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Shabnam Mousavi and Shyam Sunder

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YALE UNIVERSITY
Box 208281
New Haven, Connecticut 06520-8281

http://cowles.yale.edu/

Physical Laws and Human Behavior: A Three-Tier Framework

Shabnam Mousavi[1] and Shyam Sunder[2]

[1] Max Planck Institute for Human Development (mousavi@mpib-berlin.mpg.de)

[2] Yale University (shyam.sunder@yale.edu)

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Abstract

Social sciences start by looking at the social-psychological attributes of humans to model and explain their observed behavior. However, we suggest starting the study of observed human behavior with the universal laws of physics, e.g., the principle of minimum action. In our proposed three-tier framework, behavior is a manifestation of action driven by physical, biological, and social-psychological principles at the core, intermediate, and top tier, respectively. More broadly, this reordering is an initial step towards building a platform for reorganizing the research methods used for theorizing and modeling behavior. This perspective outlines and illustrates how a physical law can account for observed human behavior and sketches the elements of a broader agenda.

JEL Classification: B30, B40, D01

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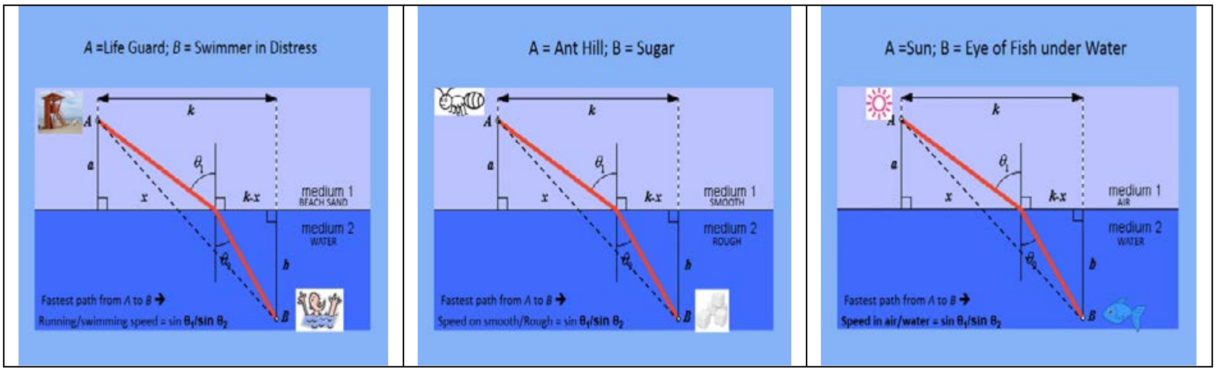
Introduction

In the history of thought, animal action has been intertwined with some form of intent, purpose, teleology, or goal, whether deliberate, habitual, or hardwired. Decision theory, at least since von Neumann and Morgenstern's [1] axiomatization of "reasonable behavior" [2], was built on the shared assumption of intentionality in game theory[-3] and operations research. These logic-based formulations of "reasonable behavior," though subject to criticism by philosophers [4], economists [5,6], and other scholars [7,8,9], claim a considerable command in the study of human behavior with variations in methodology, but a general consensus on fundamentals. Engineers have paid close and continuing attention to optimizing schemes in biological systems [10], as well as embedding robots with various forms of consciousness [11]. Cognitive scientists have explored the architecture of the mind, while questioning how mental and physical existence get combined [12,13], and also studied the nature of inquiry that precedes action [14]. However, modeling and understanding human behavior independently of reason and intention is not without precedent. For example, markets populated by simple "zero-intelligence" (ZI) agents stripped of all cognition can yield aggregate level outcomes that capture important aspects of markets, in particular allocative efficiency [15]. The work on movement of pedestrian crowds modeled as a physical phenomenon [16,17] and the use of the free-energy principle for constructing a unified brain theory [18,19] are other examples of such work. Here, we are not offering a reductionist account, nor a normative one. In its first order of approximation, our approach seeks an understanding of observed behavior with the help of physical laws before resorting to biology or higher human faculties.

Certain similarities among the three examples illustrated in Figure 1 lead us to entertain the possibility that granting priority to intent may not necessarily be the best way to understand at least some aspects of human behavior, even when it appears to be conscious and controlled. Consider (1) a lifeguard rushing across a sandy beach and swimming through water to rescue a drowning child; (2) ants making their way from their hill to a food source (sugar), traversing both smooth and coarse surfaces before returning home; and (3) photons traveling from the sun through space and water to enter the eye of a fish swimming underwater. All three could follow a straight line or minimum distance path [20,21]. Instead, they follow a kinked path that obeys Fermat's Principle that the travel time to reach the end point is minimized (also stated as Snell-Descartes' law equating the ratio of sines of the angles of incidence at the kink to the ratio of velocities in the two media—sand and water, smooth and rough surfaces, and empty space and water, respectively, in the three examples).

Figure 1: Lifeguard, Ants, and Sunbeam: All Follow a Kinked Path across Two Media



Do the apparent similarities among the paths that humans, ants, and photons take, illustrated in the three panels of Figure 1 follow some fundamental principle common to the three examples? Or is it simply a case of the same mathematical model that happens to capture diverse and unrelated phenomena in different domains? Viewed in terms of cognitive abilities alone, purpose, intent, motivation, learning, and free will are easily attributed to the lifeguard. With effort, some of these might also be stretched to fit the behavior of ants. However, it strains credulity to associate these attributes with photons or electromagnetic radiation. At a biological level, the behavior of the lifeguard and the ants can be understood as conforming to energy conservation, which is most often in an organism's survival interest. But can we systematize these empirically observed phenomena within the structure of a physical law across these three very different but commonplace (non-exotic) contexts? Our proposal, as outlined in the following section, aims to do just that. In this instance, we suggest using the principle of least action. As our framework expands, other laws of physics could be more suitable candidates to serve as organizing principles for observed behavior.

The principle of least action and the physics of human behavior

In classical mechanics, the *path of least action* is the path along which the sum (integral) of the difference between the kinetic energy and potential energy, at every point in time, is minimized [22]. We propose using this principle to isolate the elements of human action that arise based on our physical existence from elements attributable to biology and the higher faculties.

> ***Proposition:*** *Of all possible paths from a beginning point A to an end point B, the materially efficient path uses minimal action, where action is a scalar that corresponds to the dimension in which value has been conserved.*

What remains is to specify the particular value conserved in the context of observed behavior. Thereafter, to the extent that the path followed by humans coincides with the path of least action, physical laws suffice for understanding it. Note that we do not propose the physically efficient path as a normative standard and consequently do not advocate approaching it to "improve" behavior. Instead, to the extent that the observed path deviates from this physically efficient path, an explanation for such deviations will be sought in biology and social-psychological attributes associated with the biological endowments of animals as well as in higher faculties of humans. These higher tiers of the proposed structure call for an alternative, nonphysical apparatus. Thus positioned, our approach avoids the controversy over the suitability of mechanically driven benchmarks for the study of human behavior. Our three-tier framework can be visualized as a sphere with a physical core and a biological middle layer, wrapped in a social-psychological cover. A first step in constructing this framework is summarized in Table 1.

Table 1 shows six possibilities of a *path of least action* between a beginning point *A* and an end point *B*. In each case (a numbered row in Table 1), a path in a specified space is generated by minimizing action with respect to the "action element" indicated in column 3. In each case, elements exogenous to action are listed under column 2. Moving down the table from rows 1 to 6, the complexity increases and the space has more dimensions or properties. Nonetheless, the action is defined in the physical sense, even when higher-tier attributes are involved. Our main contribution is the very specification of an action element that is configured on the physical level. Deliberately confining ourselves to the laws of physics, we examine at this tier (the physical core) the extent to which behavior can be captured and characterized. We remain cognizant that nonphysical understanding is called for when examining nonphysical aspects of behavior. Examples of nonphysical aspects are natural selection [23] and survival of the fittest [24,25] in biological or social evolution [26,27,28], deliberate processes such as mathematical/logical or algorithmic ones [29], and partially or fully subconscious processes such as heuristic and intuitive decisions [30]. Thus, the modeling strategy of starting from the physical tier permits as many physical laws as possible to be attributed to this core tier, without seeking help from the outer biological and social-psychological tiers at this stage.

Table 1: Extending the principle of least action to account for behavior

	1: Description	**2: Fixed/ exogenous element**	**3: Action/ economized element**	**4: Example**	**5: Path**
1	Going from point *A* to point *B* in Euclidian 2-D space	Beginning and end in Euclidian space	Euclidian distance	Connecting two dots in 2-D Euclidian space	A straight line
2	Going from *A* to *B* in a force field	Beginning and end in a gravity (or any other force) field	Physical action (minimal energy)	A ball thrown in the air at an angle	A parabola derived from minimal action
3	Moving from *A* on one fabric to *B* on a different fabric in same space	Beginning and end in Euclidian space across change in the fabric	Time	Lifeguard rescues a drowning swimmer	Kinked line under Snell-Descartes' law
4	Moving from *A* to a specific end B at (or before) a given time	Time a fly ball takes to reach 1.5 m above ground; No need to know B or time	Keep a *fixed angle* of gaze (change=0)	Baseball player catches a fly ball	A curved path, depending on when the angle of gaze is first fixed
5	"Save wire" organizing principle	Location of ganglia in a combinatorial space	Minimal *cost (length) of connections* among ganglia	Ganglia connections in the nematode nervous system	A path of fiber connections with minimal length of connections
6	Use the simplest model sufficient for action	One cue is valued more than others	Use only the *cue of maximum validity*	Single-criterion decision-making	A non-compensatory structure: 1, ½, ¼, ….

A broad range of actions is illustrated in the six rows of Table 1 using physical properties only. Row 1 configures the simplest case of physically moving from point *A* to point *B*, where both are exogenously given on a plane, the action element is Euclidean distance, and the resulting path is a straight line on the plane, which minimizes the distance.

Row 2 presents a familiar path of minimum action that a ball thrown in the air takes in the force field of gravity to return to the ground. Row 3 provides a decomposition of the phenomena in Figure 1, captured in Snell-Descartes law, as an application of the general principle of least action. Here, the action element that is minimized is time instead of distance, the fourth dimension in Minkowski space[31].

Row 4 implements the idea of using physics to explain behavior. The action element here is not a new dimension but a physical attribute, the (change in the) angle of gaze. The exogenous element here is time, and execution of action does not require the actor's preliminary knowledge of the specific endpoint. Although a biological construct is likely at work [32]—referred to in the literature as the gaze heuristic [33]—under the action element in Column 3, our proposed configuration requires only the fixed angle of gaze. Keeping the changes to a minimum (ideally zero) is based not on the evolutionary capacity of maintaining the gaze (that resides in the biological brain) but on a physical element. Thus, this configuration remains in the physical tier.

Row 5 takes a biological phenomenon — connections among the ganglia of the neural system in a tiny worm (nematode) — that minimizes the total length of wiring. This configuration assumes fixed ganglia locations for which connecting paths have been optimized, and thus does not include the possibility that the location of ganglia and connections are co-determined [34]. With this caveat, external elements are specified along with an efficient path (network of connections) resulting from a minimization of action as measured by the length of connections.

The last row in Table 1 (Row 6) presents problem-solving behavior viewed as an act of moving from the problematic beginning to a resolved end. This signifies the use of a very simple heuristic, one-reason decision-making, for solving the problem at hand [35,36]. The external requirements or non-action elements are specific structures in the task environment that lend themselves to such solutions. Here, economizing an action element does not involve the cognitive effort spent on the search for relevant cues and the subsequent choice of only one cue/reason from the set of all available cues. Our formulation seeks to capture the action only after one cue is chosen. In this case, the efficiency (and simplicity) of the action arises from considering and acting upon one cue only, instead of taking the effort to weigh and add many cues. The path in this case is an abstract interpretation, a mathematical series that corresponds to the non-compensatory structure of the cues' environment. The caveat concerning the unknown amount of effort required for judging which cue applies in a certain situation also applies to this formulation [37]. Populating this table — i.e., representing observed behavior in terms of an action element, exogenous factors, and a path — generates physical configurations of observed behaviors in terms of the principle of least action. As we move forward with our broader agenda, it is plausible to expect that other physical laws will gradually enter the stage.

What we have discussed so far is only a part of one branch of a larger conceptual framework for organizing methods of studying human behavior or action. In this framework, a theory and its methods constitute a *lens* through which the subject matter is explored. A major difference between physical science and human science is that the investigator always remains an outsider to the subject matter in the former [38], whereas in the study of human behavior, the investigator simultaneously constitutes part of the subject matter. Interesting results arise from this overlap between the actor and the investigator. In particular, the actor can hold different views of behavioral phenomena from the investigator's views as we shall see later. The next section sketches one lens of the broader platform that our agenda aims to construct.

Lens 1: Action characterized as movement

All human behavior comprises actions. Viewing an action as a movement between two points, we define it as follows:

> ***Definition:*** *An action is a movement from state A to state B, where A and B can be specifiable (denoted as $\dot{A}$ and $\dot{B}$) or nonspecifiable (denoted as $\tilde{A}$ and $\tilde{B}$) states. A pair of beginning-end states (A, B) is a situation.*

An actor looking at an action (emic view) through Lens 1 faces one of four possible situations, labeled S1 to S4 in the following descriptions:

S1: $\dot{A} \rightarrow \dot{B}$ – Physical laws are directly applicable. All cases outlined in Table 1 fall in this situation. The observable outcome is binary in that the actor either succeeds or fails to arrive at $\dot{B}$.

S2: $\tilde{A} \rightarrow \dot{B}$ – Wishes, ambitions, and dreams exemplify this situation. No action is taken, but the end is imagined or anticipated. Once the action is taken to achieve them, S2 collapses into S1.

S3: $\dot{A} \rightarrow \tilde{B}$ – Examples are job offers or marriage proposals for which an action is initiated but outcomes are uncertain. Judgment and decisions occur by using specifiable proxies for the possible endings.

S4: $\dot{A} = \dot{B}$ $\left[and\ \tilde{A} = \tilde{B}\right]$ – Inaction or null action. It can be deliberate or not, corresponding to conscious and subconscious cases of inaction, respectively. This differentiation might be of use to those policymakers who want to tap into defaults.

Note that a modeler (etic view) specifies beginnings and ends, and therefore formally deals with S1 only. Our argument is that S1 modeling will be more effective when modelers initially confine their focus to the physical laws. Giving cognition and social-psychological attributes of humans the top priority limits the scope for physical formalization. We do not suggest abandoning the existing methods; rather, we present a platform of unifying lenses that offers, for potentially every method of studying human behavior, a shared basis for communicating with each other.

The big picture

The general conceptualization of “movement” in Lens 1 creates a worldview useful for describing and understanding human behavior. Table 2 lists two more lenses that generate other worldviews and insights: Lens 2 (labelled “match”) and Lens 3 (labelled “construction”). The labels correspond to the focal principle of investigation that figuratively constitutes the respective lens. As alluded to in the preceding section, two non-identical strands of questions arise from the perspectives of actors versus modelers. A lens can be used by both actors and modelers. In previous sections, taking the role of a modeler, we first formulate six specific items by focusing on the physical characteristics of the action configured by Lens 1 (Table 1). Then, we view the action through Lens 1 from the perspective of an actor to extract meaningful combinations of beginnings and ends with respect to specifiability. This work continues by exploring the subject matter through different lenses, each affording the modeler different working tools. So far, we have conceptualized three lenses, which are listed in Table 2 along with their related concepts and elaborations.

Table 2: Organizing methods of modeling human behavior through different lenses.

	Lens 1: Movement	**Lens 2: Match**	**Lens 3: Construction**
The core principle that describes the method of study	The observed behavior is configured as a movement from *A* to *B*, where *A* and *B* represent non-**specifiable** states. A pair of states (A, B) is a **situation** (*S*).	An observed behavior results from a perceived **match** between the mind (*m*) and task environment (*e*). Characterization of the environment can be **objective** or **subjective**.	The observed behavior is the starting point of the reconstruction of the path moving backwards. **Reasonable behavior** follows consistent rules.
Related concepts	Binary outcomes (success or failure) result from following rules.	Success results from an accurate match of *m* and *e*. Perceptions (of *e*) lead to different judgments.	Success constitutes achieving a preferred outcome by optimizing a quantifiable metric, such as Max Utility or Min Cost.
Discipline of modeler	Math & Computer Science	Psychology	Economics

These are the steps we have taken so far. First, we chose a law of physics, the principle of least action, to develop a proposition and definition that constitute a physics-based platform for decomposing observed phenomenon. Table 1 depicts the current effort to extend this development, which falls under Lens 1 in the broader platform. Some attempts exist in cognitive science to derive particular cognitive models from perception [39] and other universals [40,41], or to reconcile physics-based principles used in cognitive models [42]. Our plan is more general; it reverses the order of the study of human behavior by starting from the physical core rather than from cognition and other human faculties. The plan is to identify/develop connections between different lenses that enable them to communicate with one another by analogy. For example, consider intuition and deliberation, which are viewed as two cognitive capacities in Lens 2. One possible analogy to Lens 1 is: if intuition is one cognitive medium and deliberation is another, then arriving at a decision using both is like the lifeguard running across a sandy beach (analogous to rapid intuitive engagement first) and then swimming in the water (deliberating next, at a slower speed). Each “medium” affords a different speed analogous to the cognitive effort needed for intuition and for deliberation; and the efficiency of behavior arises from taking the longer distance (using more of one cognitive capacity) at a higher speed (where the cognitive medium operates with more ease.) That is, humans switching between intuition and deliberation tend to “stay longer in the *faster* medium”. The benefit of generating these mappings is the creation of a tractable platform for interdisciplinary exchange and collaboration.

Discussion and remarks

At the outset, we sought to understand the reason for and meaning of behaviors taken from three different examples. The human lifeguard, the ants, and the inanimate photons—all tend to follow the same law of refraction (Snell-Descartes law, or its precedents in earlier forms by several scientists, including Ptolemy and Ibn Sahl[43]), albeit with different degrees of precision. The precision of correspondence to this law is greatest in the physical domain and diminishes for ants and humans. Optimization in the form of principle of least action is a fundamental organizing principle of the universe. There is no reason to think that the matter and energy that acquire biological properties (ants) or even higher faculties (humans) cease to be subject to the universal laws of physics. Given that economizing on action is a fundamental property of the universe, ants and lifeguards do not need their cognitive endowments for this purpose any more than the photons that do so without any such endowments. For this reason, we propose a perspective on observations from all domains that share this common core.

Biology endows the animate world with attributes, tendencies, cognitive faculties, and even intentions, purposes, and teleologies absent in the inanimate world. We humans are especially proud of our exceptional capabilities in this regard and count ourselves as standing apart from all other species at the top of the pyramid. Irrespective of whether we count ourselves as part of the animal world, the additions of biological, social, and psychological endowments bring additional elements to observed behavior absent in the core physical tier. It is no surprise then that photons follow Snell–Descartes' law quite precisely, but that for ants and lifeguards the law provides only a central tendency or basin of attraction.

In summary, physical laws can explain only a part of observational variation in biological and social-psychological tiers. To explain the remainder arising from this greater complexity, we need to account for biological principles (e.g., in the case of ants) and for biological, social, cultural, and psychological aspects (e.g., in the case of the lifeguard). At the same time, the order proposed in this perspective reverses the conventional approach of seeking explanations for human behavior in sociocultural and psychological elements before resorting to biology and almost never dipping into the physical laws at the core. This proposed order generates a platform for extensive consideration of existing, well-configured physical laws at the level at which they apply and implies disengagement from them at the outer tiers.

Based on a minimal definition of action as movement, we propose a framework for a stepwise study of human behavior that begins with the physical aspects of observed behavior, then expands to biological, and thereafter to social, cultural, and psychological attributes in search of explaining the remaining behavioral variations. A corollary to our definition is that the transition from physics to biology (and from biology to social and psychological exploration) calls for alternative, domain-specific, nonphysical formalizations. This perspective sketches out an initial blueprint for pursuing an agenda of considering actions in various domains/tiers in an overarching conceptual platform. It is our hope that this approach will produce a fruitful structure for stimulating interdisciplinary discussion of the existing methods of investigating behavior and generating new methods. From a methodological angle, our platform generates investigation potential akin to what reverse Bayesian analysis brought to Bayesian analysis [44,45,46].

We emphasize that ours is not a reductionist proposal to claim that everything can be explained by physics or by anything else. Rather, we suggest that physical laws deserve the first chance to explain observations from animate and inanimate worlds because matter and energy included in biological domains do not lose their physicality by virtue of the added DNA, brain, higher faculties, and society in which individuals grow up and live. The benefit of starting at the physical core and remaining within the borders of this first tier is to eliminate the necessity for modelers who inevitably use physical forms to justify the relevance of this work to human behavior.

This perspective is not intended as a guideline for others to follow. Instead, we attempt to consider new approaches to thinking, investigating and categorizing the study of human behavior. Our hope is to elicit feedback, suggestions, and criticism that will further this objective.

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