Revised November 7, 2022

Physics, Biology and Human Faculties: A Structural Stepwise Approach to Modeling Human Behavior[1]

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Abstract

Seeking a better understanding of human behavior and social phenomena were the primary pursuits of Richard Day's scholarship, and of the *Journal* he co-founded and edited. In that pioneering spirit of adventure, the present contribution explores a stepwise structural approach to modeling human behavior in the context of nature and environment. This three-step approach to human behavior allows for the possibility that various elements of human behavior may arise from stationary action principle in physics (shared with the non-living matter and energy), from principles of biology (shared with other species), and from our own peculiar higher faculties. Success of such an endeavor will help link social sciences to biology and physics, without any attempt at reductionism.

1. Introduction

Gaining a better understanding human behavior was a primary pursuit of Dick's scholarship, and of the Journal he co-founded with Sidney Winter. In that pioneering and adventurous spirit, our contribution explores an alternative approach to modeling human behavior. As proud members of a sentient species who see ourselves sitting at the top of the evolutionary heap, we are naturally inclined to start—and stop—seeking explanations of what we do within our own higher faculties of cognition, memory, preferences, and imagination. This is understandable but unnecessarily constrained.

[1] A draft contribution to the special issue of *JEBO* on Issues of Economic Decision, Organization, and Behavior in Honor of Richard Hollis Day. A preliminary version was presented at the Annual Meetings of the Society for Advancement of Behavioral Economics at Reno in August 2022. Revised November 6, 2022.

We share our existence with other species who may not possess all or any of our higher (social-psychological) faculties but are subject to the same biological principles arising from the DNA. Going a step further, living organisms are part of the universe of matter and energy organized by the same stationary action principle (SAP)[2].

In academic training and schools of thought, animal action is intertwined with a manner of intention, purpose, teleology, or goal – deliberate or otherwise. Decision theory and game theory use optimization techniques to axiomatize purposeful/strategic human behavior. While it is a powerful approach in operation research, optimization has been contested as a tool for formalizing human behavior on grounds of our finite cognitive abilities. This has given rise to demands for justification for use of optimization in modeling human phenomena. Instead of developing justification in cognition, or contesting the propriety of optimization, we inquire: how much of human behavior can might be understood independent of reason and intention. Placing the physical existence of humans in the core, we attempt to reverse the customary order in the practice of modeling human behavior. In the first step, we propose adopting from physics the stationary action principle to ask how much of human behavior might be explainable without resorting to biological or social-psychological attributes. To the part of behavior that remains unexplained by laws of physics, one could seek explanation in biological principles, before resorting to social-psychological attributes to explain the residual in the third step.

Three distinguishing aspects of the suggested approach are: (1) higher human faculties follow, not precede, physical and biological laws of nature as instruments for understanding individual behavior and social phenomena; (2) as complex adaptive systems, organizational and

[2] Stationary action principle, also known as the principle of least action, is a variational principle to derive the equations of motion of a system. Trajectories of of a system are stationary points of the system's action functional. It can be used to derive Newtonion, Lagrangian and Hamiltonian equations of motion. See *Feynman Lectures on Physics* Vol. II Ch. 19: The Principle of Least Action; and Stehle (1993).

institutional outcomes exhibit distinct properties that emerge from interactions among micro-level elements within the constraints of their structures; and (3) just as the four E's (embodied, embedded, enacted and extended) have expanded our understanding of cognition beyond its traditional boundaries of brain physiology during the recent decades, concept of rationality also can be expanded beyond its traditional domain of individual behavior, substantive versus procedural rationality (Newell and Simon 1972, Simon 1976), to include aggregate-level attributes of social structures, what Mousavi and Sunder (2022) call structural rationality (also see zero- and minimal-intelligence agent economics, Sunder 2004 and Ladley 2012). By reversing the extant order of using disciplinary principles from social-psychology, biology and physics in modeling human behavior, the proposed framework broadens understanding without resort to reductionism. We illustrate our proposal using three examples.

2. Three Examples

When a lifeguard sitting on the highchair hears screams of a drowning child and runs through the beach sand before swimming to save a life, time is of critical importance. To reach the destination in minimum possible time, the lifeguard, who runs faster than swims, does not follow a straight line, changing slightly the direction of run and swim (see Figure 1). Compared to a straight-line path from perch to the victim, the lifeguard covers a greater distance running faster on sand and lesser distance swimming slower, cutting the total time to reach the target. Almost instinctively, we attribute the kinked path taken by the lifeguard to training, learning, intelligence, experience, and teleology (the objective of increasing the chances of success in saving the life of the child), all involving human higher faculties. Indeed, as shown in the second part of Figure 1, results of an experiment in which human subjects were asked to solve an equivalent problem quickly converge near the fastest path.

In a second example, replace lifeguard's perch by an anthill, beach sand by a smooth surface, water by a flat surface covered in felt cloth, and the child by a few sugar cubes (first part of Figure 2). It does not take long for ants to find their way between their nest to and from sugar, and in a few days or hours, the average trail ants establish is not a straight line; instead, they cover longer distance on the smooth surface where they can move faster and shorter distance on rough felt surface that slows them down (see the second half of Figure 2). Overall, the longer kinked path they follow is faster than it would take them to negotiate a straight-line path between their nest and the food. If we assume that ants do not share with us the gift of the higher faculties that we use to explain the behavior of lifeguards in Example 1, we can still resort to chemical and biological explanations. These involve ants leaving pheromone molecules along their paths for others to follow with their sense of smell, and ultimately getting crowded around the greatest density of pheromones on the trails that take the least time for ants to travel.

The third example is familiar from high school physics textbooks of light bending at the point of entry from air to water or glass, again reaching from its source to destination in minimum time—the well-known Fermat's Law of the precise relationship between the ratio of sines of angles of incidence in two adjacent media and the ratio of speed of light in the two media. Various aspects of this phenomenon have been noted, documented, and analyzed since ancient times by Euclid (Burton 1945), Ptolemy, Heron, Ibn Sahl (see Darigol 2012, pp. 20-21, 41; and Minhas 2006 pp. 761-5), Al Hassan, Snell, Descartes (1637), Fermat (DeWitte 1959), Huygens (1690), and Hamilton (see Chaves 2016, Chapter 14). See first and second parts of Figure 3.

Whether light consists of particles or waves, few would attribute any cognitive faculties to either of them, neither the higher faculties of humans or nor the (presumably) lower ones of ants.

Unlike the lifeguard rushing to save the drowning child or the ants eager to bring food to their nest, no motivations, memory, learning, or even pheromone-type sensory path-dependence can be attributed to electromagnetic radiation. Why would photons be in a hurry to reach their destination? What would be lost if the time to travel were longer than the path implied by Fermat's Law? In physics (and natural sciences) such questions are set aside as being irrelevant to study of phenomenon at hand. Optimization is not a behavioral phenomenon; instead, it is seen as a universal property of matter and energy, and unrelated to teleology, cognition, and life. Does this property disappear when matter and energy appear as life forms?

It is possible to conceive of the phenomena underlying these three examples to be distinct from one another, with mere superficial and incidental similarity of conforming to Fermat's principle. Afterall sharks and dolphins, birds and bats, and opossums and New World monkeys exhibit significant similarities despite the two members of each pair being the outcomes of quite different biological evolutionary histories. But we should also consider the opposite possibility that fundamentally similar processes can yield outcomes very different in appearances. Looking at a six ton elephant and six pound mouse-like hyrax, their shared evolutionary roots and close relationship are not obvious. In the rest of this paper, we examine if the phenomena underlying these three examples may have more important implications for scientific study of human behavior and society.

3. Extant Social Science Practice

The current practice in social sciences is to seek to understand and explain observed phenomena of interest in terms of social-psychological variables. Goals, preferences and beliefs in economics, cognition, empathy, fear, memory and ambition in psychology, solidarity, class and hierarchy in sociology, culture and ethnicity in anthropology and power and governance in political science are some examples of variables used for modeling our understanding of human behavior. These instruments of modeling and explanations have a meaning only in the animate domains of nature, and within that domain, they are assumed to arise readily from higher faculties with which we human beings believe ourselves to be endowed (along with some other higher order species).

Biological phenomena of non-human species are largely explained by evolution and properties of DNA, with little allowance for social-psychological factors that occupy prime territory in modeling and explaining human behavior. At the lower end, animate domain blends into inanimate world of molecular biology and viruses (if dictionary definition of life includes metabolism, growth, reactivity of stimuli, and reproduction, viruses are not alive). Like many other pairs of adjacent disciplines (economics and psychology being a familiar example) it is not possible, or useful, to draw precise boundaries between them. In any case, that would be beyond our abilities and the scope of this paper.

Scientific principles of physics and chemistry used to understand the inanimate domain have not been put to use in organizing human phenomena. This paper argues for why the principles deployed to comprehend the inanimate domain have a primary role in human phenomena before we resort to biological and social-psychological principles. It is in this sense that we propose to reverse the conventional practice in social sciences. If we use the metaphor of layers of earth (see Figure 4), the extant social science practice is to focus on the study of human phenomena in the crust of the earth—the most readily observable of all layers of earth—that represents our social-psychological faculties. But earth also has a mantle (parallel to biological principles) and a core (parallel to principles of physics), that play an important role in what happens on the surface (human behavior). We propose that all three layers starting from the properties of the core (principles of physical sciences) to mantle (principles of biology) to crust (higher faculties of humans) be included in study of social phenomena. Using the order of modeling that starts with the physics core obviates the need to dwell on our cognitive limitations in optimization; if interpretations stay within the bounds of physics, explaining as much as possible of the observed behavior by optimization requires no further justification.

(Insert Figure 4 about here)

4. Stationary Action Principle (SAP)

Of all possible paths from a beginning *A* to an end *B,* the efficient path uses minimal action, where action is a scaler that corresponds to the dimension where value has been conserved (Maupertius 1744, Mousavi & Sunder 2019). For example, for movement of a projectile in a gravitational field, action is the integral along the path of the difference between the potential and kinetic energy of the projectile. It is minimized along the parabolic path followed by a projectile in vacuum (without air friction). This principle can be used to derive great many laws of physics including not only the classical laws of Newtonian mechanics but also relativity and quantum physics (which is beyond the scope of this paper and our competence).[3]

When this or other maximization principles are applied to inanimate physical phenomena, it is natural to raise questions about how and why maximization occurs in such systems. As members of a species proudly self-aware of our sentience and (presumed) unique higher faculties, we tend to try to understand social-psychological phenomena in our cognition, memory, preferences, and imagination, and rarely venture further. While human cognition is an

[3] We found this lecture by Richard Feynman available online to contain a clear and useful exposition of this principle, also referred to as Principle of Minimum Action, especially for non-experts like us (accessed October 13, 2022; https://www.feynmanlectures.caltech.edu/II_19.html).

unnecessarily constrained scope for modeling human behavior, recent decades have seen an expansion of the concept of cognition beyond brain to include the rest of our body as well as our external environment under the umbrella of Four E cognition—embodied, embedded, enactive, and extended cognition[4] (see Newen et al. 2018). Let us consider two steps towards an alternative way of thinking.

We co-exist with other species who may not share our higher (social-psychological) faculties. However, all living things are subject to the biological principles arising from the properties of DNA such as order, sensitivity to the environment, reproduction, growth and development, regulation, homeostasis, and energy processing. Principles of reproduction and homeostasis (i.e., sustaining stable internal conditions under changing external environment) are two of the basic and obvious distinguishing features of living from non-living matter. Requirements and abilities for animate functioning are not necessarily drawn from higher faculties of animals:

> " In order to function properly, cells need to have appropriate conditions such as proper temperature, pH, and appropriate concentration of diverse chemicals. These conditions may, however, change from one moment to the next. Organisms are able to maintain internal conditions within a narrow range almost constantly, despite environmental changes, through **homeostasis** (literally, "steady state")—the ability of an organism to maintain constant internal conditions. For example, an organism needs to regulate body temperature through a process known as thermoregulation. Organisms that live in cold climates, such as the polar bear …, have body structures that help them withstand low temperatures and conserve body heat. Structures that aid in this type of insulation include fur, feathers, blubber, and fat. In hot climates, organisms have methods (such as perspiration in humans or panting in dogs) that help them to shed excess body heat." [5]

[4] The 4 E's form a dynamic coupling of brain-body self-regulating system. Physical and cultural embodiment (e.g., ten digits and decimal system) shape our cognitive processes. Objects in our environment are embedded in cognition by facilitating thinking. A calculator, for example, extends our cognitive apparatus. Our actions enact the world as budgeting reveals that is or is not affordable.

[5] Accessed July 24, 2022, https://courses.lumenlearning.com/wm-biology2/chapter/properties-of-life/.

In the first step of alternative thinking, it is improbable that human behavior is independent of general principles that govern the biological domain. Taking yet one more step, living organisms, too, belong in the universe of matter and energy organized by the universal physics stationary action principle [6]. Applicability of principles of physics is not confined to inanimate matter because animal kingdom including humans consists of matter and energy subject to these principles.

We propose replacing the prevailing single-step approach to modeling human behavior based on our higher faculties by a three-step approach starting from the most general principles of physics which are applicable to all matter and energy. Explanation of aspects of human behavior that cannot be explained by the stationary action principle (SAP) can be sought, next, in the principles that apply to the animate domain of biology in the second step. For the residual aspects of behavior that remain unexplained by physics and biology, we can seek explanation in higher social-psychological faculties unique to humans. This three-step procedure replaces the extant single-step procedure for modeling human behavior, and "reverses" the conventional order by placing our higher faculties as the third and final step instead of the first and only step in modeling (Mousavi & Sunder 2020).

Since intention, purpose, teleology, or goal play a key role in social sciences, it is almost always assumed that optimization must rest on cognitive foundations. Yet, since optimization is present universally, even in inanimate domain where cognition does not exist, this assumption is baseless. It has led social sciences in an extended, futile and endless search for non-existent and

[6] "…the laws of Newton could be stated not in the form $F = ma$ but in the form: the average kinetic energy less the average potential energy is as little as possible for the path of an object going from one point to another." (Accessed July 24, 2022, https://www.feynmanlectures.caltech.edu/II_19.html).

unnecessary cognitive mechanisms for optimization. Instead, we put the physical or material existence of humans at the core, and propose to reverse the customary order in the practice of modeling human behavior using a three-step process.

This three-step approach to modeling human behavior would allow for the possibility that aspects of human behavior may arise from laws of physics (shared with the non-living matter and energy), from laws of biology (shared with other species), and from our own peculiar higher socio-psychological faculties. The order in which the scientific principles governing physics, biology and human behavior are determined by their specificity, utilizing the most generally applicable principles before resorting to others. To the extent such an endeavor shows promise and succeeds, it will open the doors to linking of social sciences to biology and physics, without attempt at reductionism[7].

5. Why Laws of Inanimate Domain Might Help Understand Aspects of Animate Domain

We focus on two reasons why laws that apply to physical objects (such as stationary action principle) may also help us understand human and social phenomena: one is emergence, already well-known from complexity theory, and the second is what we shall label (for lack of an existing label known to us) *natural optimization.* As we shall see, the two are not entirely independent of each other.

(a) Emergence

[7] Reduction is understood to be a way to unify the sciences, so one theory or phenomenon is considered to be reducible to some other theory or phenomenon. Unity of Science movement during the first half of the twentieth century is an example (Neurath et al. 1938, 1939).

Emergence refers to existence, formation or arising of behavior or property of a system consisting of many parts such that the behavior or property is absent in the parts themselves. In other words, emergence refers to presence of attributes of the collective or macro system absent from its constituent parts.[8] In choosing the title of his journal (Journal of Behavior and Organization), Richard Day distinguished human and organizational behavior, implicitly recognizing emergent properties of organizations in aggregate to be distinct from the properties of the individuals who constitute them.

Relationship between parts and the whole has long been a subject of deep reflection and analysis. Philosophers Nagarjuna (Siderits and Katsura 2013) in 3rd century C.E. and Chandrakirti's *Madhyamakavatara* (in 7th century C.E., verses 152-155)[9] articulated the problem of defining the relationship between a system and its parts to argue for *shunyavada* (approximately translated from Sanskrit as doctrine of emptiness; *shunya* means zero). Although their purpose was to examine the relationship between our conscious selves, and five faculties, Chandrakirti used his famous metaphor of chariot and its parts to argue that all these seven propositions are false: (1) chariot is identical with its parts; (2) chariot is apart from its parts; (3) chariot is contained in its parts; (4) chariot contains it's the parts; (5) chariot possesses its parts; (6) chariot is a collection of its parts; and (7) chariot is its shape. There can be no chariot without its parts, yet it is distinct from them.

[8] "In conventional views the observer considers either the trees or the forest. Those who consider the trees consider the details to be essential and do not see the patterns that arise when considering trees in the context of the forest. Those who consider the forest do not see the details. When one can shift back and forth between seeing the trees and the forest one also sees which aspects of the trees are relevant to the description of the forest. Understanding this relationship in general is the study of emergence." (Accessed July 24, 2022, https://necsi.edu/emergence#:~:text=Emergence%20refers%20to%20the%20existence,they%20would%20not%20do%20alone.)

[9] See Dharma Wheel: A Forum for Discussion of Mahayana and Vajrayana Buddhism (accessed November 1, 2022, https://www.dharmawheel.net/viewtopic.php?t=37110). Also Tsong-kha-pa (2014).

In philosophy the concept of *pratityasamutpada* (translated from Sanskrit as *co-dependent arising* or *dependent co-origination*) captures the spirit of emergence. Garfield (1994, p. 221): "This term denotes the nexus between phenomena in virtue of which events depend on other events, composites depend upon their parts, and so forth. Just how this dependency is spelled out, and just what is its status is a matter of considerable debate within Buddhist philosophy, just as the nature of causation and explanation is a matter of great dispute within Western philosophy. Nagarjuna is very much concerned to stake out a radical and revealing position in this debate."

In reductionist thinking and modeling, causation is presumed to be directed from parts to the whole; in emergence, in the spirit of *dependent co-origination*, causal direction remains unspecified, perhaps indeterminate. Macro and micro-level attributes simply coexist.

(b) Natural Optimization

When more than one instruments or paths to the same destinations are feasible, it is important and consequential whether the option chosen is at least better than most others, and if possible, best of them all, by some well-specified criterion. Such selection is referred to as (imperfect or perfect) optimization. In social and behavioral domains, it is routinely assumed that optimization, to the extent it occurs, is enabled by human cognitive apparatus. Children spend years, beginning with kindergarten, learning numbers, arithmetic, algebra and other mathematical concepts, relationships, and algorithms for solving a variety of problems, they fail to advance unless they master the conclusion that maximum of (3, 6, 11, 8) = 11. This social experience fits well with the widespread belief that optimization is rooted in our cognitive apparatus and consequent learning. Indeed, that is the routine interpretation of the lifeguard example given in Section 1 above.

But what about the ants in Example 2? It is possible, though not without straining credulity, to attribute sufficient cognition and learning to non-human forms of life, even those endowed with tiniest of brains. A more credible explanation involves biochemistry of pheromones, evolution of olfactory sense of ants, and their tendency to be attracted to trails with greatest concentration of pheromones laid by others. Starting from initial random dispersion in all directions, paths that allow the ants to return to their nest with food in less time tend to attract more ants and therefore more pheromones until they approximate the path indicated by Fermat's Law of least time to travel. If this explanation holds, we have an example of optimization in nature with very little cognition (sense of smell), but no mathematics or higher human faculties.

What about the third example of photons (or waves) of light (or other electromagnetic radiation) following Fermat's Law of least time to travel. In this inanimate domain without even ants' sense of smell, without a history of evolution to have developed either olfactory organs or tendency to spread and follow pheromones, and certainly without any objective—ant is searching food to survive but the photons could not be attributed an objective to get to their ultimate destination in hurry. Yet, their behavior follows the same law, and without any brain or cognitive faculties, does so with greater precision than either ants or human lifeguards. We shall argue next that optimization is a property of nature, and it need not be attributed to our faculties, whether higher or lower.

In notes[10] of his renowned lecture on the principle of least action, physicist Richard Feynman said:

> "… If it [light] went on a path that took a different amount of time, it would arrive at a different phase. And the total amplitude at some point is the sum of contributions of amplitude for all the

[10] Accessed October 18, 2022; https://www.feynmanlectures.caltech.edu/II_19.html.

> different ways the light can arrive. All the paths that give wildly different phases don't add up to anything. But if you can find a whole sequence of paths which have phases almost all the same, then the little contributions will add up and you get a reasonable total amplitude to arrive. The important path becomes the one for which there are many nearby paths which give the same phase. …The particle does go on a special path, namely, that one for which S [action integral] does not vary in the first approximation."

And that is known from calculus to be the property of optima of continuous functions. There is a vague but strange similarity in Feynman's quantum-theoretic explanation for why light takes the minimum time path (Fermat's Law), and the biochemical explanation for ants using pheromones and their olfactory sense to converge near a path predicted by the same law. Whether we should continue to insist that higher faculties, and not the natural optimization is the source of lifeguard's behavior remains open.

6. Three Forms of Rationality: Substantive, Procedural, and Structural

Rationality in human contexts refers to the practice of selecting, when opportunity presents itself, a course of action from those known to be available such that it is known to be at least as desirable as the others by a well-specified criterion. For example, in the example given in Section 2, the minimum time path specified by Fermat's Law will be a rational choice for the lifeguard.

Traditional and well-established interpretation of rationality arising from the nature of the problem itself has been labeled substantive rationality. Mathematics (2+2 = 4), consumer behavior (choosing a vendor who offers a lower price for same goods and services) and sports (exerting effort to minimize the time to finish line in a competitive race) are familiar examples of substantive rationality. Since the optimum outcome of substantive rationality is derived under "infinite faculties" assumption, with no role for the process and for cognition.

Simon (Newell and Simon 1972, Simon 1976) distinguished the above-mentioned concept of substantive rationality that involves optimal choice in a given context from procedural rationality. Instead of choosing the best which may be unknowable to decision maker, procedural rationality focuses on the process of arriving at a choice within the constraints of her environment, knowledge, and cognitive resources. Such processes typically use simple rules iteratively, and often referred to as satisficing or bounded rationality.

Both substantive and procedural concepts of rationality are focused on behavior of individual decision maker, whether a person or a group of persons. A third form of rationality is embedded in the structure of the (social) system, beyond optimization and human problem-solving (Mousavi & Sunder 2022 call this structural rationality). Micro-level behaviors of components of the system interact in complex ways constrained by structure of the system and exhibit emergent macro-level properties absent at the micro-level.

Economics treatises mostly assume optimization as a precondition of choice in the subject matter[11], and having narrowly defined the subject matter in terms of a single approach as opposed to a domain of phenomena[12], rarely dwell on how and when it entered economic thought and discourse. Economics appears to have imported the optimization principle from science. Given the inanimate nature of its subjects, science used optimization principle as an organizing

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[11] E.g., "Economics has been defined as the study of making the best use of scarce resources, …" (Dixit, 1990, p. 1).

[12] Hodgdson (1998, p. 189) points to exclusion from this narrow definition the work of "… leading economists such as Smith, Ricardo, Marx, Keynes, Hayek, Simon, and Coase, all failed to incorporate the standard picture of 'rational economic man' in their writings or expressed profound misgivings about his behavior."

principle of nature. This is clear in the third example of light following Fermat's Law to travel from one point to another in minimum time. This natural optimization calls for no cognition or other animate faculties, even though we observe that the same law is useful for organizing observations from the animate world, albeit with less precision, as seen in the example of ants and lifeguard.

In economics, we humans and our systems and society are the objects of analysis. Mechanical application of the optimization principle to ourselves offends our selfesteem, and denies us our free will. Sunder (2006) suggests that "it may have been for this reason that the optimization principle, when imported into economics, was reinterpreted as a behavioral principle. It is not surprising that the switch from structural to behavioral principle was soon followed by a shift in focus from aggregate to individual behavior. Since cognitive sciences established that we are not very good intuitive optimizers, an increasing number of economists have been willing to abandon the optimization principle labeling it the "infinite faculties" assumption (Conlisk 1996)."

7. Concluding Thoughts

Evidence on markets populated by zero- and minimal intelligence agents indicated that it is the structure, not behavior, that accounts for the first order magnitude of outcomes in competitive settings. Computers and experiments with simple agents opened a new window into a previously inaccessible aspect of economics. Ironically, this was achieved not through computer's celebrated optimizational capability, but through our ability to deconstruct human behavior into its components so the market level consequences of simple arbitrarily chosen classes of individual behavior could be modeled as algorithmic software agents.

The social science practice of attributing individual human behavior largely to our higher faculties is common place in economics and psychology (less so in sociology). Constructing social phenomena using methodological individualism needs a careful reconsideration (Arrow 1994, Longino 2019, Mousavi & Sunder 2022). We propose, and give reasons why, it would be a better scientific practice to use the laws of inanimate domains, e.g., the stationary action principle (SAP), first to organize human phenomena. Laws of biological domain could be applied next to explain what cannot be explained by physical laws, and resort to our higher faculties to explain only that which remains to be explained after these first two steps. Conceptual frameworks that focus on higher faculties would remain essential for completing this third step. Our proposal gives structural optimization the first crack at formalizing observed human behavior, and bypass the endless debates about optimization by cognition. Essentially, we propose placing physics, biology and human faculties at their rightful shelves.

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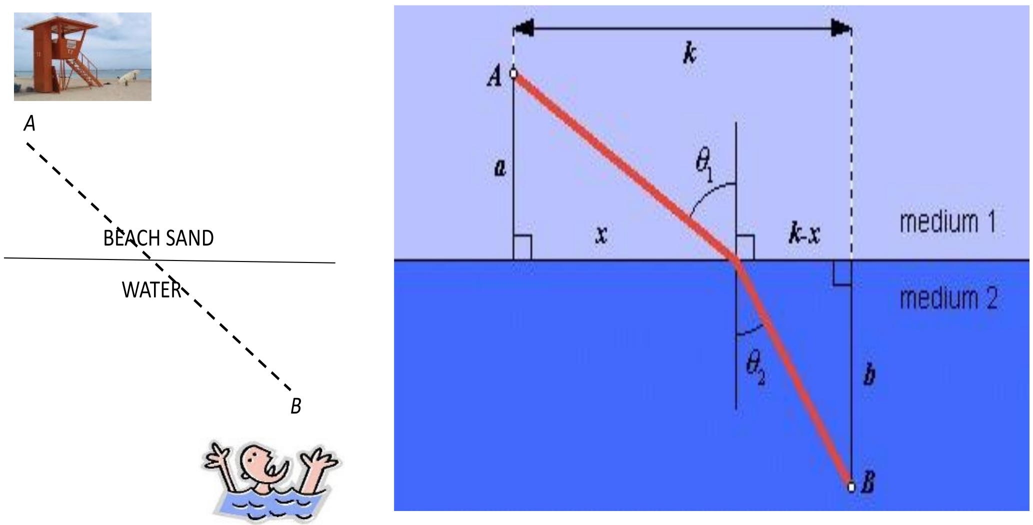
Figure 1: Lifeguard and Swimmer

A =Life Guard; *B* = Swimmer in Distress



Distribution of Life Guard Trial Times to Rescue

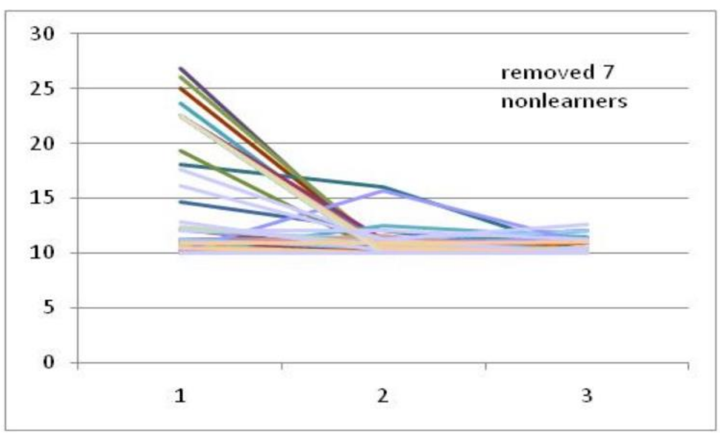
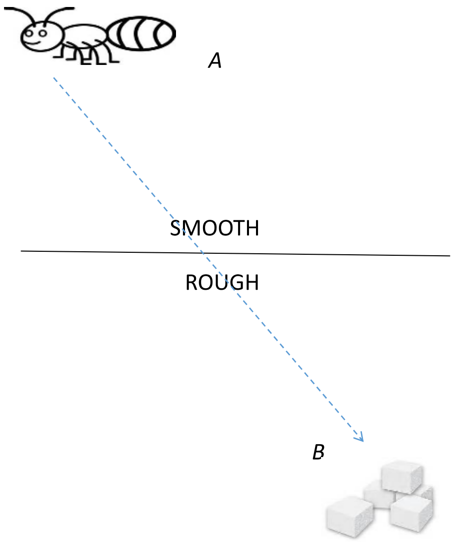


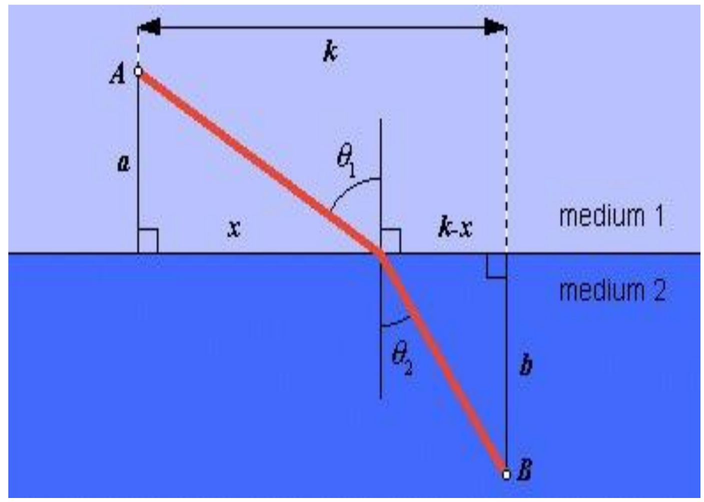
Figure 9: Evidence of Learning in parameter set 1

Humberto Barreto and Ryne Weppler. 2010. "Testing Optimization: Solving the Lifeguard Problem with Discrete and Continuous Methodologies", https://www.depauw.edu/learn/econexcel/Lifeguard%20Paper%20With%20Appendix%20v5.pdf

Figure 2: Ant Hill and Sugar

A =Ant Hill; *B* = Sugar



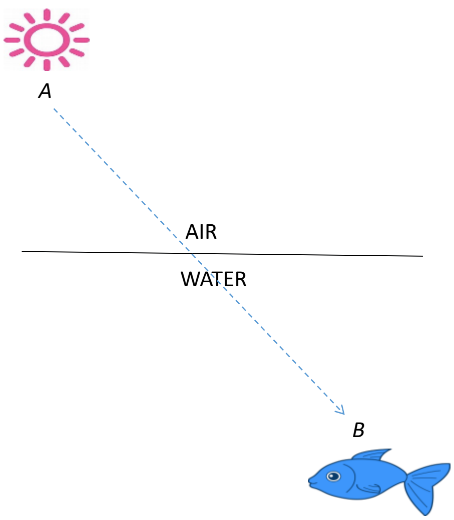


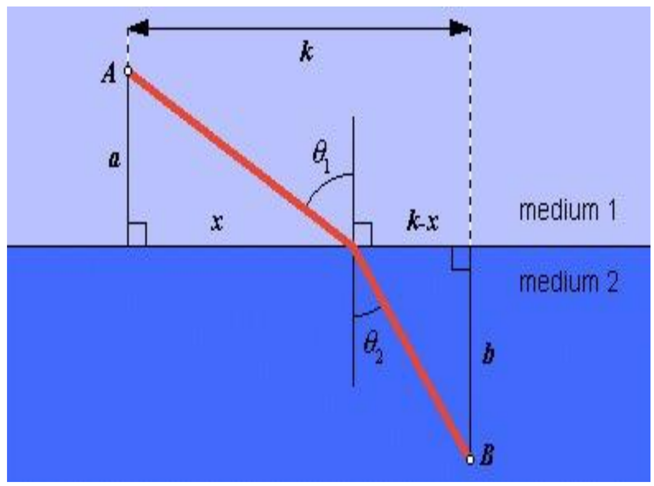
“Refracted” trail of auropunctata workers at the medium border between smooth (white) and rough (green) felt

Oettler J, Schmid VS, Zankl N, Rey O, Dress A, et al. (2013) Fermat’s Principle of Least Time Predicts Refraction of Ant Trails at Substrate Borders. PLoS ONE 8(3): e59739. doi:10.1371/journal.pone.0059739

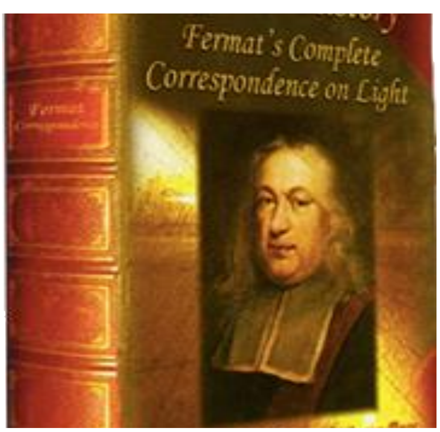
Figure 3: Sunlight and Eye of Underwater Fish

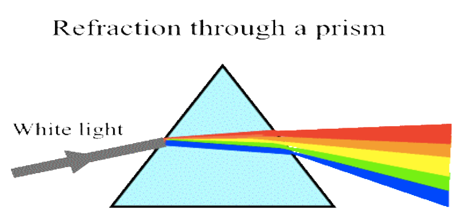
A =Sun; B = Eye of Fish under Water





Law (Euclid, Ptolemy, Heron, Ibn Sahl, Al Hassan, Snell, Descartes, Fermat, Huygens, and Hamilton)



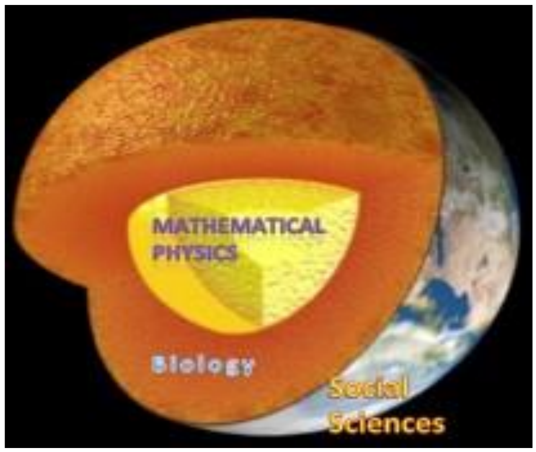


$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{n_2}{n_1}$$

Figure 4: Metaphor of Layers of Earth for Understanding Human Phenomena

THE EARTH METAPHOR

Extant Model: Crust only
Our Proposal: move outward from core=>mantle=>crust



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