Nature, Evolution, Culture, Free will and Morals: A Thermodynamic Singularity

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Summary

The purpose of this review is to examine the forces underlying changes in the natural world of physics and chemistry and those guiding evolutionary changes in biology and culture. The Second Law of Thermodynamics has recently been re-interpreted to apply to both the animate and inanimate worlds. The universal expression of the Second Law and the Principle of Least Action in ever more effective rates of energy transformation, is evident in all domains. The same forces affecting the evolution of minerals and chemical molecules are operative in biological evolution. The present paper reviews this model and extends it to apply to animal behavior as well as human learning and cognition. The implications for evolutionary fitness, animal and human behavior, genetic and behavioral variation, cognitive biases, volitional behavior, human culture and other phenomena are discussed. Scientists in all disciplines are challenged to address the threat to human survival posed by the consequences of the imperial edict of the Second Law.

Key Words

Second Law of Thermodynamics; Effective Energy Transformation; Evolution; Biology; Psychology.

1. INTRODUCTION

1.1 Energy in the Universe Varies in Form and Density.

Many forms of energy are recognized by the natural sciences - thermal, chemical, nuclear, electrical, gravitational, mechanical and elastic energy as well as energy in the form of electromagnetic radiation. In our universe, energy is spread unevenly in space [1]. Some areas have high concentrations of energy and some have lower. Temperature is a general measure of energy density. Examples in the cosmos of high energy entities include stars, suns, and black holes; examples of medium energy include the mantles of the planets; and of the lowest density, the scattered electromagnetic radiation in interstellar space. On Earth natural examples of high energy include the magma at the Earth's core and heat from the sun's rays; and of relatively low energy, the shaded surface of the Earth and the depths of the oceans [2]. All living things have higher energy levels than the air, water and land around them [3]. This is more obvious when we compare their temperatures to that of their surroundings at night or on a cold day. It is worth noting that when a plant or an animal dies, its temperature drops to that of its environment (aside from heat generated in decomposition). While it is alive the plant/animal is taking up and storing energy from the environment and of course, expending energy in living.

1.2 The First Law of Thermodynamics is Universally Operative.

In the Universe, there are some generally observed characteristics of energy which are true in all domains (cosmic or earthly, inanimate forms or life forms). These observations are so significant that they are referred to as the Laws of Thermodynamics. The First Law is that energy is conserved. It never disappears or is used up. It can be converted to matter or it can be converted into another form of energy [4]. An example of the former in the geological domain is geothermal heat causing chemical reactions in a geyser pool, e.g., precipitation of salts [5]. In the biological realm, an example is photosynthesis in plants and bacteria, in which light from the sun is converted to chemical compounds [6]. An example of energy conversion to another form of energy in the cosmos, is the conversion of nuclear energy to thermal energy in supernova; and in the biological domain, the conversion of the chemical energy of sugars into work energy (muscle contraction) and heat energy in an animal [7]. Human devices make use of the conservation of energy in many ways [8]. Matter that is readily converted to consumable energy is called fuel. Common fuels and their related energy include wood (thermal), fossil fuel (thermal) and uranium concentrate (nuclear and thermal). Many manufacturing processes use energy (electrical/chemical/thermal) to produce products, e.g., refine ores and create chemical compounds. Striking a match to produce a flame involves the conversion of mechanical energy to chemical and thermal energy[9]. In summary, in all domains, the total amount of energy is unchanged although the form of energy is readily changed. Humans convert many forms of energy.

1.3 The Second Law of Thermodynamics and the Principle of Least Action Describe Energy Transformation in the Inanimate world.

The Second Law of Thermodynamics states that energy flows from areas of high density to those of low density and that the dispersal of energy occurs in the most effective way possible (Principle of Least Action) [10]. This means that energy dispersal occurs by the shortest route between the two regions in space and involves the greatest amount of energy transfer, in the shortest time possible. The dispersal is also accomplished by incurring the least cost (uptake of additional energy into the high energy source) to effect the dispersal. Observations of the most effective scattering of energy are ubiquitous and are seen in all domains. In astrophysics, it is expressed in the accelerating expansion of the Universe as inferred from supernovae red-shifts [11], the faster rotation of the galaxies [12], and in the greater bending of light by inferred black holes [13]. In geology, the movement of tectonic plates, lava, glaciers, water in rivers, and drifting desert sands are all manifestations of the effects of energy flows [14]. Their paths and duration of flow reflect the inexorable bias for the fastest routes and the most voluminous, steepest descents in energy dispersal. In weather systems the flow of oceanic and atmospheric currents, the occurrence of hurricanes, tornadoes, and flashes of lightning all serve to discharge energy from more dense concentrations to less dense surroundings as effectively as possible [15]. To summarize, energy is dissipated as efficiently as possible in all domains of the abiotic world, e.g., cosmological, geological, and meteorological.

2. THE MODEL

2.1 A Model of Evolution as an energy transforming process in abiotic and biotic forms.

Biological forms exchange energy with their surroundings in the same way, moving energy from a dense to a less dense state [1]. From the perspective of this model, the principal difference between inanimate and animate forms is that the latter are more effective at energy conversion. For example, the breakdown of rock, soil and water into chemical constituents by bacteria is by orders of magnitude faster than the effects of weathering or other abiotic forces acting alone [2]. In general, the types of forces included in biological weathering are pressure, e.g., by roots; mixing, e.g., soil churning by earth worms and moles; chelation; acidification; moisturizing; and heat from fires. While some environments do not support life forms, e.g. the sun and the Earth's magma core [3], life forms may act on niches where non life processes have little effect. For example, organisms in stable homogenous environments may induce increased energy transfer where little occurs by natural inorganic means, as is the case with simple life forms living in the ocean depths [4]. In richer, energy dense environments, more complex life forms evolve because of the diversity of energy-rich niches available and because of the greater effectiveness of complex life forms at energy conversion in these environments than simpler life forms [5]. An example would be the extravagant speciation of plants and animals in tropical zones (latitudinal diversity gradients) and their enhanced energy conversion relative to that occurring abiotically [6]. More specifically, increased efficiency of energy metabolism has been the target of evolutionary adaptations in succinate production in ruminate bacteria [7], in bat flight [8]and human brain enlargement [9]. From this perspective, the selfish gene is selfish about transforming as much energy as it can as effectively as possible [10]. Natural selection operates to ensure the survival of the fittest where fitness is defined by adaptive features which enable the most efficient process for energy transduction [11]. To quote CHARLES DARWIN [12](1999, p. 133) "For the best definition which has ever been given of a high standard of organisation, is the degree to which the parts have been specialised or differentiated; and natural selection tends towards this end, inasmuch as the parts are thus enabled to perform their functions more efficiently." In this seminal work Darwin used the words "efficient" or "effective" twenty times to describe the effects of adaptation. The concept of efficiency or optimality of evolved processes has been found to be a key to understanding in many different areas of modern science, e.g., foraging efficiency[13], group decision making efficiency [14]; optimal language categories [15]; and locomotion efficiency [16].

If this is true in the biotic world, there should be a parallel process in the inanimate world. Congruently, the universal expression of the Second Law and the Principle of Least Action toward ever more effective rates of energy transformation is manifest in the parochial but ubiquitous case of the more efficient flow of fluids down an incline with time [17], in the chemical evolution of a chirality consensus among chemical molecules (homochirality) [18], e.g., enzymes recognize as metabolically active, carbohydrates that are right-handed and amino acids that are left-handed [19]; in the optimal stabilization of non-biological proteins [20]; in the evolution of enzymes capable of more effective energy transformation, e.g., carbonic anhydrase catalysis of carbon dioxide [21]; in the evolution of maximal flow in biotic as well as abiotic systems over time, called constructal theory [22]; in the evolution of a dozen or so urminerals into the prebiotic Earth's 1200 mineral species [23]; and in the subsequent doubling of mineral species in the biotic era on Earth [23]. Thus evolutionary physical and chemical changes have occurred in the inanimate world prebiotically and later in conjunction with biotic forces. In an analogous fashion species have adapted evolutionarily to their niches in the biological world [24].

To summarize, the Second Law and the Principle of Least Action guide evolutionary processes in the biotic and abiotic worlds toward the most efficient forms of energy transduction.

2.2 Life Forms Have Distinctive Features that Reflect Energy Transformation.

While it is apparent that both life and nonlife forms have evolved more efficient forms of energy dissipation, it is obvious that life and nonlife forms have evolved by different processes. Evolution in the abiotic world has the more general meaning of, the process of change or development over time. In attaining a more effective energy conversion process than inanimate forms, animate forms evolved characteristic life processes [25]. These include 1) the temporary concentration of energy, e.g., adenosine triphosphate (ATP) [26] into a sequestered high density form for subsequent controlled dissipation, e.g., work to acquire more energy, resulting in net energy transformation as prescribed by the Second Law; 2) the development of a bounded encapsulation to contain the energy, e.g., membrane of a cell; and 3) the development of intergenerational information replication and transmission, i.e., genetic and epigenetic codes, to ensure effective energy conversion in succeeding entities. Each of these distinctive features is clearly involved in the effectiveness of energy transformation. Human culture has analogous features, e.g., the transformation of energy into a generic storable form, e.g., languages, slavery, electricity [27], the securing of energy resources [28], e.g., in-group / out-group boundaries [29], and the passing on to future generations of the technology of effective energy transfer, e.g., skill training, oral and written language [30]. In summary, human culture shares characteristic features with all life forms, which in turn differ from abiotic forms. However, all forms evolve in the toward more efficient energy transduction.

2.3 Changes in Behavior from the Perspective of the Model of Energy Transformation.

The Second Law is equally applicable to animal and human behavior. Favourable changes in the expression of genes (epigenetic expression), in immune systems (antigen identification and antibody formation) and in nervous systems (learning) of individual organisms in relation to environmental conditions/events are fundamental to ensuring the individual's relative success in effectively converting energy. The mathematical functions (sigmoidal, logistic and power) best suited to framing the effects of the Second Law in the natural and biological domains [31] have often been used to describe and predict effects in the behavioral, perceptual, and cognitive realms [32]. Significantly, the Principle of Least Action in physics and biology [33] has its equivalent in the long recognized Principle of Least Effort in psychology [34]. The latter is as ubiquitous in the coping behavior (instinctive or learned) of all types of organisms as is the Least Action Principle in the abiotic world, in the flows of rivers and bursts of solar radiation accompanying sunspots [35]. Recently, the Principle of Least Effort has found expression in the concept of optimization free energy uptake [36] and in maximizing effectiveness in energy transfer [37] as observed in neural networks [38], differences in intelligence [39], patterns of behavioral interactions [40], in economics [41] and in communications [42].

If organisms evolved to effectively transfer energy there should be evidence of a planning mechanism capable of cost-benefit analysis in the brain. Brain structures associated with reward and planning have been identified as signaling the relative cost and benefits of anticipated effort and ensuing reward in humans [43]. The "invisible hand" of Adam Smith [44] has become visible with fMRI technology.
Heuristic biases in human cognition and social behavior point to a priority for control of energy transformation by the individual or the in-group. Examples include pattern recognition [45]; superior spatial navigation to high calorie foods by women [46]; optimal female coyness strategies [47]; totalitarian ego bias [48], causal agent attribution [49], the authoritarian response to stress [50], selective attribution of error and success [51], exaggerated sense of control by self or in-group [52], cognitive dissonance reduction [53], and preference for in-group cooperation/conformity and out-group competition/demonization [54]. The cooperative advantages of groups of individuals sharing resources and of group control of resources have been described in plants, insects and vertebrates [55]. In this context, for human culture, morals embodied in codes of ethics, in laws and in social norms are agreements on the regulation of behavior in groups to control cheating and to ensure a semblance of balance between advantages in energy control for the individual and the group [56]. Cross cultural studies and studies in young children indicate that some components of moral feeling and judgment may be genetically based and may have antecedents in other species [57]. Over millennia the coalescence of moral standards from proto-feelings about caring, fairness and sharing (sometimes to an altruistic degree) re the energy resources, is plausible if everyone feels good about more efficient energy dissipation. Mortal self-sacrifice pits the goal of efficient energy transformation against the traditional evolutionary goals of the individual of survival and reproduction, in the starkest possible terms. To summarize, the expression of the Second Law and Principle of Least Action in the natural and biological realms have parallels in animal and human behavior and in human culture.

2.4 Cooking and the Control of Fire Viewed as Energy Transformations.

The advent of the control of fire and cooking in early hominids signaled a paradigmatic shift in the human history of effectiveness in energy transduction [58]. Heretofore the energy transduced was principally in the consumption of food and oxygen. Cook fires burning wood, and eventually petrochemical fuels, radically changed the effectiveness with which humans transformed energy. Cooking significantly raised the caloric content of food (from 30 to 50% depending on the food), enhanced food safety, increased the varieties of food that could be consumed, and reduced the energy cost of digestion (by 30%) and time required for food digestion (by 300%)[59]. Biological sequelae of cooking included a smaller gut (40% smaller), reduced jaw and teeth size, enabled bipedal gait, and a larger more energy demanding brain (brain energy consumption increased 3-fold and brain size increased from 300 cc to 1600cc)[60]. The latter in turn enabled more complex social relations manifest in the development of language and a familial division of labour in tending the hearth, preparing food, and caring for offspring as distinct from hearth defense and game hunting, and a more elaborate division of labour within the camp group, e.g., manufacture of shelter, clothing, utensils and weapons, and herbal preparations [61]. Parenthetically, the control of fire was applied to non-cooking activities, e.g., weapon hardening, stone flaking, pottery hardening, glass making, masonry, metal refining, and clearing land [62]. Taken together these developments contributed significantly to increased climatological and geographic adaptability of humans, magnified the impact of cultural evolution, promoted human cultural diversification and not incidentally increased energy transfer.

2.5 Human Language, Culture, Art and Satisfaction Viewed as Reflecting Energy Transformation.

Human cultural activity in the form of artistic expression and aesthetic appreciation may be viewed as manifestations of the Second Law [63]. The evolution of human language provided a basis for the accumulation, storage and transmission of information [64] and is widely regarded as a key element in the development of human culture [65]. The concept of the transformation of energy has been successfully applied to linguistic communication [66]. Art forms, encapsulated universally in ritualized communal celebrations involving decoration, storytelling, music, dance/drama performance, and feasting, serve to increase the rate of energy transfer in human groups compared to the group member working individually. The benefits of group membership include enhanced anxiety reduction, social bonding and increased productivity [67]. This is likely a significant factor in the relative success in survival of Homo sapiens compared to Neandertals [68]. Evidence for the role of art in energy transfer is found in the accepted criteria for aesthetic appreciation, e.g., novelty, originality, the Wow! factor, and in the generation of new thought and raised emotions in the audience [69]. A basic measure in art of energy transfer is increased duration of attention by the perceiver/participant [70]. Another measure of appreciation which predicts future consumption is increased activation of the medial prefrontal cortex and dopaminergic reward circuits of the brain [71]. Manifestations of energy transfer can take many forms, whether in individual activity or in concerted group action, e.g., building monuments, fighting battles, and celebration of harvests. At a personal spiritual level, communal celebratory events are reported to be accompanied by sensations of a transcending flow of energy, of losing oneself to a greater whole, and of experiencing a spiritual dimension of being at one with the universe, expressed in view that life is common in the cosmos [72]. Recently, the highest form of personal gratification has been described as being engrossed in some activity, immersed in a state of flow - a feeling of radiating energy, losing oneself in an activity, during which awareness is suspended, and time stops [73]. Metaphorically speaking, the perception of not moving relative to a river's current when one is drifting down the river is apt. The analogical linkage with the Second Law is interesting. Energy transduction fundamental to the Second Law has been described as a flow or state of motion [74]. The Second Law is the only law of physics which deals with time and its direction [75]. To sum up, salient features of human culture including language, artistic expression and appreciation, spiritual experiences and life satisfaction may be seen as manifestations of effective energy transformation.

3. IMPLICATIONS OF THE MODEL

3.1 The Energy Transformation Model Applied to Probabilistic Outcomes, Genetic and Behavioral Variation, Volitional Control, Mental Illness and Ageing.

There are several general implications of this perspective. The premises of the model are parsimonious, readily demonstrable, applicable over all known domains with no known exceptions, and generate testable hypotheses. Because the model involves a causal chain modified by recurring feedback rather than a simple cause and effect mechanism, the outcome in any particular situation cannot be predicted explicitly [1]. However, its effect on energy transfer can be assessed and so the probability of potential alternative outcomes can be predicted. This applies equally whether predicting the particular behavior of an individual or the adaptation of a species to a novel challenge. The model provides a framework for accommodating both the adaptive outcome of natural selection acting on genetic variation and of environmental selective reinforcement acting on behavioral variation [2]. Thus, the fundamental unpredictability of the specific nature of the organisms' or species' response to a challenge is manifest in the quasi-random output of the mutation/transcription/methylation generators of variation in species [3]; in the quasi-random variability evident in behaviors [4]; and in neural variability generators in the brain [5]. Indeed, such behavioral/neural variability is critical for dealing with environmental challenges whether by exploration, or classical and operant conditioning [6]. These degrees of freedom contribute to the subjective experience of humans and perhaps some animals, of volitional control or free will [7]. Even more, the sense of exerting will power comes from exercising self-control in the form of effortful self-regulation as in focusing attention, analytic decision making, anticipating and achieving a planned outcome, overcoming unwanted impulses, and engaging in social negotiation/compromise. These cognitive activities have been shown to be relatively time and energy consuming [8]. Analytic thinking is contrasted with heuristic thinking which relies on non-conscious processes including affective feelings [9]. Compared to analytic thinking, heuristic thinking is the default mode, is used much more frequently, is relatively effortless, depends on well learned rules or on the types of cognitive biases referred to above and involves minimal exercise of will power [10].

A subjective sense of loss of volitional control follows over reliance on heuristic thinking and reduced behavioral variability and self control [11]. Such impairment may be expressed as a generalized fear and resistance to change or more seriously as mental pathology and is manifest in iterative thoughts and recursive behaviors of many addicted, anxious, depressed, schizophrenic, and obsessive compulsive individuals [12]. Their ideation fits a pattern of reduced energy/information intake (self- absorbed, isolationist, avoidant, and immersed in own emotional and thoughts) and reduced energy/information expenditure (increased heuristic, iterative thought, acting impulsively on biases, recursive behavior, minimally coping with stressful events or environmental change, and reduced planned activity/productivity/consumption) [13]. These conditions of low energy flow are experienced as unhealthy and unpleasant (anxiety-laden, lonely, depressing, confusing, and irritating) and are characterized by low cerebral blood glucose [14]. Parenthetically, physical pathology also involves reduced energy intake and energy consumption.

Treatment/therapy for mental illness, may be seen as restoring the individual to a normal level of energy input/output, e.g., increasing behavioral variability and self-control [15]. Exceptional mental pathologies include those that increase energy intake/output for personal gain beyond the socially accepted in-group norms, e.g., manic behavior and psychopathy. Congruently, these states are experienced as not unpleasant and show elevated levels of blood glucose in brain reward structures [16].

Ageing, a quasi-random accumulation of somatic damage through senescence and disease [17] is expressed as reducing this effectiveness, e.g. insulin signaling dysfunction, cortisol dysfunction, mitochondrial dysfunction – all energy controlling pathologies, till the body becomes identical with that of nonliving forms [18]. In summary, variability is inherent in the model's probabilistic outcomes and finds expression in the experience of volitional control, making choices, modes of thinking, health, illness and ageing.

3.2 Implications of the Model for the Reductionistic-Holistic Conundrum, the Determinist/Indeterminist Debate, the Mind-Body Problem, the Meaning of Life, the Uniqueness of Humans, the Is-Ought Problem and the Search for Life in the Universe.

The hierarchy of the levels science runs from particle physics, through many body physics, chemistry, molecular biology, etc. The model's built-in variability and probabilistic predictions permit the emergence of new properties at any scientific level. Because of this and because the premises of the model can be directly applied at any level of the system, the reductionistic/holistic conundrum of explaining/predicting emergent phenomena through levels of the scientific hierarchy is avoided [19]. Similarly, the model's probabilistic outcomes arising from a deterministic set of forces namely the inexorable drive toward efficient energy dissipation, avoids the fallacy of the "exclusive or" of the determinist/indeterminist debate [20].

The model provides a unifying perspective encompassing both the mental (behavioral) and physical (brain) worlds, laying to rest the historic conundrum of their incommensurability, i.e., the mind body dualism of Descartes, and Kant [21]. Indeed, the model goes beyond that to emphasize the unity of humanity not only with other life forms but also with the basic processes of the inanimate physical and chemical world. The fundamental purpose/meaning of life can be viewed as effectively transforming energy [22]. In this regard humans are at one with the animate and inanimate universe. Conversely, the uniqueness of the human species is clearly manifest in its greater effectiveness in transforming energy, e.g., fuel consumption, and especially in the emergent manifestation of energy transduction, namely the transformation of information, i.e., its creation, storage and exchange [23]. The present model provides a scientific basis for these end goals and resolves the "is-ought" problem of David Hume [24]. Ethical "ought" judgments about an act under consideration being "good" or "bad", can be assessed by an estimation of the probability that commission of the act will bring about the desired goal. The precise framing of the goal, i.e., efficient energy transformation, would be context dependent, e.g., particular energy source, time frame and group identity. The latter two are critical because they define who we share our energy resources with. Other objections to a scientifically based morality include the lack of universal agreement on what is the appropriate goal e.g., well-being, happiness; how to define it; and the lack of a simple way to aggregate it over many individuals [25]. Some may find the goal expressed in the Second Law unacceptable as a fundamental creed for human behavior. However, it is the de facto goal. It is what is controlling our short term actions and dictating our long term goals. If we choose to ignore it and act as if it is not relevant, it will bring us to a rapid end as individuals and extinction as a species. Our principle hope for survival is that we utilize our species' unique capacity, for information creation, control, and exchange to give us some solutions to extending our species' existence. Development of a moral scientific calculus is well under way, so aggregating the effects of energy transduction across individuals to include any sized population is not a problem [26]. Examples of using science to address moral issues are found in studies identifying strategies for maximizing efficiencies in health care delivery [27].

The current perspective also affords a model for the development of life-like robots and for the search for life processes on other planets [28]. The proximal cause of evolutionary selection of a species is its survival to reproduce but the ultimate cause is its relatively greater effectiveness in energy transduction compared to other species, as well as compared to abiotic natural processes [29]. Evolutionary selection for fitness whether in individual survival, group survival, or sexual survival is selection for more effective energy transduction. A good phyletic example is the greater metabolic efficiency of homeotherms compared to ancestral poikilotherms, both at the organ system and molecular level [30]. To summarize, adoption of the common framework provided by the model affords resolution of several philosophical issues.

3.3 Complexity and Hierarchy as Evolutionary Directions; Gaia and Medea as Global Models.

The model offers a plausible parsimonious alternative to existing models of the direction of evolution [31]. The theories that evolution is devoted to building complexity [32] or hierarchical relations [33] are contraindicated by the fact that some living forms have simplified rather than become more complex over millions of years [34]. However, congruent with the current perspective, these evolved simpler forms are measurably more effective at energy dispersion, requiring fewer resources to process more energy, than their more complex ancestors or than any other species in their environment [35]. More complex forms incorporating hierarchical integration as has happened in humans will evolve if they can access energy sources unavailable to simpler forms [36] but this is anticipated to be exception rather than the rule in the universe [37]. Depletion of those resources will result in the disintegration, remodeling and perhaps eventual extinction of the complex forms [38].

The global Gaia process is a theory that offers a homeostatic end point for evolution - a benign environment optimally suited to continued life on Earth [39]. The Earth's history of a Medean succession of cataclysmic extinctions of life forms clearly points to exceptions to the hypothesis of the Earth as a benign "Mother" [40]. However, both sets of observations (Gaian and Medean) are congruent with an eventual universal state of dissipating electromagnetic radiation in cold interstellar space [41]. In a word, energy gradients are causes and energy flows are effects. Life forms merely facilitate the universal process, expressed in the abiotic world.

4. LIMITATIONS AND CHALLENGES

4.1 Caveats to the Model.

In this paper the term "model" is used as similar in meaning to paradigm, or hypothesis rather than to mean a formal model in the mathematical sense. Although the work of Annila and colleagues re-formulating the Second Law using formal postulates has been published in highly regarded forums, e.g., Proceedings of the Royal Society, Entropy, Biosystems, the model has not yet been widely cited by independent researchers. In addition, the implications of the model for biological, behavioral and social sciences have been formally addressed primarily by the same group. Consequently, the work of others cited in support of the model in this paper has not involved direct tests of the model but has been tangential. However, in many cases others have arrived at findings that are congruent with the conclusions of Annila's group. Good examples of this are the findings of Karl Friston at University College London, Aljoscha Neubauer at the University of Graz and Richard Wrangham at Harvard University. Clearly what is needed are direct tests of the model employing alternative hypotheses in the evolutionary and behavioral realms by independent groups. Critically, assessment of energy transduction efficiency is needed in ecological evaluations of species' relative fitness. The measurement of optimization/effectiveness/efficiency of energy transformation is especially difficult in different domains. For example, to what extent does effectiveness involve the value o f the cost of securing/utilizing the energy as opposed to the value of payoffs or benefits? How should costs be weighted against benefits in arriving at a net value? Then there is the fundamental question of how to define energy in various realms. Can some sort of depreciation measures be used to assess the value of dwindling resources, species extinction, accumulating pollution, increasing income disparity, population dissatisfaction? Recently, brain structures have been identified that assess the cost of effort against reward value [1]. Economists today are grappling with this issue when they are forced to include effects previously regarded as externalities in their cost/benefit analyses [2]. Despite the vagueness of the concepts, it is hoped that their broadness will prove an offsetting advantage in their adaptation and application to wide range of issues and because of their common origin, afford beneficial linkages between domains.

4.2 Challenges the Second Law Poses to Scientists Regarding Human Survival.

Finally, the model has a significant message regarding the future threats to our ecology posed by resource depletion and environmental degradation [3]. The universal imperative to effectively transfer ever more energy, expressed in the individual's preoccupation with consumption [4] and quest for wealth and status [5], and in the universal political focus on economic growth [6] and attendant increased resource consumption [7], will severely challenge our signal ability to accurately forecast the future and to adopt conservative corrective measures in a timely fashion [8]. The present model clearly identifies the seriousness of this fundamental anthropogenic threat to our survival [9]. Given the inexorable forces driving us to consume ever more, a feasible solution is much more likely to involve the discovery of alternative sustainable sources of energy than adoption of "slow growth" [10] or "small is beautiful" [11] solutions. Diamond [12](2005, p.523) has suggested that finding the political will to change our core values is our best hope. However, the compulsion to consume ever more energy that locks us in to the corporate quest for greater productivity and profits, beggars the likelihood of utopian scenarios of voluntarily regulating increases in income disparity [13]. A slim ray of hope is offered by the highly innovative unit cost reductions in products recently incubated in the emerging world [14]. Ultimately however, the austerity imposed by dwindling resources consumed under the edict of the Second Law will shape our destiny.

It is clear that the scientific community will be a crucial player in finding solutions to this challenge to our survival. Engagement in this mission for physicists and chemists will mean recognition that the world of closed systems with its fixed parameters cannot deal with the probabilistic indeterminacy characteristic of open systems which incorporate environmental fluxes. For biologists, psychologists, and economists the ecologically validity of measures and manipulations will of necessity be stretched to include environmental and long term temporal externalities [15]. If adopted, the Second Law and Principle of Least Action will eclipse the theoretical hegemonies of history and operating as a theoretical singularity for the long sought consilience of the sciences and will hopefully stimulate research that will increase the probability of our survival [16].

NOTES

1. INTRODUCTION

[1] For a description of the origin and future of the universe see the article by FRIEMAN et al. 2008 and textbook by KOLB and TURNER 1994. For general info on energy sources and their distribution see Wikipedia.

[2]For an article on the earth's core, ALFÈ et al. 2002; energy forces on land and sea, FIELD et al. 1998; a textbook on the biosphere, PURVES et al. 2001.

[3]Even seeds, spores, ectothermic animals have higher energy levels than their environments, PURVES et al. 2001.

[4] For a classic textbook on the Laws of Thermodynamics, ATKINS 2007. Wikipedia also provides a summary. Because temperature is a generic measure of energy it is logical that laws dealing with energy flow should be called thermodynamic. The present paper does not deal with the other Laws of Thermodynamics. The Zeroth Law and the Third Law describe limiting conditions which are not relevant. The entropy of a system is its degree of disorganization. The higher the entropy the more disorganized it is. Heat dissipation results in a state that has higher entropy. So the Second Law states that entropy is the end state of all energy flows. Entropy is not referred to in this paper because the concept of organization/disorganization has very different connotations in lay terms when applied to human culture than it does in physics when applied to the relation between molecules.

Regarding the title of the paper, "singularity" means a rapid change in the rate at which a process occurs leading to outcomes that are difficult to predict. "Thermodynamic singularity" refers to the rate at which energy dissipation occurs in the universe and particularly on earth with the arrival of life and subsequently the human species.

[5]This book on the universe and life provides examples of inanimate processes that are similar to life processes, SCHULZE-MAKUCH and IRWIN 2004.

[6]This article covers various forms of photosynthesis, OLSON 2006.

[7]FRIEMAN et al. 2008 describe cosmic energy phenomena and PURVES et al. 2001 deal with the biological equivalent.

[8] A basic book on energy and its manifestations by ALEKSEEV 1986. RISTINEN and KRAUSHAAR 2006 deal with energy in the earthly environment. This book is more readable.

[9] Check out Wikipedia on energy and fuels.

[10] BOLTZMANN 1974 was responsible for much of the modern thinking on the Second Law. This book is a classic in the area, FEYNMAN and HIBBS 1965.

[11]ANNILA 2009 a physicist is the principle architect of the thesis presented in this paper. This article describes the relationship between on space and time. See this book for a description of changes in the universe, GUTH 1998.

[12] Again GUTH 1998

[13] Again ANNILA 2009[11] and FRIEMAN et al. 2008[7].

[14] A good source on the basics in geophysics LOWRIE 2008.

[15] A scientific article on forces shaping the biosphere, FIELD et al. 1998; A book on climatology, OLIVER and HIDORE 2002; A readable book on geophysics O'NEILL 2004.

2. THE MODEL

[1] This is the initial article by Annila's group linking thermodynamics and natural selection SHARMA and ANNILA 2007. This article is an earlier attempt to do the same thing WICKEN 1980.

[2] An overview of weathering GOUDIE and VILES 2008; LOVELOCK's (2009) more recent overview describes the enhanced effects of biotic on abiotic weathering; A general text on weathering PIDWIRNY 2006; This book includes a description of weathering in general SCHULZE-MAKUCH and IRWIN 2004; A good article on biotic enhancement of weathering SCHWARTZMAN and VOLK 1989.

[3]A good discussion of the conditions necessary for life SCHULZE-MAKUCH and IRWIN 2004.

[4] An article on life in the ocean depths KARNER et al. 2001; A description of life deep underground PEDERSEN 2000.

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[6]Diversity gradients vary with global latitude in this article by MITTELBACH et al. 2007

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[10] DAWKINS 1976 describes the gene as selfish about survival and replication; JAAKKOLA, EL-SHOWK and ANNILA 2008 provide evidence that the gene is selfish about dissipating energy more efficiently.

[11] Evidence that natural selection is for least action KAILA and ANNILA 2008 and SHARMA and ANNILA 2007; This is an earlier version but not as well developed SWENSON 1998; Least action in the realm of flow systems, e.g. lava, blood circulation ZIMPAROV et al. 2006.

[12] CHARLES DARWIN 1999, p. 133.While the word "effective" means to produce a result, "efficient" means to produce the maximum effect with the minimum cost. Thus an effective process may or may not be efficient depending on the definition of the expected result. The Principle of Least Action concerns efficiency because the shortest route, least time and least energy expenditure to achieve maximal energy flow are part of the Principle.

[13]Women are better than men at remembering the location of high calorie stationary foods NEW et al. 2007; PLANK and JAMES 2008 present a general model of optimal foraging strategies that fit many types of data; PRAVOSUDOV 2003 describes the high efficiency of food caching by birds; PRESTON et al. (in press)show how foraging data fit models that incorporate efficiency and flexibility in meeting environmental change.

[14] Collegial decision making leads to optimal resource utilization AME et al., 2006; the efficiency effects of optimal decision making in brains and in social insect societies MARSHALL et al., 2009.

[15] Cross cultural categories for naming colours efficiently partition the colour spectrum REGIER et al. 2007.

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[17] This book was ahead of its time in applying the Principle of Least Action to flow systems of all sorts BEJAN 1997.

[18] Sugars are have right-spiraling and amino acids have left-spiraling molecules allowing for efficient action of catalysts JAAKKOLA, SHARMA and ANNILA 2008.

[19]Homochirality may have evolved because of the polarization of starlight CLARK 1999. This book on the origin of life describes instances of evolutionary change in abiotic forms SCHULZE-MAKUCH and IRWIN 2004.

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[21]Efficient breakdown of carbon dioxide is possible because of the evolution of catalysts ANNILA and KUISMANEN 2009.

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[24] The laws of thermodynamics guide evolutionary processes ANNILA and SALTHE, in press; Thermodynamics in the evolution of petroleum deposits KENNEY et al. 2002; evolution of vasculature design is dictated by the laws of thermodynamics KIM et al. 2008; This article is an earlier version of the thermodynamic governance of evolution VOGEL 1998; The role of environmental change in shaping thermodynamic effects in evolution WÜRTZ and ANNILA 2010.

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[27] Language evolution EISENLOHR 2004 and HIMMELMAN 2008; Slavery and its economic effects NUNN 2009; the evolution of the utilization of electricity RIDLEY 2010.

[28] Resource competition and mortality in human males KRUGER 2010; Energy resource competition in the recent past SMIL 2000.

[29] Biases in human between-group behavior HEWSTONE, RUBIN and WILLIS 2002.

[30] Consumption and exchange of information in human societies ARIELY and NORTON 2001; Energy consumption and transfer RIDLEY 2010.

[31]Examples of mathematical functions in physics GRÖNHOLM and ANNILA 2007.

[32] Mathematical functions in cognitive science ANDERSON 2000 and 2005; Sigmoid functions in optimal foraging GETTY 1985; Mathematical functions in muscular exercise GUNNAR 1982; Mathematical functions in social psychology LATANE 1981; Sigmoidal functions in invertebrate predation LUCK et al. 2006; Power functions in human perception WARD 1972; A general source on mathematical functions in psychology YAREMKO et al. 1986.

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[34] Least Effort in behavioral extinction MOWRER and JONES 1943; Least Effort in the study of language THORNDIKE 1946; A book on Least Effort in psychology ZIPF 1949.

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[37] The classic paper outlining the reinterpretation of the Second Law re natural selection SHARMA and ANNILA 2007.

[38] The cellular operation of brain networks obey the Second Law Greater in the efficiency of energy transfer DEARY et al. 2010, FRISTON and STEPHAN 2007 and NEUBAUER and FINK 2009.

[39] Abstract reasoning requires greater levels of glucose metabolism HAIER et al. 1988; Intelligence is correlated with brain efficiency in energy transduction NEUBAUER and FINK 2009)

[40] Reinforced behavior and energy transfer FRISTON et al. 2009; Social behavior and brain energy consumption MARVEL et al. 2009.

[41] Energy dissipation guides adaptation by economies ANNILA and SALTHE 2009; Economic adaptation and the Second Law BUENSTORF 2000.

[42] The Second law controls information creation and transfer KARNANI et al. 2009.

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3. IMPLICATIONS OF THE MODEL

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[21] The mind-body problem FODOR 2006.

[22] The Second Law and the origin of the cell HARTMAN and MATSUNO 1992; The Second Law and evolution SHARMA and ANNILA 2007.

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[35] Pelvis size reduction in stickleback fish BELL 2010; Examples of evolved simpler forms MCSHEA 1991; Genome size reduction in bacteria SILVA et al. 2001.

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[37] Evolution of more hierarchical forms in the universe SALTHE in press and SCHULZE-MAKUCH and IRWIN 2004.

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4. LIMITATIONS AND CHALLENGES

[1]Brain dopamine release signals cost-benefit analysis DAY et al. in press; Brain functions related to analysis of optimality of planned actions RANGEL and HARE 2010.

[2]Optimal strategies for control of greenhouse gases BOSETTI et al. 2007.

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