Anthropogenic entropy acceleration and its relationship to Shannon information in the context of socioeconomics

B. E. Layton
The University of Montana, USA

Abstract

The primary purpose of this paper is to familiarize the reader with the potential role that the relationship between entropy and information plays in socioeconomics. The secondary purpose is to explore the proposition that the volumetrically normalized terrestrial entropization rate is ~10^{23} greater than that of the cosmic rate. This is done via a quantitative exploration of entropy generation at scales ranging from the nanoscopic to the cosmic. A working quantitative relationship between entropy and information in several systems is then explored in the context of "informational fitness." Exploitation by selfish dishonest systems of contingencies implicit in socioeconomics are then discussed in the context of the entropy-information relation to reveal how these systems persist. Finally, an argument is presented for embracing Kelvin's quantitative basis of science rather than abandoning the use of numbers because of misperceived semantics (McShea, 2013 "Unnecessary Complexity" Science 342: 1319–1320).
Keywords: Clausius entropy, Shannon information, sustainability, game theory, contingency, entropic acceleration, anthropogenic activity, selfish dishonest systems, terrestrial entropization, Carnot entropy.

1 Introduction: entropy in general

Since Clausius formalized the work of Carnot into what is now known as the second law of thermodynamics, it is implicit that for any closed system, that entropy must either increase, or at most, remain constant as a function of time. There are innumerable ways in which this law manifests itself. But simply stated the second law tells us that, "*Tomorrow the universe will be more disorderly than it is today*." We all have observed the second law at the human scale: coffee cups shatter, books collect dust, teeth decay, etc.

WIT Transactions on Ecology and The Environment, Vol 186, © 2014 WIT Press
www.witpress.com, ISSN 1743-3541 (on-line)
doi:10.2495/ESUS140271

One of the primary motivations for using entropy generation (J s^{-1} K^{-1}) rather than specific power (J s^{-1} g^{-1}) [1, 2] as a universal metric is to examine how certain individuals as well as entire societies organize their information systems to build energetic systems in order to *entropicize* other individuals or societies. I.e. one society may collaborate – share information – in order to build a destructive device such as a weapon to destroy a competitor. This competitor could be an individual or a society attempting to acquire either physical objects such as natural or manufactured resources or memetic structures such as instructions or belief systems. Success and survival may thus defined by a system's ability to process information in order to avoid an internal entropic event.

In physical terms, the second law tells us that the universe is constantly "reverse funneling" energy from dense, easily accessible forms, e.g. gravitational, kinetic, chemical, nuclear, etc. into diffuse, less accessible forms: e.g. radiation, acoustic, thermal, etc. In this preliminary treatment, several human-scale examples will be presented in order to quantify entropy and information generation rates of common human activities. However, before examples can be given, a thorough quantitative exploration of entropy at scales both above and below the human scale is required. This is followed by a discussion on information content of various physical systems, and finally by the introduction of an "informational fitness" coefficient that relates entropy production rates to information generation rates.

2 Entropy and energy at the large scale

Consider the thermodynamic entropy generation rate of the sun. The total annual solar incidence – the light that hits the earth – is 1.4 YJ ($1.4 \cdot 10^{24}$ joules) and the incident solar radiation is 44 PW ($44 \cdot 10^{15}$ watts), which is approximately one tenth of one billionth of the sun's output of 383 YW ($383 \cdot 10^{24}$ W). Note that the sun's radiation is one of the least accessible energy forms mentioned above. Nevertheless, it is this relatively diffuse energy form that photosynthetic systems have been exploiting for 3 BY+. In other words, the earth's chemical energy stores were essentially on "trickle charge," awaiting the furnaces and forges of the Industrial Revolution. As of this writing, human energy technologies convert chemical and nuclear energy into thermal energy at a rate of 16 TW, and we are therefore at one 2738th of Diamond's photosynthetic ceiling [3], which incidentally is the equivalent of a Kardashev Type I society [4]. At this point in time, we also appear to be at the peak of nearly all fossil fuels, meaning that we have burned through nearly half this resource. Thus in approximately 300 years (1780-2080) we will have consumed three billion years of resource accumulation, implying that we are consuming the earth's chemical energy stores at a rate ten million times greater than their deposition rate.

2.1.1 Entropy generation of the sun

To find the entropy generation rate of the sun, we simply divide the sun's radiant power of 383 YW by its temperature (5600 K) and arrive at $\dot{S}_{sun} = 6.84 \cdot 10^{22}$ W K^{-1}. Assuming that to a first approximation, the sun is an average star, multiplying its power by the total number of stars ($6 \cdot 10^{22}$), then dividing the result by the average temperature of the universe, 2.73 K, results in an approximate value for the entropy generation rate of the universe of $\dot{S}_{universe} = 8.4 \cdot 10^{48}$ W K^{-1}. To the author's knowledge, this is the first published estimate of this value and thus should be treated as a ballpark estimate. Nevertheless, how does the universal rate of entropy generation compare to terrestrial entropy generation?

2.1.2 Volume-specific terrestrial entropy generation rate

One hundred percent of our 500+ exajoule-per-year technological diet becomes thermal. In other words, regardless of the energy mode being used, 100% of the energy we extract from nature turns into heat. The average temperature of the atmosphere, where our technologies convert chemical, and nuclear energy into thermal energy takes place, is 15°C (288 K). Thus the entropy generation rate of the technosphere is $\dot{S}_{earth} = 5.53 \cdot 10^{10}$ W K^{-1}. Normalizing both the universal and the terrestrial rates of entropy generation by their respective volumes results in $\dot{S}_{universe,V} = 2.14 \cdot 10^{-32}$ W K^{-1}m^{-3} and $\dot{S}_{earth,V} = 4.33 \cdot 10^{-9}$ W K^{-1}m^{-3}. In other words, on a volumetric basis, humans entropicize their environment at a rate $1.80 \cdot 10^{23}$ times greater than the "background" entropy generation rate of the universe.

Of course, not all societies or individuals generate entropy at the same rate. Later in the paper, the modes through which information is used to intentionally or unintentionally direct or shed entropy towards other societies or the environment is discussed. A discussion is also presented regarding how each individual's or society's entropy generation rate is proportional to the rates at which financial and material wealth are acquired as well as a discussion regarding how the majority of this lopsided entropy production is conducted by selfish dishonest systems.

2.1.3 Universal entropy acceleration

Note the units on $\dot{S}_V$. This metric is the rate at which energy becomes inaccessible to do work. Even though living systems, and indeed entire celestial bodies, can reduce their entropy locally, $\dot{S}_V$ will always be non-negative when considered on a sufficiently large scale. With the addition of each energy technology system such as a coal-fired power plant, nuclear power plant, wind farm, etc., that the rate at which $\dot{S}_{earth,V}$ is increasing is also positive, i.e. $\ddot{S}_{earth,V} > 0$.

From a cosmological perspective, this "entropy acceleration" may be related to the relatively recent discovery that the rate of universal expansion also appears to be accelerating, i.e. $\ddot{V}_{universe} > 0$. Since the volume of the universe is increasing at an increasing rate, there are thus an ever-increasing number of states in which the universe can find itself: there are more places for things to be. Furthermore, since the velocities and thus the kinetic energies of the galaxies – which may be represented as mechanical energy, W, which as Carnot pointed out, must be no greater than the heat, Q it produces – appear to be increasing and the average absolute temperature, T of the universe appears to be diminishing we can better understand the second law, $\Delta S \geq \Delta Q / T$ on a cosmic level.

Since a rational implication of an ever-expanding universe, is a universe with a growing number of states, $S_{universe}$ must increase commensurately. Furthermore, for astronomers, this constant expansion makes it increasingly challenging to keep track of where everything is [5, 6], thus increasing the demand for better information systems [7].

3 Entropy at the small scale

There is also a means of quantifying thermodynamic entropy for microscopic systems. For example, the Gibbs entropy [8] of a system is defined as:

$$S = -k_{\mathrm{B}} \sum_i p_i \ln p_i, \tag{1}$$

where k_B is Boltzmann's constant, and p_i is the probability of finding a particle within the system under consideration occupying a particular energy level. This expression is only valid for purely thermodynamic systems, not physical systems in general. However, if one were to develop an exhaustive set of independent physical variables for a physical system, in principal the same general statistical approach may be taken. The primary utility of (1) is to account for the total number of states that a system of particles, i.e. gas molecules, may have. Of special significance is that the units of k_B are joules per kelvin and that p is unitless. So, just as two distinct, unrelated, and unique physical objects might have the same mass, but otherwise share no characteristics, two non-identical physical systems might be equally entropic. For example, a small, naturally formed plume of prehistoric volcanic ash and vapor might have the same amount of entropy as the dust cloud formed by the three World Trade Center buildings that were brought down on September 11, 2001.

As a quick preview into the main thrust of this paper let's look at how the physical world is becoming "informatized." We are quickly approaching a precipice at which all humans will soon have the ability to access all of known history via the internet. We are also able to instantly access information about the present, e.g. www.worldometers.info. For example, one of the variables we can instantly access is the temperature of our immediate environment, as well as the earth's average temperature. It therefore is worth considering the fundamental nature of both temperature and time in the context of energy and entropy. The ideal gas law has dimensions of energy:

$$PV = nT. \tag{2}$$

In words, "the product of pressure and volume equals the system temperature multiplied by the number of particles in the system." Rearranging eqn (2) to isolate temperature yields, $T = PV/n$, i.e. temperature is simply energy per particle.

3.1 Microscale entropy accumulates at larger scales

This energy per particle manifests itself both kinetically (how fast the particle is traveling and rotating) and vibrationally (how quickly its bonds stretch and compress). This molecular scale energy is essentially unavailable to do work (in a turbine for example) and is simply exhausted into the atmosphere, waterways, or the ground. As a result, the 500+ exajoules of annually discarded anthropogenic thermal energy manifests itself as hotter global temperatures, and thus more powerful and destructive storms. And it is this additional inaccessible thermal energy that is termed the "greenhouse effect." The contributions of key greenhouse gasses to global warming has been recently discussed by numerous authors including Solomon *et al.* [9] via equations such as

$$N = F - \lambda \Delta T_{surface}, \tag{3}$$

where N is the rate of increase of thermal energy of the atmosphere, F is the rate of solar "forcing" energy from the sun, and thus λ, although the authors do not name it as such, is the anthropogenic entropy generation rate.

3.2 Entropy rebound?

Recall that the working definition of the second law states that entropy cannot decrease for any closed system, i.e. any system from which energy neither leaves nor enters. As Schrödinger observed in 1944, organisms consume energy in order to locally and temporarily reduce their own entropy. An organism however, even though it may reduce its own entropy, does not violate the second law, because it is an open system. Place this organism inside a sealed vessel [closed system] with no access to nutrients or any means of eliminating waste, and it will soon die, having become a victim of entropic forces.

The earth itself is also an open thermodynamic system, with photosynthetic energy coming in and low-grade thermal radiation leaving. Could it be however, that since carbon dioxide prevents a significant fraction of our waste heat from leaving our planet, that we accelerating our own demise by basking in our own entropy? There are already a growing number of people who have been designated as "climate change refugees," see Hollifield *et al.* [11] and Sachs [12].

Now it is time to move onto a discussion of information and to attempt to unify the concepts of entropy and information while keeping in mind that every single technology that persists today through a process recently coined as "mechanoevolution," exploits the second law [13]. As mentioned above, every single biological system also exploits the second law. Both technological systems and biological systems do so by using their information structures [microprocessors or brains] to minimize their own entropy while shedding excess entropy either by default or willfully towards other technological systems, biological systems, or the environment in general.

4 Information

The discipline known as information theory emerged from Claude Shannon's efforts in the early 1940s to formalize the quantification of how large of a message can be packed into a string of symbols carried via a physical system such as a radio transmitter. In what is perhaps his most famous equation, he essentially ushered in the digital age by stating that the capacity of a channel C in bits per second is proportional to the product of the frequency of the signal and related to the power of the signal and noise of the signal via

$$C = \omega \log_2 \frac{P+N}{N}, \quad (4)$$

where ω is the bandwidth of the channel, P is the power of the signal, and N is the power of the noise. In the theory, each symbol in the message being carried by the channel, which can take any of a number of forms such as a radio wave, a person talking, a person doing sign language, etc., has a certain probability of appearing next in the string, and once these probabilities are summed, via

$$I = -\sum_i p_i \ln p_i, \quad (5)$$

a single scalar value, I, which in this case represents "self-information" can be assigned to the string. The variable p is the probability of event i occurring, where i denotes the i^{th} symbol in a string (Shannon's original work, uses H rather than I). This string of characters, in turn can represent anything from the lyrics of a song, to the words in a book, to the instructions for how to build a nuclear bomb. There are many more subtleties to information theory, but for the purposes of this paper, we can simply think of information as how much thought, planning, and level of detail must go into an individual decision, design or set of instructions in order to faithfully reproduce it.

Two easily accessible examples of physical entities that lend themselves to a quantifiable amount of information are the string of letters that represent the chemical formula for an organism's DNA or a digitized version of a building's blueprint. In the case of DNA, more "complex" organisms have larger genomes in general, which in turn require more information. In the case of blueprints, buildings with more features, plumbing, air conditioning, specialized materials, etc., require a larger set of drawings and thus a greater amount of information to fully describe. In either case (the organism or the building) if some portion of the information required to reconstruct the physical object is missing, then complexity is also compromised, and more than likely loss of some function, i.e. eyesight in the case of the organism or a plumbing component in the case of the building.

4.1 Key distinction between entropy and information

Notice the similarity of (5) and (1). Both S and I are scalars and both contain the product of a probability and its logarithm. The key difference is that information is dimensionless, and [physical] entropy has dimensions of energy per unit temperature. The word "physical" is in brackets for two reasons: first to emphasize that *entropy* is just as physical as mass, space and time, and second to stress that *entropy has dimensions of energy per unit temperature*. The formal proposal for an internationally recognized unit of entropy is long overdue. A reasonable SI unit would be J/K and dubbed the "carnot." In fact a major motivation for this paper, was to address Feynman's 1963 claim that the only two engineers who had ever contributed to the scientific body of knowledge were Carnot and Shannon and that their theories were related [14].

4.2 Information and entropy examples

In any information system, each character used in the language/code being transmitted can thus be assigned a level of importance in terms of the integrity of the message and thus the likelihood of the speaker/transmitter being understood by the listener/receiver. For example, when transmitting driving directions via a series of symbols, confusing "turn east" with "turn west" could have serious consequences. This incorrect message occurring would require that "ea" be replaced with "we." Thus only "ea" and "we" contain information, whereas "st" contains none.

One outcome of information theory was coining a name for the fundamental unit of information: the binary unit or "bit," which is either "on" (1) or "off" (0). Any character string, song, image, or the DNA sequences or blueprints mentioned above with an appropriate algorithm, can be mapped onto a string of ones and zeroes, the length of which equals the number of bits. (Note that an original string of information can be compressed given an appropriate compression algorithm. An example is the creation of compact computer files, e.g. the ".zip" extension.) The algorithm for converting a particular string of characters into a single scalar is irreversible: two non-identical strings can contain the same amount of information, and thus may be considered to be equally "complex," even though they may represent two very different systems. As a simple example, the string "mother" and "rehtom" contain the same set of letters, just reversed and thus have equal information content if we assume that letter order is independent. But clearly, only the word *mother* is readily intelligible. The word *rehtom* is only intelligible with the proper code: $r_i = w_{n+1-i}$, where i represents the position of the letters in the original word, r_i represents the letter in the reversed word, w_i represents the letter in the original word, and n represents the number of letters in the original word. In the above example, $n = 6$, and thus $r_1 = w_{6+1-1} = w_6 =$ "r."

Information theory as originally published by Shannon [15] is more subtle than discussed above in that the order of the characters also contains a measureable probability and thus measureable amounts of information. For example the sequence "th" is much more likely to occur than the sequence "ht," therefore "ht" contains more information because it is rarer. This underlies a subtlety of information theory in that bits only have utility insofar as they can be either transmitted or physically manifested.

4.2.1 Information content of the Mona Lisa vs. a Boeing 787

Let's consider an approach for comparing the amount of information, or the level of *complexity* of two well-known physical entities: the Mona Lisa and a Boeing 787. (As of this writing there is no "unit of complexity." For the sake of this paper we thus use the binary unit to quantify complexity: i.e. the complexity of a fully compressed binary string is equal to the minimum number of bits required to faithfully reproduce it.) The Mona Lisa has been photographed numerous times, and has thus already been digitized. Undoubtedly the resolution of none of the various photographic media used to represent the painting is great enough to physically reproduce it molecule-by-molecule. However, *in principle*, since the painting itself is finite, one could imagine an imaging technique (non-destructive or destructive) with sufficiently great resolution to map the position and orientation of every molecule in the painting. With this information in hand, and a sophisticated 3D printer, the Mona Lisa could *in principle* be reproduced. Thus the Mona Lisa can be represented by a finite and quantifiable amount of information, I_{ML}. In a similar manner, one could reverse engineer a Boeing 787. A simpler method, however, would be to access Boeing's documents on fabrication and assembly details, and build one with conventional means. These documents, along with institutional knowledge held by Boeing engineers and technicians are finite, and can thus be represented by a quantifiable amount of information, I_{787}. In comparing these two numbers, I_{ML} and I_{787}, one could then state whether a Boeing 787 is more complex (requires more information to reproduce) than the Mona Lisa. The actual level of complexity for the airplane is likely well above the terabit range and the painting is likely another dozen orders of magnitude greater (assuming that any two given Boeing 787s are identical). Assuming non-identicality would raise the complexity to many orders of magnitude greater, based simply on the number of atoms in the plane. One approach to "informatize" the Mona Lisa would be to give the type and location of all its atoms. With a mass on the order of 200 g, this yields approximately 200 g × 12 g mol^{-1} x 6.022 × 10^{23} ≈ 1 × 10^{27} atoms. Allowing for 64 different atom types (6 bits per type) and 90 bits per location equals 5.7 x 10^{30} bits for a full recreation of the Mona Lisa.

4.2.2 Entropy generation of the Mona Lisa vs. a Boeing 787

Both the Mona Lisa and a 787 are entropy sources and entropy sinks. They are entropy sinks in that as they age, they degrade and thus become victims of the second law, essentially absorbing stray energy from the environment into their physical structures, which will ultimately lead to their total degradation and dispersion of all of their atoms into the universe. On the other hand, while in operation, the Boeing 787 with approximately 100 kN of thrust traveling at 200 meters per second generates entropy at a rate of $\dot{S}$ = 70,000 W K^{-1} while in flight and perhaps at an average rate of 14,000 W K^{-1} if we assume a duty cycle of 20%. The Mona Lisa is also an entropy source in that approximately six million people expend energy to travel to and crowd around the famous painting every year. With each of the six million visitors spending an average twenty hours at an average energy expenditure of perhaps ten human powers (1 kW) to get to Leonardo da Vinci's most famous piece, the Mona Lisa's entropy generation rate is on the order of

$$\dot{S}_{ML} = [6{,}000{,}000\text{Y}^{-1} \times 20\text{H} \times 3600\ \text{S/H} \times 1000\text{W}]$$
$$\div [290\text{K} \times 8742\ \text{H/Y} \times 3600\ \text{S/H}] = 24{,}000\ \text{W K}^{-1}.$$

So if these estimations are correct, the Mona Lisa at 24,000 W K^{-1} generates more entropy than a large commercial aircraft at 14,000 W K^{-1}.

Both the Mona Lisa and the Boeing 787 rely on information-processing systems in order to "survive." Moreover, their respective survival probabilities are contingent upon the proper functioning of their respective information-processing systems. The 787 has navigation systems, flight control systems, fuel gages, thermostats, etc. These systems and gages are used to transform the physical condition of the airplane: position, velocity, aileron angle, fuel level, cabin temperature, etc. into numbers (information) that is then used to minimize the probability of crashing (entropicizing) the aircraft. The Mona Lisa has security cameras, temperature monitoring systems, lighting control and humidity control systems, all of which have convert the physical status of the painting and is surroundings into *information* which is relayed to security guards and museum staff for the purpose of preventing theft and physical degradation (*entropization*). Examples of physical states of a fully entropicized Mona Lisa include the painting being stolen and lost forever, burned in a fire, eaten by moths, broken down by ultraviolet light or moisture, etc. So in both cases, the continuous, high-fidelity flow of information is critical to avoiding an entropic event.

5 Lin's three questions resolved

From the above discussion, it should be clear that we have addressed each of Lin's three questions which were published in the inaugural issue of *Entropy* [16]: 1) Information is indeed related to entropy loss. Or conversely, information loss can result in entropy gain. In our painting/airplane examples, loss of information about the physical state of either the Mona Lisa or the Boeing 787 will likely result in their respective entropization, e.g. failure to detect and suppress a fire. 2) "information-theoretic entropy" has a very strong relation to the second law of thermodynamics in that a malfunctioning information system will accelerate the second law for its associated system, e.g. misinterpreting a weather forecast that calls for foul weather could result in a plane crash or water damage inside a building could result in canvas degradation and 3) "information-theoretic entropy" and thermodynamic entropy are indeed correlated in the sense that a fully entropicized system takes more information to describe than an intact one and inversely correlated in that properly interpreted "preemptive information" can be used to avoid an entropic event as seen in the examples given in 1) and 2).

To reiterate, every living system and every machine that is Type II or higher [17] is processing information in order to survive. So using time as an independent variable, and taking the time derivative of both entropy and information we can, *in principle*, find the entropy production rate and the information processing rate for every discrete system in existence and produce expressions for the universal entropy generation rate and universal information generation rate:

$$\dot{S}_{\mathrm{u}} = \dot{\sum}_{i=1}^{n} \dot{S}_{i}, \tag{6}$$

and

$$\dot{I}_{\mathrm{u}} = \sum_{i=1}^{n} \dot{I}_{i}, \tag{7}$$

where u represents the universal sum of the respective variables, and i represents the i^{th} discrete system out of a total of n systems. We have already made an estimate for $\dot{S}_{\mathrm{u}}$ of $8.4 \cdot 10^{48}$ W K^{-1}. What about $\dot{I}_{\mathrm{u}}$? Our own brains of course have served the purpose of information processing since, and even prior to the dawn of humanity, and written records have served an auxiliary role for a few thousand years. So taking a Kurzweilian approach where each human brain processes approximately 10^{13} bits per second, and making similar estimates for other organisms and Type III machines, yields $\dot{I}_{\mathrm{H}} \approx 7 \cdot 10^{22}$.

Since only Type III systems or greater are capable of information processing, we can safely say that the only information processing systems that we are aware of exist within our own solar system. (The one exception to this is the spacecraft Voyager, a Type III machine that recently left the solar system.) So with this, as well as the Kurzweilian estimate for human information processing, the total information processing rate of all organisms and Type III machines is likely no more than three times that of $\dot{I}_H$ (this allows for all other organisms on earth to possess an information processing rate equivalent to that of humanity and all Type III machines to also have an information processing rate on the order of $\dot{I}_H$. In other words, $\dot{I}_U \doteq 20 \cdot 10^{23}$. An ever-increasing fraction of our Type III technologies are devoted to "informatizing" the environment, i.e. computerized mapping. If Kurzweil's predictions are correct, the information processing capabilities of our technologies will surpass our own neural computational capacity by the end of this decade [18].

5.1 The Google car and "informational fitness"

To further address Lin's three questions, how can we quantitatively illustrate the relationship between information and entropy? More specifically, how might having accurate information allow one to forgo the generation of "excessive" entropy? Consider Google Maps. The reader may have seen a Google car driving through her neighborhood generating entropy with its internal combustion engine at a rate of $\dot{S}_{\text{Google car}} = 50$ to 100 W K^{-1} and "informatizing" the environment at a rate of $\dot{I}_{\text{Google car}} = 1$ to 10 Gb s^{-1}. We can thus assign a coefficient, α that acts as a scalar between information generation and entropy generation:

$$\alpha = \frac{\dot{I}}{\dot{S}}. \tag{8}$$

This scalar α could be considered to be the "informational fitness" of a given system, which essentially quantifies how capable the system is of storing its manufactured information as it generates entropy. Using the entropy generation rate and the information processing rates we estimated above for the Google car, we arrive at $\alpha_{\text{Google car}} \approx 10^9$ b s^{-1}/10^2 W K^{-1} = 10^7 b K J^{-1}. Or in words, the informational fitness metric of the Google car is 10,000,000 bit-kelvins per joule. To take this one step further, since the fundamental dimension of temperature is unit energy per particle, $\alpha_{\text{Google car}} \approx 10^7$ b particle^{-1}. In this case the particle is simply the car. But assuming approximately 10^{29} atoms in the car, yields $\alpha_{\text{Google car}} \approx 10^{-22}$ b atom^{-1}. For further quantitative examples of this informational fitness, see pending journal publication.

6 Information, entropy, and game theory through the lens of contingencies

We have already examined how physical, thermodynamic entropy, S, with units of joules per kelvin is related to non-physical, mathematical self-information, I, with units of bits. So it is now time to examine how some systems can use their own information systems to exploit, deceive, and in some cases destroy competitors. The primary mode for doing so is either to make one's own information structure invisible to a competitor or to intentionally misrepresent oneself in such a way as to elicit an action from a competitor that will work to one's advantage. A simple example that we have all likely observed is bluffing in poker. If a player gives away her hand by showing elation or disappointment, it will tip off other players on how to bet. A bank robber wearing a mask is another example. How might bluffing work at the societal level?

Companies, governments and religions cannot survive without secrets: Coca Cola, Kentucky Fried Chicken, Mars, etc. all rely on keeping their information within a select inner circle. Without secrecy (protected information) capitalism as well as national security become compromised. Wikileaks is a prime example of the consequences of shared insider information. What type of entropy might ensue if more than a handful of people knew the locations of atomic weapons storage units, etc.? Religions too rely upon staying shrouded in secrecy. They often thrive by turning a blind eye to scientific revelations in order to "capitalize" on mysticism and faith in the unknowable. Common to each of these examples is an extraordinarily convoluted set of procedures intended to either uninform or misinform those outside an inner circle. If you've ever told a white lie, then you know how complicated it can become to continue weaving a false reality that is consistent with someone else's perception of reality while maintaining your secret.

The world is replete with successful liars, most of whom have certainly not been caught. Typically we only hear of the more famous cases: Lance Armstrong, Martha Stewart, Bernard Madoff, Eliot Spitzer, Bill Clinton, etc. Obviously then, there is an allure to lying in order to take advantage of other people. The individuals mentioned immediately above are fairly innocuous, as none of their most famous lies involved life-or-death circumstances. However, the entire course of human history can be *contingent* upon other obfuscations of the truth: "We have no nuclear weapons." "I'm not pregnant." "I did not kill that person," etc. Each of these statements is essential binary with a critical bit or a few bits of information that either matches reality or not. The consequences of their respective inaccuracies can be monumental with respect to the potentially ensuing entropy added to their respective systems: a geographic region, an unborn child, an adult. The key concept here is essentially the converse of the informational fitness we discussed with the Google car: misinformation or disinformation (a system's inaccurate internal representation of the external physical world has the potential to lead to that system's entropization.

7 Concluding remarks

As we move forward into the future, if we as a species are to remain successful, and if we are to move towards a global society where fewer people are victimized and where the planet's resources are harvested in a sustainable manner, it seems critical that all people have better access to information. More importantly, it is critical that we open our eyes to information systems built upon deceit. We must also continue to develop information systems that allow us to monitor and begin to rein in our entropy production rate so that we can avoid an anthropogenically driven collapse of the beautifully complex planet we have inherited. In conclusion, we turn to Kelvin, who stated:

> *"When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science."*

The author would therefore like to embolden the reader to refute McShea [19] who suggests abandoning words like complexity, information, entropy, etc. and embrace them for what they are. We have already done so with words like "work," "power," "energy," "stress" and "strain" in the engineering disciplines. The physical sciences and information sciences should follow suit.

Acknowledgements

The author would like to thank Eric Chaisson, Dick Coren and Russ Genet for their fruitful conversations on the topics of entropy and information. The authors declare no conflict of interest.

References

[1] Chaisson, E.J., Energy Rate Density. II. Probing Further a New Complexity Metric. Complexity, 17(1), pp. 44-63, 2011.
[2] Chaisson, E.J., Energy Rate Density as a Complexity Metric and Evolutionary Driver. Complexity, 16(3), pp. 27-40, 2011.
[3] Diamond, J.M., Collapse: How Societies Choose to Fail or Succeed, Viking: New York, p. 491, 2005.
[4] Kardashev, N., Transmission of Information by Extraterrestrial Civilizations. Soviet Astronomy, 8, pp. 217-221, 1964.
[5] Krauss, L.M., A Universe from Nothing: Why There is Something Rather than Nothing. First Atria Books trade paperback Ed Mar 2013 ed, Free Press: New York, pp. 75-89, 2013.
[6] Hawking, S. & Penrose, R., The nature of space and time, Princeton science library, Princeton University Press: Princeton, pp. 25-40, 2010.
[7] Cern. CERN Data Centre passes 100 petabytes. 2013; http://home.web.cern.ch/about/updates/2013/02/cern-data-centre-passes-100-petabytes
[8] Jaynes, E.T., Gibbs vs Boltzmann Entropies. American Journal of Physics, 33(5), pp. 391-398, 1965.
[9] Solomon, S., *et al.*, Persistence of climate changes due to a range of greenhouse gases. PNAS, 107, pp. 18354-18359, 2010.
[10] Schrödinger, E., What is life? The Physical Aspect of the Living Cell with, Mind and Matter & Autobiographical Sketches, Cambridge University Press: Cambridge; New York, 2012.

[11] Hollifield, M., Thompson Fullilove, M. & Hobfoll, S.E., Climate Change Refugees. Climate Change and Human Well-Being International and Cultural Psychology, ed. pp. 135-162, 2011.
[12] Sachs, J., Climate Change Refugees. Scientific American, 296, p. 43, 2007.
[13] Layton, B., The Role of Mechanoevolution in Predicting the Future of Micro- and Nanoscale Technologies. Systems Engineering for Microscale and Nanoscale Technologies, Darrin & Barth, CRC Press: Boca Raton, FL, 2011.
[14] Feynman, R.P., Leighton, R.B. & Sands, M.L., The Feynman lectures on physics, Vol. 2, Addison-Wesley Pub. Co.: Reading, Mass, 1963.
[15] Shannon, C.E., A Mathematical Theory of Communication. Bell System Technical Journal, 27, pp. 379-423 & 623-656, 1948.
[16] Lin, S.-K., Diversity and Entropy. Entropy, 1, pp. 1-3, 1999.
[17] Layton, B.E., Recent Patents in Bionanotechnologies: Nanolithography, Bionanocomposites, Cell-Based Computing and Entropy Production. Recent Patents in Nanotechnology, 2(2), pp. 72-83, 2008.
[18] Kurzweil, R., The Singularity is Near: When Humans Transcend Biology, Viking: New York, 487, 2005.
[19] McShea, D.W., Unnecessary Complexity. Science, 342 (13 Dec), pp. 1319-1320, 2013.