Infoenergetic Systems

Ricardo Salim K.
Tercer Medio, Caracas, Venezuela

Carlos Ferrán-Urdaneta
Boston University, Boston USA

ABSTRACT

We define an Infoenergetic System as a system that responds to information with physical work, particularly those systems using digital or biological brains. We discuss how the study of these systems helps in understanding the post-industrial emphasis on the informational component of production and products. We also propose a formalization for the traditionally intuitive relation between energy and information, and look for its place in the synthesis path that goes between statistical thermodynamics and information theory.

Keywords: Information, Energy, Information Theory, Statistical thermodynamics, Post-industrial.

1. INTRODUCTION

The objective of this paper is to propose as a theme of study, with its own basis, those systems characterized by an intense relation between information and energy.

Some of the most important technological advances of the 19th century were powerful machines and systems that transformed inputs of large quantities of energy and relatively little information in the form of control signals, into outputs of another form of energy controlled by that information (for example steam engines). Artificial systems that have inputs and outputs of little energy but of great quantities of information (for example, computers) are an advance of the 20th century. The growing and frequently inextricable coupling of both types of systems gives rise to a new type of system where a great deal of energy is controlled by a great deal of information (for example, a line of production or distribution controlled by data processing). See as an example, *Cybernetics in electric power systems* [1]. These systems, that we shall call infoenergetic systems, characterize the so-called post-industrial era and are likely to be ubiquitous in the next century.

Infoenergetic systems are partly the subject of study in thermodynamics, energetics, information theory, systems theory, cybernetics, and information technology. However, none of these theoretical fields views them as a whole, especially in respect to their output, which is neither energy nor information but a combination of both.

Take for example a distribution system whose product is maximum on-time delivery at minimum cost. Obviously, this output is neither just energy (handling and transportation work done by man or machine) nor just information (precise interpretation of incoming orders in terms of optimum path and schedule), but a combination of both. Such a system can be suboptimized by a flaw in energy or information, and are rarely characterized by fixed proportions such as, say, 2 units of work for 1 unit of information. More information could imply more work in some cases (more orders have to be satisfied) and less work in other cases (more details in each order for better scheduling).

So neither energetic calculations nor informational calculations, separately, can tell us how much human work, machine work and information processing capacity is required by the final product. Simultaneous energetic and informational calculations are needed to deal with new units, measures, relations, ratios and expressions that involve both energetic and informational concepts. For example, we may be interested in the number of work units (say man-vehicle hours) under control of the information system per total work units; or, the number of work units under control of the information system times number of information units needed for control, etc. We are in fact dealing with a special kind of system. And given the growing importance of such systems, we think they merit investigation.

Underlying this theme is the relation between energy and information, two variables considered today to be orthogonal determinants of the operation of practically any biological, social, economic or political system. This relation has traditionally been recognized, from the intuitions of a non-material entity -spirit, psyche, etc.- which regulates the corporal behavior, through expressions like the classic *Scientia potestas est* or the popular “Skill will do where mere force won’t”, to the modern “Information is Power”. But, formally, this relation is known only in the form of some corollaries of theories whose main theme is thermodynamics or information theory.

Statistical thermodynamics (developed mainly by Boltzmann around 1872) is an important synthesis of science. By adding the dimension of order or probability of state to the classic mechanical concept of energy, it shows that heat is not a separate entity (the caloric), as it had been believed to be, but simply a disordered form of energy, a more probable state than potential energy. It also explained the natural tendency of energy to be disordered, or in other words, to not be available for work (see for example [2], [3]). The tendency of systems towards energetic disorder is called entropy. Later, Shanon [4] defined information probabilistically, and its inverse relation to entropy became obvious. Other authors identified information with negative entropy or neg-entropy ([5], [6], among others).

However, the thermodynamic concept of neg-entropy does not comprise the entire relationship between energy and information. If we imagined energy as a set of forces, they would reach maximum work (maximum potential energy and highest neg-entropy) when pushing in just one direction or obeying one single instruction. When pushing at random, not following any direction (i.e. in as many directions as forces there are) the result is maximum heat (maximum dissipation and the most probable state, or entropy). Neg-entropy differentiates disordered energy (or heat) from ordered energy (or energy with potential to do work), but it does not address the number of directions or instructions that the maximum work (all the forces at once) could follow. That number could be calculated by means of information theory, but it will measure something that is not neg-entropy. It would measure another type of information that is closer to what is called pragmatic information [7]. And it will characterize a third kind of energy in the line of heat and work, a still more informed kind of energy, an infoenergy.

In other words, currently established formal relations between energy and information (based on thermodynamics and information theory) are not sufficient to describe an infoenergetic system. Thermodynamic theory is useful to differentiate between motors with different potentials (or levels of performances), but information theory would be required to appreciate the difference between a motor with just one drive and another with a range of drives. Infoenergetic theory would examine energy and information from the point in which the energy is ready to come out of the motor or thermodynamic system and a external information takes control of it, a point where neither statistical thermodynamics nor information theory have anything more to add to energy and information, respectively. That is the point in which the energetic stallion is ready to be mounted by the informational rider. From this point on, the relation between energy and information is as important and subject to quantification as in the thermodynamic phase, but now the information has changed, and its measures and interactions with energy are also different.

In this paper we hope to take a step towards the synthesis between statistical thermodynamics and information theory.

2. DEFINITIONS

We begin by reviewing the definitions of the three key terms of this study: potential energy, work, and information. Then we define the concept of infoenergetic information.

2.1. Potential energy and work

In this study we subscribe to the widely used and accepted concepts of potential energy and work. Potential energy is identified as the capacity of an energy source to perform work, for example the weight or the friction of a given material body along a given distance. Work is identified as the application of a force along a given distance, which in general is equivalent to the movement of a specific mass against certain specific resistance forces (see as an example [8]).

2.2. Information

There are several definitions of the notion of information, from very precise and specific to certain contexts (communications, information theory, economy) to very vague and general. We have not found a precise definition of general usage. Some dictionaries [9] define information as “the knowledge that we have of some object, the sum of what we perceive, discover or infer from it”, implying that it pertains only to organisms with a central nervous system, mainly the humans, their groups or societies. In more contextual definitions organs, muscles, cells and genes as well as information processing machines and other complex systems can possess information.

In the context of information theory [4] information is identified with the binary logarithm of the inverse of a probability. Although this is not satisfactory as a general definition, it has the enormous advantage of emphasizing a quantifiable aspect of what we call information. And it gives birth to its only widely accepted measure and unit, the bit (binary unit), which are frequently used in the data processing field. This probabilistic concept of information also relates it to statistical thermodynamics, in particular to the concept of negative entropy ([5], [6] among others).

Included in the etymology of the term information is the concept of form, and this concept is still present in its current meaning. When we say that a system reacts to the information of its environment, we are not saying that it reacts to its matter or energy, but to certain forms of matter and energy. So, when the wolf smells or sees the rabbit and undertakes its hunt, it has received some molecules lost from the rabbit's skin or a reflection of the rays of the sun upon the rabbit. The molecules are the matter and the reflection is the energy that the wolf eventually returns to the environment. But it is not just any matter or any energy that activates (through the olfactory and vision systems) the hunt; it is a certain mixture or chemical formula (the form) of those molecules, or the image (the form) of that luminous reflection that triggers it. Those forms are, for the wolf, signals, information coming from its environment.

Not all forms cause systems to react. Following this fact, three classes of information have been defined: pragmatic, semantic and syntactic information [7]. Pragmatic information refers to the forms that cause reaction in some systems, covering in general the stimuli and all kinds of activation signals, instructions, commands, and orders. Semantic information includes the forms that keep relation with other forms, being their symbols or representations but without causing necessarily reactions in any system. Syntactic information are the forms that neither cause reactions nor keep relation with others, as the form of a cloud.

2.3. The infoenergetic information

The information that constitutes input to the infoenergetic systems is by definition pragmatic information. And not just any pragmatic information, but the type that causes controlled reactions, as opposed to unexpected, undesirable, or out of control reactions.

The intuition of a form or non-material (or at least relatively imperceptible, small) entity that controls the behavior or movement of matter is a traditional one. The meaning of the Greek word “psique” was originally butterfly, something light, ethereal, almost with no matter, and later became soul. The word “soul” is a synonym of “anima”, which roots with the Greek “pneuma” (air) and connotes low weight, scarce matter. The ancient meaning of the word “spirit” was breath, a symbol of animation of matter. Also terms such as “verb”, “logos”, “idea”, “mind”, and “reason” tend to include a meaning of control of the body, of the matter. The words “government” and “cybernetics” originate from the Greek “kibernetes” (rudder), alluding to the relatively small wheel obeyed by a whole ship. Even in the second half of the twentieth century, computer engineers continued this tradition, surely in an unconscious way, by calling software (something soft, light, intangible) the programs or information that controls the computers hardware (something hard, heavy, tangible).

Besides this tradition, we will see that, in fact, since a) the control of matter is the control of its movements, which implies control of the energy that prompts them; and b) the control of energy implies the selection of a few among many possible forms of freeing energy from the tense material equilibria that retain it in its potential state; then c) because this selection implies information, the control of matter and energy also implies information.

a) The control of matter is the control of its behavior, its movements, or its changes. This is evident in at least the visible or macroscopic movements of matter. Nobody would assert that s/he controls an arm, if s/he does not have control of its movements (see for example [10], [11]). Even at the microscopic level we should remember that physical and chemical transformations respond to a change of relative positions of the molecules, atoms and sub-atomic particles, thus we control them by controlling those movements or changes in position.

   The movement of matter, or more precisely the real or potential change of the magnitude, or direction of the velocity of a material object, is what we understand as energy. Therefore, the control of matter is the control of its energy.

b) The control of energy is based on the balance between opposite forces (weight and counterweight, role and counter-role -i.e., control-), and is a third element (neither weight nor counterweight) capable of orderly breaking the equilibrium. This third element controls more as it becomes lighter, leaving the counterweight simply as part of the body being controlled. Thus, something light or almost non-material is able to control the movement of heavy matter.

   Opposite forces in a state of balance or tense equilibrium allow for the control of their internal energy, and are found in matter in either a natural state (see for example [12]]) or in an artificial one. Matter contains energy in the form of a tense equilibrium between its fundamental forces -nuclear, electromagnetic and gravitational- and its derived forces. The rupture of a tense equilibrium frees up energy. For example, if you break the gravitational equilibrium between the two sides of a balance or the nuclear equilibrium of an atom, you will observe diverse movements. In the first case just with your eyes, while in the second by means of an adequate theoretical-practical apparatus.

Organisms and machines are meshes of forces (mechanical, chemical, and others) that maintain different levels of tension among themselves. This tension gives rise to diverse control points which interact in a hierarchical way. An internal combustion engine requires the dynamic equilibrium between the chemical energy freed by the combustion of fuel and the resistance of the materials that channel that energy. In a similar manner, there is a dynamic equilibrium in muscles between the chemical energy taken from food by the muscle cells, and the resistance of tissues that contain and transform this energy into movement, all under the control of subtle nervous impulses (see for example [13]).

Of course, some energy is required to break an energetic equilibrium, but in many cases it is much less than the energy freed by the break. For example, an almost imperceptible spark can break strong chemical equilibria and starts a great fire.

The fact a large amount of energy can be freed by a smaller amount of energy implies that the greater energy, once freed, is able in its turn to free still an even greater amount of energy. Furthermore, a minuscule amount of energy could have freed the initial small amount of energy. Thus, we can build a chain of energy amplification. In principle, the upper limit of this amplification chain is all the energy in tense equilibrium of the universe, and the lower limit is a quantum or minimum “grain” of energy. A moderate but common example is the nervous signal originating in the brain that activates the muscles of the finger that pushes on the starter that ignites the engine that opens the floodgate of a dam, freeing with the water its enormous potential energy.

Among the cases in which a small energetic impulse or a sequence of them frees a greater amount of energy, a causal relation may be observed between certain quantifiable characteristics of the impulses (for example, its intensity or frequency) and the quantity of energy freed. Thus, although the size or intensity of an initial spark has little or no relation to the size or intensity of the open fire that it may have caused, in the case of the internal combustion engine the frequency of the spark from the sparkplug determines with precision the frequency of the explosions of the fuel inside the cylinders and consequently the quantity of energy freed in per unit of time. Thus, one or a sequence of pulses becomes a trigger when properly applied to an activation device. In a similar manner, a sequence of nervous pulses activates distinct muscular reactions, and a sequence of binary pulses activates distinct functions of a computer.

The appropriate selection of a pulse sequence, among many possible combinations, can determine the quantity of energy that will be freed in a given time and space. In other words, energy control is based on selecting correct pulse sequences.

c) Pulse sequences are differentiated one from another by characteristics such as frequency, intensity, relative size of each impulse, their temporary distribution, and so on. And these characteristics are simply forms, like the bumps on a key. If the key is lost but its form is preserved in a blue print or as a remembrance in the neurons, then it is always possible to later replicate the key. Similarly, an energetic pulse sequence can maintain its form while its energy is reduced to the physically possible minimum. For example, if we have an impulse of twenty kilocalories followed by another of ten, their relative sizes can be maintained even if we reduce the impulses to two and one kilocalories, respectively, or to two and one electron-volts (to take a very small unit). With this procedure we could minimize the required energy without altering its form, and we could later amplify the pulse to its original levels.

To select the proper pulse sequence or form is to control energy. And selecting one form over another is like selecting symbols or letters from among many possible ones. The forms of the pulse sequences are therefore signs, words, keys, codes, control messages, formulae, information. So amplified information becomes controlled energy.

Thus, the strings of minimal binary electronic impulses that controls computers are a chain of machine-interpretable symbols, which in turn may be the result of the transformation of another symbol sequence easily readable by humans and destined in many cases to the computer mediated control of highly energetic machinery. But in any case, it is information that controls the energy of the machines or of the organisms; it is the information that controls the energy. So we can therefore say that infoenergetic information is the minimal pulse sequence, the software that controls not only machines, but also any infoenergetic system.

3. THE INFOENERGETIC SYSTEM

We can now say that an infoenergetic system is a system that is capable of amplifying an energetically minimal but informationally large input to mechanical energy levels, or work (i.e. levels that are manifested by macroscopic changes in the matter). As we will see later, the energetic form that controls an infoenergetic system is generally a signal that originates from a control center which could be one or several biological or electronic brains. Thus, a car is controlled by signals originated in the brain of the driver, who at the same time can obey orders originated from the brain of someone else or follow a route previously determined in a map or electronic guidance system.

Most animals do not respond with work to signals originating from brains or nervous systems other than their own. We could consider their bodies and part of their nervous systems as infoenergetic systems exclusive to their own brains. This characteristic of “exclusive” or “closed” infoenergetic system makes them in general of little interest. Beasts of burden do certain work obeying to external instructions, but a large part of their movements occur only in response to their own brain signals, so we must consider them as “partially open” infoenergetic systems. Humans are much more open, as we shall see.

A partial or totally open infoenergetic system should possess an entrance, port or input subsystem, sensitive mainly to external cerebral or digital signals. By definition, digital systems possess this entrance. Today’s voice interfaces allow the finger mediation (typing) or other mechanical contacts to be skipped when sending orders or messages from the brain to the machines. Soon advancements in signal recognition and remote control technologies will allow for the control to happen without even the voice command and have it directly from the neural signals that cause the voice itself. Furthermore with the help of miniaturization and satellite technology those commands could cleanly and instantaneously come from a biological brain located half a planet apart from the machine following the orders. But at present day we have to conform ourselves to just household appliances that only obey the brain through mainly muscular movements, especially of the fingers and hands.

Humans, from an infoenergetic systems point of view, are used to obeying oral or written instructions, or to various sensorial stimuli produced by other humans. Beasts of burden also react from time to time to verbal orders, when not to gestures or to physical stimuli of contact by means of gears as the whip or the reins. So we will include in the infoenergetic system input devices, those sensitive to muscular movements, such as buttons, levers or pedals, keyboards, etc., as well as those capable of oral or written recognition, or those that react to gestural or sensorial stimuli, that is to say, the senses.

Besides those input devices that we can call control devices, which are sensitive to neural or digital signals, an infoenergetic system should also include the following elements or subsystems:

a) One or more energy sources with potential to do work. This sources could be of chemical potential, as with flammable fossils or their derivatives; biochemical potential, as with food reserves; gravitational potential, as with water in dams; or nuclear potential, as with radioactive rods. In any case is an energetic equilibrium contained in some matter, breakable by means of a much smaller energy source. In the case of the car this deposit is the gas tank. In the case of an electric train, the deposit would be in a dam or external fuel deposit, connected to it by means of a generation system and electrical power lines. In the case of a human or a beast of burden, the deposit would be the food reserves that may have already been assimilated or are accessible outside the body.

b) A controlled release subsystem for the energy potential obedient to the control device, with functions like floodgate, lock, faucet, valve, interrupt, trigger, etc. Or a command, chain of command, servomechanism, mechanism, device, or any apparatus linked by one end to the energy source and by the other to the control device. It should be capable of freeing or repressing the energetic potential, and of obeying the control signals of the control device. In the case of the automobile, this would consist of the entire internal combustion apparatus from the engine to the control panel.

c) A subsystem of force transmission -straps, gears, axes, etc.-, capable of receiving the energy freed and transforming it into mechanical work. In the case of the car this subsystem extends from the gearbox to the wheels.

Thus, an infoenergetic system receives information from its control device, amplifies it using the energy source by means of the controlled release subsystem, and produces work through the force transmission subsystem. This scheme includes the machines and organisms that produce simple work extending to the productive society, with all its individuals and machines. Such systems could contain the energy or information that another system employs, forming infoenergetic chains that at the same time comprise an infoenergetic system as a whole. An infoenergetic system is more complex when it is composed of other infoenergetic systems which in turn are composed of other infoenergetic systems, and so on.

A productive society, understood as an infoenergetic system, receives information through its more sensitive or intelligent organs, the intellectual vanguards –from artists to scientists-; disregards some of it and assimilates the remainder. The society then transforms part of that information into control information through political, economical or institutional bureaucracies. It amplifies this information downstream to factories where labor and machinery, along with large energy resources, finally transform it into products and services which are then offered for societal consumption. Medium, small, and even individual businesses replicate this scheme: they grasp part of the societal information, they apply it to part of the societal energy, and they produce part of the societal work (see for example [13]).

3.1. Infoenergetic measurements

We now look into the quantitative properties and relations that characterize infoenergetic systems and the values that differentiate one from another.

Out of a thermodynamic system it is interesting to know how much work is produced by each unit of heat used, by each unit of energetic material that burns or becomes energetically degraded for that end. From this relation we can derive, by means of mathematical simplifications and statistical approximations, properties such as the number of kilometers per liter of gasoline that a car yields.

An infoenergetic system that accomplishes work but does not obey information, or obeys information without doing work has an infoenergetic value of zero. Thus, it is of interest to know, at least, to how much information is a system capable of responding and with how much work does it respond to such information.

The quantity of information to which an infoenergetic system responds can be measured, employing Shannon's formulae [4], in binary units or bits. An elevator that only moves between two floors can only obey to the order of rise or descend, which requires just one bit. This is the size of what we can call the base instruction of that system. Another elevator that moves between four floors has a base instruction of two bits, since two bits are enough to represent those four possibilities. If it goes to N floors, its base instruction would be the binary logarithm of N, or log2(N).

The base instruction of a car that can select among 360 possible angles of displacement is 9 bits of information (rounding off bit fractions), since log2 (360) = 8,49. If at the same time it allows for speed selection in entire units of kilometers per hour, with a maximum of 256, we would say that the base instruction was increased by 8 bits, since log2(256) = 8. And thus, the base instruction for this car would be of (9 + 8 =) 17 bits.

A bird has even more movement possibilities than a car (since it can move in any spatial direction and not only upon a surface), but in general very few or none of those option occur in response to an instruction, information or external control. Birds are, in general, "closed" infoenergetic systems. One must resort to airplanes or helicopters to control work in the air.

A beast of burden has without doubt more possibilities of movement than a car, but by their characteristics of "partially open" infoenergetic system only some of them can be controlled from the outside (such as go forward, go quicker, stop or rotate). The smaller rank of velocity and power of the former with regards to the latter is compensated by a larger resolution of the former inside its rank. Thus, the base instruction of the beast of burden should not be very different from that of the car.

A human with average training has many more movement alternatives in response to external instructions, since its members, as opposed to those of a beast of burden, are not limited to coordination from three or four routines, but with greater independence among themselves, they can perform a greater variety of movements. Its arms, hands and fingers, mainly, can carry out an enormous combination of movements with high energetic and temporary-spatial precision. We have calculated a base instruction to be on the order of 100 bits.

An estimate of the externally controlled movement possibilities of a society of humans, excluding animals and machines, can be calculated from the individual base instruction and the number of people that constitute the labor force.

The number of bits of the base instruction (Ib) is at the same time the size of the minimum instruction to which an infoenergetic system responds and a measure of the total number of distinct instructions to which it can respond (2 to the Ib or $2^{Ib)}$. Different parts, subsystems, or functions of a system can have different base instructions.

Using the base instruction, another measurement can be built that we call informational power (Ip) equal to the number of bits to which the system is capable of reacting per unit of time. An elevator of a few floors not only responds to a base instruction smaller that that of a car, but it also takes at least as much times as is required to move from one floor to another to respond to the signal. A car on the other hand obeys instructions as directional or velocity changes in a mater of seconds, or less. A gross calculation throws an average of one base instruction per second of operational time. A car, therefore, has much greater informational power than an elevator.

Base instruction and informational power are therefore two important measures of the informational aspect of infoenergetic systems. We will now proceed to examine energetic measures that we will then use to discuss infoenergetic measures.

The work produced by a system can be measured with great precision. The current or potential work of people, animals, and machines is measured in Julius, kilocalories, Volts-hour, horsepower per hour, or any other physical unit of energy. Those people who are careful with their diets decide with certain accuracy how many calories to ingest in each meal and how much do they spend in their physical activities. It is well known how many kilocalories are contained in a liter of gasoline of a given octane or its equivalent in kilowat-hour. It is also known how many liters, in average, are required by an internal combustion engine of a vehicle per kilometer traveled, or how much electricity a refrigerator requires per day. It is also known the number of kilocalories consumed per capita in a city, a country or a society (see for example [14], [15]). In turn, the energetic potential of a system is the amount of work that it can carry out per unit of time, generally measured in kilowatts or horsepower.

The work that a two-floor elevator produces in one hour of operation is obviously greater than that which an ATM would be able to carry out in similar amount of time, both at the maximum of their capacities. While the former elevates heavy loads, the latter only selects and moves bills. But the base instruction of this elevator is of barely one bit, while that of the ATM is at least 4 bits. Both are infoenergetic systems, one dominated by work and the other dominated by information. Both factors comprise the infoenergetic measure of such systems.

We will call infoenergy (IE) the product of the energy (E) and the number of bits of the base instruction that controls such energy (Ib), or in other words, IE = E x Ib. This is obviously a pertinent measure of an infoenergetic system. Likewise the infoenergetic power (PI) would be PI = IE/t, where t is a unit of time. The ratio or infoenergetic proportion (RI) is also relevant and would be calculated with the formula: RI = E / Ib. Other combinations of these factors would measure, in thermodynamic style, magnitudes like infoenergetic efficiency, among others.

In order for these and other combinations of infoenergetic factors to have a practical use, we need to explore several areas of application, select the units or calculation basis appropriate for them, complement them with conversion factors, determine validity ranges, and establish infoenergetic paradigms that could provide a basis for quantitative comparison. Furthermore, an infoenergetic system could have different energy and base instruction combinations in its different parts, subsystems, or functions. This would create the need to treat these parts, subsystems, or functions separately or to resort to averages or other methods to obtain a result applicable to the whole.

3.2. The fundamental infoenergetic relation

The relation between information and energy in infoenergetic systems is not generally linear, that is to say, rarely do we see fixed proportions of information inputs and controlled energy outputs. Such a proportion is fundamentally dependent on the following factors: the quantity of matter that is necessarily degraded (by loosing its tense equilibria, reducing its potential energy) to produce work; a work production factor by unit of mass characteristic of each type of matter; and an applied function or set of information dependent factors (form, formula, energetic exploitation technique).

If we burn 50 liters of gasoline -or its equivalent in kilograms- but not in the interior of a combustion engine or another device capable of converting the generated heat into controlled movement, we will not obtain work. If, on the other hand, we use the technology of the internal combustion engine but we do not use fuel, once more we will not obtain work. Thus, the work or obedient energy (Eo) of an infoenergetic system is the product of the mass (M) that is energetically degraded to free it, and of the information (I) that makes possible its controlled liberation. This may be expressed as Eo = M c f (I), where c is a constant of proportionality and f (I) is a function of the information.

The equation Eo = M c f (I) follows the model used in physics to define energy, in particular, potential energy. Lets take as an example the gravitational potential energy E = m g h, where m is the mass of a body elevated to a height of h in the gravitational field characterized by the constant acceleration g. The greater the mass or the height, the greater the energy required to raise that body to that height against gravity.

Matter that is in an infoenergetic deposit –such as gasoline in the tank of a car- possesses certain informational height just as a rock placed upon a table possesses certain gravitational height. Upon falling, the rock frees an energy equal to its mass multiplied by the gravity constant and by its height. The infoenergetic gas, upon energetic degradation, frees an obedient energy proportional to its mass multiplied by an infoenergetic constant and by the number of bits of its base instruction.

A fuel not obedient to any instruction has an infoenergetic potential of zero, the same as a rock sitting on the floor has a gravitational potential of zero. If we raise a rock with half the weight to twice the height we would obtain the same gravitational potential. Likewise the infoenergetic potential would be the same if half the fuel could be submitted to twice the control information. Zero mass would require infinite gravitational or informational height to maintain its potential, but before approaching the infinite many physical conditions limit the increase of both height or information.

Gravitational height can be understood to be a particular case of informational height. Gravitational height is in effect a semantic piece of information that describes the position of the matter but also, and more important, pragmatic or infoenergetic information, that determines such a position with the help of an infoenergetic system. In our previous example the height of the elevator is measured in floors and is determined by the base instruction. If it was measured in meters or in any other unit of length, and there were controlled “stops” at each unit, the number of bits of the base instruction would still be the binary logarithm of the height.

This relationship of the height to the information could be extended to other spatial-temporal measures, so in general, we could say that all spatial-temporal terms -such as distance, time, acceleration, velocity and others- that accompany mass in physical equations of energy are, if this energy is controlled, cases or particular functions of infoenergetic information. This allows us to state that all the physical equations of energy are special cases of the fundamental infoenergetic equation, provided that the energy be controlled.

The simple equation $f(I) = Eo / (M \times c)$ synthesizes all the discourse that traditionally has related information with energy and matter. This discourse is summarized in the statement: “the more information, the more things that can be done with or by less matter”, where the prepositions “with” and “by” refer to the following two interpretations, that we call objective and subjective:

Objective interpretation: The more information –from genetic to cultural- that we have regarding matter, the more energy that we can extract from it. Consider as an illustration the following data. In round numbers the human body is genetically designed to perform the work of about five hundred kilocalories for each kilogram of food consumed. A similar number may be obtained by domesticating beasts of burden. With current chemical combustion technology we can extract ten thousand kilocalories from a kilogram of petroleum, that is, about twenty times more energy by kilogram of matter. The theoretical maximum (according to Einstein’s equation, $E = m c^2$), is around twenty-one million million kilocalories by kilogram of matter, but we currently do not have the technology required to get those results. Nuclear fission technology is the closest technology that we currently have, but its risks are widely known. And, of nuclear fusion we have yet to get some practical results. But lets remember that, to our knowledge, in the entire universe, only stars and technologically advanced human societies are capable of causing nuclear fusion with the consequent enormous liberation of energy. The first by means of the pressure of an enormous quantity of matter that collapses by gravity, and the seconds with relatively little matter but a great deal of science, a great deal of information.

Subjective interpretation: The greater the information -formation, estructuration, education, organization, etc.- of specific material units -cells, organisms, societies-, the greater the quantity of energy that it can control. Lets consider as an example the following widely accepted data: before having the knowledge of how to control fire, a human could dispose of around two thousand kilocalories daily (equivalent to his alimentary ration). After, that number doubled. Later, with the primitive agriculture, it became six times greater. With more advanced agriculture technology - where it existed-, twelve times. With the lower technology industrial revolution -in the leading nations-, about 36 times. And with the present technology industrialization -in the developed societies- more than a hundred times the consumption previous to the control of fire. This is more than two hundred thousand kilocalories daily (99% of which are in extrasomatic forms, as electricity or internal combustion) [16]. Post-industrial society now faces the need to once more increase its per capita energy consumption but with concurrent decrease on ecological damage (see for example [17]), which means that we will require informational increases (see for example [14]).

4. INFOENERGETIC VALUE AND CONCLUDING REMARKS

Nobody would give much in exchange for energy that does not obey information (as the energy of lightning or the solar heat that is lost in the space); neither for information that does not direct energy (as instructions on how to drive a vehicle that does not exist or a poem that does not moves or influences anyone). The value of energy and information is therefore in their infoenergetic relation, i.e. in the infoenergy produced by both. However, the joint value of energy and information is not always as obvious as in these extreme examples.

Using the concept of an infoenergetic system and its measures, we can assign value to a system in which the lack or the excess of energy or information is not entirely obvious. Thus, we do not need to confine ourselves to measuring the power of a machine or system in terms of horsepower, for example. We can also figure out the size of the base instruction to which that power responds, roughly how intelligent the machine or system is, so that could arrive at the measure of bits per horsepower. Furthermore, when we speak of a system controlled by a computer capable of obeying so many instructions per second, we can ascertain how many of those instructions per second direct how much energy, or how many of those instructions have practical meaning. In both cases these infoenergetic measures will allow us to assign a more meaningful value to a system than is currently available.

Once an infoenergetic paradigm is established, we can use it to compare systems that are otherwise incomparable, weighting our investment decisions towards the informational component or towards the energetic component. Thus, those systems with very uninformed energy or very un-energetic information, might indicate worthwhile investment into acquiring the complementary information or energy, in order to balance the system according to the infoenergetic model or paradigm. Clearly, these types of investments or infoenergetic exchanges are realizable among all kinds of systems.

A person with muscular work capacity who is scarcely informed (that is to say, with scarce education or poor technical formation, experience, null inventive capacity, etc.), makes a good investment by creating a relationship (forming a company, subscribing a contract, being employed, etc.) with a person sufficiently informed to direct or to productively orient the work of others. The informed person would benefit from the physical work executed by the worker, and the worker would benefit from the other's information (unless the information is used to obtain only individual benefit in which case we are talking about deceit, seduction, myth, fraud, which is also information). As a whole, they will have formed an infoenergetic system, such that the information and the physical work have greater value together than either had individually. As a whole, they will have produced infoenergy.

A society that has abundant raw materials, raw energy, or unskilled labor force, should consider investing in enlarging its manufacturing capacity in order to create value. This implies investing in development or acquisition of technology, in human training, in science, in research, in management, in administration, in data processing, in communications and so many other concepts with a high informational component. Reciprocally, a society with high informational assets but a shortage of raw materials, raw energy, or unskilled labor, should consider investing in societies as the former.

Such exchanges or infoenergetic complementarities have traditionally occurred but recently they have become more frequent. The displacement of industrial plants from high technology regions of the world toward the areas that offer labor and other prime resources at a lower cost, is an example of a large-scale infoenergetic complementarity. The infoenergetic formalism enables formalization and measurement of such exchanges and comparisons against theoretical models. That might permit the timely correction of negative system deviations that in the long run could be costly to society. Infoenergetic theory has wide-ranging applications and in itself is infoenergetic, since its new information directs a better use of available energy.

From an academic point of view, the concept of infoenergetic system extends the statistical thermodynamic synthesis of the concepts of energy and probability (and through the latter, the probabilistic concept of information) to the use of the energy once it exits the thermodynamic system, and to the use of information once it exits the data processing system. We have illustrated the relevance of the infoenergetic focus in areas ranging from the organisms capable of following instructions to perform work, to machines and industries, to society itself as a productive system. And with the post-industrial movement towards an increased role for informationally-driven productive apparatus, its increasingly relevance is clear.

The concept of an infoenergetic system constitutes, therefore, a step towards an interdisciplinary, comprehensive, and timely synthesis of statistical thermodynamics and information theory.

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