Dynamical Systems and Event Perception: A Working Paper, Part I

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I am working to develop a program of research concerning an interrelated set of problems in human visual event perception:

(1) *The identification problem.* How are events recognized? In particular, what is the information specifying types of events.

(2) *The scaling problem.* How is scale in an event determined perceptually? What is the information specifying scale magnitudes (e.g., mass-related values) associated with the various dimensions in an event?

(3) *The sampling problem.* To what extent might identification and/or scaling be possible with apprehension of restricted portions of the space-time pattern (e.g., due to occlusion, scanning, attention, etc.)?

I am hoping that event types can be approached as dynamical systems thereby allowing a description of events in terms of manifolds (within an appropriate space) embedding trajectories of the system. With respect to the aforementioned problems, event types might be distinguished in terms of specific space-time morphologies; scale specific morphologies might reduce the scaling problem to the identification problem; and the sampling problem requires the study of the relation between qualitative properties of individual trajectories (or pieces of trajectories) and the distinct morphological properties of the embedding manifold and the dense set of trajectories representing the event *qua* dynamical system.

All of the above involves Kinematic Specification of Dynamics (or KSD): Invariant patterns of motion provide information for an observer about dynamic properties of an event by virtue of a *unique* correspondence between such patterns and the environmental circumstance (Runeson & Frykholm, 1983). This approach will be elaborated in the present working paper, divided into three parts. The history and evolution of this way of thinking is chronicled in Part I. The empirical challenge—to discover salient space-time patterns and the corresponding types of perceptually significant properties of events—is illustrated in Part II. The theoretical challenge—to provide a formal characterization of the KSD thesis that addresses uniqueness—is taken up in Part III with a consideration of the suitability of dynamical systems theory.

Historical background

Research on event perception was initiated by Gunnar Johansson (Johansson, 1950). Over nearly forty years, Johansson has studied the ways in which a pattern of relative motion among points spontaneously evokes perception of an event property. For instance, dots can be manipulated on a graphics screen so as to give an impression of a rigid rod either rotating or translating in depth (Johansson, 1975). Johansson's demonstrations of motion-generated perceptual effects culminated in his creation of the so-called "point-light people" displays. Johansson (1973) filmed people performing various activities so that only twelve points of light attached to the performer's major limb joints (i.e., shoulders, elbows, wrists, hips, knees, and ankles) could be seen moving against a dark background. When the performer sits still with legs crossed, the display merely looks like a random array of dots. As soon as the performer moves, the display is recognized by naive viewers for what it is, a moving person. Point-light people can be distinguished from point-light stick-figure puppets in under half a second (Johansson, 1976). Particular activities—walking, running, stair climbing, bicycle riding, dancing in couples, gymnastics, and so on—can be recognized almost as well as under full illumination. Additionally, gender, fatigue, and even the fact that someone is carrying a weight are perceptible. It has been shown that the metric amount of weight being lifted by a person can be judged with remarkable accuracy (Runeson & Frykholm, 1981). Collectively, these results support Johansson's insightful recognition that trajectories provide perceptual information about events.

Three limitations of Johansson's program should be noted. First, mechanical constraints on the form of an event have been ignored. His application of a kinematic description ("perceptual vector analysis") to the optics in order to derive the 3-D geometric structure of objects and paths in space means that both optics and properties perceived were described as geometric (dimensionally, L) or at most kinematic (L,T), but not as dynamic (M,L,T). As a result, the approach has been subject to some confusion. The distinction between "rigid motions" and "rigid objects" is frequently blurred. So-called "rigid motions" merely fail to provide information for "object non-rigidity". A swinging weight on a string may move rigidly but is not a rigid object. Motions providing information for the (relative) rigidity of the object would be produced if the string were struck at mid-length by another object.

Second, Johansson's application of kinematic descriptions directly to the optics also means that a cross section of the light-to-the-eye is described inadequately in terms of motions of independent points. The optic array is densely filled by optical pattern marked by discontinuities and gradients in intensity and/or hue. Changes in optical pattern are better described in terms of transformations operating over a continuous array. This is a point made by Gibson (1968). Johansson's computer generated displays often are ambiguous because the points are extended and have shape but do not transform in a fashion consistent with the transformation among "points." Patch-light video displays of real events rarely exhibit such ambiguity.

Third, perceptual vector analysis, in seeking common components among the relative motions of points, is limited to common components, phase relations, amplitudes, and perhaps, frequencies. Generally, patterns of continuous variations in rate over time or position have not been considered.

Consideration of continuous variations in velocity is found, however, in Michotte's studies designed to refute Hume's denial that causality in events can be perceived (Michotte, 1963). Hume's argument was that since we cannot separate specific kinematic patterns from the generating dynamics and since there are only motions (no masses) in the optics entering the eye, only motions—not material causes—can be seen. Hume argued that causes must be inferred. Michotte's move was to design display generation apparatus that minimized dynamic constraints (e.g., the ratio between inertial and power generating characteristics) so that trajectories of more or less arbitrary kinematic form could be generated along straight line paths. He showed that the perceptual significance of a motion varied with specific patterns of variation in velocity along the trajectory. Launching (collision) was distinguished from triggering (spring release) and from entrainment. Some patterns looked like something in particular while others merely look strange or nonsensical. The idea that can be extracted from Michotte's work is that patterns of motion can have intrinsic perceptual significance.

Michotte paid scant attention to potential dynamic constraints on events when manipulating the kinematics in his displays. He never focused on what made some patterns of motion sensible or intrinsically significant to human perceivers while others were nonsensical or nonsignificant. Runeson (1977) revised and extended Michotte's work emphasizing the importance of dynamic constraints on the resulting kinematic patterns in events. Runeson suggested that unique correspondence between dynamics and kinematic pattern in naturally occurring events allows observers to apprehend dynamic properties such as relative mass in simple collisions or amount of lifted weight (Runeson, 1977; Runeson & Frykholm, 1983). Runeson's idea was that specific spatial-temporal characteristics of optical pattern described in terms of length and time provide information for dynamic properties of an event described in terms of length, time, and *mass*.

Kinematics is used to describe events, not optics

The general picture you should have in mind at this point is as follows: An observer perceives an event by virtue of specific patterns mapped into the optic array from surfaces in the event. The event has a particular spatial-temporal structure that we describe using kinematics. This structure is produced by physical constraints that we describe in terms of dynamics. Patterns of motion of the surfaces in an event are mapped into the optics as specific transformations occurring with specific patterns of variation in rate. My interest is in discovering which properties of events can be conveyed through event kinematics and perceived visually. [Remaining problems include how event kinematics map into the optic array (requiring descriptions of specific optical transformations and invariants) and the means by which optical patterns are detected.] An upcoming set of experiments illustrate how this question might be addressed.

I have referred to all of the dynamics as constraining the resulting form of an event. But in dynamics, "constraint" is a technical term referring to the way in which, for instance, solid surfaces are handled (i.e., as "infinite" potentials [e.g., Arnol'd, 1978]). Such constraint surfaces contribute to the common forms of terrestrial events in ways that one might investigate. In the experiments under discussion, a patch-light ball will be filmed rolling on surfaces of different shapes. The events will be filmed from above. The question is can observers determine the shape of the surface from the way the ball moves?

Figure 1 shows how the kinematics of the event are mapped into the optics. The event kinematics (here represented by vectors $\dot{x}_1$ and $\dot{x}_2$ tangent to the path of motion) and associated forms are distinguished from the changes occurring in the optics that correspond to the event kinematics. Components of the event vector $\dot{x}_1$ are mapped into different aspects of the optics. So $\dot{x}_1'$ maps into a vector in the projection surface, whereas $\dot{x}_1''$ corresponds to the rate of dilation or contraction of the image of the ball in the projection. (Note: Two lines of research associated with Johansson's event perception work and Lee's time-to-collision work, respectively, have focused alternatively on one of these components to the exclusion of the remaining component. The extant time-to-collision analyses de-emphasize $\dot{x}_1'$ while current event perception analyses ignore $\dot{x}_1''$. The challenge is to bring these two aspects together in a single analysis.) Ultimately, describing optical space-time patterns corresponding to the salient kinematic properties of events will require development of a new variety of descriptive apparatus sufficient for patterns of rate variation of both components ($\dot{x}'$ and $\dot{x}''$) in both local (motion in the environment) and global (self-motion) flows.

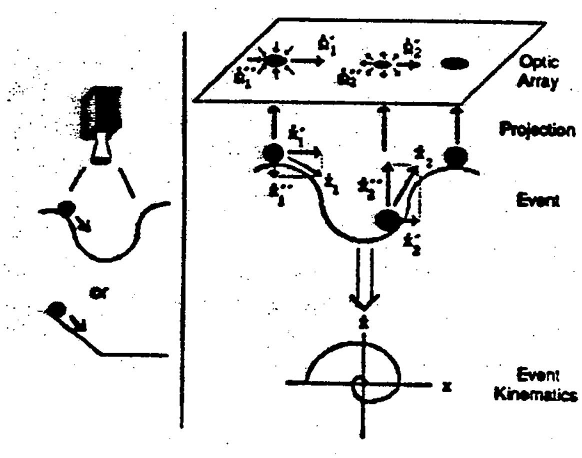

Figure 1. Event kinematics map into the optic array via components.

Inverse dynamics and the emergence of an approach to event identification

Runeson characterized KSD formally as a problem in Inverse Dynamics. The inverse dynamics problem (Anger, 1985; Parker, 1977; Peil, 1979; Sabatier, 1985; Wells, 1967) is to write the differential equation describing the system dynamics given the solution(s) to the unknown differential equation. The solution describes position as a function of time and is called, informally, "the motion." The differential equation contains both kinematic variables (e.g., time, position, velocity, acceleration, etc.) for which, by assumption, values are known, and kinetic parameters (e.g., mass, the friction coefficient, stiffness, etc.), which are unknown. The literature of "Physical Systems Modelling," "Systems Identification," and "Applied Inverse Problems" is dominated by linear systems with little discussion of nonlinear systems. As I understand it, the inverse problem for linear systems can be given a more or less algorithmic treatment using least squares (or similar linear techniques) to determine an optimal configuration of values for coefficients on kinematic variables where inclusion of derivatives of specific orders also can be optimized (i.e., non-inclusion when coefficients go to zero). So the inverse problem for linear systems more or less reduces to problems of parameter estimation. The difficulties that prevent linear modelling from being a strictly algorithmic affair are associated with the necessity of linearizing or approximating inherently nonlinear aspects of the systems being modelled. Of course, the vast majority of phenomena of interest are strongly enough nonlinear to require nonlinear models (especially within the life sciences). The "coefficients" on kinematic variables in nonlinear equations include kinematic variables themselves. Determining the form of such terms is hardly trivial, in fact, dynamicists are only sure to succeed when they are able to recognize specific familiar equations (e.g., Miodek, 1978; Parker, 1977).

An interesting question arises in this context. Given the kinematic behavior of a system, how does the dynamicist recognize the form of the underlying dynamical system? The typical engineer, building a linear model, can draw from a repertoire of a finite and relatively small number of force laws that go into the models. Assuming that the system to be modelled is truly (close to) linear, the task amounts to recognizing relevant force laws. How might a particular constraint force (e.g., a table top or a rigid connecting segment) or a specific force function (e.g., gravity or a spring) be recognized? Clearly, such forces produce characteristic kinematic patterns. For linear systems, patterns corresponding to individual force functions superimpose, maintaining their identifiable characteristics. In a linear oscillator with damping, for example, the conservative force produces semi-periodic trajectories with velocities that vary smoothly in a regular and nearly symmetric fashion while the damping acts to reduce the amplitude of oscillation over successive cycles producing the characteristic spiral on the phase plane.

Since the dynamicist has to recognize individual terms to be included in the modelling equation, nonlinear systems provide a strong challenge. However, visual recognition of events in general does not require recognition of individual constraints as long as their interaction produces a characteristic and distinguishable kinematic pattern. An interesting problem for those studying event perception, then, is to describe the specifically categorical characteristics of kinematic patterns corresponding to particular types of events and to understand how discontinuities arise in the universe of kinematic pattern.

What generates categories as opposed to an undifferentiated continuum of pattern variation? Various force laws appear as candidates from a cursory examination of engineering dynamics. However, the theoretical and ontological status of such laws varies widely, from those associated with a potential to those generally viewed as convenient and empirically based approximations (e.g., Santilli, 1978). They vary likewise in generality and applicability. For instance, the relevance of force laws for damping to the resulting form of an event may vary with values of either kinematic variables or kinetic parameters. More to the point, visual perception requires a qualitative or morphological understanding. The morphological consequences of the various force laws are not always obvious nor is it necessarily the case that force laws produce unique or consistent morphological characteristics. An oscillation can be produced by either gravity or a spring. Alternatively, gravity can produce simple free fall or can hold an object at rest on a surface. Finally, a "force law" approach may be inappropriate for some events, for instance, human limb motion. A taxonomy that is based directly on morphology is preferable. Experiments on the visual identification of patch-light events illustrate the need to taxonomize in terms of kinematic forms and are described in Part II.

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Dynamical Systems and Event Perception: A Working Paper, Part II

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How are events recognized? In particular, what is the information specifying types of events? This *identification problem* (Bingham, 1987a, this volume) requires an appropriate and adequate means of describing events with respect to perceptually salient categorical characteristics. In Part I of the present series, it was argued that the Kinematic Specification of Dynamics, or KSD, Principle (Runeson, 1977; Runeson & Frykholm, 1981, 1983) sits at the heart of this problem. In particular, event identification requires a mapping between locally sampled structure of the kinematics (i.e., specific trajectories) and the global structure of the kinematics of the event in question (i.e., the complete set of trajectories) which can be equated to the dynamics, the field of tangent vectors. The experiments to be reported here (performed with Lawrence Rosenblum and Richard Schmidt) explore the visual recognition of nine events by virtue of kinematic form using the patch-light technique (see Bingham, 1987b, for other experiments of this sort). Nine video displays were created:

(1) A 30 cm compression spring sliding along a vertically held wooden dowel was allowed to drop 1 meter in free fall and to bounce. Only one cycle was recorded. A single patch, attached to the spring, was visible in the display.

(2) The same spring was moved by (an invisible) hand along the same path as in (1), at the same frequency. A metronome tuned to the frequency of the free fall and bounce was used. Again only a single patch was visible.

(3) A 50 cm wooden dowel was hung from a peg by a metal ring and allowed to swing freely through about 75 degrees of arc. Two complete cycles were recorded. Two patches were attached to the dowel, one at each end.

(4) The same dowel as in (2) was moved by hand along the same path and at the same frequency again using a metronome. In (3), amplitude of swing decreased slightly over cycles due to friction. This pattern was impossible to imitate by hand with any precision or reliability while also reproducing the original frequency of movement.

(5) A lacrosse ball was allowed to roll down a track from a static start. The ball was covered randomly with small irregular patches which were all that could be seen in the display. The camera was tilted so that the incline was eliminated in the display, that is, the ball rolled horizontally across the screen. The ball rolled off screen in the display.

(6) The same ball as in (5) was nudged along a horizontal track by (an invisible) hand. The ball was nudged and rolled to a stop three times.

(7) White tickets of paper were floated on the surface of water in a large bowl and filmed from above. Only the paper tickets, appearing as irregular patches, could be seen in the display. The water was stirred around the edge of the bowl with a (n unseen) stick.

(8) Unseen objects (small clay balls) were dropped into the bowl of water from (7).

(9) Tickets of paper were blown out of a person's hand (off screen) onto an invisible surface and then blown off the surface and off screen. Only the paper tickets appearing as irregular patches could be seen in the displays.

None of the above displays is recognizable when seen in freeze frame.

All displays were shown to naive observers who were asked to identify the events, to describe the motions, to describe the objects involved, and to describe the causes of motion. Briefly, all of the events were recognized generally. For instance, the compression spring in (1) was not usually identified as such, but the bouncing of an elastic object after free fall was recognized. Often the constraint provided by the dowel was noted. The pendulum, stirred water, objects dropped in water, and "autumn leaves" were easily recognized. The ball rolling down an "unseen" inclined plane was recognized as such and easily distinguished from the nudged ball. Occasionally, observers saw the ball rolling downhill as being blown instead. Of especial interest, the compression spring moved by hand was distinguished from the free falling and bouncing spring and frequently observers recognized that it was being moved specifically by hand. They had much greater difficulty distinguishing or recognizing the pendulum moved by hand, although occasionally, it was so recognized.

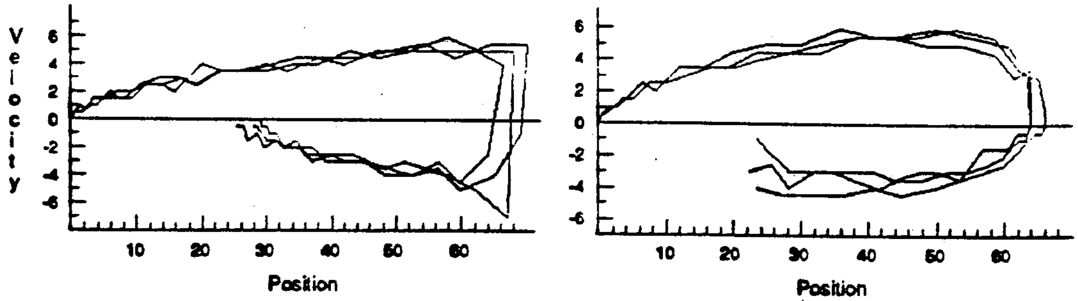

Figure 1. Free fall and bounce of a compression spring sliding along a dowel (left) and compression spring manually guided along a dowel (right). Trials 1-3 are shown. Arbitrary units on position and velocity.

The difference between (1) and (2) can be seen on the phase plane (Figure 1, where the kinematics were sampled directly from the video screen, i.e., at 60 Hz). Free fall and bounce produces a characteristic parabola with a flat base corresponding to impact, while the manually controlled movement exhibits a close to elliptical trajectory typical of human limb movements. The only difference between phase plane trajectories for the freely swinging pendulum and that moved by hand is in amplitudes.

Further experimental conditions demonstrate that orientation is an essential characteristic for the particular significance of a kinematic form. The displays were shown upside down to naive observers who were unaware that we had inverted the video monitor. The identity of all of the events was changed except for (2) and (9). Orientation had no effect on the identity of (2). Event (9), shown last, was recognized as having been inverted. Some of the events were unrecognizable and odd. The ball rolling downhill became incomprehensible when inverted. If a potential (and dissipation function) remained sensible when inverted, however, then a different potential was recognized. The free fall of event (1) became a contracting elastic band pulling up some object. [The results from inverting these events are very similar to results obtained by J. J. Gibson who investigated reversible and irreversible events by showing films backwards (Gibson & Kaushall, 1973). Some of the dissipation functions remained sensible when inverted. Others did not.]

In a third condition, inverted naive observers judged upright displays. The results were the same as for upright observers judging upright displays. Thus, it is the orientation of the kinematics relative to the context of constraint (i.e., the gravitational field) that determines the significance of the pattern. These results were confirmed in parallel experiments employing a "circle the properties that apply" task.

These experiments were fairly simple but the results are not trivial. The differences between events (1) and (2) and between events (3) and (4) were extremely subtle and the information was fairly abstract. However, the differences and the information were enough for observers to detect a difference, and often, to make an identification. Clearly, observers are sensitive to variations in kinematic form (e.g., variations in velocity over position or time) as information for what is happening in an event. In general, particular kinematic *morphologies* enabled observers to identify specific types of events involving constraints ranging from rigid body dynamics to aerodynamic or hydrodynamic constraints to biophysical constraints. Finally, by manipulating the orientation of the kinematics, it was demonstrated that the informative character of the kinematics is based on the observer's relation to the kinematics, where the relation is determined by dynamic constraints contributing to the form of an event as well as to the form of the observer's activity. These results underscore the need for a means of characterizing types of events in terms of dynamics. The importance of morphologies, in particular, suggests that a qualitative approach to dynamical systems would be useful and this provides the focus of Part III.

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Dynamical Systems and Event Perception: A Working Paper, Part III

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Dynamicists have been working to devise a taxonomy for dynamical systems in terms of configurations of generic attractors and types of transitions between specific attractor morphologies (See Abraham, 1985; Abraham & Marsden, 1978). This strategy is attractive as a potential approach to the classification of (perceived) events for the following reasons. First, it is a taxonomy that is based directly on the morphology of events. Classification is based on qualitative properties of events directly relevant to the manner in which they might be perceived. Second, the approach is prepared to deal with the pervasive nonlinearities of natural events. Properties associated with the nonlinear aspects of events (e.g., specific stabilities) are likely most important for visual recognition. Third, a focus on attractors should be useful in studying the visual anticipation of the course of an event. Forth, the differential geometric approach to dynamical systems addresses the relation between local and global structure in an event. KSD is best understood as a mapping between locally sampled structure of the kinematics (i.e., specific trajectories) and the global structure of the kinematics (i.e., the complete set of trajectories) which can be equated to the dynamics, the field of tangent vectors.

What kind of mapping is it that can take a trajectory from the kinematic domain into event types understood as dynamical entities? KSD has been characterized as a missing dimension problem, that is (M, L, T) from (L, T) (Warren & Shaw, 1985). This characterization puts KSD squarely in the domain of mysteries. The reason is that KSD is portrayed as a mapping between incommensurable kinds, namely, lengths and times as opposed to masses. As argued by Shaw, Turvey, and Mace (1981), such approaches inevitably require resort to *petitio principii* style solutions. An alternative characterization using a differential geometric approach to dynamical systems casts the problem in terms of a mapping between local and global morphologies. This is a mapping between entities of like and therefore commensurable kind. If we can discover unique relations between local and global structures produced in a sufficiently constrained domain then the "missing dimension" problem dissolves.

Are the formalisms associated with dynamical systems theory well suited to a characterization of problems in event perception? Given certain characteristics of the mathematical apparatus employed in dynamical systems theory, one might wonder how well the methods would generalize to the great variety of perceived events. For instance, smooth mappings and continuity of space, force, velocity, and so on generally are assumed and required. In this context, impulses are problematic. However, in a cluttered terrestrial environment, discontinuous contact forces are the rule rather than the exception. As a means of describing terrestrial events, dynamical systems will have to be able to accommodate discontinuities in events (e.g., the impact for a bouncing ball or the heel strike for a running person).

Another symptom of this potential shortcoming is the typically asymptotic nature of the approach to a point attractor. In real events, a resting state is reached in finite and typically short time. There is a discontinuity that occurs as damping critically transforms, grabbing and halting movement. This is portrayed in dynamics as the difference between static and kinetic friction. These properties of events are of great importance because they focus on the *intrinsic temporal boundaries of events*. Real events have beginnings and endings. They are bounded in time as well as space. The *problem of anticipation* in psychology can be addressed within perception if events are perceived as definite space-time objects of specific scale. Scale in events is restricted intrinsically not only along spatial or mass related dimensions, but also temporally. So, seeing an event of a particular type also is seeing an event that will last a characteristic period of time. One can by reflex catch a glass falling from a nearby surface but never move to grab one falling across the room. Might a dynamical systems approach be tailored to a portrayal of properties of events associated with intrinsically scaled beginnings and endings?

A partial solution of the scaling problem might lie in a solution to the identification problem. Event types are scale specific at least up to some degree of tolerance. People lifting weights fall within a certain very restricted range of size, so too, must possible amounts of lifted weight. The ability to recognize the event as human weight lifting provides some account for the ability of observers to judge scale values of lifted weight correctly. How well might a taxonomy developed within dynamical systems theory be used to describe the large variety of specific types of events occurring at specific scales? The scaling literature in biology is divorced from the literature of dynamical systems modelling in biology (Calder, 1984; McMahon, 1984; Peters, 1983). In biology, scaling is largely an empirical matter of establishing relationships among dimensions using correlational techniques. Occasionally, attempts are made to theoretically motivate empirically discovered scaling relations using physical principles within the context of similarity theory (e.g., McMahon & Kronauer, 1976). On the other hand, the primary interest among dynamical systems theorists seems to be in scale free forms such as vortices in water and in galaxies. Generic attractors occur in systems which diverge widely in scale. Limit cycles, for instance, describe orbiting planets as well as some human limb motions. This circumstance suggests that dynamic systems theory might not be suited to developing an understanding of the scale specific forms in nature. However, consider how easy it is to distinguish scale models from the real thing in motion pictures (e.g., of collapsing bridges, dams, or skyscrapers). It is kinematic properties that enable this recognition. Dynamics *is* the appropriate discipline in which to address problems concerning the relation between specific types of motion and physical constraints producing them.

The scale specific nature of objects and events makes the practice of scale modelling in engineering extremely difficult and, most often, strictly impossible (Baker, Westine, & Dodge, 1973; Emori & Schuring, 1977). The laws of nature amount to statements about scaling relations between measurable dimensions in events. Intrinsic, event-specific measurement systems (often called "natural" measurement systems) can be established for an event given an appropriate number of laws relevant to specific aspects of interest in an event (e.g., Baker et al., 1973). Natural measurement systems have been avoided by physicists as inconvenient and as circumstance-specific. It is just such unique relations, however, that might provide a foundation for KSD. No doubt a large part of what makes KSD possible are the particular material properties found in the terrestrial domain, the particular values associated with gravity, with various properties of the atmosphere and water, and with various common materials (e.g., wood). It is just these properties that make scale modelling in engineering difficult. The scaling problem requires an understanding of how such scale specific values on dimensions in events are associated with specific kinematic qualities of events. It seems that dynamical systems theory in its current state of development does not have much to offer to an understanding of this problem.

The treatment of dynamical systems in Marmo, Saletan, Simoni, and Vitale (1985) is of nonrelativistic, smooth, finite dimensional systems. Starting with position measurements from multiple perspectives, they work from the properties of transition mappings between corresponding data sets to, first, the construction of a (configuration space, Q) manifold and thence, from the information provided by pieces of trajectories on Q, to construct the vector field TQ.

Concerning the usefulness or appropriateness of a dynamical systems approach to perceived events, there are two related general points to consider. First, the construction of TQ (or T^nQ, vector fields associated with higher order derivatives) and Q starts from observations of positions over time. However, visual perception need not be restricted to positions over time. The derivatives may be observed directly. This may bear on the second point which is that many of the properties of dynamical systems, of TQ (T^nQ) and Q are imported from the mathematical apparatus being used, for instance, the calculus, rather than from the events observed or from the observation. Marmo et al. state that it is desirable that Q have a number of simple, fundamental structures, namely, that it be (i) metric or metricizable; (ii) continuous; (iii) smooth; (iv) locally homogeneous; (v) isotropic; and (vi) have well defined dimension. These properties are rationalized, offhand, as those "common experience associates with space." This rationale is weak and, really, incorrect. For instance, as shown in the experiment described in Bingham (1987, Part II, this volume), the relevant space is not isotropic. The "technical requirements" of continuity and differentiability are both "most important" for the mathematical tools available to dynamicists and most restricting of applicability to problems of interest. Marmo et al. refer to them as "conventional, but not arbitrary." Is there any way that such requirements can be weakened with respect to modeling perceived events (especially in view of perceptual abilities with respect to motion) without destroying the power of the modeling apparatus? It is differentiability that provides the strongest constraint, for instance, the topological structure of Q is mostly determined by differentiability (e.g., compactness, connectedness, dimension). But what if the derivatives are given to start with?

Marmo et al. begin by rejecting the independence of manifolds and motions, but when they get around to considering the (defining) properties of dynamical systems that are invariant over representations, they draw up separate lists of invariants associated with Q and with trajectories where those associated with Q are just those imported with the mathematical apparatus, that is, those associated with differentiability. The only exception to this is dimension. (Perhaps this might be different for TQ or T^nQ for appropriate n.) Invariants associated by Marmo et al. with trajectories are the sort of thing that should be sought when modeling events—period, closure of orbits, embedding properties, equilibrium points, and so on. In view of Marmo et al.'s stated objective, it would be preferable if such invariants were represented in the structure of embedding manifolds themselves.

Next, Marmo et al. consider the problem of translating the set of trajectories (S) on Q into a vector field on a suitable manifold, T^nQ. (They immediately rule out rigid body collisions.) As expected for dynamical systems, they require determinacy (i.e., no bifurcation or overlap of trajectories). Next, they take derivatives and set up a recursive definition of the flow over the particular parts of the manifold covered by observations. The problem is then to fill out the vector field on the remaining portions of the manifold. This is exactly where KSD comes in. The following is a quote from Marmo et al.'s discussion of this point with my commentary inserted in italics:

> In general, there is no unique way to extend X [*the vector field*] to the entire manifold, to obtain a unique maximal extension... this is the point at which the theorist 'makes science'. [*And indeed, this is exactly where event perception research must 'make science'!*] At some point the theorist must leave the experimental observations and construct a model which includes not just them, but significantly more. There is no recipe for this procedure. [*Nevertheless, dynamicists often do succeed.*] It is inherently ambiguous. [*However, since there are successes, the ambiguity must be distinctly limited.*]...There is no deductive procedure for constructing the dynamical theory which encompasses the experimental data. [*What about abductive procedure? See below.*] The theory is probably never unique. [*Might this be because the domain under consideration is not sufficiently constrained as it might be in nature by natural law?*]

They invoke the traditional inductive picture of science. The literature on "scientific method" and "induction" always focuses on verification and ignores the problem, called by C. S. Peirce, "abduction." Namely, how are the "desirable properties" of the model observed in the first place or, in terms of hypothesis testing, how are potentially viable hypotheses generated from the infinitude of possibility? Something must be recognized directly. This is the problem of recognition for which all "inductive" accounts provide question-begging, regressive explanations. This is a point argued repeatedly by R. E. Shaw (e.g., Shaw & Pittenger, 1978).

An alternative formulation of the problem in the spirit of Gibson's central insight might avoid the regress. How can we discover and describe nonambiguous, unique relations between local structure and global structure that enable us to recognize what is happening despite the specifically restricted nature of our observations? This problem requires that we describe the specific nature of the restrictions on observations. There must be enough structure in observations to allow us to perceive the events and properties of events that we do perceive in fact. Also, we must describe the global structure of events. The restrictions on the possible types of structure must be strong enough to allow a solution. Sources of constraint lie in the functional relations between perceivers and their environment as well as in the specific nature of the terrestrial domain. Terrestrial events are restricted in scale in ways specific to their type. Terrestrial events commonly include collisions and contact. Can we devise a morphologically based taxonomy for events using a dynamical systems approach that allows for these characteristics? Might we start with more structure in our observational data, for instance, allow derivatives up to perhaps second or third order to be given, and in this way, reduce prerequisites on the topological structure of manifolds and/or trajectories on manifolds? We must be careful not to confuse any particular piece of mathematics (i.e., descriptive apparatus), and problems specifically associated with it, with the natural phenomenon to be described by us within a particular scientific domain. Event perception is not to be confused with solving differential equations or any other mathematical activity. It is to be hoped that some mathematical apparatus (e.g., the approach to dynamical systems as geometric objects) will be of use in the attempt to describe event perception. Apparently, currently existing mathematics is not adequate for a description of KSD, and hence, of event perception. Nevertheless, there must be some kind of unique mapping between kinematic form and event types that supports and enables the perceptual abilities exhibited by people every day. The question is whether some version of dynamical systems theory can be developed to provide a means of describing that mapping.

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REVIEW

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As used by the psychologist James J. Gibson, the term ecological psychology refers to a strategy for attacking problems of perceiving, acting, and knowing at the scale of behaving animals. The *Perceiving-Acting Workshop* is a forum for the discussion of issues—both empirical and theoretical—that are of interest for ecological psychology so construed. The workshop atmosphere encourages preliminary or exploratory investigations as well as completed works. All included topics are of relevance to the ecological approach although not all participants are committed fully to the premises of that approach.

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