

The Challenge of an Ecological Approach to (For Wagman & Blau book)
Event Perception:
How to Obtain Forceful Control from Forceless Information

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ABSTRACT: We review the Event Perception chapter of James Gibson's 1979 book and evaluate its promise. Its merits include the strong case he makes for why events should be the primary ingredients of any theory of visual perception. A major shortcoming was the general lack of insight into the problem of how the optic array might be a source of kinetic information and not just of kinematic information. In mathematics this is the problem of resolving *dimensional inhomogeneity*, that is, how a source of forceless (L, T) information might also be a source of forceful (L, T, and F) information. Without commensurability of dimensions no relevant equations can even be formulated. Consequently, there can be no true scientific progress toward an understanding of event perception until this theoretical thwart is eliminated. We discuss several situations where actors nevertheless seem to obtain information specifying forceful control from forceless optic array information. This poses a theoretical conundrum that we argue can be resolved by the Dual Frame Discrepancy Hypothesis introduced here.

PROLOGUE

For the year (1969-1970), James J. Gibson invited Robert Shaw, who was at that time an assistant professor at the University of Minnesota, to visit Cornell so that he could learn more about Gibson's ecological approach to psychology. Shaw had met Gibson at Minnesota in the Summer of 1968 while taking his Ecological Psychology seminar at the Center for Human Learning's Summer Institute. It was from their lively interactions in Gibson's seminar that they had, so to speak, "a meeting of minds". Shaw's duties at Cornell would be to help teach Gibson's graduate seminar and to teach the undergraduate perception course. He expressed the hope that Shaw, who had a background in mathematics and logic, might see ways in which fundamental

principles of ecological psychology might be made explicit—even formalized. Shaw gratefully accepted because he had an inkling that the fundamental significance of invariants in Gibson's theory of perceptual information might be amenable to a group symmetry interpretation—a concentration of Shaw's. The purpose of this Prologue is to impress upon the Reader that everything discussed in this chapter benefited from that year of close almost daily interaction with Gibson and having been granted license by Gibson to query him about any facts, concepts, or principles of his approach that Shaw might need help with (Shaw, 2002).

TWO CHALLENGES OF AN ECOLOGICAL APPROACH TO EVENT PERCEPTION

The biggest challenge to explaining Gibson's ecological approach to event perception is not understanding the problem he addresses but understanding the problem he fails to address. Although the role of ecological information, as expressed in terms of his optic array construct, deals perfectly well with kinematic event properties, it scarcely addresses the problem of kinetic events at all. Although this is disappointing, it is not surprising since the physical concepts needed are not generally known outside of physics.

Consequently, our paper will attempt to achieve three goals: First, to assay the problems that a complete theory of event perception must resolve if progress is to be made; second, to show that Gibson's opening gambits on the event perception problem were promising if incomplete; and, third, to show how a physical concept, d'Alembert's principle, introduced into ecological physics by the Authors (Shaw and Kinsella-Shaw, 2007), can provide a method for solving this dimensional inhomogeneity problem.

To anticipate: What seems to be needed is a major innovation in the way event space-time geometry is conceptualized. Gibson helps to clarify what this new approach must overcome. Unfortunately, an adequate characterization of the problem is not possible given the space allocated for this chapter. Nevertheless, we offer this chapter as a promissory note for what is needed.

WHAT ARE ECOLOGICAL EVENTS?

James J. Gibson (1979) tells us that to make progress on the problem of event perception, we should begin thinking of events at the ecological scale as being the primary realities for perceptual theory—with time and space being abstractions from them. For Gibson time and

space are distinct orders in the global layout of events and the structure over which they are defined. 'Time' is an abstraction from *successive-order** and 'space' from the *adjacent-order* of structures in the ecological-scaled event space. There were no competing theories of event perception available at the time—except one.

*[FN: Actually, Gibson contrasts *adjacent* order with *sequential* order. We chose, instead, to contrast the terms “successive order” and “adjacent order” because, in mathematics, sequences are usually taken to be infinite sets arranged in successive order. A *sequence* is usually defined as a set of successive orders that is unending, while a *succession* is defined by an effective procedure that builds it up step-by-step and is finite up to every step. Thus, where you cannot perceive a sequence in its entirety, you can a succession. This makes “successive-order” a more agreeable selection over “sequence” for a perceptual theorist such as Gibson.]

Early last century, Einstein (1905) built his Special Theory of Relativity on the fundamental notion of point-events and points of observation on those events as defined at locations in space-time. The virtue of using space-time over ordinary space is that dynamics is achieved intrinsically by the mere placing of points in space-time without the need to add change "cinematographically" by sequences of views. However, Einstein's space-time (Minkowski geometry) event theory was not what Gibson (1979) had in mind, for he did not think relativity theory was relevant for perception at the ecological scale. He asserted:

The optical information for distinguishing locomotion from nonlocomotion is available, and this is extremely valuable for all observers, human or animal. In physics the motion of an observer in space is 'relative,' inasmuch as what we call motion with reference to one chosen frame of reference may be nonmotion with reference to another frame of reference. *In ecology this does not hold, and the locomotion of an observer in the environment is absolute.* The environment is simply that with respect to which either locomotion or a state of rest occurs, and the problem of relativity does not arise (p. 75. Italics added).

As mentioned above, Gibson offers a different take on the nature of the temporal and spatial dimensions over which Einstein's space-time is defined. Gibson offers the concept of successive-order as a replacement for the temporal dimension and the concept of adjacent-order

as a replacement for the spatial dimension. In addition, the ecological approach also recognizes that events exhibit both structural change, or variants, and structural persistence, or invariants, over these orders.

Evidently, animals and humans have the general perceptual capability not only to distinguish between change and nonchange but also to classify styles of change, as well as the objects that undergo the styles of change (Kim, Effken, & Shaw, 1995). Consequently, *event perception* can be defined as *the detection of information specifying a style of change that a structure undergoes over some determinate region of space-time, or better, over determinate adjacent places in a succession of durations*. Two fundamental problems of event perception include, first, how one perceives change at all, and, second, how one perceives particular styles of change as such. A shortcoming of our field was (and still is) the lack of consensus on terminology for discussing what it is about events that might be perceived. What abstract aspects of events are specified in optic array information that are likely to be detected?

GIBSON'S PRINCIPLES OF EVENT PERCEPTION

In his approach to event perception, Gibson (1979, Chapter 6) declares his focus to be on just three kinds of events:

1. Changes in surface layout include translations and rotations of an object, collisions, deformations, and disruptions.
2. Changes of surface color or texture, significant alterations of the surfaces of plants and animals.
3. Changes in the existence of surface transitions of evaporations, dissipation, melting, dissolving, and decay.

Dynamics is the branch of physics that studies time-dependent processes and includes both kinetics and kinematics. Kinetics is the branch of classical mechanics that is concerned with the relationship between motion and causes, specifically, forces and torques. Kinematics on the other hand, is a branch of classical mechanics that describes the motion of points (e.g., particles), bodies (objects), and systems of bodies (groups of objects) without considering the mass of each or the forces that caused the motion. Consequently, kinematics, as a field of study, is often referred to as the "geometry of motion," while kinetics might be referred to as the "causes of the geometry of motion." An additional complication, Gibson notes, is that some of these events are

reversible, but many are not. Such invertibility plays havoc with causal structure since causes must precede effects.

This fact alone would make one question whether causality has any role to play in scientific explanation (d'Abro, 1951). For clearly, since the advent of quantum theory with its superposition principle, information specifying such inverted events cannot be restricted to causal structure alone. (A telling subtitle to d'Abro's book is *The Decline of Mechanism*.)

Where traditional mechanical causation requires that for a cause to give rise to a noncontiguous effect in a nonlocal fashion, there must be a causal chain linking the two. In many cases, unfortunately, mechanical causal chains may run aground because some of the mediating linkages involve nonlocal constraints, such as least action, conservation laws, or field effects. Gibson and his followers have recognized such nonlocal constraints as making possible both *retrospective* and *prospective control* (Turvey, 1992; Shaw and Kinsella-Shaw, 1988). Such processes exhibiting nonlocal control were called 'entelechal' by Aristotle, and have also been called *conative processes*, and recently discussed in detail by Shaw, Kinsella-Shaw, and Mace (2019).

THE OPTIC ARRAY: INFORMATION FOR VISUAL PERCEPTION

It is most important to notice that all three kinds of events mentioned by Gibson involve only kinematic dimensions, i. e., space and time, without kinetic dimensions (mass, energy, force, or momentum). There is a reason for this emphasis on the kinematic side of dynamics. Gibson introduces a theoretic construct, called the *optic array*, as an aid in characterizing the optical information that is detected during visual perception. The optic array is a cone of light rays defined at any point of observation (moving or stationary) that might be occupied by an actor (but need not be). More precisely, an *optic array is a 360 degree solid angle of adjacent light contrasts concentrated at a point of observation* (Figure 1, from Gibson, 1966, p. 196).

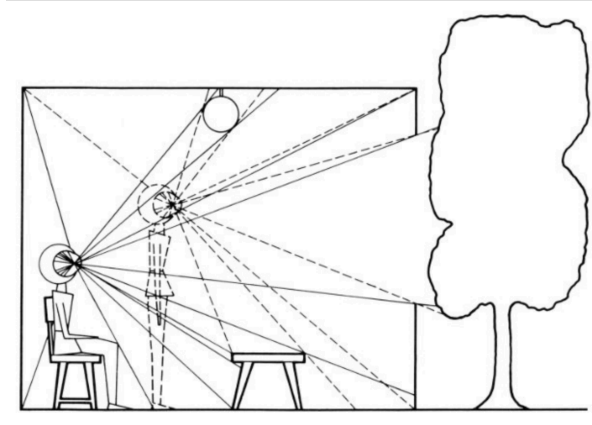


FIGURE 1 The transformation of the optic array defined by a locomotor movement. The solid lines represent the optic array before the observer stands up, the dashed lines after he has moved. The path of locomotion of the head is forward and upward by which the whole array is transformed (Gibson, 1966).

Although, intuitively speaking, optic array geometry seems to be a kind of projective geometry construct, it is not intended to be. Gibson uses its projected rays only as a heuristic to facilitate communication, and refuses, on principle, to embrace projective geometry as a general method for ecological optics. He cautions us to beware of the important distinction between projective geometry descriptions of the optic array and what they should be. When speaking of the array structure, we should refer to optical forms, not to environmental forms, and to a change in the array structure, as a transformation, not as a motion of objects or surfaces. There are no objects or surfaces in the optic array corresponding to those in the environment! Hence the use of the term here is more closely allied to some kind of (as yet unknown) 'perspective' geometry than to projective geometry since abstract mathematics has not yet been applied to the problems of ecological optics.

Gibson's admonishes us to be circumspect in treating the optic array as ordinary geometry because the constituents of ordinary geometry, such as point, line, plane, lack realistic dimensions that actual material objects possess. Points are deemed to be 'ghostly' zero dimensional, lines to have unrealistic zero width, and areas as having no thickness at all. The lack of thickness to surface area is inherited from its generator—the moving line segment, and the lack of width to a line is inherited from its generator—the moving point. Since surface

opaqueness is lacking, there can be no occlusion of one surface by another, nor the self-occlusion needed to specify an object's shape.

For Gibson (1979) there is also always some degree of recurrence [transformational invariance] and some degree of nonrecurrence [transformational variance] in the flow of ecological events. And, although Gibson alludes to points of observation in the environment, he is careful to explain that they are not to be thought of as being stationary discrete 'ghostly' points in space but rather are pauses in the movement of an observer along a path through the environment.

Also, all lines of projection pass through a point (the point of projection) with the resultant loss of the topological property of orientability. This loss renders the projected object's orientation ambiguous, in that it cannot tell the front of an object from its back (thus precluding self-occlusion) or tell its left-side from its right-side, making all surfaces unrealistically "see through." Because of these impossible properties, projective geometry and its Euclidean bases provide unrealistic models of the real world (Shaw and Mace, 2005).

For these reasons one might accept that the proper use of projective geometry is *not* constructing facsimiles of real world material objects but only in describing heuristic guidelines for their placement in geometric space. For instance, it can specify centers of objects by points and margins surrounding areas of light contrasts or object edges by lines. Such use is extrinsic and *post hoc* at best. Gibson (1957) asserts this admonition in a paper on optical motions and optical transformations:

The notion of point-to-point correspondence in projective geometry, simple and powerful as it is, does not apply to the optics of events any more than it applies to the optics of opaque surfaces, for it leaves occlusion out of account. The fallacy lies deep in our conception of empty space, especially the so-called third dimension of space. Whatever the perception of space may be, if there is any such thing, it is not simply the perception of the dimension of depth (p. 289).

Keeping these cautionary notes in mind, scientific prudence dictates that we approach the problem of event perception with a degree of trepidation.

GIBSON'S EVENT PERCEPTION

Gibson (Chapter Six, 1979) presents the rudiments for an ecological approach to event perception. (For the reasons given, he preferred to call it "an approach" rather than

a theory). Since his book is limited to vision, we should not be surprised that his discussion concentrates on the optical information for events. Consequently, our discussion in this exegesis is also restricted to vision.

It goes without saying that no adequate event perception 'theory,' can ignore the likelihood that all the senses act together as a perceptual system, such that one sense modality not only complements the others but also supplements their modality specific event information with additional event information from its own sense modality. In the place of cooperating sense modalities, the idea of amodal information that lacks sense modality specificity has been raised (e.g., Michotte, Thinès, and Crabbé, 1964). More recently, some contemporary psychologists have argued that in the place of multiple modal specific arrays there should be only a single general sensory modality (Stoffregen, Mantel, and Bardy, 2017). However, one complication for this view is the relative independence of the senses under loss, namely, when one sense modality is lost or weakened, not all are lost.

Two fundamental assumptions of the optic array: First, the information for recognizing an event is captured through "projection" of the physical disturbances (i.e., mechanics) into optical disturbances of the ambient optic array. Second, the information that directly specifies an event's identity resides in the invariant properties of the optic array disturbances caused by the actual event and reside at the place of observation—whether that place is occupied by an observer or not. By placing the optic array information source outside the observer, an important goal of ecological optics is automatically achieved. Since the place of observation may not be occupied by an observer, no cognitive abilities of an observer (memory, inference, mental images) can be relevant to the make-up of the information of interest. Thus, information is *sui generis* and since there can be no mediator, it must be directly apprehended.

Gibson (1979) argues that optic array events and real world events are so dissimilar that they do not even deserve to be called by the same name:

These disturbances in the optic array are not *similar* to the events in the environment that they specify. The superficial likenesses are misleading. Even if the optical disturbances could be reduced to the motions of spots, they would not be like the motions of bodies or particles in space. Optical spots have no mass and no inertia, they cannot collide, and in fact, because they are usually not spots at all but forms nested within one another, they cannot

even move. This is why I suggested that a so-called optical motion had so little in common with a physical motion that it should not even be *called* a motion (p.109).

In short, Gibson informs us that disturbances in the optic array lack mass, inertia, and even motion and therefore do not resemble events in the world involving material objects with those properties. Event perception presumably still works because, as impoverished as the array disturbances may be, they somehow still share common event invariants with real world events. The fundamental problem of information as specification is revealed in this assertion. If so, then this way of posing the problem leaves us facing a conundrum of how purely kinematic optical information can specify kinetic events. And emphasizing the extreme dissimilarity of optical array disturbances to the actual events, except for sharing invariants, as true as it may be, seems to obscure the path to a solution.

The laws of optics and the laws of mechanics provide the bases for determining all the invariant properties involved in each event and must somehow be the means by which we recognize the physical event and the optical event as having the same referent. To be recognized as being about the same event, the force driven disturbances in the environment and the forceless disturbances in the light projected from them into the optic array, must share the same invariant information. How they might is the major puzzle to be addressed later in this paper.

Specifically, we will ask how Gibson's theory of event perception which assumes only optic array kinematics might be expanded to include optic array kinetics. Formally, the issue is one of *dimensional inhomogeneity*, a mismatch in dimensionality between events with dimensions of mass, length, and time versus events with only dimensions of length and time. This problem is profoundly serious because a theory of living systems based on a mismatch in dimensionality can never, even in principle, solve Bernstein's *degrees of freedom problem* that must be solved if a perceiving-acting system is to be capable of adaptive interactions with the environment (Bernstein, 1967)*.

*[FN: The *degrees of freedom problem* (or motor equivalence problem) in motor control asserts that there are many ways for actors to perform a movement that will achieve the same goal, i.e., under normal circumstances, no simple one-to-one correspondence exists between a motor problem and a motor solution to the problem. This problem was first formulated by the Russian neurophysiologist, Nikolai Bernstein, who proposed ways a system with N-degrees of freedom could be made to act as if it had but 1.]

For instance, lacking kinetic information, the negative affordances of lethal or injurious encounters with surfaces, misses, or other life forms would not be recognized and thus not avoided. There would be no information to distinguish the extreme danger of a charging bull from the friendly encounter with a running child. Stepping-off places would not be informationally distinguished from falling-off places since the relative impact due to the force of gravity could play no part. This is not to say that the optic array might not register some useful kinematic information, such as a global transformation of the optic array which specifies to the actor that s/he is moving rather than some part of the environment, which is specified by local patches of change.

THE CHALLENGE OF ABSTRACTNESS

One thing that makes Gibson's theory of perception difficult to grasp is its degree of abstractness, that, in general, information for x is not x *per se* but how x fits into the layout of the environment and changes with it on some occasions but remains stationary on others. For instance, to begin with, we need to explain the abstract role of the ambient optic array in characterizing ecological information, and how being defined at the ecological scale entails it being directly detectable.

In what follows, we appreciate why the optical array is so brilliant a theoretic construct, namely, because it forces any perceptual theory that adopts it

- (i) to be ecologically scaled,
- (ii) to be about information based on invariants, and
- (iii) to be directly picked up.
- (iv) It objectifies information by being outside the observer; so no cognitive or mentalistic contributions are possible.

This is perforce the case since no actual observer need be at the point of observation toward which the optical array is projected, thus no contribution from the observer's memory nor inference is even, in principle, possible. It merely needs to be directly detected. And being both of the environment and of the place where perception might occur, but need not, the optical array is most thoroughly ecological—respecting the observer no more than the observed. And like the affordances whose information it may frame, it "points both ways," toward environment and organism alike.

An example of information about x not being x *per se* is the fact that a square shape and a

trapezoid shape may project the same 2D form, a trapezoid, while they project different isometric invariants when each is rotated around the same axis.

Since symmetry theory is our strategy for explaining the invariant information specifying events as made available by the optic array, it would be useful to provide some scientific background on symmetry group theory. We do this next.

THE PROVEN IMPORTANCE OF SYMMETRY THEORY IN SCIENCE

At the first conference on ecological optics at Cornell in 1970, as agreed, Shaw presented a paper entitled "The Role of Symmetry in Event Perception" in which he attempted to introduce symmetry principles to ecological theory (Shaw, McIntyre, and Mace, 1974). Here is a pre'cis of his introduction:

He began by presenting the views of Cassirer (1944) because Gibson had cited him twice in his 1950 book (e.g., pp. 153 and 193). Cassirer argued for the fundamental role of group theory in perception, asserting that the primitive form of understanding is that of the intuitive concept of a group. The usefulness of the group concept in contemporary mathematics and physics offers strong support to the validity of this insight. For instance, one of the chief functions of group theory in mathematics and physics, as shown by Emmy Noether (1918), has been to describe what properties of objects, events, or even natural laws remain invariant, or symmetrical, across different domains, or under modification by transformations.

THE DUAL ROLE OF SYMMETRY IN EVENT PERCEPTION

Symmetry has a double role to play in theories that make it a highly prized commodity in science. It is by nature a duality in that it refers equivocally and simultaneously to both a property left invariant *under* a transformation (a *structural invariant* = SI) and to the invariant specifying the transformation that leaves the property invariant *over* transformations (a *transformational invariant* = TI) (Pittenger and Shaw, 1975). Hence if you base your approach on a symmetry principle your perspective on the phenomenon of interest is, philosophically speaking, necessarily a *double aspectism*—an ontology well designed for analyzing systems founded on duality symmetries. (For example, a rotation of a circle is a symmetry operation since both order of points and distances between them remain invariant after the application of the operation).

As already mentioned, Shaw, McIntyre and Mace (1974) argued that symmetry group theory

provides one way for making clear what invariant properties all events exhibiting the same style of change must share by virtue of being the same kind of events. In an attempt to address this problem, using the terms *transformational invariant* (TI) and *structural invariant* (SI), an *event* (E) is said to be perceptually specified when both of these aspects of invariant information are available to be detected, that is, when an object is seen as being structurally invariant (SI) under a style of change (TI). Hence when the two-variable function, E(TI, SI), can be informationally specified, then an event can be said to be perceived. For instance, an event involving a bouncing ball might be denoted as

$$E(TI = \text{bouncing}, SI = \text{ball}) = \text{bouncing ball}.$$

HOW TO BUILD A PHYSICALLY LAWFUL SYSTEM

Two unicycle wheels are free to roam anywhere unconstrained by what the other one is doing. But when coupled by a constraint, say, a rigid frame to make them into a bicycle, the two wheels must act symmetrically and follow the same course. Thus, we see that symmetry is the expression of a constraint. For forceless kinematic optic array information to become forceful kinetic optic array information requires the addition of constraints. A system that is kinematic is free to take on all possible temporal and spatial values. This freedom allows the system to enter any states unencumbered by which other states it might enter—so long as the next states are successively ordered (i.e., are temporal) and adjacently ordered (i.e., spatially ordered).

For a kinematic system to become kinetic, it must take on symmetry constraints it lacks. In other words, it must give up some freedom for making changes to its state configurations. Hence a move from being merely kinematic to being kinetic is to assume some constraints that were missing. For instance, kinematically there is no difference between a 100 lb. girl running at 10 mph into a 4 ton stationary truck or a four ton truck rolling at 10 mph into a stationary 100 lb. girl; but kinetically there is a great difference. Recall that *momentum = mass x velocity* determines impact force, then 10 mph x 100 lbs.= 1000 is considerably less than 10 mph x 8,000 lbs.= 80,000. The difference is 80:1 A strong *prima facie* case can be made that kinetic event perception, as opposed to kinematic event perception alone, redefines affordances in such extreme ways as to make its lack extremely maladaptive for any species.

The expanded events, in taking on additional symmetry constraints in going from (L, T) to (M, L, T), will satisfy conservation laws beyond those satisfied by the kinematic events. But what laws?

Fortunately, Emmy Noether (1918) answered this question for us by proving that from symmetries in Nature the conservation laws arise intrinsically. Noether's theorems show that if a physical system behaves indifferent to its orientation in space, then its Lagrangian (which governs its laws of motion) will be symmetric under continuous rotations, which means angular momentum is conserved. Similarly, assume a physical system behaves the same regardless of place or time, then its Lagrangian is symmetric under continuous translations in space and time, respectively. Then as predicted by Noether's theorems, the system will obey the conservation of linear momentum and conservation of energy laws.

And, finally, if the behavior of a physical system does not change upon spatial or temporal reflection, then its Lagrangian has reflection symmetry and time-reversal symmetry, respectively. Then by her theorems a system with these symmetries will exhibit parity and energy conservation laws, respectively.

An Additional Conservation Law?

Ecological psychology treats information and control as complements:

$$information + control = 1,$$

such that,

$$1 - information = control \text{ and } 1 - control = information.$$

How we justify this will be dealt with in a moment. For now, we want to reveal intuitively how the new conservation law arises from this new symmetry of complementation between information and control. The key is to understand that we interpret information different from its use in traditional information theory. Traditional information is defined as a purely syntactic measure of the total number of exclusive disjunctive decisions needed in counting N things by means of a \log_2 units. It is a dimensionless number in that its units are "bits." Instead of a purely syntactic measure, we use a pragmatic information measure. Where the traditional syntactic measure has no natural semantic basis, ours does.

Ecological information is used as a measure of how much of an actor's intended goal-directed action remains unfinished. Complementary to this "still to do" information measure is an "already done" control measure. Summed together they specify how much "work over the selected goalpath" is required to complete the intended task.

HOW TO BUILD A PHYSICALLY LAWFUL ECOSYSTEM

You will need a toolbox with a minimal set of conceptual tools—among them, duality, reference frame, and discrepancy. Here we provide an intuitive introduction to these concepts eschewing formal treatment at this time.

DUALITY

In mathematics, a *duality*, generally speaking, translates concepts, theorems or mathematical structures into other concepts, theorems or structures, in a one-to-one fashion, often (but not always) by means of an involution (e.g., reflection) operation: if the dual of A is B , then the dual of B is A . Such involutions sometimes have fixed points, so that the dual of A is A itself. The clearest case of this can be seen in digraph theory where the dual is obtained simply by reversing the arrows that couple its states (See Figure 3).

Gibson (1979) treats affordances as dual aspects of an ecosystem that refer mutually and reciprocally to both the organism and the environment components. He tells us:

An affordance cuts across the dichotomy of subjective-objective and helps us to understand its inadequacy. It is equally a fact of the environment and a fact of behavior. It is both physical and psychical, yet neither. An affordance points both ways, to the environment and to the observer (p.129).

Gibson's insight that an affordance provides two perspectives, one from the organism on the environment and one from the environment on the organism, is an example of a duality (dual perspectives) that reminds us of a quote by a major mathematician (Atiyah, 2007, p. 69)

Fundamentally, duality gives two different points of view of looking at the same object. There are many things that have two points of view [agent, patient; organism, environment] and in principle they are all dualities. (Sir Michael Atiyah, Fields Medal Winner).

The key to understanding the ecological approach is to see that, like Noah after the flood, it construes everything as coming in pairs: organism-environment, affordance-effectivity, information-control. These dual relationships can be conveniently summarized in a directed graph (i.e., a digraph):

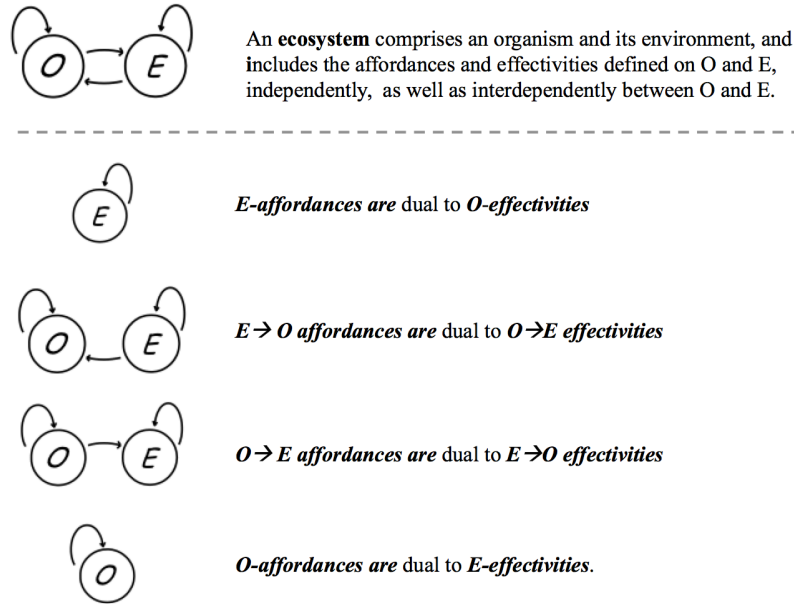


FIGURE 3 Illustrating the dual components of an ecosystem.

**THE DUAL FRAME DISCREPANCY HYPOTHESIS:
FINDING FORCES FROM FORCELESS INFORMATION**

The most fundamental fact to recognize is that in an ecological approach every major concept has a dual partner—they necessarily come in dual pairs because, by definition, there are always two points of view—one from the organism (O) to the environment (E) and another from the E to the O. Consequently, we begin with the organism's frame of reference with respect to the environment and immediately recognize that there is an environmental frame of reference with respect to the organism. If the two reference frames are in total agreement, such that information about x in E-terms and information about x in O-terms are in thorough agreement, then perception, memory, and inference also will reveal no discrepancies. In such case, the O-frame and the E-frame will be dual isomorphs, and perception and action will be perfectly coordinated.

REFERENCE FRAME

The notion of reference frame is not the same as a coordinate system or traditional reference system with a point origin, (0, 0, 0, 0), and metric coordinates, (x, y, z, t). Instead

reference frame, as construed under the ecological approach, begins with a *point of view* (POV) around which perspectives are variously organized (See FIGURE 4). The POV might be global in being the perspectives surrounding O taken with respect to all of E—an open vista delimited by the visual horizons alone, or something more focal, ranging from an object and how it is situated in E being at a nearby place or at a place some intermediate distance away, or, even most locally, being just defined on the self alone. A reference frame is not located just by places surrounding a POV or lying at various distances away but is also taken relative to immediate-to sustained-encounters of various durations.

Most importantly, the surround is always filled by distributions of affordances toward which actions might be taken more or less easily. The metrics are pragmatic, being restricted to action limits, such as, being easily reachable (e.g., arm length, steps away), or navigable over a measured duration (e.g., a few minutes, an hour or so, a day trip), or reachable by locomotory treks of certain durations (e.g., walking, running, by bicycle car, train, etc.). The POV may also be dynamically delineated as revealed in the "field of safe travel" surrounding automobiles or pedestrians, as explained in Gibson and Crooks (1938).

If O and E belong to the same ecological frame, then they are mutually and reciprocally *dual*, but the dual relation ($\langle, \rangle, \diamond$) may be ordered or unordered. However, if the dual relation is *ordered*, then we use the terms *primal* for the dominant member and *dual* for the dominated member. Where primal means *dominant* (like an independent variable) and dual means *dominated* (like a dependent variable). Primal denotes where the origin of the reference system is located and dual is where the object to be related to the origin is located. For instance, John (primal) throws the ball to Mary (dual); Mary (dual) catches the ball that John (primal) throws. Mary (primal) then throws the ball back to John (dual).

- O and E are dual reference frames in any ecological system (ecosystem). An ecosystem supports two major symmetries:
- $O \diamond E$: O's perspective on E (dual) and E's perspective on O (dual);
- $O > E$: O's primal perspective on E vs E's dual perspective on O.
- $E > O$: E's primal perspective on O vs O's dual perspective on E.

A key duality is the primal affordance an actor intends to realize and the dual action effectivity by which it does so (e.g., Catches the ball thrown, lifts the baby down from its highchair, trims the bushes with the hedge clippers).

DISCREPANCY

In general, discrepancy theory describes the deviation of a situation from the state one would like it to be in, say, to be the dual action to some primal affordance goal. You intend to hit the bulls eye with the dart but your throw is errant. Consequently, on the next throw you adjust the direction of the dart 's release by a slight hand rotation. The kinetics of neuromuscular control is felt directly through kinesthetic information. Said differently, the *information frame* of the situated dartboard and the situated *control frame* of the hand holding the dart dynamically share a common force bases, one that is rooted in visual and neuromuscular kinesthetics (felt weight and momentum of arm, stiffness parameter, etc. in the context of visual information about target parameters).

THE DUAL FRAME DISCREPANCY HYPOTHESIS

The work-to-be-done as specified in the primal visual information frame must be matched by the work-actually-done in the dual neuromuscular control frame. If not, then there is a discrepancy to be eradicated by reactive adjustments. For the information and control frames to coalesce into the proper ecological frame vis a vis the perceiving-acting cycle, a synergy comprising the two frames must emerge that has both the intended specificity (goal-path accuracy) and efficacy (properly focused dynamics, or ecological work) (Shaw and Kinsella-Shaw, 1988). Gibson formulated this idea in his 1966 book. This idea is so important and central to the ecological approach, we should have the authority of Gibson's own words (Gibson, 1979):

There are various ways of putting this discovery, although old words must be used in new ways since age old doctrines are being contradicted. I suggested that vision is kinesthetic in that it registers movements of the body just as much as does the muscle-joint skin system and the inner ear system. Vision picks up both movements of the whole body relative to the ground and movement of a member of the body relative to the whole. Visual kinesthesia goes along with muscular kinesthesia. The doctrine that vision is exteroceptive, that it obtains "external" information only, is simply false. Vision obtains information about both the environment and the self. In fact, all the senses do so when they are considered as perceptual systems (p. 183).

APPLYING THE DUAL FRAME DISCREPANCY HYPOTHESIS

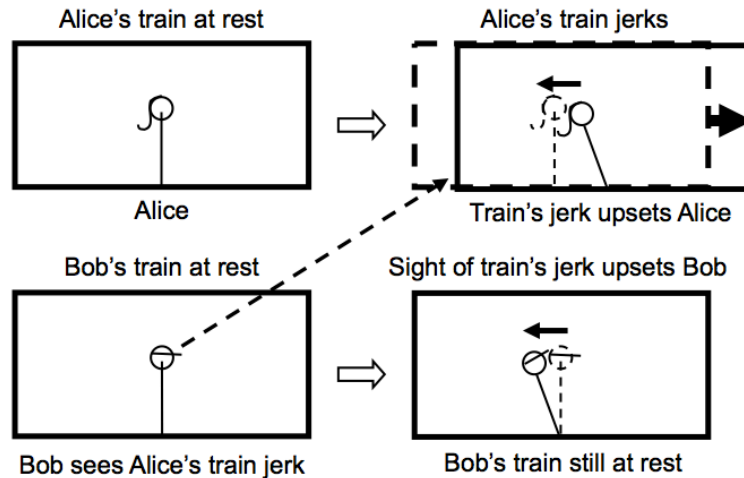


FIGURE 4 The Dual Frame Discrepancy Hypothesis.

The means are depicted by which an information coupling to a frame other than Bob's own allows forceless kinematic information to induce a forceful effect.

Case 1: Consider two trains standing next to each other on adjacent tracks in a train station. On each train there is a person standing in the aisle, facing forward, holding a full cup of coffee. Call them Bob and Alice. Unaware that Bob is watching her through the adjacent train car windows, Alice is lost in thought when her train jerks into motion. Bob's train remains stationary. The sudden jerk naturally causes Alice to spill her coffee and Bob seeing Alice's train's abrupt motion, even though his train remains at rest, also spills his coffee at the same time. Why? (Figure 4)

While there is no mystery regarding what caused Alice to spill her coffee, it remains surprising that Bob being on a train at rest should spill his coffee just from watching Alice's minor calamity. This puzzle is instructive and solving it will make clear one way that forceless optic array information about a forceful action can induce a forced outcome. Or, stated differently, how can a strictly informational coupling between an event taking place in one local reference frame, somehow induce a second hand forceful outcome to take place in another distant reference frame?

The answer is straightforward. Because of relative motion effect, Bob mistakes the sudden motion of Alice's train to be that of his own train. This relative motion error causes Bob to make an unnecessary

postural adjustment response that upsets his own coffee cup. This chain of events is depicted in Figure 4. Notice that this is a solution sought to the dimensional inhomogeneity problem posed earlier.

Case 2: A clever experiment done by David Lee at the University of Edinburgh many decades ago illustrates most dramatically the reality of optical pushes (Lishman and Lee, 1973). Assume someone stands in a room whose walls and ceiling are detached from the floor (Figure 5). Further assume that the ‘room’ (without the floor) swings on a very long cable attached to a high ceiling so that it appears to glide. The result is the room’s walls can glide but of course the room's floor cannot.

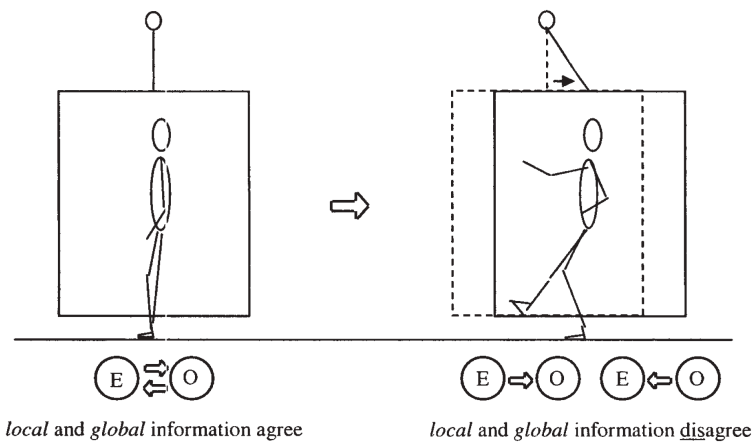


FIGURE 5 Lee's Swinging Room. When local and global information agree (left), then posture is not compromised. But when local and global information disagree (right), then there is a Dual Frame Discrepancy and posture is upset by an optical "push."

If the room is swung toward the person (who sees the wall’s motion), he will sway backwards; if the room is swung away from the person, he will sway forward. Note that at no time does the wall touch the person; thus, no mechanical force can possibly be responsible for the person’s swaying. Also, since the person faces a wall that fills his visual angle, he sees only the wall and nothing else in the environment, especially not the floor. The motion of the wall projects a global optical transformation into the person's optic array information that specifies to the perceiver that he has moved from being upright.

The information does not cause the person’s reaction—information is forceless and, therefore, cannot be a mechanical cause. Since the information-to-control coupling is

forceless, we need an answer to this question: By what means, metaphorically speaking, does the language of information get translated into the language of control? The answer is clear. The kinetics are supplied by the person's own neuro-muscular system whose postural equilibrium is upset by an optical push.

It is known that optical disturbances may trigger involuntary reactions from the perceivers (Shaw and Kinsella-Shaw, 2007). Here it was found that a movement of the wall so subtle that it goes unnoticed can still induce the person to sway in phase with the wall's movement. Although instructed to stand still without moving, precise (goniometric) measurements at the person's ankle joint show he still sways in phase with the room's movement.

d'ALEMBERT'S PRINCIPLE AND INERTIAL FORCES

We follow the arguments given in Shaw and Kinsella-Shaw (2007). In Newton's original analysis, his first law was based on impressed forces, $F = mA$, inertial forces were omitted. Newton's laws of motion only apply to frames of reference in which a body remains at rest or moves uniformly at a constant speed when no forces are impressed upon it. This is called an *inertial frame of reference*. The frame itself need not be at rest—it can be moving at a constant speed relative to another frame of reference. No inertial forces are felt when a frame is inertial.

In all these cases, an optical 'push' arises whenever an abrupt change in optical structure occurs that transforms the person's inertial frame of reference into a non-inertial frame. Put simply: Optical pushes arise from information specifying 'frame discrepancy.' By examining its physical foundations, we shall see what this hypothesis means.

Newton's laws as originally formulated however do not apply to objects in non-inertial frames, that is, in frames that are accelerating. But they may be reformulated so that they do, as shown by the French physicist, Jean le Rond d'Alembert (1717-1783). His principle states: When any object is acted on by an impressed force, an inertial force is produced as a reaction. In keeping with the Principle of Virtual Work, the resultant of this impressed force and the inertial force is zero. In other words, when a car is at rest or moving uniformly at a constant velocity, no impressed forces act on it or its driver and thus no inertial forces. However, when the driver depresses the accelerator, the car's motor impresses a force on the car that

accelerates it. At the same time, in reaction to the impressed force, an equal but counter-directed inertial force is produced that acts on the driver pushing him back against the seat.

As observed earlier, Newton's laws only apply to objects in inertial frames; therefore they do not apply to the accelerating car—a non-inertial frame. But by invoking d'Alembert's Principle, Newton's laws can be generalized to cover this case too. Behind this principle was a simple but brilliant insight by d'Alembert, which is clearly revealed in four steps. (For a general discussion, see Lanczos, 1970):

First Step: We start with Newton's Second Law of motion which asserts that mass multiplied by acceleration equals an impressed force, the familiar, $m\mathbf{A} = \mathbf{F}$.

Second Step: Rearrange the equation as follows: $\mathbf{F} - m\mathbf{A} = 0$

Third Step: Define a new vector, $\mathbf{I} = -m\mathbf{A}$. This is called an inertial force. Notice, this is a counter force; its sign is the opposite of the sign on the impressed force vector.

Fourth Step: We can now reformulate Newton's Law as $\mathbf{F} + \mathbf{I} = 0$.

The third step looks a bit trivial, being nothing more than giving a new name to the negative product of mass x acceleration. In fact, it allows the expression of an important principle in the next step. In Newtonian mechanics, the concept of a system being in equilibrium entails the nullification of all impressed forces acting on it. *Static equilibrium* applies to objects not in motion. With this reformulation of Newton's law, d'Alembert showed us how to generalize the concept of equilibrium to objects in motion. To make this generalization required a brilliant insight—d'Alembert had to see that inertia itself is a force that can be included with impressed forces to make up the total effective force of the system, i.e., effective in the sense of summing to zero. This now allows us to extend any criterion for a mechanical system being in static equilibrium to a moving mechanical system being in dynamic equilibrium.

Inertial forces are experienced daily by those of us whose bodies are carried along with a variety of accelerated frames—automobiles, trains, buses, airplanes, swings, carnival rides, horses, or rocket ships to the moon. The origin of these 'unimpressed' forces is the tendency for objects to resist change of their state of motion or state of rest, in accordance with Newton's Second Law, which asserts that a force is anything that accelerates a mass, i.e., $\mathbf{F} = m\mathbf{A}$.

Inertial forces differ from impressed forces in how they are produced. An inertial force is created by the accelerating frame moving out from beneath the objects it contains—temporarily leaving them behind—until the train's impressed force drags them along as well. Armed with d'Alembert's Principle we can now show how it is possible, at least in one case, to transform kinematic optical array information into kinetic optic array information.

Given dual frames of reference are involved in a situation, such as Alice and Bob being on the two trains (or seeing both the wall and the floor simultaneously in Lee's room). The two frames of reference must be confusable by an observer (e.g., Bob). There must also be two potential energy sources, say, A and B—A for the impressed force and B for the reactive force—that are informationally coupled (e.g., Bob sees Alice's train start-up and mistakes it for his own). If the shades on Bob's train car were pulled down, then he would have no information regarding Alice's train and experience no optical push. (Or, likewise, there would be optical push while standing in the Lee room with eyes shut.).

Again, please study Figure 4. This is how a kinematic display becomes the control for kinetic forces. The information coupling of the two observer-two train frames into an ecological physics field lends support to the Dual Frame Discrepancy Hypothesis.

CONCLUSION

One goal of this chapter was to critically review Gibson's approach to event perception, as discussed in Chapter 6 of his 1979 book. We stressed the importance of event perception for having a generally adequate ecological approach to visual perception. A second goal was to discuss the importance of symmetry theory as a precise way to conceptualize Gibson's invariants approach to information. Here we followed Gibson in recognizing that successive order and adjacent order were useful replacements for time (temporal order), an abstraction from the former, and space (spatial order), an abstraction from the latter.

A third goal, and one we consider most significant, was to review the problem of how forceless kinematic optic array information could also specify forceful kinetic information so that the language of control might somehow be a direct translation of optic array information. We argued that it is possible to do so by means of the Dual Frame Discrepancy Hypothesis. A perceived discrepancy between dual frames that should be congruent causes the perceiver to make neuromuscular adjustments to eradicate the discrepancy that manifests as a self-produced

inertial force. Then, by applying d'Alembert's Principle in the usual way the reactive response can be shown to be dimensionally homogeneous with a Newtonian force when the second law is reformulated in the manner of d'Alembert to include inertial forces.

Our interpretation of the most fruitful aspect of Gibson's approach to event perception is the intrinsic duality of the affordance concept. For this allows a natural way to have dual frames between which a discrepancy can arise, and is the insight needed to map kinematics into kinetics, in the context provided by Gibson's construct of the optic array.

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