bellugi (19), there are at least eight aspectual modulations that a large variety of predicate signs can undergo. That is, a given sign would consist of a particular handshape, located in a particular space, with a particular movement. These modulations change the meaning of the sign, syntactically "modifying" it, through superimpositions of movement, and therefore constitute extensive variations that give rise to intensive effects. The general handshape and general location remain invariant under the modulational movement. Thus, these are movement changes that can be described in terms of acceleration. These eight are by no means the only ones that apply across large classes of signs, but they do constitute a special subset, formed by a network of oppositions of features (see Bellugi, this volume).

The three dimensions that minimally separate these eight modulations are: single movement or reduplicated, tense versus lax, hold manner (stopping at a point in space) or continuous manner. Individual signs can be modulated in many of these ways. Consider the basic sign BLACK; the hand configuration is a pointing hand, the side of the index finger moving across the forehead in a single brushing motion. An intensive form of BLACK, meaning something like 'very black,' is made with a single motion, an initial and final long hold, and a tense musculature, resulting in a rapid movement. This form contrasts minimally with the resultative form of BLACK, meaning something like 'become completely black.' It is also made with a single motion and tense musculature, but the initial portion of the sign has a continuous slow onset, ending in a rapid movement and final long hold.

For both of the above forms of BLACK, the index finger moves across the brow ridge in a rapid motion and a final hold. What distinguishes the two forms essentially is the difference in acceleration of the onset of the sign. In other words, the handshape, movement, duration, and location of every intermediate spatial point of the two forms may be identical; the relative accelerations of the onsets differ.

The fact that two signs may differ only in the point at which acceleration occurs implies that certain intensive effects indexed by the second derivative of movement are perceived and used for perceptual parsing. Imagine an array of synthesized (using the point-light technique, e.g., (4)) signs differing only in relative acceleration. If this array is processed in some nonlinear way - that is, if there are certain regions of this continuum in which the visual system can easily make discriminations and others in which it cannot easily make them - then something like categorical perception may be obtained. In this way, a phase space for sign events of this type might become a reality and provide both a guide to analyzing and a basis for comparing events in general.

CONCLUSIONS: TOWARD A PHASE RULE FOR SIGN EVENTS

In closing, we propose a goal for event theory in regard to the most general constraints it might place on perceptual information for language events in general and sign events in particular. Under the ecological view, perceptual information, H, is a function of the structural components, C, of an event, the dimensions (degrees of freedom), F, over which they change, and the intensive effects, P, that such changes in structure produce on the perception, judgment, or action. Perceptual information as determined by events (for a properly designed and attuned perceiver) is

$$H = f(C,F,P).$$

For an event with C components specifying P phases (stable intensive effects), in order to fix the structural variables, it is necessary to know the values of the relationships among (C-1) components in each phase (e.g., the relative size of the attached angles on each Müller-Lyer figure in producing each perceived length effect). Thus each phase possesses (C-1) independent variables. Since there are P phases, it follows that structurall speaking, the event possesses P(C-1) independent variables. However, in any event other structural variables, L, than those directly contributing to the intensive effects are implicit and must be controlled (such as the number and length of lines used to create the Müller-Lyer figures). Thus altogether an event of C components in P phases possesses P(C-1) + L independent structural variables.

Perceptual information then is a measure of the constraints which determine completely an event's state description and is given by a system of "equations of constraint." For complete specification of an event, there must be as many such equations as there are variables to be evaluated. Given fewer equations than variables, one or more of the variables will have an undetermined value. The number of these undefined values provides a measure of the variance, or degrees of freedom, of the event. For the event to be completely specified all values must be defined.

The equations by which the perceptual information for an event is to be defined are obtained from the structural variables, extensive changes in the value of the structural variables, and the dependent variables of the response measure. Event information is stable (reliable) when the functional role the components play is the same (commensurate) across all phases. Therefore, if one of these commensurate phases is arbitrarily selected as an intrinsic standard, then the rule explaining the intensive effects arising by variation of the components of the standard phase can be generalized across all other phases. For each phase whose stability is commensurate with the standard phase, there will be a definite equation of state for each component in that phase. Thus if there are P phases, there exist (P-1) equations for each component, and for C components we obtain C(P-1) equations of constraint.

Recall, however, that there are P(C-1) + L variables. Since we have only C(P-1) equations, then there must be P(C-1) + L - C(P-1) = C + L - P variables undefined. This provides a formal characterization of the degrees of freedom problem. Thus the variance F of an event consisting of C components in P phases is F = C - P + L. A measure of perceptual information, H, specific to an event is given by H = C - P + L - F. Thus, only when all the variables in this equation are evaluated such that $H = 0$ do we obtain a completely specified measure of the information made available by an event. By contrast, when $H \neq 0$ then the variables required to define information for the event are under-specified.

To see the significance of a Phase Rule for event information, let us apply it to a familiar situation - the Müller-Lyer figures. To construe this situation as an "event," merely consider the change in angularity to be the style of change, or transformational invariant, and the pair of attached angles undergoing the change as the structural invariant. (Clearly, through film animation, the Müller-Lyer figure could be depicted as a kinematic event.) Consider the following definitions:

C = the two pairs of attached angles. The "stem" between the angles is functionally invariant over the phases; hence, it is not a component of the relevant perceptual information but only a controlled constituent. The angles are the functional constituents, or components. Since the angles in each pair covary but do so independently of the other pair, their change requires two degrees of freedom, or that $C = 2$.

P = the three intensive effects, or phases of perceptual information that arise as a function of extensive variation of the informational components, the angles. Let Figure A consist of the angle pair α and Figure B of angle pair β, then P is the perceived relative lengths of the stems of A and B, represented as $|A|$ and $|B|$. As the pairs of angles α and β vary from $0^\circ \rightarrow 180^\circ$ and $180^\circ \rightarrow 0^\circ$, respectively, then A - B goes through three phases:

$|A| < |B|$, $|A| = |B|$ and $|A| > |B|$.

Hence $P = 3$

L = the control variables invariant over all phases are the <u>number</u> and <u>length</u> of the line segments composing the two figures. Since there are two such structural variables, $L = 2$.

Therefore, the total number of degrees of freedom for the Müller-Lyer "event" is $F = C - P + L = 2 - 3 + 2 = 1$ where F, of course, is the independent variable of angularity, whose extensive variation produces the observed intensive effects.

Several important implications arise from the application of a Phase Rule to define perceptual information made available by events. For instance, given the evaluation of any two of the variables in the equation H = f(C,P,F,L), since L is fixed, the other variable can be specified: that is, C = f(F,P), F = f(C,P), and P = f(C,F). Say one knows the perceptual effects, P, determined by an event (or other display) and the extensive parameters, F, whose variation yields those effects, then one might determine the degrees of freedom of the specific structural variables, C, responsible for the perceptual information. Knowledge of the degrees of freedom of the structural variables is a powerful constraint on determining what candidate structural constituents might be manipulated to explain the effects. In natural displays or events, the combinatoric richness of such candidate structural variables renders unconstrained brute-force search unfeasible.

Similarly, knowing the variance, F, and the components, C, allows prediction of the number of perceptual effects, P. Hence some clue would be given as to what additional experiments might be run. From Phase Rule F = C - P + L, a search for all the phases of a perceptual phenomenon is seen to be of the greatest importance: the greater the number of phases, the fewer are the degrees of freedom, for a fixed number of components. With increase in the number of phases, the perceptual information made available by the event becomes more precisely specified, that is, less ambiguous.

Probably the most important use of the Phase Rule, however, is to classify events (e.g., sign events) whose higher order perceptual information yields the same intensive effects. Indeed, events quite different in character may behave in an abstractly equivalent manner while events that appear superficially the same may behave quite differently. The Phase Rule, however, provides a way of classifying <u>all</u> events in terms of the abstract type of perceptual information they make available. Simply put: Events with the same degrees of freedom by definition determine perceptual information of the same variance-type. This follows from the fact that the Phase Rule defines invariant, univariant, bivariant, and multivariant information as that type of information determined by events for which F = O, F = 1, F = 2,..., F = n degrees of freedom, respectively. (For instance, a so-called "reversible geometric illusion" like the Necker cube has an F = 1). In addition to the general methodological constraints on event perception research, which carry over in toto to the study of language events, a specific consequence might be noted. A Phase Rule would provide a means of predicting how sign events might present equivocal information to a perceiver and what constraints might provide disambiguation.

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