Entropy Demystified:

Potential Order, Life and Money

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About This Book

Although the concept of entropy has been under discussion for one and a half centuries, its philosophical depth has still not been properly explored and it is still one of the most complicated and controversial concepts of science. Its application to the study of social processes has started only in recent decades and no doubt this trend will continue. The author's first goal in this book is to provide those who are interested in social studies, but not familiar with physics, with a comprehensible explanation of the concept of entropy. The value of the knowledge of entropy for the social scientist is at least two-fold:

1. Entropy is characteristic of a level of disorder in any statistical system and for this reason can be successfully used for the description of the communication process, music or economic activity as well as the behavior of inanimate matter. In this use, one is dealing with the order and disorder of a system independently of physics: entropic characteristics can be used no matter what makes a system orderly or disorderly, be it the laws of mechanics or our manipulations with symbols, like the alphabet letters of musical notes. The example of the use of the entropy concept as a characteristic of any statistical system is the well known Shannon's Theory of Information which found its application not only in the technology of communications but in biology, linguistics and other areas.

2. Whenever we are dealing with matter and energy be it heat machines, biology, economy or the use of natural resources, we must take into account the second law of thermodynamics, which states that the level of disorder (entropy) in an enclosed system can not decrease and that one has to spend energy to decrease disorder in any part of the system. The processes of life and social life are characterized by increasing local order, but are still subject to limitation as dictated by the second law of ther-

modynamics. This brought scientists to the development of the physics of open systems thanks to the ideas of Schrodinger, Prigogine and others. Now we understand that the world is a place where destructive tendencies coexist with creative forces.

For many decades the traditional topic for passionate debate among scientists and moralists has been whether we are masters of our behavior or whether and to what extent we follow biological prescription - instincts. In this book, the author tries to go one step deeper, to the following inquiry: *what are the inevitable consequences of the fact that we are built from matter, and how much our willing - together with instinctive - behavior is defined and limited by the laws of physics?* Limitations imposed on life, social life, economics and the use of environment by the second law of thermodynamics are particularly interesting.

After an extensive explanation of what entropy is as a measure of disorder, the author shows how entropy can be used as a bulk characteristic to measure order. He introduces the concept of *potential order*, which characterizes the ability of an open system to become orderly or to create order in another system. Potential order is a property of fields of subatomic particles and atoms which provide for the primary organization of matter. It is also a property of complex molecules within the living cell which provide for the organized behavior of living entities. Further, human will and economic enterprise possess potential order to increase order around us, be it material order or the creation of information.

The author is showing that the second law of thermodynamics is fundamental in putting limitations on certain automatic behavioral patterns of all living creatures - including humans - such as entropy lowering activity and self-isolation from the disorderly matter surrounding us.

The entropic approach permits the author to do further inquiry into the connection between physics and economics. It is well known that the ideas of classical mechanics provided the basis for the development of mathematical economics since the time it was established in the nineteenth century. In recent decades more economists started to realize the limitation of such an approach and started to connect economic thinking with a thermodynamic approach as well as with systems' theory.

The concept of entropy in relation to economics and sociology was under discussion in the works of Faber, Georgesku-Roegen, and others. More authors started to see the deep analogy of economic development and the behavior of a thermodynamic system. After all, human activity, which is the subject of economic study, is a local entropy lowering process and it is exactly physics which can permit us to see the unavoidable limits of this activity.

The author shows that the low-entropic component of an economy, which is the order producing activity of people, should not be treated in theory the same way as the purely energetic component. On the basis of this, the author shows the limitations for the use of variational calculus in economics, discussing particularly the maximization of utility function.

In his analysis of the monetary measurement of order and potential order, the author shows that some important problems connected with the evaluation of goods produced by economy, inflation and monetary policy come from the fact that the same measuring device—money—is used for both—the purely energetic and low-entropic components of the economy.

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CHAPTER 1: Entropy and Disorder[1]

The Fall Of Mechanical Philosophy

In the late eighteenth and early nineteenth centuries, scientists had a good reason for celebration and even arrogance about their understanding of the world. The laws of mechanics were formulated in all their perfection, and the world looked potentially explainable by solving sets of equations for the movement of particles, similar to what had been done to calculate the precise movement of the planets.

Many centuries earlier, at the dawn of the development of mechanics, the arrogance of science found its expression in the following proclamation, ascribed to Archimedes: “Give me a place to stand and I will move the Earth”. The triumph of science as it was known in the nineteen century led Laplas to popularize a much more arrogant teaching of mechanical determinism: if we were to know the initial coordinates and momenta of all particles in the Universe we could, by solving equations of mechanics, predict the future.

The further development of science placed a veil of doubt over this simplified picture of the world. The twentieth century brought the knowledge that what was considered a particle for purposes of mechanical calculations

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1 I assume that the reader is familiar with the elementary approach and conclusions of probability theory, and with the elements of combinatorial calculus. As to the introduction to the statistical concept of entropy in this book, I am giving only the most elementary formulas necessary to my discussion, as there are many books that discuss it in detail. An elementary yet quite accurate introduction into statistical mechanics is set forth in Johan D. Fast, *Entropy*.

actually has a complicated internal structure and in some respects behaves not as a particle at all, but as a wave. The development of quantum mechanics and subatomic experimental physics left little remaining of the classical belief in the mechanical determinism of the physical world.

But even in the middle of the nineteenth century, when there was a sacred belief in the overwhelming power of the equations of mechanics, practical problems made physicists look for other ways to describe multi-particle systems; one can write equations for many particles, but there is no way to solve them. Even a general solution of the equation for three interacting particles has not yet been found. Thus how can one describe the behavior of gas, each cubic centimeter of which contains $2.7 \cdot 10^{19}$ molecules?

To describe such multi-particle systems, scientists resorted to bulk characteristics like temperature, pressure, heat energy and so on. The technology of heat machines required the additional scientific study of the nature of heat. Scientists discovered limitations in our ability to extract useful energy by means of heat machines: no matter how we may perfect our technology some energy will be lost to us, in the form of heat spreading into the surrounding environment. It was also discovered that heat travels irreversibly: only from a hot body to a cold body unless we are willing to spend energy to extract heat from the cooler body. This was the discovery of the famous second law of thermodynamics. (The first law of thermodynamics states energy conservation that is not specific to thermodynamics.)

The second law of thermodynamics was a discovery of epic proportions for mechanical philosophy, which was based on equations that did not allow for irreversible processes; in theory all mechanical movements can be put in reverse in accordance with the same equations. To illustrate: if we put a planet's movement on film and then watch the film backwards, there would be no violation of mechanical laws. Yet a backward movie about the work of a heat machine would not make any sense: we would see heat traveling from a cold body to a hot body, which is thermodynamically impossible.

The German physicist Rudolf Clausius in the middle of the nineteenth century was the first to introduce a new and rather mysterious characteristic of physical systems: *entropy*. This characteristic had no analogy in mechanics, and its property is that in all natural processes in any isolated (closed) system it irreversibly grows until it reaches the maximum when the system reaches thermodynamic equilibrium. Only in some processes it may remain constant—though only approximately so. This function—entropy—is to characterize energy losses in heat machines, the spread of heat from hot to cold bodies, and other irreversible ways in which a physical system behaves.

It took the genius of Ludvic Boltzman to explain part of entropy's mystery by introducing the methods of statistical mechanics. He showed that entropy is a measure of disorder in the system, that a multi-particle system has a tendency to develop to a more probable state, and such a more probable state is a state of higher disorder. This development (toward disorder) continues until a system reaches thermodynamic equilibrium, which is the highest state of disorder for any given system.

The introduction of statistical methods into physics was quite disturbing for many whose way of thinking was trained on the beauty of the precise equations of classical mechanics. This triggered a rather painful reevaluation of philosophical principles in science. Physics had earlier been thought of as the refuge for those who seek to study orderly relations within Nature, as opposed to the uncertainty and disorder of human existence. Now with statistical methods, the probability approach and the study of disorder of many kinds are as naturally a part of physics as the equations of mechanics or an electromagnetic field. Despite the great body of results in statistical physics and its technological applications, some basic problems connected with uncertainty and probability in science are still the subject of debate.

Entropy As A Measure Of Disorder

The crucial question in the statistical description of any physical system is: how many possibilities exist for the arrangement of the elements of the system in a given space, the elements being atoms of gas, ions in crystal or stars in the galaxy. Knowing the number of possibilities, one can calculate the probability of certain positions and certain velocities for the particles. This is crucial, as systems of particles interact with each other through the interaction of particles.[2]

It makes a big difference if we are dealing with the same particles or those which can be distinguished from each other. Indeed, the probability of finding a child in the school yard is usually high but the probability of finding a certain child can be quite low. If in a vessel with air we are looking for any atom, the probability of finding it is high, yet, the probability of finding an atom of Hydrogen is much lower as there is small percentage of that gas in the air. This of course affects the physical and chemical behavior of the air in the vessel.

The concept of the indistinguishability of elements of a system is crucial in statistical physics and here is a sim-

[2] The analogy is a game of roulette: each time we are dealing with only one number as a result of the game, but to calculate the odds for our bet, we need to know all the possibilities of outcome.

ple experiment to illustrate this concept and its relation to order among the elements of the system. If we put a few layers of small vitamin pills of the same color and other physical properties in a glass, there will be only one arrangement of those pills even if we shake the glass and try to rearrange it. No doubt some individual pills will change position during shaking but to us they are indistinguishable, and the order of all the pills on the bottom of the glass will look the same after shaking.

If we put a few layers of N small red pills and then, above them, a few layers of M green pills of the same size in the glass, they may remain in that order indefinitely if undisturbed. But if we shake the glass thoroughly, the pills will mix and, after each good shake, the positions of the pills in the glass (or microstate, as it is called in statistical mechanics) will change.

If we continue to shake the glass indefinitely, we will witness the basic fact of disorderly changes of any system: the pills will not resume their initial order again. This irreversibility is an observable fact of nature and gave birth to passionate philosophical debates during the last one and a half centuries. The simplest way to explain irreversibility is that the quantity of possible disorderly distributions of pills is incomparably larger than that of orderly distributions, so the probability of disorderly microstates is much larger than that of orderly microstates.

Indeed there are

$$W = (N+M)! \,/\, N!\, M! \qquad (*)$$

possibilities of distribution of pills altogether, according to combinatorial calculus. Even for a small number of pills, if N=M=50, W equals about 10^{29}. Yet the quantity of possibilities for arrangements which we would call orderly—like in separate layers of color—is only a tiny fraction of this huge number, so the odds against reaching the initial orderly distribution of pills accidentally are astronomically small.

Our experiment with the pills gives us a good illustration of what will happen if we connect two vessels with different gases, let's say Oxygen and Nitrogen. In this case there is no need to shake the container, as molecules of gas are in constant movement. The gases will mix and there is no chance at all (or practically no chance) that they will separate again without our interference. Of course, the quantity of possible microstates of molecules of gas in any container is much much larger than the quantity of arrangements of pills in our experiment.

The classic elementary approach to the calculation of the quantity of microstates of gas is to break the space of the container into cells large enough to house one molecule. If there are Z cells and N molecules in the container, the quantity of possible arrangements of molecules in space is

$$W_p = Z! \,/\, N!\,(Z-N)! \qquad (**)$$

This number is so huge that one author[3] stated: in statistical mechanics we are dealing with numbers which are the "largest that arise in any scientific context, swamping astronomical numbers to insignificance". Nevertheless, this is the order of numbers of possibilities of molecular arrangements. Accordingly, the probability of each arrangement of molecules in space at a given moment is $1/W_p$.

This is not simply an exercise in combinatorial calculations. It was discovered that the physical properties of matter, its energy and ability to produce work, depends on the quantity of possible arrangements of particles in space and also on the distribution of the particles' mo-

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3 Goldstein, Martin & Ingre, *The Refrigerator and the Universe*, 1993, p. 168.

mentum. The latter is characterized by the number W_m which accounts for all possibilities of momentum distribution among particles. In the case of the pills in a glass, the momenta of the pills during each shake will depend on how energetic we are in our shaking effort. With gas, the momenta of the molecules depends on the temperature of the gas, and each molecule at each given moment will have a momentum between zero and some maximum defined for this particular temperature. For each arrangement of molecules in space there are W_m possibilities of momentum arrangements, so the total number of microstates is

$$W = W_m W_p$$

Accordingly, the probability of each microstate is 1/W. Logarithms of huge or very small numbers are handier to use than the number itself. So physicists use lnW and call it the *entropy* of a particular gas in a particular vessel.[4]

$$S = \ln W$$

Because the logarithm of the product equals the sum of the logarithms, we may split full entropy:

$$S=S_p + S_m$$

and deal with positional entropy $S_p=\ln W_p$ separately. This is convenient for us because the momental part of entropy S_m in most cases will be outside of our interest

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4 I omitted Boltzmann constant $k=1.38 \cdot 10^{23}$ J/deg°K—in the formula above—in order to concentrate the attention of the reader on the relation of entropy and probability. If one is to look at tables of the entropy of certain substances, one needs to know that in thermodynamics entropy is measured in units of energy divided by the degree of temperature. Unlike thermodynamics, in information theory entropy is measured in bits. Also note that information theory usually deals with logarithms with a base equal to 2, which simplifies the formulas of that theory and does not affect the conclusions in substance.

in further discussion. We will see that in most cases order in our world is actually *positional order*. Examples are:

arrangements of atoms in molecules and crystals,
molecules in a living cell,
living cells in an organism,
letters and words in a text,
houses in a city and so on.

Of course, particles of matter are usually in movement, including atoms in molecules inside of living cells. But if they are in an orderly arrangement their movement is limited by the field of other particles unless their kinetic energy is excessive and order is destroyed[5]. The key factor for the existence of order around us is that the kinetic energy of particles (temperature of the system) is kept within certain limits.

Formula (**) shows an unusual and interesting property of entropy as it is not simply proportional to the number of molecules in the container—the quantity of possible arrangements growing with N very fast. This means that generally entropy is not characteristic of this or that substance, but characteristic of the system of particles of that substance. Unlike many other physical properties, *entropy is not characteristic of matter but characteristic of the state of matter*. Indeed matter, like the gas inside a vessel, is sufficiently characterized if we know what kind of gas it is and how many molecules there are. But the same gas can be found in many different states depending on the temperature or volume of a vessel. For example, it can be in a state of liquid or even of a solid body with low entropy, if the temperature is low enough; and it can have very high entropy if it is very hot

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5 Excessive kinetic energy is the most usual but not the only cause for the destruction of order: a strong enough outside force field, for example an electric one, can also be destructive.

or if the molecules are spread over a large space. Gas in the vessel also can have temporary low entropy if the gas in one end of the vessel is hot and in the other is cold. Temporary because according to the second law of thermodynamics in time the temperature will equalize throughout the vessel and entropy will increase.

Positional Disorder

This elementary introduction to the concept of entropy shows that entropy is characteristic of disorder: entropy grows with the increase of the number of possible arrangements of elements in the system. In the case of gas, disorder (and entropy) is higher:

1. if we put the same portion of gas in the larger vessel, because the number of possible arrangements in space will be larger; and
2. if we increase the temperature, because the quantity of possible momenta for each molecule will be larger.

Liquid is more orderly than gas, as the molecules' movement, though disorderly enough by itself, is limited in space: in formula (**) Z is smaller as the space is smaller, so W_p is smaller accordingly. A solid body has a smaller entropy yet, as its particles are more limited in movement.

A crystal is an example of a low entropy system, as the atoms or molecules are positioned in mutual order. They are still moving but they are generally not mixing; their movement is limited as they are vibrating around certain points in space. As a result, the entropy of a crystal is considerably lower than for a solid body with an irregular structure. Still, it is not just structural order that counts in the level of entropy; it is also how closely the particles are packed to each other. Crystals of ice with poorly packed molecules have a higher entropy than a diamond with carbon atoms being close to each other.

The example of crystals, which are orderly bodies, shows that entropy—introduced historically as a measurement of disorder—may be used to characterize the level of order as well: the lower the entropy, the higher the order.

Irreversibility

As mentioned before, far reaching conclusions about the thermodynamics of any isolated system was expressed in the law that the entropy of such a system goes up or stays the same. Let's illustrate what this means in different isolated physical systems.

Let a system contain two vessels of equal volume, one with gas which has entropy S_1, another empty so entropy $S_2 = 0$. This means that the entropy of the system is $S=S_1$ as entropy is an additive value: the entropy of the system equals the sum of entropies of the subsystems.

Let us connect the two vessels. Gas from the first vessel will expand to the second vessel, and soon the pressure in each will equalize and thermodynamic equilibrium will be achieved. At that point the quantity of cells Z available for molecular arrangement will be doubled, with the quantity of molecules N remaining the same as it was in the first vessel at the beginning of the experiment. Entropy will be higher than in the beginning of the experiment, as W grows with Z.

This is a classical example of an irreversible process. Entropy grew in accordance with the second law of thermodynamics, which is also called the Entropy Law. Once entropy is increased, there is no way back, no way for the system itself to regain the initial state when all the gas was in one vessel and the other vessel was empty.

The best minds in the scientific world were bewildered about why this is irreversible. The prevailing view, at least in our day, is that randomness is an inherent part of atomic and molecular behavior and the laws of mechanics at this level work only statistically, so that we cannot expect a system to go back to its initial state despite the fact that mechanical laws would permit it. The classical explanation of irreversibility is that there is some probability of reaching the initial state, but that the probability is diminishingly low.

Thermodynamical Equilibrium

When the second law says that entropy goes up, the question is how far up? Well, for each isolated system it goes up to a point of thermodynamical equilibrium and then remains constant. If there is a higher density of particles on one end of the vessel than on another it means that entropy is lower than if the concentration would be uniform throughout the vessel. So, the concentration will equalize with time, entropy will grow until the uniformity of concentration is achieved. The same if there are different temperatures in the parts of the vessel—in the state of equilibrium temperature is the same throughout the system. As equilibrium is the ultimate end of the development of an isolated system, it is a more probable state than any other.

A following note about equilibrium is in order here. Often we depend too much on the language, taking the terms of one art and not applying it properly to another. The term equilibrium is widely used in sociology and economics. The meaning ranges from the purely mathematical understanding of it as in “equilibrium market price” to the picture that “all is well and God is in his heaven”. I have to warn the reader, that human activity is actually opposed to the state of equilibrium in the thermodynamical use of this word even when we sleep. Human activity is aimed at keeping order within the human body and the surrounding world. As we go through life we are spending energy arranging things (be it molecules or ideas) in ways exactly opposed to reaching equilibrium. If occasionally society goes through periods of tranquil life it is not because such a state of human affairs is more probable and represents equilibrium, but because the harmonious effort of many defended us from mishaps of a more probable development with growing entropy and reaching thermodynamical equilibrium.

There is a rather dramatic history in the development of the perception of the term "equilibrium" in sociology. Herbert Spencer apparently took it from classical mechanics. Then he learned in 1858 the meaning of equilibrium in thermodynamics (I assume, together with all the gloomy interpretations of that time) and this caused his "being out of spirits for some days afterwards".[6]

On The Subjectivity Of Entropy

The following experiments are illustrative of another problem that caused debate among the creators of statistical mechanics. The problem is called the Gibbs Paradox, and demonstrates the importance of what we choose as elements of the system for the purpose of entropy calculation.

Let the first vessel contain Oxygen, and the second Nitrogen of the same pressure and temperature. When the vessels are connected the gases will mix and will never separate by themselves. Entropy will grow as in any irreversible process. This is similar to our experiment of shaking the glass with the red and green pills.[7]

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6 For a detailed account see Kenneth D. Bailey. *Social Entropy Theory*, 1990, p. 53-65.

7 For calculations see Fast, J. D. *Entropy*, 1962, p. 219.

If we connect two vessels as in the previous experiment but both with the same gas, no change of entropy will occur, similar to our experiment with pills of the same color.[8]

James Maxwell asked: what if we mixed two gases thinking they are identical and later discovered they are different? We would have to correct our evaluation of the entropy in this experiment, which means that entropy is not an observable property, but depends on our knowledge about the system.[9]

This question is very important for understanding how different entropy is in comparison with other physical properties. Indeed, for a daltonic (someone who is colorblind), our experiment of shaking the red and green pills is the same as an experiment in which there were only red pills. Yet if we know that the pills are different, the entropy after shaking is different in these two experiments. For Maxwell himself, with all the laboratory equipment that existed in his time, two isotopes of oxygen would be indistinguishable yet entropy grows when they are mixed.

Consider a different approach. If we number each red pill in some orderly fashion in our red pills shaking experiment, we would have to conclude that after shaking the positional entropy increased, as the initial order

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8 These experiments are a good illustration of the fact that entropy is the measure of disorder among elements in a system; it is a property of a system which may contain matter, and not a property of matter as such. This immaterial character of entropy permits us to use it to characterize a system of any elements, be it particles, information, logical statements and so on.

9 Maxwell's article "Diffusion" written for *Encyclopedia Britannica*. See discussion on Gibbs Paradox in Stephen G. Brush, *The Kind of Motion We Call Heat*, 1976, p. 592.

would be destroyed. So Maxwell's question is not trivial at all, and cannot be answered by a recommendation to examine the elements more carefully before mixing them. The depth of his question is in the concept of indistinguishability. If one day we discover that each molecule of the same gas has individual traits, the result of our calculation of entropy and our criteria for order of a system of those molecules will be different.

Of course, in this case one must remember the difference between theoretical knowledge—that elements of the system differ from each other—and the physical consequences: if there are none of those, there is no reason to treat those elements as distinguishable for the purpose of calculating entropy. Indeed, if there is a sequence of molecules A,B,C,D but the molecules are absolutely the same, that sequence will behave physically just like sequence D, B, C, A. In other words, it is for us to choose what to count as elements of the system, but it is not for us to dictate to nature what produces the physical effect. If gas with numbered molecules behaves the same as with indistinguishable molecules, physical entropy will not be affected by the fact that we can distinguish the molecules.[10]

This is a problem which arises only in the statistical approach to entropy. Indeed in the thermodynamical (not

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10 Often it is important to know in which sense elements are indistinguishable. Socially we are dealing with two portions of humankind: those we know as individuals and those we know from opinion polls and other social statistics. The majority of elements of the system called humankind is indistinguishable to us, so we accept a statistical description of that system. If persons A and B are of the same qualification and general behavior, replacing one with another in a production line will not affect the production process so for that matter they are indistinguishable. Yet, they are different to those who know them.

statistical) approach if there was a change of energy ΔE due to a change of entropy ΔS, then

$$\Delta E = \Delta S\ T,$$

where T is temperature. Peculiarities of entropy definition simply do not exist in thermodynamics if there are no corresponding changes of energy as a function of temperature.

Maxwell's question gave birth to a discussion on the extent to which entropy is subjective. In this discussion one should remember the difference between the following two questions:

1. Does the state of a physical system depend on our knowledge of the initial state of that system? and
2. Does our knowledge of the state of a physical system depend on our knowledge of the initial state of that system?

Since Maxwell's time, the extent to which our knowledge of entropy is subjective remains an open question.[11]

In physics the thermodynamical meaning of entropy is a good guaranty against subjectivity: we are dealing there with measurable quantities of temperature and energy and it is not for us to choose what brings a measurable effect.

In cases outside of thermodynamics, when we want to use the concept of entropy for evaluating disorder and order, the choice of elements of the system can be arbitrary and depends on our needs and understanding of a particular system. Disregarding particles of dust when we want to evaluate the order of the movement of billiard balls is an easy choice under average conditions, but in a precise game dust may interfere with the interactions of the balls. Statistically this dust is similar to noise in the

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11 See valuable overview of this problem in "How subjective is entropy?" Kynnet Denbigh in *Maxwell's Demon. Entropy Information Computing*. Harvey S. Leff and Andrew F. Rex, ed.

information flow—noise can be of a level that we can easily disregard, or it can interfere with communication. Analysis of the interaction of noise and useful signals actually brought to life Shannon's theory with its first use of the concept of entropy outside of physics[12].

Depth of Knowledge

There is another potential confusion we should keep in mind: entropy depends on the level we care to take into account in our description of disorder in the system. In our discussion about gas, following the great thinkers who developed statistical mechanics, we ignored many things that could interfere with the calculation of entropy: quanta of light and other radiation that go through the gas and might interfere with the behavior of molecules; and high energy particles of cosmic rays that may from time to time hit the molecule and change its momentum. We also dealt with atoms as a whole and ignored the movement of electrons and other particles inside the atoms of that gas. In calculating the entropy of pills in the glass we did not take into account the particles of dust that might cover the pills. So it is for us to identify the elements of a system that are under discussion when we describe the level of disorder of that system. This is an example of typical scientific idealization of the system under study.

The real question is not about the depth of our knowledge of a system. We can go as deep as our abilities to calculate carry us: we may choose to count each particle to be found within the system. The real question is: what is important to count for the noticeable effects we care about? Indeed, in an explosion of fuel mixture with air in

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12 Claude E. Shannon, The Mathematical Theory of Communication.

an engine, our calculation of entropy is good enough without taking into account passing cosmic rays, because their effect is discountable. Yet if we are to calculate the state of vapor in a device for the observation of high energy particles—a Wilson camera—cosmic rays are exactly what should be taken into account.

A simple example from an entropy-lowering activity of humans: by weeding the garden we produce order. The system here is the garden, and the elements of the system are the cultivated plants and the spaces between them. Weeds are creating disorder; by removing them we decrease entropy in this system as far as an aesthetic evaluation goes. Yet from the point of view of physics, by replacing weeds with air we actually increase the entropy of the garden, due to the fact that weeds are living organisms built from organized matter having entropy lower than that of air.

At least we gave an answer to one part of the question about the possible subjectivity of entropy: if the choice of elements of a system is subjective, then the level of entropy calculated is also subjective. As we proceed with our discussion on the entropy of life and social life, we will see many examples of the subjective nature of entropy: literally, one man's order can be another man's mess.

Where Is That Isolated System?

The second law of thermodynamics is well proven and helps to calculate the behavior of statistical systems.[13]

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13 There are voices of doubt about the applicability of the second law of thermodynamics to the processes of life. I don't see a reason to join the critics and in this book the econd law, as far as a truly insulated system is concerned, is treated as one of the major commandments of Nature.

But we should not forget that this law is valid only for an isolated system.

Strictly speaking such a system does not exist putting aside the hypothesis about the Universe itself being closed or open—we know too little about the Universe to judge. Earth with its atmosphere may be considered a practically isolated system in many ways, as we are surrounded by almost empty space, but in the thermodynamic sense it is not isolated. We are getting energy from the Sun and we are radiating energy into space. Nothing on Earth can be called properly isolated, because the loss of heat is a universal process no matter how well we insulate our houses or laboratory equipment.

There are still ways, however, to consider some systems isolated due to the fact that the processes we study may be much quicker than the flow of heat through the walls that separate the system in question from the outside world. The explosion of a gasoline mixture is quick enough not to be affected by the cooling of the walls of the engine's cylinder. The effect of a heating device in a well-insulated house is quick enough for the temperature to almost equalize throughout the room. In any case scientists can calculate the influence of imperfections as far as the isolation of the system is concerned. But in the long run, given enough time to loose heat or to acquire heat from outside, no system known to us is isolated. So strictly speaking, the second law, being absolutely correct as far as we know, does not preclude creating order.

We should remember however an important difference between material and energetic isolation. In a closed container we can keep gas or even liquid under pressure sufficiently isolated from a material exchange with its surroundings. A solid body is also isolated by itself against most material intrusions thanks to the inter-atomic fields inside the body. Earth is materially isolated for most practical purposes due to the gravitational field which keeps particles within the atmosphere and thanks to the fact that there is not too much matter in immediate outer space (well, we are losing Hydrogen but the rate is not too high). The special case is the material isolation of a living cell: its outer membrane which, with some level of success, protects the inner cell from an intrusion of unwanted matter.

Energetic isolation is a different story. No container exists which would hold energy as well as it can hold matter. Even if we would limit heat loss due to thermal conductivity by placing the hot body in a vacuum, radiation will find its way out. And this is one of the key factors for our existence and the existence of order around us because if the kinetic energy of particles is high enough, no arrangements between particles is possible. With high energy collisions in accelerators, physicists can split even many elementary particles not only atoms or an atom's nuclei.

The Earth is cool enough for molecular and intermolecular bonds needed for life exactly due to radiation of heat. In our environment, temperature (which is the measure of the kinetic energy of particles) is generally under control thanks to the radiational loss of heat and we can enjoy order within and outside us. Indeed, Earth would be a burning hell, if it would collect all the energy which is coming from the Sun and not be able to lose energy by radiation. It is this exact point (the so called green-house effect) which many scientists are concerned about in relation with industrial pollution: the rise of the level of carbon dioxide has the potential ability to reduce Earth's radiation which is responsible for cooling our planet.

I should emphasize that the question is about keeping the level of kinetic energy in the environment under control and not just lowering it. Kinetic energy of particles from the outside is the enemy of orderly arrangements within a living system. At the same time a certain level of kinetic energy is a must for chemical reactions within living matter which are responsible for that ordering.

As we see in the real world, everything is open for radiational heat loss or gain. Even if a system is closed for material exchange with the outside world as Earth practically is, we are dealing with a quasi-isolated system. Thanks to energy exchanges with an outside world in such a system entropy can decrease. Indeed, imagine a sealed container partly filled with water. If we put this jar in outer-space, water will freeze due to radiational heat loss and entropy will decrease: entropy of ice, as we know, is lower than that of water. In this simple example, entropy went down due to the loss of energy. Can entropy decrease not just due to energy loss but due to the self-organization processes of the matter? We are speaking of course about some non-isolated system. Our existence is an answer to that and also the answer to the gloomy philosophical predictions connected with the second law of thermodynamics which we will discuss.

All that was said here about the real world with its absence of completely isolated systems, should not create the wrong impression in the reader's mind that entropy is growing only in isolated systems and if there are no isolated systems around we can forget about the increase of entropy. In fact in any system, unless it is cooling by the loss of energy, entropy will grow or stay the same if no effort is taken to reduce it.

Philosophical Exaggerations

On the basis of the previous examples of a systems' behavior, we may conclude that for all practical purposes, *averaging* is entropy's middle name. Indeed, the impression from knowledge of the second law of thermodynamics is that, left to natural development, whatever is hot will get warm, whatever is cold will get cool, and whatever is pure will get mixed with other substances. This is exactly what the entropy law is telling us: disorder is growing if we don't struggle against it.

This law was taken by many as a promise of decay and destruction, as a pessimistic prediction of the end of the world. Indeed, if disorder is growing in any system without ordering interference from the outside world, disorder in the universe must be increasing, as there is no outside world. This shaky logic gave birth to the theory of the heat death of the universe: give it time and all matter will be mixed, temperature will reach some average level for all the universe, or—as one authoritative source put it long before the discovery of the second law—dust will come to dust. This picture is gloomy, indeed and such a perception of the second law is in not all in the past: contemporary *The Columbia Encyclopedia* states: "entropy of the universe as a whole tends towards a maximum."[14]

Two points should be made, though.

First, my personal view: what do we know about the Universe? The answer is: almost nothing, despite loudly advertised theories like the Big Bang, despite careful observation of the observable area of the universe, which is huge on our scale but may be an insignificantly small part of the Universe. We don't know if the Universe is a closed system; we don't know if excessive heat in the form of radiation goes to infinite space or returns to us. And do we know what infinite space is?

Although the first law of thermodynamics tells us that energy cannot be produced out of nothing, we actually don't know how existing energy was produced. Maybe it was created out of "nothing" and maybe that "nothing" still feeds the Universe with energy or accepts part of the

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14 *The Columbia Encyclopedia*, Fifth Edition. 1993, Columbia University Press.

energy back. Energy conservation law is an unshakeble foundation of physics but it doesn't address the question of the source of energy in the Universe. Thanks to the growing technology of observation the visible part of the universe is growing in size together with undestandable exitement of those scientists who often rush to make universal conclusions on the basis of insufficient information.

Second, and the main point: the existing forms of order appeared somehow—planets, crystals, living cells, human beings and their civilizations. Why would the Universe proceed to total disorder not consistently, but through some rather high levels of order? There must be natural ordering factors that balance the natural tendency toward disorder.

It is interesting to note that people instinctively consider themselves to be part of some universal order. Religions, from the most primitive, presented hypotheses of world creation and often of the world's end, as well. Ethical norms provided to humans by religion are, one way or another, connected with a picture of universal development. It is no wonder that the heat death theory prompted some pessimistic feelings, despite the fact that given the potential time frame involved, humans have more chance to evolve back to amoebas than to witness the beginning of a universal catastrophe.

Potentially there are more than pessimistic feelings at stake. Every religion opposed the denial of gods or disregard for divine ethical rules simply from an understanding that an atmosphere of permissiveness could ruin the ethical order in society. As the hero of Dostoyevsky's novel put it: "If there is no God, then everything is permitted." Expectations of a senseless end to the world without any final judgment on the deeds of humans can very well create a feeling of permissiveness. It is interesting to note that under the atheistic Soviet regime, the heat death theory was not just considered the result of nineteenth century limited knowledge but judged ideologically and always labeled a bourgeois, false theory, most likely in order to guard the existing ethical order.

Pessimism arising from the heat death theory exemplifies the problems of looking to only one side of natural forces. Later in this book, we will discuss cooperation between two sources of world development: destruction and creativity. We will see that together with the drive for destruction and averaging, there are forces in nature that bring about order and civilization. Indeed, those scientists who came out with an understanding of entropy in the mid-nineteenth century had very limited knowledge of the building blocks of matter. Original statistical theory dealt with a model of atoms as elastic spheres without any structure within or structure of an outside field.

Advances of atomic physics of this century brought an understanding that sub-atomic particles and atoms are surrounded by a highly orderly field which provides for the ability to create selective bonds with other particles and atoms. So in fact the potential for order exists already on the level of sub-atomic particles.

Contemporary Misconceptions

Philosophical exaggerations connected with entropy did not end with the heat death theory of the nineteenth century. As more economists turn their attention to the promising analogy of economics and thermodynamics, entropy is also often perceived with the gloominess. Writes Georgesku-Roegen[15]

> ... from a purely physical viewpoint, the economic process is entropic: it neither creates nor

15 Nicholas Georgescu-Roegen, *The Entropy Law and the Economic Process*, 1971, p. 281.

consumes matter or energy, but only transforms low into high entropy.

This is quite a pessimistic picture of human activity indeed and in fact it is wrong and opposed to what an economy actually does. The essence of the economic process is that it performs local reduction of entropy and may be viewed as one of the universal mechanisms to create order. There is an increase of entropy in over all balance, of course, but we are not living in an isolated system, so a good part of the entropic waste from the economic process is taken care of by the radiation of heat to space.

The use of the concept of entropy for the analysis of environmental processes is a new trend and is very promising if taken seriously. Yet, somehow the entropy concept continues to invite apocalyptical exaggerations. Indeed it is an obvious fact that human activity is mostly ordering, be it the creation of other humans or building industries and theories. From the Entropy Law we know that for ordering we must spend energy. As we are getting smarter and wiser, we invent technologies which permit us to economize on energy spent and find ways to hurt the environment less. Yet, Jeremy Rifkin comes to the opposite conclusion:

> …we must first recognize that the Entropy Law tells us that a society's energy flow must be reduced to as low a point as possible in order to sustain the infolding of all of life as far into the future as possible.[16]

In other words, let's use minimum energy just to survive and never learn how to use less and less energy for a more interesting life.

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16 Rifkin, Jeremy. Entropy: Into the Greenhouse World, 1989, p. 281.

I think there is a reason why the entropy concept leads to pessimistic conclusions. There is the Entropy Law in physics which predicts growing disorder. Yet, there is no single law in physics which would psychologically neutralize it by predicting the creation of order. It looks like disorder is the result of a universal law but order is just an unintentional fluctuation in Nature. This perception is wrong. There is no single law for the creation of order in Nature, but there many factors which let Nature build order. We will analyze these factors and show that there are strong tendencies for Nature to be orderly.

Profanation of the Concept and the Purists' Revolt

The intrusion of scientific terms of art into every day life did not pass entropy. As Peter A. Corning and Stephen Jey Kline[17] noticed,

> entropy is now a household word for any kind of disorder, disorganization, uncertainty, waste, confusion, inefficiency and, most flagrantly, willful sabotage. Entire best-selling books have been devoted to exploring the (supposed) philosophical, ideological, economic, even social and psychological implications of the second law.

One probably should be less purist as far as linguistic development goes: people always search for new words and assign new meanings to old ones. One also might find the unexpected use of a scientific concept sometimes

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17 Peter A. Corning and Stephen Jey Kline, *Syst. Res.*, p. 15, 273-275, 1998.

amusing, as in the case of Rick Telander[18] who called actress Jane Fonda, the Queen of Entropy, as she "wants everybody to exercise all the time." (From a physical point of view he is right though: exercise does increase entropy of the world).

Physicists might very well be less possessive about their secret terms of art. Sometimes referring to the every day experiences of people can be useful for the introduction of hard to understand abstract concepts. Here are examples:

> Anyone who has tried to reunite two socks after a tumble in the dryer is well acquainted with entropy.[19]

> Back in the good old days of less expense, I once encountered a sign on the beverage machine at my office: "You can't get your dime back by pouring the coffee into the machine." The second law of thermodynamics sets time's arrow—and this universal direction leads to accumulating disorder measured as increasing entropy.[20]

Such examples can be silly, funny or educational. It is quite different though when a concept, clearly defined in science, starts to play the role of a mysterious evil force

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18 Rick Telander, "Viewpoint: Wasting Away At Health Clubs: Fitness fanatics should find better uses for their energy," *Sports Illustrated*, 06-04-1990, p. 6.

19 Kestenbaum, David, Physics: Gentle Force of Entropy Bridges Disciplines., *Science*, 03-20-1998 (I should note here that the concept of indistinguishablity discussed above might help to reunite socks: if they are all of the same kind and color, the probability of making a pair increases.)

20 Report to the Librarian. Stephen Jay Gould, *The Sciences*, Nov.-Dec. 1995.

in social discussion as we saw above in the examples from the books of Rifkin and Georgescu-Roegen.

For one and a half centuries, entropy and entropy law were used by physicists and other scientists but it is still surrounded by an aura of mystery. Together with lamenting about the profanation of the concept, Peter A. Corning and Stephen Jey Kline[21] recently pointed out a number of over-reaching uses of this concept in scientific literature as far as its application to biology and the attempts to explain evolution. The basis for such a purist revolt is that the concept of entropy is well defined in thermodynamics and works well there within strict limitations for its use. One should remember though, that entropy should not solely belong to thermodynamics just because thermodynamics was the first area where entropy found its use.

It is my understanding that there is nothing wrong with the use of the entropy concept by anyone, any time and for any system in which the arrangement of the system's elements matters. After all, if we free entropy from its mysterious aura it comes down to a very simple characteristic: *the quantity of possibilities* be it the quantity of microstates of gas in a vessel, or arrangements of letters in a text. We can take the logarithm of that quantity, reverse the sign and use it as a physical variable or characteristic of information. Or we can discuss the probability of a certain microstate in which case we don't even need a logarithm. Or we can just deal with the number of permutations as in the case of numbers, letters or musical notes. Conceptually it all comes down to the same characteristic: the quantity of possibilities of elements' arrangments.

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21 Peter A. Corning and Stephen Jey Kline, *Syst. Res.*, p. 15, 273-275, 1998.

If we do it for intellectual exercise or for an explanation of the concept, we can use simple examples like the permutation of numbers. Or we may get serious and use the concept of entropy in calculating the direction of a chemical reaction using standard tables of the entropy of substances. Or we can try to use a qualitative approach and use the entropy concept in discussions about the destiny of life or development of an economy.

The real profanation of the entropy concept actually comes with the illegitimate use of the second law of thermodynamics and with stating without reason that entropy must grow. When someone tries to scare people with the growing entropy of our planet forgetting that it is not an isolated system and it radiates heat - it is not a proper use of the second law. Can we subscribe any mishap in Nature to the forces of entropy?—of course not. We shouldn't even use entropy as a synonym of disorder as this implies that entropy can only grow: in fact entropy does not mean disorder but simply a measure of disorder.

Actually, if we look back to the development of this concept over one and half centuries, we will realize that mixing entropy and disorder came from the underevaluation of the ordering forces which exist in Nature.

Here I am trying to address both problems: to demystify entropy and to show a variety of factors in Nature which permit the self-organization of matter.

Generally any new and difficult to understand concept in physics attracts speculation in other science and among popularizers. One can write a long list of inappropriate attempts to use the concept of relativity or Heisenberg's principle in different areas of knowledge. We may even go farther back in time and remind the reader of the wide use of the concept of magnetism by entertainers who experimented with hypnotism and body electricity in the eighteenth century.

So there is nothing new in the over-reaching use of a physical concept, except for the fact that unlike the relativity theory or quantum indetermenism, the concept of entropy can be quite legitimately used outside of the field in which it was originated. Indeed, in a purely therodynamical approach entropy characterizes the amount of energy which can be extracted from a physical body—this side of entropy is too technical to invite its use or misuse in philosophy or social science. But then there is the statistical interpretation of that thermodynamical concept as the quantity of possibilities and through this interpretation the concept of entropy is applicable to literally anything in the world as it gives a definable and often calculable way to characterize order and disorder, certainty and uncertainty (as in information theory) and often even the spectrum of probability of certain states of any system.

One just has to remember, that as soon as the entropy concept is taken out of thermodynamical contents, one shouldn't use thermodynamical laws. Indeed, we can speak of the entropy of billiard balls on the table but not of the temperature and free energy of the system of those balls. The same goes for the movement of cars in a country's transportation system or children running in the school yard. The trick for a scientific purist is not to try to ridicule or to forbid the use of the concept of entropy in non-thermodynamical contents but to watch that thermodynamical conclusions will be not used together with a wider use of entropy.

Entropy is a much wider and more useful concept than the field in which it was born, or to better state it, in which its role was first noticed—I am referring to Clausius' discovery of entropy in his study of the performance of heat machines.

Second Law Or Not, Entropy Can Grow

So far so good: I have explained that entropy can be used outside of a thermodynamical context. But the entropy concept loses a good amount of its attraction without the second law of thermodynamics. It is not too interesting to calculate the level of order of some system without guidelines of whether that order will diminish with time or not. Is there a law of Nature analogous to the second law of thermodynamics, is there a rule for the entropy of any system to grow?

As we saw, if the state of the system or its behavior depends on the overall quantity of possible arrangements of its elements, the concept of entropy is applicable.

Here is a rather silly, but legitimate example. In Europe and in America the payoff for the winning number in roulette is the same 35-fold. Yet European roulette has one zero and American roulette also has a double-zero position. This makes the odds of winning correspondingly 1:36 and 1:37. Although the player is dealing only with one number at a time, the overall quantity of possibilities plays a role in the game. The entropy concept is applicable and we may say that the entropy of European roulette is lower than the American. Obviously it doesn't have any connection with the original use of the entropy concept in thermodynamics. We can not state that European roulette is under pressure by the second law of thermodynamics to become like American roulette with its higher entropy.

But there are plenty of examples when entropy grows despite the absence of connections with the second law. In fact, one might seriously think about introducing a more general law of Nature than the second law of thermodynamics, something along this line: *disorder in any system will grow or stay on the same level if the system does not lose energy or no special effort is taken to in-*

crease order. I will refrain from declaring this as a law of Nature simply because I don't know enough about Nature in general. I can suggest though, to keep this phrase in mind as the most likely rule for our everyday experience (let's call it the *rule of growing disorder*). Of course, we can create or imagine a system with orderly initial conditions and with good protection from the mess of the outside world and such a system would be almost immune from action of the rule of growing disorder. In the real world though, messy initial conditions and the outside application of kinetic energy sooner or later will find the way to destroy order. It could take a long time: texts carved in stone thousands of years ago are still readable but it was exactly the intuitive knowledge of the rule of disorder that made ancient people choose stone and not wood or sand as a medium for informational exchange with us.

Here is a useful example of growing disorder and how some ancient people dealt with it. If we are to do consecutive copying of a text on a Xerox machine, we will deal exactly with a process in which mistakes will multiply and after a good number of steps our copy of the text will become unreadable and the original information will be lost. The second law of thermodynamics can not be applied to this case, yet the entropy of dots on the paper grew so this is the *rule of growing disorder* in action. Why? Simply due to the nature of the copying process which makes some mistakes every time but in a tolerable quantity when we make just a few consecutive copies from the original, not thousands.

The opposite is correct, or more or less correct, in the process of copying under strict control and with a procedure of correction. It can be a procedure accompanied by a correcting code as in contemporary systems of communications. In fact this is one of the main achievements of Shannon's information theory—the discovery of the possibility for economical ways to transmit messages with correcting codes. So, disorder grows only if there is no effort to control it.

It is worth mentioning here a very non-economical way of the correct transmission of a message: there is an ancient rule in Judaic practice that the whole copy of the Torah should be destroyed if a mistake was found in that copy. Apparently ancient intuitive understanding of entropy growing in the consecutive transmissions of messages was so strong that this rule is surrounded by the belief among some Jews that using a copy of the Torah which contains a mistake will bring misfortune—a relic of the beliefs in magic which contradicts the spirit of religion defined by the text of the Torah itself. Never the less this rule did work by forcing generations of scribes to make an effort to preserve the order of a valuable text.

CHAPTER 2:
Entropy and Order

It is easy to accept that the reduction of disorder may qualify as growing order so the decrease of entropy gives us a quantitative representation of growing order. From this one characteristic we can not, of course, see what kind of order is growing. It is just a bulk characteristic but in many cases it gives us sufficient knowledge.

Limitations on Disorder as a Source of Order

The simplicity of the above introduction to the concept of entropy called for the assumption that all microstates of a system may be realized with equal probability. This should not make us forget, however, that there are certain laws of mechanics governing the movement of a body, and these laws forbid certain microstates. Disorder is present, but in some ways it is *limited disorder*. Obviously the sum of the energy of all the particles in an isolated system will always be the same due to the energy conservation law—this is already a limitation of disorder. Other laws prescribe that the vectorial sum of a particle's momentum and the vectorial sum of the moment of momentum must equal zero if a body is at rest as a whole.

There is nothing mysterious about these limitations. Each time particles interact the laws of mechanics are followed in defining the particles' movement, so if the laws are followed in each collision of gas atoms and their interactions with the vessel, then the result of trillions and trillions of collisions will not violate the mechanical laws.

By disregarding these limitations we may arrive at a wrong conclusion. Indeed if all microstates would have equal probability it would be possible that all the molecules of a body at some moment would have velocities in the same direction, which would cause that body to move as a whole in that direction without any outside interference. But this is forbidden by the mechanical laws: chaotic movement of molecules within a planet can not make the planet jump from its orbit. This is so not because the probability of such an event is very small but because it is forbidden by the law of momentum conservation.

These mechanical laws—the conservation of energy, of momentum and of the moment of momentum—actually limit the quantity of possible microstates W of any physical system and statistical physics, of course, takes these limitations into account. For this reason the actual entropy is lower than if we would assume that all microstates are possible. This means that the disorder in gas is lower due to a certain limitation on the number of possible microstates.

We came to the valuable philosophical conclusion that *limitations diminish disorder*. In fact, an understanding of this was reached at the dawn of civilization, when this reason gave rise to taboos, human customs and laws limiting behavioral choices, thereby decreasing disorder within community.

Guided by the meaning of the words, it is easy to identify decreasing disorder with increasing order, so we may also state that *limitations constitute an increase in order*. Examples from physics are countless. The walls of the vessels filled with gas are the ordering limitations: they prevent gas from occupying space outside the vessel and becoming more disorderly. In crystal, the forces between atoms are the limitations of the atoms' free movement, and for that reason order is higher. Outside magnetic fields limit disorder in the orientation of particles of some substances, iron for example, and this limitation causes a more orderly state.

Generally speaking, the free movement of particles is a source of disorder in nature, and any limitations on that movement are the source of order. In a way this is the answer to the heat death theory: it would be a correct theory if there were no limiting factors responsible for order. Identifying those limiting factors is in fact the endless task of science. Even as far as inanimate matter is concerned there are many factors limiting the free movement of particles.

It took time for science to begin to understand the nature of these ordering factors and the reasons behind observed order in the world. After centuries of fantasizing about the reasons for celestial order by many thinkers, Newton's law of gravity gave some clarity as to why planets move with regularity and why particles of planets are held together. Then the discovery of electromagnetic forces gave an introduction to understanding the interaction of atoms and molecules. The explosive development of quantum theory early in the twentieth century gave more details as to structure of the field of atoms and sub-atomic particles. The micro-world turned out to be full of order, either realized by existing bonds between particles or *potential order*—orderly fields of particles which were waiting for other particles to come and create bonds. This internal structure of the particles' fields is an endless source for the self-organization of matter.

Conflicting limitations

Imposing different limitations on a system at the same time can increase or decrease order of the system. This is an important difference with the property of disorder: any disorderly factor added to a system increases disorder. If a system has W microstates, its measure of disorder—entropy is lnW. Adding ΔW possibilities to the quantity of a system's microstates increases entropy so it becomes $\ln W + \ln(\Delta W)$.

Not so with order: order, even when we can measure it by only one parameter, is not additive. What is more, we can't always say that ordering an orderly system brings more order as orderly limitations can be conflicting.

Limitations of any kind imposed separately increase order—this is a general property of any statistical system. The crucial question in each case is how the combination of limitations affects order.

An especially interesting situation accrues if elements of a system have their own order or have the ability for self-organization. Then it is a fascinating task to analyze under what conditions and in which situations outside limiting factors are increasing order, destroying order or preventing elements of the system to realize their potential for achieving order. Here are some simple examples of such situations.

Erasing tape. The magnetic field imposed on ferromagnetic material provides some ordering of the internal structure on that material. This orientation is stochastic. If a magnetic tape contains a recording of music, the orientation of the particles is following a certain order along the tape. By placing this tape into a magnetic field we destroy the recording of music which is a higher order than the stochastic orientation of the particles.

Separation vs. bonding. Oxygen and Hydrogen kept separately in two compartments of one vessel have a smaller entropy than if they were mixed—the wall between compartments in this case is an ordering limitation. Yet, if these gases are mixed, their atoms would collide and enter into bonds with each other making molecules of water which are more orderly than those of the initial gases.

Political practices of different countries give many examples of how government limitations are helping to order society or preventing people's self-organizational activity.

There is no general answer as to the interaction of outside limitations with internal self-organization factors be it in physics, or the biology of political theory. The best known human experience with conflicting ordering limitations is the desire to separate jurisdictions: a considerable mess can result from having more than one manager overlooking an organization be it on a battle field or in the factory.

Perception Of Disorder

The physical concept of disorder does not exactly correspond to our every day understanding of disorder, so let us analyze it for clarity. An example similar to molecular disorder may be observed in children running erratically in the school yard. We would perceive that disorder is higher:

1. if the schoolyard is larger; or
2. if the speed of the running children is higher

in accordance with the perception of disorder in gas.

But this is a special situation. In our everyday use of the word "disorder" we tend to think of the level of disorder in relation to order. What is more, we usually perceive the momentary picture, without any elements of the system changing their position. Disorder in a room is perceived in comparison to its orderly state. For instance, such a comparison can be made by comparing the distance of each piece of furniture from its position in what we consider to be the orderly state. Disorder in a text means an abundance of misspelling or a high frequency of logical imperfections.

Psychologically we tend to compare disorder with order and usually are not inclined to estimate the level of disorder as such. This is why it is very important to emphasize that in gas there is only the possibility to compare disorder with disorder of another level, as, except for a frozen state, there is no state which we would recognize as order of certain kind. And this is the reason why one parameter—entropy [22] is enough in describing the level of disorder of gases.

Crystals provide an example of an orderly body. The entropy of crystal is a general characteristic that tells us about the bulk level of order, but not about what kind of order exists in a particular crystal. In three-dimensional space for a proper description of the crystallic order without irregularities we need to know at least six parameters: three angles for positioning crystallic axes, and three distances that give the coordinates of particles in relation to each other.

Obviously there are more parameters needed to describe more sophisticated order. Often the quantity of those parameters exceeds our ability to deal with it. This leads to the necessity of using bulk parameters and entropy is among them.

Static Entropy Of Numbers

How to characterize order when the level of disorder—entropy, reaches zero? This occurs—theoretically—when a physical system reaches the lowest possible temperature: absolute zero. Does this mean that anything frozen at that temperature is in perfect order? Hardly, as no matter how cold it is, glass—a solid body with disorderly arranged particles—does not reach the same level of order as a crystal. The similar case is the static arrangement of billiard balls—the positional entropy of such a

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22 I am reminding the reader that entropy is actually the sum of two: positional and momental entropy.

system equals zero, as the balls are not jumping to choose different positions. Indeed, in most cases we don't observe anything like children running in the schoolyard, or a cloud of mosquitoes attacking us; we are usually dealing with static order or disorder, which is characterized by the positions of objects in space. Can we use the same approach to characterize static disorder as we introduced for gases with moving molecules? It is possible, if we treat a particular static arrangement as one of the microstates of the system, and deal only with positional entropy. (When elements of the system do not move, momental entropy equals zero any way).

Here is an easy to imagine example. The string of numbers

2,1,3,5,4

represents static disorder. Because these numbers do not jump and hit each other as gas molecules do, one would not be comfortable treating them as molecules and to calculate entropy for this string. Yet if we are to imagine all the possibilities of presenting the numbers from 1 to 5 in different orders (there are 5!=120 of such possibilities), and treat our set as one of the possibilities, we can say that the entropy of these numbers is ln120.

This characteristic of static disorder I will call *static entropy* to designate the fact that this arrangement of numbers is already written down and not changing, as the arrangement of molecules in gas does. Now, why do we need to know the entropy of a string of numbers? Actually this is a way to illustrate how entropy can characterize order as well disorder. A similar approach is in use for characterizing the order of texts, music and so on.

In any system of elements there are usually much more disorderly arrangements than orderly of a certain kind. Those last words are very important in all approaches to characterizing order: we can not call a configuration orderly without specifying the kind of order (except for cases like 1,2,3,4,5 which are in what I would call default order, that is, the order we assume if none other is specified).

This is a crucial distinction between order and disorder: generally we don't need to specify the kind of disorder. There are many kinds of observable order, and also there could be an infinite number of hidden orders, about which we may know nothing. In fact the arrangement 2,5,4,3,1 appears disorderly, but it actually expresses the word "words" in code, when the following letters are represented by the following numbers:

w—2, o—5, r—4, d—3, s—1

which means that this arrangement is not random, not disorderly. But it can be known only by people who know that such a code exists.

One can give similar examples about any possible arrangement of numbers. This does not necessarily mean that there is no disorder possible, but it means that to characterize order we need to know the type of order. Then we can count the quantity of arrangements that satisfy the requirements of a particular type of order, and all the rest of the arrangements will be disorderly.[23]

Let's proclaim that the orderly state of a set of numbers is when the difference between neighboring numbers is plus or minus 1. Two sets are orderly in this sense: 1,2,3,4,5 and 5,4,3,2,1, which means that the entropy of this particular type of order equals ln2, which is quite smaller than ln120 calculated for any arrangement of these numbers. Indeed, the entropy of an orderly state is usually lower than that of any state.

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23 This is a dangerous road to follow. We actually may arrive at a conclusion that there is no disorderly set of numbers at all, that each set represents some order in some code. Would this mean that all our knowledge of disorder is subjective?

This shows us the relation between static and dynamic order and disorder. In a dynamic system the arrangement of elements is changing all the time and entropy equals the logarithm of a number of possible arrangements. If such a system is to be frozen at a certain moment and the arrangement of the elements ceases to change, there will be one unique arrangement and dynamic entropy will become zero, no matter whether that arrangement is orderly in any particular sense. Yet the introduction of static entropy let's us characterize the level of order of that arrangement in relation to our definition of order. It also clarifies the issue of subjectivity to some extent: if the elements of the system are well defined, the quantity of possible arrangements in a dynamic case, and entropy for that matter, is not subjective. Yet static entropy can be subjective, depending on our definition of order or disregard for order: we either choose to count the probability of a certain microstate in relation to all possible arrangements, or in relation to the quantity of certain orderly arrangements.

The example with numbers also reminds us about the relations of entropy and probability: low entropy means low probability. Indeed, if there only two orderly arrangements out of 120 possible arrangements, the probability of one of orderly arrangements is 2 /120=1/60. The rest are disorderly arrangements and there are 118 of them. So the probability of disorderly arrangement is 118/120 which is much larger than the probability of orderly arrangements. Of course, the probability of a particular order highly depends on what we consider to be that particular order.

Why Use Entropy To Describe Order?

As we saw with the example of gases and crystals, the level of disorder can be measured by just one parameter: entropy. Order, on the other hand, can be multifaceted and requires, generally speaking, many parameters to describe it. Indeed, only in the simplest cases is one, or a few, parameters enough due to the complexity of the types of order. Order in a warehouse with stacks of similar boxes can be described by a few numbers that give the coordinates of rows. As we load new types of boxes, more parameters will be needed to specify which kind of box is positioned where. Description of the order of books on library bookshelves needs at least one entry for each book. (If there is only one copy of each book in the library, the catalogue describes a unique order: only one microstate of the system can satisfy the order described by the catalogue.)

One may ask: why not leave entropy as a physical measure of disorder and not try to use it to characterize order of any kind?

Three reasons are worth mentioning. First, there is a basic physical law about entropy: it definitely grows to reach maximum in isolated systems. There is also the plausable rule of growing disorder as entropy has a tendency to grow in any system if there is no effort to preserve order. This rule works not only when we mix gases or when we study heat machines, but it is also valid for a variety of systems—be they inanimate, living or social systems. There is no similar universal tendency for any particular parameters of order.

Second, there is actually no easy way to establish the boundary between order and disorder, so if entropy can be used as a tool for the comparison of levels of order in different systems or in the same system at different moments in time, it is actually very important, despite the fact that the particulars of this or that order remain unaccounted for.

Third, there is no universal measurement for order. Order in general, as well as the complexity of the system, is still a stumbling block to a scientific approach. The entropy approach provides a way to describe order through the level of disorder.

Static Entropy Of Gas

We saw that in the case of a certain gas inside a vessel, the main reason for the incredible number of possible arrangements is the empty space between the molecules. We divided that space into cells each of which may host one molecule, and the quantity of those cells—Z—largely defines how big the quantity of possible arrangements—W_p—will be. Now let's suppose that we put a certain amount of Oxygen into a balloon made from imaginary rubber that stays elastic no matter how cold it gets. When we lower the temperature of this balloon, the volume of gas decreases according to physical law. The balloon shrinks, and the molecules get closer to each other. This means that Z decreases, and so does entropy.

How far can this process go? According to thermodynamics there is a limit for temperature, which is absolute zero, equals -273.16C°. Although this temperature point is unreachable in practice, we may reach a temperature that is very close to it. At that temperature there is no molecular movement: the molecules stop hitting each other and for that reason there is no free space between molecules large enough to host a molecule. Our gas becomes frozen and the system of molecules has only one arrangement, Wp =1, and the positional entropy equals zero.[24] If entropy is a measure of disorder and it equals zero, does this mean that absolute order is achieved?

Yes, but only in the case of a substance when its molecules are indistinguishable. The state of this frozen substance would be the same as that of vitamin pills of the same color when the glass is at rest or a string of the same numbers like 2,2,2,2,2. But if there are not just molecules of Oxygen, but molecules of other gases involved in our frozen system, then this would constitute frozen disorder like the vitamin pills of different colors after shaking or a string of different numbers. Because it is frozen there will be only one possible arrangement and S_p=0. We arrived at a situation where the measure of disorder, entropy, is zero, but there is no order as the different molecules are positioned without any regularity. Entropy in traditional physics, as we see now, is a measure of disorder in a system of constantly moving elements, in a system which is not only disorderly, but which also is in disorderly transition from one state of disorder to another. For this reason it is natural to call it *dynamic entropy*. This dynamic entropy equals zero at absolute zero temperature and it signifies not the end of disorder, but only the end of dynamic disorder—the end of the disorderly transition from one disorderly arrangement to another. Static disorder remains (except in the case of indistinguishable particles).

Is there still a way to use entropy to characterize frozen disorder at absolute zero? Apparently we already dealt with such a situation, when we treated the string of numbers as one microstate of the system, and counted

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24 According to the Nerst theorem, entropy equals zero at absolute zero temperature. Quantum mechanics ascribes some energy to particles at absolute zero, but this does not effect our discussion as we are preoccupied with positional entropy.

the static entropy.[25] Physically it is equivalent to the experiment in which we freeze and unfreeze the same system of particles over and over, recording each time the positions of all the molecules and counting the quantity of possible arrangements.

Apparently our static entropy of the frozen system is defined the same way as entropy for the red and green pills, so I actually discussed an example of static entropy before this formal introduction. This property—the static entropy of a system—characterizes the level of disorder in a frozen system and it is not outside of physics: static entropy may be physically important in some cases when the energetic characteristics of a system depend on the order in which the different molecules are positioned in respect to each other when a substance is frozen, despite the fact that the thermodynamic entropy of a frozen system equals zero.

As to the relations between static and dynamic entropy, I note first of all the obvious fact that the concept of static entropy does not apply to the arrangement of momenta of a system's particles. As to the positional part of entropy, static entropy might be viewed as equal to dynamic entropy at a certain moment if we imagine that

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25 Erwin Schorödinger, in his thought-provoking book *What Is Life?* suggested to use entropy with a negative sign—nega-entropy—for characterizing the order. The basis for this is that if W shows a level of disorder, then 1/W shows a level of order and ln(1/W), which equals the negative number -S, is a measure of order. The concept of static entropy is preferable from my point of view, as it emphasizes the fact that we are dealing with frozen—static—order or disorder. Since Schorödinger, the term "nega-entropy" was used by many authors in different contents. To be strict, I have to notice that this term does not go well with the philosophy of entropy but I learned long ago that a dispute about the use of words can hardly be productive.

chaotic changes in positional arrangement in a system go very slowly.

Absolute zero, of course, is not the only temperature at which the concept of static entropy is useful. Despite the movement of molecules at room temperature, pieces of furniture in a room do not move by themselves, so static entropy applies to the furniture arrangement, as well as to the arrangement of genes in DNA, notes in music or words in a text.

Does The World Have To Be Messy?

Physics is accustomed to dealing with many characteristics which are subject to conservation laws. Conservation of matter-energy, momentum and moment of momentum permits us to write equations and calculate the properties of physical processes. The second law does address the question of the conservation of entropy only in an isolated system stating that

1. With some approximations, in cases of reversible processes in thermodynamics entropy does not change.

2. Entropy remains the same once a state of equilibrium is reached.

This doesn't tell us too much as far as the real world is concerned with a variety of not isolated systems. Can we count on the conservation of order and to what extent? Let's more closely analyze the second law in some circumstances.

In social science there is recognition that rules and laws can be either normative or descriptive. Physics usually doesn't need this division as all laws there are assumed to be normative. This might sound as revelation or heresy, but the second law of thermodynamics is actually descriptive as far as entropy increase is concerned: *things get disorderly not because there is a deep law of the Uni-*

verse which requires them to get that way but due to the initial disorderly conditions.

Now I will present a few illustrations of how atoms can remain in an orderly state at least theoretically. Following classical idealization we can picture atoms of gas as ideally elastic balls of radius b. Let that gas be inside a cylindrical vessel of radius R and length L with ideally elastic walls.

Case 1—perfect initial order. Let atoms of that gas have the same velocities parallel to the axis of the cylinder with no two atoms flying along the same line. At the initial moment they are all at one end of the cylinder. With such orderly initial conditions there will be no collisions of atoms with each other and there will be no factors which are random or difficult to account for. All atoms in the same spatial order will fly from one end of the cylinder to another and back. All the time they will remain within a cylinder of length 2b and radius R. Such a system will not be statistical in the usual sense of the word as we can follow the movement of each particle and predict its position at any time. But like for any system we still can define and discuss entropy. Positional entropy should be counted in relation not to the volume of the whole vessel but in relation to the cylinder of radius R and length 2b, as there are no atoms outside this cylinder. Overall entropy of this system of atoms will not change due to movement and we are dealing here with the conservation of order—a case which is covered by the second law. Order can stay the same due to the initial orderly condition and absence of disorderly factors.

Case 2—imperfect initial order. All conditions are the same but the initial velocities of atoms are slightly different (although are of the same direction). Initial entropy (momental part of it) is higher than in case 1. Movement with different speeds will change the spatial arrangement of atoms and after a while the atoms will be spread all over inside our vessel. Positional entropy will become higher. Momental entropy will stay the same as there are no collisions between atoms. Disorder in initial speed led to an increase of positional entropy.

Case 3—even less perfect order. Now there are slight deviations in the initial direction of the atoms. With time the atoms will start to collide with each other and both, positional and momental entropy will grow.

We saw that the conservation of order is possible in the case of perfectly orderly initial conditions. But slight disorder in initial conditions brings considerable disorder as atoms continue to move despite the absence of outside disorderly factors.

Case 4—cyclical entropy. Now I will use the same conditions as in case 2 to give an example of a mental experiment with an isolated system which actually goes against the second law of thermodynamics. In case 2 we didn't specify how different the velocities are. Now, with the same directions, the velocities are such that the first atom will return to its initial position after time T hitting the opposite side of vessel once. Its speed $v=2L/T$. All other atoms have speeds nv, where n is any integer randomly assigned to each atom. During time T all atoms will be randomly spread inside the vessel so the positional entropy of the gas must be counted in relation to the whole volume of the vessel and it is higher than at the initial moment. But at the end of each interval T all the atoms will be in their initial position within the short cylinder of length 2b and radius R. It is the volume of this cylinder that will define the entropy of the gas at that moment. And that entropy will be as small as at the initial moment. What we have here is entropy increasing and falling periodically with period T in an isolated system. Such a situation is certainly not covered by the second law.

Possible objections to case 4.

Obviously, this is not the case of falsifying the second law as it is a law of Nature and not a law regulating mental experiments. In nature there are no such ideal initial conditions and no ideally elastic atoms or vessels. Still, even a mental experiment of this kind can raise objections and I will address some of them.

1. *The system is not statistical as certain mechanical variables were defined as initial conditions so the second law does not apply*.

This objection should be overruled as the key words in the second law are “isolated system” not “statistical”. In fact, at absolute zero temperature, the system is also not statistical as all momenta are known and equal zero. Yet, we do not hesitate to apply the second law to such conditions. I agree, that the initial conditions are too well defined for the usual statistical system, but speed proportional to nv was assigned to the atoms randomly so even the initial conditions are not well defined to solve this case as a mechanical problem. What is more, inside of interval T we have no way to know the positions of each atom.

2. The system is not statistical so the concept of entropy can not be used.

The first answer showed that the system is in a way statistical, but here it is irrelevant. The concept of entropy can and should apply to any system with any elements. Whenever the behavior of a system depends on the quantity and mutual positions between its elements, the entropy of that system with a proper choice of elements is an important characteristic of that system. In a way the whole of this book is the answer to this objection.

Actually, the inclination to deal with a statistical system in order to make use of entropy already expresses an implicit assumption that the system has to be messy in its initial conditions. The way for me to illustrate it was to replace the initial disorderly conditions with orderly ones.

3. The illegal use of entropy at the given moment.

This is an interesting controversy in physics. Despite recognition that entropy grows from one point of time to another, physicists often avoid describing entropy as a function of time. What is more, the classical approach was that entropy is defined only near equilibrium. With the development of thermodynamics of systems far from equilibrium[26] the situation has changed. Generally speaking, there must be very persuasive reasons to forbid physics to connect certain properties with a certain moment of time. Thermodynamics nor statistical mechanics did not present such reasons.

Our mental experiments with more or less orderly initial conditions made the point that the second law is descriptive in a way that it does not prescribe the world getting disorderly. In reality of course, there are no ideally elastic atoms and collisions of atoms often produce radiation of quanta of energy which go in unpredictable directions, changing the velocity of atoms. Also mutual collisions of atoms create disorder even if there were initially orderly conditions.

Conservation of order is possible in an isolated system in ideal conditions and with orderly initial conditions. As to the conservation of order in an open system, there is none as long there is enough kinetic energy to destroy the existing order. Yet order achieved by strong bonding fields between atoms and molecules can exist for a long time in favorable conditions. On Earth, as far as we can judge, we still have crystals formed billions of years ago.

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26 See Ilya Prigogine, Introduction to Thermodynamics of Irreversible Processes; Nicolis, G. and Prigogine, I. Self-organization in Nonequilibrium Systems.

As to the conservation of disorder, in an isolated system it is stated by the second law once a system reaches a state of equilibrium. In an open system disorder diminishes if the system loses energy through radiation or by other ways.

CHAPTER 3:
Self-Organization of Matter

If everything tends to achieve the most disorderly state according to Entropy Law, why do we exist as quite orderly creatures? No wonder earlier thinkers had to assume divine interference to explain the creation of an orderly world. They observed erosion of the land, destruction of mountains, rotting of wood and death of living creatures. From the first words of the Bible we see a deep intuitive understanding of the law of entropy, as the inanimate world before divine interference was a mixture from which God created separate entities: Earth and Heaven. Mixing is the result of natural disorder**,** *separation* is the key act to resist the natural forces, to create, to resist the law of growing entropy. Interference of divine energy had to be presumed by authors of Bible (actually in accordance with an intuitive understanding of the second law: energy is needed to decrease entropy).

Ancient people observed only destruction as the law of inanimate Nature. They did not manage to understand the duality of natural laws, as together with decay and averaging, inanimate nature itself provided for the creation of order. That order then produces more order, in a constant struggle with destructive forces. Despite the ignorance of ancient people as to the ability of Nature to initiate order, the constant competition of order and disorder was not only noticed, but reflected in human culture as far back as we can judge. At first it was only the struggle of humans against the elements of inanimate nature and the disorganized animal world. Then the time came to inject social order into human behavior, and the great saga of the human struggle against the disorder of human passions began—a saga that did not end with the establishment of civilized laws, as every human being has to repeat this struggle as he grows because we are born without civilized restraints.

Minimizing potential energy

In the example of pills in the glass, we saw that the loss of original order occurred after shaking, which means that kinetic energy, the energy of movement, must be applied to produce disorder. A simple experiment will show that a certain threshold of energy must be crossed to get a disordering effect: try to move the glass with pills gently, and there will be no mixing effect due to the gravitational force and friction force between pills. This is also a law of nature, no less important than the law of entropy. This Threshold law is actually complementary to the Entropy law: the entropy of a system can grow only if there is enough kinetic energy to produce disorder. Indeed, any orderly object we know can be ruined by a sufficient amount of kinetic energy: a man can be killed by a falling brick, crystal can be crushed by a hammer, and a piece of wood can be burned if the temperature is high enough. Even in the micro-world, orderly structures—molecules and atoms—can be destroyed if enough kinetic energy is applied.[27]

What is the nature of this threshold? How does it defend order against destruction when kinetic energy is small? Let us imagine some balls on a platter which stands on the floor of the room. If the balls are at rest each ball remains in its position inside a platter. The dynamic entropy of the balls at rest equals zero. If we apply

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27 In thermodynamics, observed disorder is usually discussed at the atomic and molecular level. The particles of the subatomic world, as shown by contemporary physics, is full of order with even radiation following strict rules of energy levels.

some kinetic energy to the balls they will start to move in the platter, changing mutual positions and occupying new positions on the platter. The entropy will be somewhat higher but the balls will remain in the platter; the kinetic energy did not cross the threshold, it is not high enough to make the balls jump over the edge of the platter. If we apply a high enough kinetic energy, the balls will do exactly that, and roll on the floor. The quantity of possible positions on the floor is far larger than in the platter, so the entropy of the system of balls will increase considerably. This is a model of transformation from a low to high entropy state in many systems. The threshold of kinetic energy in our example can easily be calculated. If the weight of the ball is P and the height of the edge of the platter is h, then the kinetic energy of a ball must be more than Ph in order for that ball to jump over the edge. This Ph is also known as an increase of the *potential energy* of a ball of that weight when raised to the height of h. So the threshold of the orderly state of the balls for each ball equals the level of the potential energy of the ball when it is on the top of the edge of the platter. In other words, the threshold equals the height of the *potential well*. In most cases of order in nature there is no platter or hole in the ground, but there is a certain configuration of a force field for which the term potential well is very appropriate, and which acts the same way as do the walls of the platter in our experiment. In quantum mechanics this picture is somewhat more complicated but this simple description based on classical mechanics is sufficient for our goal to show sources of order in Nature.

The electric field inside a crystal of table salt holds the ions in an orderly state; a gravitational field holds planets in one system and the particles of a given planet together; intermolecular bonding forces hold together parts of DNA—long molecules that contain our genetic code.

Each known orderly system in nature has its own threshold of destruction. To preserve the order of any system, one must keep its elements inside of a certain potential well, and protect them from excessive kinetic energy.

And *vice versa*: if there are systems of potential wells, wandering particles with small enough kinetic energy will get into those wells and stay there in a more orderly state, a state of lower entropy. The natural law behind this local entropy-lowering process is the inclination of particles or bodies to reach the lowest potential energy. We witness this physical law at work not only when we see rocks rolling down a hill, or observe the result of electrons in a television tube being attracted or repelled by the electric field. The fact that things in a room stay put is a result of the same law: having been placed on the table, our computer remains inside the potential well formed by the forces of gravity, the elastic forces of the table's material, and the force of friction of the table's surface. Its potential energy is lowest in the given circumstances, as our own potential energy is when we are comfortable in our chairs.

So the constant movement of particles is responsible for increasing disorder in any physical system, but the existence of potential wells in the fields of particles or groups of particles provide for creating order in some part of the physical world.

Properties Of Potential Wells

A model of a platter with balls in a gravitational field is helpful for understanding the simple characteristics of a potential well as far as its ordering capability goes. The *depth* of the potential well was already introduced as *Ph*. In the gravitational field on Earth it depends on the actual depth of the platter. For other fields the depth of a potential well is simply the threshold measured by the smallest kinetic energy needed for a particle to live in the potential well. Apparently depth characterizes the stability of order achieved by placing a particle into a potential well. Examples of order of different levels of stability are everywhere in Nature: there are stable and unstable atom nucleuses, there are more and less stable molecules and so on. Usually instability is the result of the fact that a potential well created by a field or combination of fields for a particular kind of order is not deep enough to resist the attack of kinetic energy prevailing in the given environment.

Let's imagine our platter is placed in the midst of balls flying back and forth in the room. The chance that a passing ball will hit the platter depends on the width of the platter so the *width* of a potential well is another characteristic of ordering ability.

When a ball hits the platter it needs to have low enough kinetic energy in order to remain on the platter. This is a crucial characteristic of a potential well: how *cushy* it is. If highly elastic steel balls are chaotically hitting a steel platter, most of them will bounce out. Yet, if a platter is made from lead or another soft material, the ball's collision with the platter will result in a loss of the ball's kinetic energy and the ball will remain inside of the potential well. That kinetic energy will of course be transformed into thermal energy and as a result the temperature and entropy of the whole room will rise. But the system of balls will become more orderly as balls will stay on the platter. In the case of atoms flying around each other, there is no cushy platter, but there is the ability of atoms to radiate out excess kinetic energy and create bonds with passing atoms and acheive local reduction of entropy.

Potential Wells And Probability

There is a well spread misconception as far as the relations between probability and entropy. Entropy is a logarithm of probability but it is a probability of this or that microstate of a system. It does not give us the direction of development of a non-isolated system. The unfortunate reasoning often is: it is more probable for a system to increase its entropy *ergo* if a system reaches a more probable state, its entropy must be growing. That is not so for an open system.

When a rock is falling down or a particle falls into the potential well of a field of another particle, the corresponding system (rock—Earth, particle - particle) reaches a more probable state yet ordering is achieved and the entropy of the open system be it rock—Earth or particle - particle definitely becomes lower. The trick here is that as a rock or particle reaches lower potential energy, some overall energy has to be taken somewhere. In the case of a falling rock potential energy is transformed into kinetic energy of the rock and then, as the rock hits the ground, into thermal energy directly if the ground is soft or through seismic waves if the ground is hard. In the case of an electron falling into the potential well of an atom's nucleus, energy is radiated in the form of a photon. So, here we are not dealing with an isolated system and it is exactly why a system can become more orderly. If an open system reaches a more probable state it does not necessarily mean that the entropy increased.

How Order Starts

Seeing so many examples of growing disorder in the world and knowing the physical law behind it, one might be in doubt that the order of such a high level as life can be born from a disorderly state of matter without divine interference or without some special undiscovered law which some authors were hypothesizing about. Indeed we are in the dark about the origin of life. Calculations of the probability of the random appearance of highly organized and reproducing organic molecules are discouraging: the belief is that there would simply not be enough time on Earth for the origination of life through a random process according to such calculations. The hypothesis of panspermia—the assumption that simple life forms originated elsewhere and might have spread through space on meteorites—is still awaiting experimental verification.

On the other hand, order in inanimate matter has been very well studied. We know that crystals, being highly organized, can originate without divine interference or being brought from outer space.

Let's suspend a little crystal of table salt on a thread in a glass with a saturated solution of the same salt. Let it stand in a warm room for a few days. As a result of this simple experiment we have a chance to witness the result of the amazing process of crystal growing. We are dealing with the self-organization of inanimate matter, with lowering entropy around our initial crystal in the solution. The inclination of matter particles to reach a minimum of potential energy is the source of this ordering. The crystal grew due to the fact that ions of Sodium and Chlorite "fell" to the potential wells near the surface of our initial crystal. Let me emphasize that it is only local self-organization, local reduction of entropy. As the second law prescribes, the entropy of the whole room that hosts our experiment—goes up. The crystal grew because the solution became over-saturated due to evaporation of water from the glass; evaporation of course means increasing entropy, as gaseous water is less orderly than liquid water.

This experiment solves only part of the mystery: inanimate matter can achieve order if some initial order exists, in our case the initiating crystal. Potential wells, if orderly placed, attract ions and, once in place, those ions create new potential wells also orderly placed. So at least we see that order can be achieved from disorder if there is initial order.

But how can crystallic order be born without an initializing crystal, without organized ions that tell the new ions about the order to be followed? The best answer science can give is the organizing role of fluctuations. If we leave for a few days the same glass with a salt solution without the initializing crystal, water will evaporate, the solution will become over-saturated, and ions will start to stick together because there are not enough molecules of water to keep them apart. And here is an interesting fact: the field of forces around the ions of table salt is such that a minimum of potential energy will be reached only if those ions place themselves in a certain order. For table salt NaCl the only order is a cubic crystal. The field of forces of ions, atoms or molecules of different substances may allow for alternative crystallic orders. Indeed, carbon can crystallize in a variety of orders: graphite or diamond, to say nothing of Fulerans which can be viewed as in a state partly crystallic partly molecular.

Apparently fluctuations in the random movements of particles in a solution of salt or cooling liquid metal brings the particles together, so forces of the particle's fields can originate order for the further growth of crystals. It is the structure of the particles' field itself, however, that is responsible for crystal growth. It is fair to say that the crystal order exists as an idea in the internal structure of the particle. One might also say that the *code of crystallic order* is written in the language of force-field configuration. Apparently this is the case, as the fluctuations themselves are powerless to produce sustaining order; they can only provide for the proper taining order; they can only provide for the proper initial positioning of particles. Indeed, if there is no possibility of orderly bonds between particles, there would be no crystal despite the fact that the body would become solid as happens in the case of glass or many other amorphous substances.

This brings us to the conclusion that order can be achieved if there is existing hidden order, order in the structure of a particle's field. The force-field of an atom has been well studied and, in many cases, the scientist can predict which structure of crystal and molecules is possible with given atoms.

The following illustrates this point. Imagine loading small spheres of the same size into a box. We can put them in order: when they are well packed, the distance between the centers of the balls is equal to the ball's diameter. If they are not spheres but cubes of the same size order also can be achieved, as the idea of order already exists in the shape of the elements of this system. But what analogy of the crystallic order can we achieve with gravel, which contains little stones of different sizes and shapes? Apparently none, for the simple reason that no mutually corresponding ideas of order is written in the shapes and sizes of the stones.

Of course, for any shape A we can imagine a corresponding shape B which would allow good packing in a two dimensional box. We can say that figure B can respond to the potential order coded in figure A just like a key responds to the potential order of a lock or specialized immune cells respond to intruding molecules.

This example illustrates the possibility of predicting order. In the case of balls or cubes of the same size predicting the packing order is trivial—we actually can calculate what size boxes to use for the most orderly packing. If we have similar objects of a more complicated shape then the idea of order expressed in the shape and size of those objects is more complex, it may take a good geometer or a good computer program to figure the best packing order which is analogous to stable crystallic order.

A scientist's joy is to observe and describe orderly objects created by Nature, like crystals or complex molecules or shapes of living creatures. As physics and the calculating ability of computers progresses, more and more kinds of order can be predicted from knowledge of the structure of atomic and molecular fields. Once predicted this kind of order can be created in a laboratory or searched for in Nature.

Ordered World

We see now that the world is not too disorderly after all. There is a high internal order of the field of those particles that are wandering disorderly in space, there is the code of crystallic and molecular order written in the language of a force-field (or, using a more contemporary expression, in the configuration of energy levels of that field). This knowledge of the internal order of a particles' field certainly changed our picture of the world. Indeed, nineteenth century scientists who discussed entropy were dealing with atoms as the smallest objects of matter (still hypothetical then, by the way), and did not imagine the highly organized structure of an atoms' field. As a result, the statistical physics of the nineteenth century unlike classical mechanics pictured the world as fundamentally disorganized, with occasional order as the exception. It took the genius of Nills Bohr to introduce the first model of an atom with a structured field. As far as our knowledge goes now, atoms and molecules are highly organized entities, and they are exactly what provide the ability for the creation of organized structures. Of course, these organized structures as well as the atoms themselves can exist only if the level of kinetic energy in the environment is low enough to protect them from destruction; in other words, orderly structures are possible only if the temperature is not too high—in this sense Earth is a lucky place to observe order.

The foundation of our knowledge about order in Nature is already in our possession: the two physical laws we discussed above—the desire of a system to reach a minimum of potential energy, and the Threshold principle. These laws work as basic ordering tools in Nature. With the existence of highly structured atomic fields these basic laws provide for highly structured order including the order of living matter.

As science looks deeper and deeper into the microworld, a natural question arises. What will we find there: order or disorder? Is there a pre-existing order to the order of atoms and particles known to us? Whatever answer is found in the future we have enough knowledge to conclude that in the world known to us there is a physical basis for order as well as for destruction of that order. The equal importance of physical principles beyond order and disorder is not always easy to recognize. It is quite possible that an optimistic observer will pay more attention to those forces which are responsible for the creation of our orderly world. The pessimism of others finds equally inspiring support in the second law of thermodynamics which, in broad interpretation predicts destruction and decay. One of the Doomsday prophets[28], stated: "The Entropy Law will likely supersede Newtonian mechanics as the ruling paradigm of science because it, and only it, adequately explains the nature of change, its direction, and the interconnectedness of all things within the change process". But we just saw that such a pessimism about our world is without foundation.

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28 Rifkin, Jeremy. Entropy : into the greenhouse world.

Energetic And Entropic Costs Of Order

As I mentioned before, any reduction of entropy—be it the result of the self-organizing of inanimate matter or our willful act—is only a local reduction. It creates more order in some areas, like the growth of a crystal or the cooling of a room; but it necessarily leads to an increase of entropy in the surrounding space. In other words, if we want to achieve order, we have to deal with entropic waste.

There is also an energetic cost for the local lowering of entropy. The simplest example is from thermodynamics: one must spend energy to cool the room in hot weather. An air-conditioner provides coolness in the room and therefore the entropy of the air inside the room decreases; but the electric meter records the use of energy. That energy goes out of the house through the radiator of the air-conditioner, which is sticking out the window. By cooling the room we are heating the outside world. This is what the second law of thermodynamics tells us: decreasing the entropy of part of the system leads to an increase in entropy of all of the system. In other words, for any local decrease of entropy we have to:

1. spend energy; and
2. deal with entropic waste, because the entropy in the overall system is increasing.

To achieve an orderly arrangement of atoms in building proteins, the cells of the living creature must spend energy. The same is true when a bee is building a honeycomb, or a human puts bricks into an orderly state or develops a theory. But this energy expenditure for reducing entropy is only part of the overall energy-entropy balance: as a living creature reduces entropy within itself or around itself it must have mechanisms for dealing with energetic and entropic waste. Radiation of heat or cooling by evaporating water through the pores of the skin is part of a waste-management system, similar to the air conditioner radiator in our window. The task is more complicated due to the fact that many creatures receive energy by consuming highly organized matter: organic food. Extraction of energy from this food leads to the collection of less organized matter, which also must be extracted from a low entropy area as waste. So living creatures have to deal with both: energetic and material entropic waste. This leads to certain properties of living organisms that will be discussed later.

Potential Order (P-Order)

Back to our experiment with the growing crystal of table salt. Our initial crystal with a high order of ions has an interesting property: the ability to direct outside wandering ions to assume an orderly position. Manifestation of this ability is conditional. A crystal of table salt does not use this special ability to organize molecules of nitrogen or carbon dioxide when it is surrounded by air; it would not organize molecules of alcohol if we put it in vodka. So we can view the crystal of NaCl as an agent possessing the power to organize certain kinds of inanimate matter in certain conditions. I will call this organizing ability, this property of the crystal surface, *potential order*: for convenience, p-order. The word potential is used to signify the fact that an object is, we might say, waiting to realize its ordering ability when conditions become right. If the kinetic energy of the passing particles is too large they will not fall into the potential wells. If there are no proper particles to take advantage of the p-order, it will similarly stay unrealized. Billions of little crystals of table salt in sacks at the stores, and in our salt shakers, are waiting for the proper conditions to start organizing other ions into crystals. Only a few will get lucky, but those which do will perform the miracle of self-organization of inanimate matter.

I already mentioned that before a crystal is created, the idea of it exists in atoms in its internal structure. The atoms themselves, and not just the initial crystal, possess p-order as to organizing in crystals, and in fact also for organizing in molecules with other atoms.

The existence of p-order of atoms raises a question about the nature of Nature. Disorder in a system of atoms and molecules made physicists of the nineteenth century worry about the heat death of the Universe. Now we know that a relatively high level of kinetic energy makes a system of atoms in gas disorderly, but atoms themselves are orderly systems and possess p-order for ordering those other atoms with which a given atom can enter into molecule or crystal.

If we accept that the p-order of an atom's field is a physical property, we might as well generalize that any ordering agent has this property. For example, if a piston moves in a cylinder to put air under pressure, which lowers entropy inside the cylinder, then whatever is moving that piston—such as a machine or the muscles of a human hand—being organized matter itself also possesses p-order. I will go further and state that the information in the paragraph describing the crystal-growing experiment also possesses p-order, as it describes how potential order of the initial crystal can be realized. Further, I can say that our will to conduct this experiment also posses potential order.

I noted before that the entropy of a system (and order in a system) is only indirectly connected with the matter of the system: it characterizes a state of matter but not the matter itself. Potential order may not at all be connected with the matter which is to be organized. The energy field near a crystal plane does not belong to the ions which have yet to fall into the potential wells; the catalyst is an outsider in relation to the products of chemical reaction (except for auto-catalytic reactions), and the human hand arranging billiard balls does not contain any molecules of the balls. This note may make it easier to accept immaterial agents as will, and information as possessing p-order.

Level Of Involvement And Universality

There are differences in the level of universality of various agents that possess p-order, and differences in the level of involvement. The initial crystal and the atoms in a chemical reaction become part of the order they organize. An army officer commanding a platoon to follow him in order is part of that order. But in most cases of human activity, information and will are not directly involved in the order that is to be created with their participation. This makes them more or less reusable in the achievement of order in other systems. Reusability of information is obvious enough as long as it is sufficiently spread or preserved. Will can be called informed energy so only the informational part of it is reusable without restoration, as long as the person remembers that information. Human energy and low entropy of the body must be restored.

As to universality, the initial crystal of NaCl organizes only certain types of ions, so we are dealing with a particular p-order. The same could be said about the p-order of the molecules of the catalyst that provide the conditions for certain chemical reactions. But information about our crystal-growing experiment possesses potential order to organize many kinds of ions in solution, because instead of table salt other substances can be used for growing crystals. We may state that information in most cases possesses universal p-order. Our will has the ability to be directed toward organizing matter or nonmaterial elements of many systems. For this reason will possesses universal p-order, as we could use the same will to build a machine or a house of cards, or write a text.

Again the word potential is used here to signify that an entity possessing this property may or may not realize its ability as a local entropy lowering agent, depending on conditions. What is more, in some conditions information or will may even be used as disorderly, as an entropy-increasing agent. This should not surprise us. We know about fluctuation in any complex stochastic system. If fluctuations can help to produce occasional order in disorderly systems, there could be fluctuations that produce occasional disorder in orderly systems.

The discussion further in this book will show, however, that the typical use of human will or information—and even living will in general—is to increase order within and sometimes around those who use these tools. Further, sustaining or increasing order in a chosen part of the world may be viewed as our destiny and the destiny of life itself in the physical evolution of the world. Even when agents of p-order are used for destruction, it is usually (except in cases of a mad will) done for some kind of ordering purpose, as one man's entropy loss can be another man's entropy gain. This is often exactly the case due to the fact that any ordering activity has to deal with the supply of low-entropy resources and with entropic waste: if one is ordering his domain in this world, he might very well appropriate the low-entropic resources of a neighbor, or throw his entropic waste into the domain of his neighbor. Many cases of conflict between people throughout history can be rightfully ascribed to competition for low-entropy resources.

Is It Physics?

To what extent is p-order a physical property? There is no question about it as far as the influence of a particles' field structure in the creation of molecules or crystals goes, nor about the role of gravitation in ordering the planets' movement. These ordering processes are well studied by the methods of physics, and are no less real than atoms or the planets themselves. The fact that physicists did not specify p-order as a property of an ordering field does not mean that there is no such property. But how do will and information fit into a discussion on the physics of human behavior or social life?

One way to deal with this question is simply to pretend, at least for the purposes of one book, that these partly abstract entities are objects of the physical world, and see how it may persuade or irritate the reader. Another way is to state that it doesn't matter. Indeed, the world exists undivided by departments of knowledge, and artificial traditional distinctions between areas of science are irrelevant for gaining understanding of the world. So, I will follow a path of logic and observation that will show, that in many ways will and information are subjects of the same physical laws as traditional physical objects. In partial justification of such a position I should remind the reader that information is probably the most abstract entity among those possessing p-order; yet it is precisely the theory of information that made it calculable in some limited way and demonstrated that use of the entropy concept in this area is fruitful.

CHAPTER 4: Measurement of The Immeasurable

Measurement of Order and P-Order

If p-order is a physical property, the question arises of how to measure it.

For practical applications measurement of a particular p-order can be done without too many difficulties if we measure p-order in action. One may suggest, for example, that in certain standard thermodynamic conditions the p-order of a crystal plane should be measured by the quantity of ions which can be added to the crystal by a unit of area of the plane in one second. One may connect the amount of p-order with the rate of entropy which can be lowered per second. Measurement of the p-order of a catalytic agent can be suggested along the same lines. Of course, we are talking about measurement by bulk characteristic without going into detail of the organizing ability of a p-order agent. Indeed, even in the simplest case of ordering potential wells we know that a potential well can be deep or shallow, wide or narrow, rigid or cushy. These qualities determine the ability of a potential well to organize particles and can not be measured with one parameter. The situation is similar to the measurement of order by one parameter only: if entropy goes down we know that order is increasing without knowing what kind of order is increasing.

Although a mainly qualitative approach is important for my discussion, I should note that the measurement of a p-order does not present a problem if there are ways to measure order itself. The problem is that in complicated cases we have no idea how to do that. In cases of the simplest types of order, like the order of soldiers in the rank and file or the order of boxes in a warehouse, we can describe it by single instructions like “each soldier occupies a certain square on the plat”, or “each red box follows two gray boxes” and so on. Accordingly we could introduce measurement of p-order in such cases.

But there is a great number of possibilities for ordering systems, whether of a set inanimate objects, social structure or sets of ideas. Of course order can be described even in the most complex cases. Complex molecules of protein can be described by a chemical formula or by a 3-dimensional model or a set of parameters. A machine containing many parts with a high degree of interdependence may be the subject of instructions on how to put the parts together. A text can be described by itself, or by a summary or review. But description is not measurement. Measurement and even a simple comparison of the levels of order of two various systems presents great difficulties, if measurement is possible at all. For two similar kinds of systems, let’s say machines of a similar function, we can see that one machine is simpler than another, so we may make a comparative conclusion about the level of order on the basis of the quantity of parts or the quantity of connections between parts.

This is nearly impossible in the case of different kinds of systems. Is the order of a certain position of pieces on the chess board higher than the order of parts in a lawn mower? We might take a simplified approach and compare the shortest way in which we can record chess positions and the position of parts of a lawn mower. Yet this way to evaluate order would deal with chess figures as if they were pieces of wood without meaning, without interconnection between the pieces’ fields of action. It also would ignore the fact that parts of a lawn mower are interdependent. In reality both the chess pieces on a board and the parts of a machine constitute a system, the complexity of which goes far beyond description by the naming of pieces and their coordinates.

Many questions about the order of different systems can be asked, but not many can be answered. Once we enter the world of complex order our expectations of simple measurement fail, and we must completely redefine our expectation of our ability to measure and be ready for unusual solutions which are far from being precise. The problem is so difficult that finding even rough and approximate methods can be considered a success.

Measuring P-Order of Information

Kolmogorov's method of measurement of the complexity of mathematical procedures provides an example of an innovative approach to the measurement of p-order. This method simply measures the complexity of a procedure by the length of the shortest computer program able to execute this procedure. In our terms, description of a mathematical procedure as well as the computer program is information that possesses potential order. Can p-order possessed by information be measured by the length of the message, similar to Kolmogorov's method?

Most likely this would be a very crude way, useful only for comparison of p-order in similar cases. What is more, in Kolmogorov's method messages are written in formalistic language in which every symbol presumably has only one meaning. Not so if we are dealing with messages written in a natural language: the meaning of words in most cases depends on the context. Still, in similar cases the length of the message can be a crude but useful characteristic of p-order. Take, for example, a case in which two companies try to sell furniture to be assembled by the buyer. A retailer might very well evaluate the simplicity of the assembly procedure by the length of the assembly instructions, in order to select the company from which he wishes to buy. And, of course, that retailer can make a dreadful mistake, because brevity of the text in natural language may reduce the clarity of the instructions.

Measurement of P-Order by Money

Will and information are used for creating order of an incalculable variety. In the absence of reliable methods of measurement, the amount of money paid for such activity in each case can give us a crude assessment. If $10 is paid to a worker for stacking one cord of wood in an orderly pile, $100 or so will take care of putting ten cords in order. At least in many cases it is an approximately proportional way to measure. It is also simple in comparison of similar cases. This is in itself a good basis for establishing standards of measurement as physical measurements in general should be proportional and consistent (duplicable).

One may argue that the worker received payment not for the abstract idea of ordering the pile of wood but for the actual energy spent during his work time. This is correct, the result of measurement is a mixture of payment for energy and organizing. We have to remember though that human energy itself has no value in economic activity if that energy is not properly directed by will, be it the will of a worker or of a foreman supervising the work. Ordering work requires energy channeled for performing certain tasks according to certain rules. In other words it calls for *informed energy*, and this is, I dare to say, the best description of manifested human will. At least I have not seen any better since Arthur Schopenhauer's attempt to put will on the list of the main psychological entities.[29]

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29 Arthur Schopenhauer, The World As Will and Representation.

Can this money method be used in more complex cases for measuring the order and p-order in economic activity? Not only can it, but it has already been in use for almost three thousand years since, reportedly, the Greeks of the Ionic Islands invented coins. Of course, a great variety of order and p-order can not be measured by one parameter, this is obvious and this means that measurement by money is unscientific and not too reliable. Yet it is reliable enough for people to pay money on the basis of this measurement.

To evaluate how good the monetary method is, let us formulate what we expect from a measuring method. As we saw in the example of wood stacking, this method works well in evaluating p-order in similar cases: payment is often proportional to the amount of matter to be organized. The price can also be higher for a more accurate performance of a job if more perfect order is desired by the employer. This means that payment for work reflects fine measurement of order: accurately stacked wood is more orderly than that which is stacked sloppily. This is to be expected. The amount of p-order is higher if the order produced is higher.

As to the precision of measurement, in a free market economy there are no set rules on the price of a given amount of ordering work. Therefore it can depend on many factors, such as location, type and weight of wood, the generosity of the employer or his own ability to do the job, and so on. The important thing is that on average, this type of application of organizing will has a certain price. The probability is very low that someone would perform this job in the U.S. for $2 per cord, or that someone would pay $50.

This method should be used with caution, it can lead to a paradoxical imprecision in some cases. If a scientist was paid, say $100,000, for creating an innovation in a computer system, does it mean that an order for 10,000 cords of wood equals the improvement in the order of the computer system? This and many other similar cases show us that measuring order and p-order by money can give reliable results mainly in more or less similar cases. What complicates it more is that a market does not measure the value of things, only prices and those prices depend on the level of supply and demand. Prices also depend on the value of money. Still, good or merely tolerable, this method is actually the only universal way to measure the p-order of will. More discussion about problems connected with this method is presented in the chapters on economics.

Qualitative Measurement By Vote

Another method is measurement by people voting without money; not just voting according to a defined procedure but in all kinds of ways, including opting to restrain themselves. For instance, if the majority of people do not kill it is a result of purposeful restraint. We may say that they voted against killing and thereby offered a qualitative (not numerically expressed) measurement of a certain moral norm which of course possesses p-order. Another instance of informal voting is following a charismatic leader. This shows us that charisma, itself a p-order quality, can be measured, although this measurement may not be expressed in numbers.

When people vote to approve certain moral values, or to give a mandate to a person to be a tyrant or a representative, the question of quantitative measurement does not arise unless there is a formal procedure for voting and we want to count the votes. In many cases voting is done informally, just by the acceptance of certain fashions in the design of houses and gardens or the acceptance of certain moral norms or a certain ruler by the majority. It is only a qualitative measurement but it is measurement nevertheless.

Voting by wallets in a free market is another matter, as it provides a numerical measurement of the value of labor, goods and resources of low entropy. How far will the analogy with measurement in physics hold in this case?

When physicists measure values in an experiment, they care about the precision of the measuring device, the qualifications of the technicians, and so on. Still, one measurement is usually not enough because there is no device that will give absolute precision. Physicists obtain a set of numerical results and then average the results according to certain mathematical procedures; so measurements in physics although often very precise are still only statistically precise.

Let us suppose that instead of trained physicists with a common understanding about scientific ethics and impartiality, we have many factions who are not impartial at all about the result of the measurement of, let's say, the constant of the polarizing effect of a solution of sugar. Each faction will measure this constant with its own equipment, operate with numbers its own way, perhaps even will cheat sometimes and reach results corresponding with its own interests. Nonetheless, if there are many biased factions presenting different interests, we might very well be satisfied with the average results of measurement.

This situation is not unthinkable in science, although not too probable in pure physics. Indeed, throughout the years we hear on the news that sugar or salt or other substances are bad for one's health, then that it is not so bad, then that it is actually good for all or some people. A different approach to the measurement of the health effects of sugar or salt achieves different results. Then there is the influence of different industrial or other interests on medical science. So science itself gives us an analogy of imprecise measurements that often can still be used for practical purposes. Again, if there are many researchers and all kinds of interests affecting the researchers' partiality, the results can be averaged and used.

This is precisely the situation with which we are faced when we try to evaluate the precision of measurement by money. There are many factions and interests on the market, some pushing the price down, some working in the opposite direction. If there is free competition among those interests, we have reason to accept the result of these biased measurements as a proper value of labor, goods and resources at a given moment, as economists understood long ago.

Of course, if there is a strong influence of powerful factions, say a monopoly or a criminal group or government, the results of the measurement will be distorted. A tyrannical government may dictate prices, but this should not affect our judgment about the monetary method of measuring order and p-order simply because the same government also can dictate distortion of the results of those scientific measurements.

This analogy of scientific measurements and measurement by money may provide the idea to revive an intriguing question that has bewildered economists, politicians and ideologists for at least three centuries. If in science there are two ways to measure values, one highly ethical, impartial and relatively precise, and the other by averaging the biased results of different factions, why is there only one way of measuring the value of labor, goods and resources, namely, by averaging the results of deals in a free market? Why not organize groups of trained, impartial and highly ethical economists and other experts, let them define the prices of everything, and stop the risky swings of the market that bring so much unpredictability in our life, cause an apparent waste of resources, and so on?

Many attempts to do precisely that have been made throughout the industrial history of our civilization. In so called communist countries defining prices was viewed not as a matter for arbitrary decision by this or that commissar, but as a scholarly matter: many formulas were created to define prices according to the Marxist labor theory of value, and then plenty of coefficients were used to correct the theoretical results thus obtained and make them more or less useable in practice. And even Soviet economists understood that this was not the way to define prices, as these pricing methods created numerous and unsolvable problems for the Soviet economy. In countries with a prevailing market mechanism of price generation, governments often interfered with setting or freezing prices on some commodities and many disturbing consequences in economic life were blamed on such interference.

So why did the “impartial” and “scientific” methods not work with defining prices? Is it because the science of measurement by money is not developed enough? Or are there no impartial people to do the job? The answer may be issued in two parts. First, government attempts to define or regulate prices are usually static, and this is one of the main attractions of it for those who try to establish the prices. Usually governments justify their interference by citing the need for stability. But economic life is not static; it changes every minute, along with peoples’ changing needs, their preferences, their creativity and so on. Price changes in a free market reflect these continual changes in the value of numerous objects possessing order and p-order.

The second and most important part of the answer is that the millions of factors can be evaluated only by millions of observers. The multiplicity of factors involved in evaluating the p-order of this or that commodity is such that no group of experts can take them all into account. The complexity of interdependence between the value of different kinds of labor, goods and resources is uncountable by any such group or computer, even though powerful.

Indeed, if measurement in physics by trained physicists is still viewed as the ideal for any measurement, look what they measure. No matter how deep they go into the micro-world, or how far they reach into the Universe, they are actually measuring very simple things. If they have to deal with more complex systems, they come out with some bulk characteristic that simplifies the system in order to make it susceptible to physical measurement. So the secret of the precision of measurement in physics is its simplicity. Naturally, as we go to complex systems any measurements become either more difficult to perform or less precise. And as we come to so problematic a task as measurement of the value of activity of the most complex system known to us—human beings—we have to be pleasantly surprised that we have results at all, namely monetary results and not worry too much about precision.

Without formulating reasons for it, humankind has produced a sophisticated measuring device for resources of low entropy, for order and p-order—the *vox populi* be it voting by money or by behavior. The precision of this device increases with the quantity of people involved in making the measurement. There are still many cases of rare or unique p-order to evaluate for which there are not enough people with wallets, be it a rare painting or the creativity of a rare brain. We have to deal with the under-pricing or over-pricing of rare commodities, and this too has an analogy in science: measurements concerning rare events are often drastically imprecise as in the case of a mass of rarely observed subatomic particles.

With such a sensitive measurement device as the free market we can treat p-order of human will and of economic enterprises as a quite real property of a social system. Still, I have to remind the reader that p-order is not a mysterious characteristic but rather the ability to produce order, and can be measured very simply each time order itself can be measured. The problem is the complexity of the many types of order that humans produce. As to the *vox populi* method of measurement of complex order and p-order, maybe it is only natural to entrust the task of measurement to those who produce and consume this complexity: to people themselves. After all, when an entomologist wants to measure the level of attraction of a certain chemical to ants, the only way he can do it is to ask the ants about it.

CHAPTER 5:
Order of Living Matter

Life is an enormously complex phenomena so I agree in advance that characterizing life from one or just a few points of view is too primitive. Yet, this is the human way to attack a complex subject of study—piece by piece. Extraposition of order and disorder looks like a simplified approach to life but it can provide clarification of some points about the connection of life with physical laws.

To enrich our knowledge of life, we should of course deviate from the simplified knowledge of order as a condition opposed to the spatial disorderly arrangement of particles. Life as a process requires one more dimension of order—order in time. Particles of living entities are of course arranged in space in orderly fashion, but among all possible orderly arrangements only those can belong to life which carry the ability of certain orderly behaviors in time: orderly arranged molecules of a dormant cell for example must, after activation, perform certain chemical reactions one after another.

Observing even the simplest mechanical devices we get an idea of the combination of spatial order and order in time. Parts of those devices are arranged orderly and once in motion, the device produces a chain of orderly arranged operations, be it cutting metal or stapling paper. These devices are programmed to do certain operations. For the last half century we learned much more complicated ways to program operations in time—through computers. Our knowledge of what a computer does and can do can be very helpful in the mental modeling of the processes of life (or it may influence us with its simplicity). I will start a discussion about the order of life with a reminder of the types of order achievable in inanimate matter.

Chemical Reactions And P-Order

In addition to crystallization, chemical reactions provide an example of ordering in inanimate matter. That is, in chemical compounds the bonds holding different kind of atoms together often are much stronger than in many crystals. The bonds are selective but often less selective than in crystals. Irregularities aside, ions in table salt crystals are waiting for ions of Na or Cl to join them for further growth of a crystallic cube. In chemical reactions each atom can enter into compounds with a variety of other atoms. There are certain limits and rules for creating stable molecules. Those rules are dictated by an atom's field structure. For example, Oxygen can join Hydrogen in a stable molecule of water only if there are two atoms of Hydrogen for each atom of Oxygen. Two atoms of Oxygen can also join two atoms of Hydrogen to form a less stable molecule of hydrogen peroxide. As we discussed above, this selectivity means that some idea of molecular order, i.e., some potential order, exists in the structure of an atom's energy field in the same way it exists for creating crystals, although the variety of implementations of this idea of order is much wider. One should not, by the way, over-estimate the power of these ordering ideas hidden in an atom's field structure. Obviously, atoms do possess p-order as far as the creation of molecules is concerned, but as a rule this p-order cannot manifest itself too far in space; an atom's field structure is selective usually as far as the closest association is concerned. The enormous multiplicity of molecular structures is not written in the structure of the field of each atom. Allowing some simplification, we can say that each atom defines the bonds with atoms which will be next to it, but generally speaking does not control which atoms will join those atoms that join it. One might view it as a hierarchy of ordering control: each preceding level of the complex order has the idea of possibilities for the next one or maybe two levels of ordering. This can be used as a way to illustrate what complexity is. Indeed, if from the first elements of the structure we could definitely or probabilistically predict what the whole structure will be, there would be no complexity.

As orderly entities, molecules, built from certain atoms, are characterized by lower positional entropy than a group of the same atoms without chemical bonds. This is clear from the fact that bonds in general limit the quantity of possible arrangements in space. In practice we rarely provide just separate atoms for the creation of molecules; it is done through chemical reaction. Molecules exchange atoms or break down and provide atoms for new molecules. This process is highly dependent on thermodynamic conditions: temperature, pressure, presence of light, and so on. A chemical reaction gives another example of two major tendencies in nature: the tendency of entropy to grow and the tendency of particles to reach minimal potential energy and create orderly structures.

Indeed a chemical reaction often produces highly organized molecules with lower entropy than the initial molecules. In fact some molecules can be very long, where many groups of atoms are joined together in a chain by chemical bonds creating highly orderly structures (molecules of polymers, like polyethylene or nylon for example).

What Is Not Yet Life?

The growth of crystal and polymer molecules, with its considerable reduction of local entropy, is the closest analogy of life's order we can find in the inanimate world. The orderly system of an atom's force fields on the ends of long molecules, are waiting for appropriate atoms to fall into the potential wells and reproduce a similar order in the next organized element of the molecule. This is a high level of ordering, but there is a consequence of the second law of thermodynamics: if there is a highly organizing chemical reaction going in our isolated laboratory tube, the entropy inside of that tube will increase. This means that highly organized molecules in that tube are surrounded with entropic waste: less organized matter and energy. In the following paragraphs we will discuss a main property of life from an entropic point of view. Before doing that, however, we need to state with certainty what is not life among highly organized system, of particles. (Assuming of course that high organization is an obvious requirement for the state of living matter).

With our illustrative examples, we followed the natural ordering processes from a simple potential well up to the creation of polymer molecules. In each example, the rules of the game are the same: local organization can be achieved but entropy around it is growing. There always has to be a mechanism of separation of organized matter from entropic waste. In the case of a particle falling into a potential well, such a mechanism is spreading thermal energy among neighboring particles or a radiation of energy. In the case of growing crystals, due to the evaporation of a solution it is spreading heat and water molecules in the outside air. In the case of growing polymer molecules in a laboratory tube the scientist must take care of separating orderly matter from entropic waste.

Any kind of such an organization is not life. Only then did life become possible when methods of separating order from disorder become part of the ordering process. This is a point where the second law of thermodynamics put absolute and indisputable barriers between life and non-life. As far as we can tell now, there could not be a shadow area between life and non-life: either a group of particles can or can not separate itself from entropic waste which is unavoidable when local ordering is performed. To achieve such separation, energy must be directed in such a way as to extract heat and disorderly matter from the area in which order had been achieved. It must be energy that knows what to do, namely, get rid of entropic waste. In other words, it must to be *informed energy—will*. Once this was achieved, it was the beginning of life and the beginning of the will of life.

Will is an entirely new type of order by itself. Until now we dealt with spatial order: order achieved in a certain point of space can, through the p-order of potential wells, create an order in the next point of space. Will includes potential order that unfolds in time, it is not just spatial, but functional organization. In fact it is a chain of potential order of higher and higher levels. This chain can be short as for the simplest life forms or it can be so long that it produces an impression of completely non-automated behavior which we call the exercise of conscious will.

The will of living systems also reacts to outside conditions, can adapt to it, but even with the clever description of functional organization provided by system's theory we still have no complete picture of what will is and what it does.

For us in this discussion though, it is enough to note that will is informed energy as I limit myself by a description of order which can be characterized by a main bulk parameter—entropy. We have to remember though that entropy, as far as functional organization goes, must include a new dimension—time for the characterization of life processes. Life itself can be characterized by saying that the entropy of a life unit has to be kept low and to be protected from forces which try to increase it.

Together with the appearance of informed energy—will— the concept of goals appeared in Nature, something inanimate matter didn't have. The separation of order from entropic waste is the first goal of life. Despite many available possibilities to achieve order, and despite the actual achievement of order, inanimate matter does not have the goal to achieve that order. It even may have the ability to preserve that order as in crystals, but no goal to do it.

Where there is a goal, there are values and a readiness to pay which means to give up certain values for achieving that goal. Will, goal and values—these characteristics of life had to exist even in the simplest forms of life. As we see, these characteristics got highly developed in social life.

The turning point of matter in becoming living matter—the moment when will of life is born—is still a mystery to science. Over the last century genetics and molecular biology penetrated very deep in understanding the molecular basis of life; yet we are still ignorant as to what is the exact border between life and non-life. There are some expectations that a still-undiscovered physical law will account for the origin of life. In a way, waiting for the discovery of such a new law is a continuation of the traditional approach that there must be something special, if not divine, about the creation of life. First there was the belief in divine interference, then the vitalistic hypothesis, now (among some scientists)—the hope for a special law of nature to open the door from the kingdom of dead matter to that of the living.

From my point of view which I am elaborating here, the crucial point of matter becoming alive is not the ability to order itself, as potential order exists in a field of atoms and molecules, but the ability to separate order from entropic waste. The task for science is to uncover and identify those conditions that are necessary for an inanimate organized system to become self-cleaning, able to separate itself from entropic waste. Despite the fact that all we know is carbon based life and also genes based life, the main property of life is organization and separation of order from disorder. Our mind has to be open to other chemical possibilities for achieving that.

Main Property Of Life

Many definitions of life are known that are rather descriptive of life as we know it, with its characteristics of chemistry, behavior *et cetera*. My goal is to emphasize the main property of life from the point of view of the entropic behavior of matter, property which is dealing only with an ability to sustain and develop order, and would be indifferent to such factors as the type of chemicals involved or even the type of matter. [30]

Unavoidable behavioral properties of living entities that are essential to life itself can be stated as follows:

1. The first requirement: a life unit is a group of matter particles that is in a low entropic state in comparison with the surrounding matter—the “low entropy rule”.

An obvious comment on this point is that groups of matter particles should be large enough to become a complex system. Yet I am not inclined to include this requirement as the complexity of the particles’ fields theoretically may provide for the complexity of living entities regardless of how large the actual number of particles is.

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30 Matter in the usual sense: atoms, molecules and their combinations. There is not enough knowledge about sub-atomic particles to be sure that they cannot, in certain thermodynamic conditions, be involved in a life-like state. Indeed, from what we know about their fields they definitely carry p-order and they may be highly organized. So, if the idea of order is there, in a field of those particles, there may be other ways for the particles to be involved in highly organized states, not just in the form of atoms known to us.

Crystals and polymer molecules, as well as bacteria and multi-cell organisms, meet this first requirement. I stated above the necessity of life to be able to be active in separating itself from entropic waste. Activity, of course, calls for energy, so the second requirement for matter to be alive is:

2. A life unit is a group of matter particles able to direct energy into an entropy-lowering process—the "informed energy requirement". In other words, life must have the will to live, because at the moment when the ability to have an entropy-lowering activity will disappear, the forces of the surrounding chaos will take over and life will be no more.

I am talking here only about the *ability* to direct energy and not about the active directing of energy. As we see from many examples of dormant life, the mere ability to use energy for lowering entropy is a sufficient requirement, although the manifestation of life (actual living) is possible only through the actual use of that ability.

This cautious wording covers both: life and the messengers of life. Indeed, seeds, spores and maybe viruses, are not actively living creatures when dormant, but they definitely don't belong to inanimate matter. Frozen organisms, with their metabolism put completely on hold, can be viewed as being in the same category: the manifestation of life is not there, but life is. So I emphasize the order and the p-order of life as primary characteristics. The processes of realization of that p-order (and in fact the process of the creation of new p-order) are left outside of the main requirements, and constitute consequences of the existence of a life entity and depend on thermodynamic and other environmental conditions.

The origin of life is still a mystery, although plenty of hypotheses have been suggested. Scientists are searching to find physical entities which may be recognized as transitional between animate and inanimate matter. All we know is that there are inanimate physical entities with low entropy and some potential order as we discussed: crystals, polymer molecules and so on. In fact, polymer molecules of a very high complexity are created, but complexity itself is not enough for being alive without satisfying the informed energy rule.

On the other side of the fence there are viruses, which are cleverly packed polymer molecules of RNA or DNA. Although they lack the ability to transform energy, by itself in an entropy lowering process, they contain information that forces (or permit?) appropriate living cells to do that work for the viruses.

Our discussion does not depend on the chemical characteristics of known forms of life. One day we may discover—be it in outer space, in a laboratory, or somewhere on Earth—that the chemistry of life in different thermal, pressure or gravitational environments may be based on an element other than carbon, yet may still be life as long as it is able to reduce the entropy within itself by means of energy transformation.

Some Consequences of the Main Property of Life

• The manifestation of will follows from the second law of thermodynamics[31] as energy expenditure is a must for the local lowering of entropy. An acting life unit must consume energy due to the first law of thermodynamics: energy is spent by a life unit to lower entropy, so it must come from somewhere.

• For sustaining and manifestation of life as local entropy-lowering activity there must be isolation from a

31 Here I take as an established fact that matter, whether inanimate or alive, follows the Second Law. The question is still under discussion as far as living matter is concerned.

high entropy environment—this follows from the second law also.

•Will augmentation is a property of life that is a secondary consequence of the physical laws. Theoretically, one can imagine will without a desire to expand; a will of life satisfied with sustaining. Such life units would not survive for long though, due to attacks of high energy particles and other factors which destroy order. As it happened, will in the world of living creatures expanded in both directions:

1. individual will expands to assure the success of life manifestation;
2. the living world expands to produce more and more sophisticated creatures able to manifest more will. As a result the will for life (and p-order) on Earth was growing.

•Although we don't know any life forms without the ability to reproduce, theoretically a life entity can exist without such an ability. How long it will manage to exist in a given environment under attacks of high energy particles which eventually will alter genetic information, is another matter. We do have examples of such life in some cells of multi-cell organisms that do not reproduce.

Will of Life

The informed energy requirement lends a physical meaning to the old concept of will. In the case of minimal manifestation of life, i.e., sustaining low entropy despite the entropic attacks of the outside chaos, will would be directed at the preservation of order within the living entity, and this includes consuming energy and matter.

The more usual existence of life units is to be involved in a process of building another unit. Be it bacteria or part of a multi-cell organism, cells consume energy and use this energy to find and process more food and to organize chemicals from food into new living cells in the reproduction process. They also use energy to get rid of waste—particles of disorganized matter, not needed for reproduction or further energy extraction.

The crucial distinction between the manifestation of will and any inanimate manifestation of energy is that will has a goal: to lower entropy, at least within the life unit. If there is the goal, there is value, and also a hierarchy of values depending on what is more useful or important for achieving the goal. The will of a living cell is informed energy, and this creates a problem for the anatomy of life that is unknown in inanimate matter: energy and matter come and go, but the information responsible for directing informed energy stays with the life unit and there must be a place for it to be stored safely and to be defended from the outside chaos. This stored information manifests itself in directing the production of certain chemical agents that perform certain chemical reactions. This is a manifestation of will, in the form of a chain of commands on how to achieve certain life sustaining goals; and it is natural to call the group of commands that achieves a certain goal "automatism of will" for this or that goal (automatism simply because it automatic or programmed, and not supposed to depend on making a decision each time).

Will, as the ability to direct energy, should not be confused with conscious will, which we humans possess and can direct according to our own decision and which, for that reason, we consider to be free will. The will of a living cell most likely lacks freedom, as there are many immediate goals merely to sustain life. This is why it is reasonable to assume that ways for directing will are programmed in the genetic material of a cell, and the manifestation of will is regulated by automatisms.

Universality Of Life Mechanisms

The informed energy that a living creature uses to lower entropy within itself, or even around itself, is similar to what Schopenhauer called the will of life. This author did not go into scientific detail, but his observation of human behavior turned out to be valid for any form of life due to the universality of life mechanisms.

This is one of the most amazing things in observing the development of life: certain attributes of life are the same for the simplest and for the most sophisticated life forms. The apparent reason is the similarity of goals and tasks for living entities of any size or evolutionary level: the struggle against entropic attacks from the outside world and cleaning its own domain. Will and many automatisms of will—which can be observed on the level of separate living cells—also characterize the behavior of animals and human beings and human society. To name a few examples: finding and processing food, extracting entropic waste, competing for more favorable environments, etc.

This similarity in the will automatisms of living creatures of different levels of complexity can be viewed as Nature's preference to economize, not to invent new mechanisms if existing mechanisms can be used. Or it can be interpreted as evidence that once found, mechanisms of sustaining and developing life are perfect—or at least serving the purpose sufficiently—so there was no evolutionary pressure to try other mechanisms. At the same time, this similarity of automatisms on different evolutionary levels is the direct result of the physical requirements that living creatures have to follow in order to exist, and the second law is one of those requirements.

The following is an example of how one automatism of will, developed no doubt in the very beginning of life existence, still characterizes behavior not only of separate cells, but of organisms—and even human society. It is probably strange for the reader to find out that the basis for our desire to take a shower as well as for the existence of our country's border patrol and immigration agency is the same, that is, the second law of thermodynamics, but let's follow the reasoning.

Insulatory Automatism

As mentioned before, living matter must have ways to isolate itself from the outside chaos and clean itself from the internal production of disorganized matter. In fact, this is a restriction directly imposed by the second law of thermodynamics: a life entity is not an isolated system in the thermodynamic sense, as it consumes matter and energy from the outside world, and is ejecting material and entropic waste into the outside world. In order to exist as a lower-entropy entity, it must be separated by some field or material barrier so it can keep low entropy inside of that barrier as a trade for increasing the entropy of the outside world. In this way, the second law is not being violated, and local reduction of entropy of the living creature is possible.

This need for insulation eventually created mechanisms that affected the behavior of any living structure. In a way, this is similar to what Ilya Prigogine noted about dissipative systems in general, which are physical systems in a state of instability: "The possibility of a dissipative structure depends on boundary conditions, but they themselves are modified by the occurrence of dissipative structures".[32]

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32 Ilya Prigogine, "Unity of Physical laws and Levels of Description" in *Interpretations of Life and Mind*, Marjorie Green, ed. 1971, p.12.

This is one of the main attributes of living creatures: to be isolated from the orgy of the high entropy of the outside world. Life can grow, multiply and change its appearance in future generations, but it cannot mix with disorderly matter as it would lose its most distinctive characteristic: lower entropy. If there is an unavoidable necessity to be insulated, there must be a package of genetic programs of how to achieve that, which I call the Insulatory automatism of will.

Acquiring Insulatory automatisms of will is one of the first necessities of life and also one of the first results of will augmentation in action. Indeed the Insulatory automatism is actually a struggle for territory, for the space occupied by the life-unit itself. This struggle is usually quite selfish: a living creature that has p-order is advancing in space not just against high entropy but against everything which is not its own order, except for cases of cooperation with some other life units. Lowering entropy in the world as a whole is not the first goal of living creatures. The state of the world, or the state of life in general, or the survival of one's own species, as a rule is not the concern of a living creature. Its narrow but powerful goal is to lower entropy within its own individual domain, be it that space surrounded by a cell's membrane, or its own skin, or a wider space that includes part of the outside world somehow consumed by a given living organism or used by that organism alone or cooperatively with others.[33]

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33 This observation is actually instrumental in clarifying the old controversy about super-organisms discussed by author of *Creative Evolution* Henri Bergson: should a bee hive be viewed as a society of organisms or one super-organism? From the point of view of entropic isolation we can say that it is both, as bees have an automatism to insulate their own body from outside chaos, and also defend the hive from the invasion of higher entropy.

This necessity for isolation is universal for any life form. In life on Earth now known to us, the insulatory goal is achieved by a number of insulatory mechanisms. Here are some examples of how the Insulatory automatism is functioning and malfunctioning:

A cell's membrane protects the inner sanctum of the life unit from invasion by unwanted outside molecules. It is not perfect. Viruses can cross it, and many substances can be used for medicinal purposes thanks to this imperfection.

Skin protection. There are receptors in the skin to send signals for the protection of the skin of animals. There are also cleaning instincts, which are part of the Insulatory automatism of will. The imperfection of skin protection is well known: insects bite us, bacteria enter through tiny scratches, and so on. This makes more work for the next defense line: the immune system.

Immune system. As organisms become more complex, specialization in cell function developed. There are soldiers in multi-cell organisms who literally kill invading living cells and clean the system from unwanted chemicals.

Social protection. There are guards in bee hives and ant colonies. Small invaders are killed and thrown out. Mice who get into the bee hive are too large to be thrown out, so bees kill them and cover the corpse with wax, which serves as an insulating barrier. Human society used, uses or wants to use walls around cities, radar and fighter planes against air attack, lasers against rockets, immigration restrictions by law, and so on. For the defense of the low entropy of social organization from within, there are police and prisons.

This list includes just a few of the countless mechanisms of the insulatory activity of life units, and all of them are a direct consequence of the second law of thermodynamics: if we are to lower entropy in some area of space we have to insulate this area form entropic invasion.

Reproduction

High energy particles, such as cosmic rays, that often destroy elements of the structure of living cells are examples of physical entities from which there is no defense in the living word known to us. The Insulatory automatism is powerless against such an invasion simply because it operates by molecules whose order can be destroyed by the high kinetic energy of those particles. This destructive invasion alone would be enough to bring to an end any life entity after some time, similar to the gradual destruction of messages on computer disks by high energy particles. There are mechanisms thanks to which a cell can repair damage, but their effectiveness is limited. Living creatures will die sooner or later, as there is no defense against stochastic attacks of high energy particles.

So there are actually only two ways life could exist on this planet: by constant origination from inanimate matter or by reproduction. Apparently the first possibility has not been observed by scientists.

Reproduction is a convenient way for life to survive the damage from entropic attacks, whether from cosmic rays or fluctuations in the environment. I want to emphasize that reproduction had to develop as a compensation for the insufficiency of Insulatory mechanisms, namely, the inability of life to protect itself from attacks of high energy particles. In this sense, reproduction is a consequence of the second law of thermodynamics.

Order In A New Dimension

Life introduced a new type of order: order in time. In our discussion of the behavior of inanimate matter we saw two types of disorder that affects the thermodynamical state of matter: positional and momental with corresponding two parts of entropy. There could be positional disorder with chaotic placement of molecules or there could be an orderly arrangement like in crystal. As to momenta of molecules, there could be chaotic movement or movement in a certain direction which constitutes certain order in movement. Living matter in addition to spatial order utilized a new type of order—the sequence of events prerecorded in memory storage.

The behavior of inanimate matter is not completely alien to a certain sequence of events.[34] Planets rotate around the sun and electrons move with periodicity in the field of an atom's nucleus. Ice in a comet is melted as the comet is getting closer to the Sun and then freezes again. There are periodical chemical reactions known. Such a sequence of events occurs over and over but they are not prerecorded, they just accrue due to the repeating occurrence of circumstances and due to mechanical and other laws.

In living matter, order in time is an essential part of creation order. The simplest way to imagine the role of time in life processes is to compare it with a computer program. At least it is how contemporary molecular biology pictures the way a sequence of genes is giving commands to chemical reactions which are the building

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34 Behavior of inanimate matter as it is observed in natural conditions is under discussion here. In a laboratory or factory inanimate matter can be organized in time in many fashions but this is the result of human interference.

blocks of living cells. But all we know is that organization in time is essential for life. The exact mechanisms of this organization are still waiting to be uncovered.

CHAPTER 6: Intrusion in Economics

Justifying Intrusion In Economics[35]

As ordering the world is the destiny of living creatures, it is natural for me in this book to analyze different kinds of human ordering activity. Unlike most of the creatures who affect distribution of the entropy of the world mainly by lowering entropy within their own body, humans extend their ordering activity far beyond the limits outlined by their skin. This activity reaches areas outside of their immediate livelihood and even goes outside of our planet. A substantial part of this ordering is economic activity which means the production, consumption and exchange of low entropy entities which can be characterized by *value*—a quality unknown in the inanimate world.

There are two interconnected questions society poses before economic theories. First "how it is?" as far as production, consumption and exchange goes. Second, "how it should be" if we want a firm or nation to perform satisfactorily within existing constraints and with certain goals. Behind both of these questions is the main one:

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35 I am very grateful to Aron Katsenelinboigen of Pennsylvania University for two decades of discussions on a variety of subjects including the connection between science and economics and his deep concepts of indeterminism and aesthetic methods in economics. I have no doubt that his concept of a system's predisposition greatly influenced my thinking on potential order. I am also grateful to Gregory Freidin of Stanford University for general discussions on my approach.

what constitutes value and how to measure it, be it value *per se* or value in exchange.

The first question arises because economists didn't build the economy, it was created and was functioning for millennia without the help of economic theories, so obviously there is something in human nature that directs people to produce, exchange and regulate their consumption and altogether it constitutes a good object for study and a good test for economic theories. Human economic activity despite being complex and multifaceted, shows certain patterns invariant of the type of products, taste of consumers, cultures and other traits of people. These common traits of economic activity give theorists the idea that there are certain trends governing our economic behavior. It was reasonable to assume that such trends would directly follow from supposed laws of basic human behavior which are very complex and largely unknown. There was no other realistic choice for economists as to make certain assumptions about human behavior despite the fact that such assumptions are usually crude, simplified and often influenced by the political beliefs of this or that economist.

The danger for the rulers of society who would take the conclusions and predictions of economists as guidance is obvious: due to the simplifications of behavioral assumptions, an economists' conclusions and predictions are not about real people but about anthropoids invented by the economists. With time the mental shape of those anthropoids is changing as new economic theories are introduced but they are still only distant relatives of real humans. As a result, the overall success of an economists' answers to the first question can be compared with the early stages of astronomical knowledge when people could predict sunrises and sunsets but not eclipses.[36]

The second question "how it should be" is not a complex one if asked about a limited set of variables. Given certain market conditions, economists can prescribe certain productive behavior of certain firms in an approximation of the rational behavior of the economic actors. Society wants more though, it wants economic theory to guide the economic and monetary policy of a whole country if not the world. In this task problems are mixed with those of the first question and the success of the answers depends on how realistic is the model of collective behavior which is the foundation of this or that theory.[37]

Let us look into the epistemological structure on economic theories. There are

1) shaky foundation: assumptions about human behavior

2) intellectual constructions of variables and functions representing specifically economic behavior

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36 Early in this century quantum mechanics came up with the idea about the effect of measurement on the physical system. In economics we have a much stronger influence of measurements and theoretical interpretations of economic events on a subject of study. Economists do not just study society, they literally participate in developing the course of economy simply by informing people what is going on. In such a situation of strong feedback, the goal of economics as a science might be not to predict eclipses (crises), but warn about the possibility of such in order for the economy to avoid it.

37 It would be fair to note that there could be a professional bias among many theorists in economics toward increasing government regulation of the economy. Indeed, regulations increase the numbers of solid connections of theories with reality. Even if government regulation often is not followed by people to the letter, it is still creating more visible order in human economic behavior than an open sea of choices.

3) mathematical struggle to solve connections between said functions and variables.

The second epistemological layer is actual economics. Observing how clever the economists were in building this layer, one may conclude that economics would be a real science

— if it would be provided with reliable knowledge about human behavio;

— and if it would be given ways to deal with complicated mathematical problems which arise in solving economic models.

The reality is that economists are dealing not only with embryonic knowledge about human behavior but also have to simplify that already primitive knowledge in order to make their models mathematically solvable.

The inquisitive reader probably noticed that in the list of epistemological levels above one is missing: figuratively speaking, the ground was not leveled before the shaky foundation of economics was built. Indeed, if we don't know enough about human behavior, we should at least find solid points in physics and biology which would put limits to our freedom of assumptions about that behavior.

My goal in this discussion on economics is to work on this zero epistemological level and show that there are certain limitations which physics imposes on our assumptions about human behavior.

A Life Unit As A Heat Machine

As noted earlier, the concept of entropy was born out of the study of heat machines as physicists were studying ways of squeezing out the maximum useful energy from thermal processes. A life unit behaves as a heat machine as far as the basic manipulation with energy goes.

Usually heat machines work cyclically, repeating the same process over and over. The most familiar kind is in an automobile: it uses the explosion of the fuel-air mixture in the motor's cylinder which produces high temperature and high pressure gases inside the cylinder. The gases move the piston, become cooler and go to the exhaust: part of the energy of the disorderly movement of molecules inside the cylinder is transferred into the energy of orderly movement of the piston. We see local lowering of entropy here: the energy was spread among molecules flying in different directions—high entropy—and then a portion of that energy was given to particles of the piston which is moving in a certain direction—low entropy. Local reduction of entropy by a heat machine is usually not emphasized in a discussion on thermodynamics but in fact, this is why we call such devices machines.[38] They are transferring disorderly thermal energy into the energy of orderly movement, be it mechanical or electrical. A device which just lets us use thermal energy as such we don't call a machine, we call it a heater.

The second law of thermodynamics tells us that there is an energetic cost of such local reduction of entropy and indeed, some portion of the chemical energy stored in fuel goes into the outside air in the form of heat. This entropic waste is similar to that of a living creature—entropy of the surrounding space increases due to the work of a machine or the activity of a creature.

We can write an equation for the balance of energy for a heat machine:

$$E_f = E_u + E_w$$

Where E_f—energy extracted from fuel during burning, E_u—useful energy and E_w - wasted energy which goes to the environment and which is our payment for the local

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38 This word is believed to derive from the Indo-European root *magh-* and connected with ability and having power.

reduction of entropy. The level of waste of course depends on how effectively fuel is used in this machine but the entropy law puts a limit on what we can do to minimize it.

This equation—balance of energy —is the result of careful work of physicists of the nineteenth century who established the first law of thermodynamics: energy can be transferred into another form, can be lost for us through radiation or spreading heat, but it does not disappear. Thanks to that law we can write the balance of energy for any process.

Entropy is another story. There is no conservation of entropy, so we can not calculate the balance of entropy. Following the second law, we can only write the inequality for the change of entropy which in the case of an isolated system with a heat machine inside is

$$\Delta S_u + \Delta S_w > 0$$

Here ΔS_u stands for the local reduction of entropy, and it is negative, ΔS_w stands for entropy's gain as result of the machine's work. Entropy of the whole system grows despite the local reduction of entropy. From the energy balance we know that there is a payment by energy for the local reduction of entropy. But, generally speaking, we can not calculate the amount of that reduction of entropy knowing the amount of payment by energy—it depends on the efficiency of the machine and its construction. This is the tricky part in evaluating the energy-entropy effect of a heat machine and it is analogous to the difficulties of evaluating the energy-entropy effect of human labor: the same amount of energy spent by laborers can create different levels of order as the result of their work.

Where Does This Analogy End?

We can see now the similarity between the work of a heat machine and living creatures. The machine consumes energy in the form of fuel, and spends it for transforming part of it into “organized” energy, performing local reduction of entropy, and sends entropic waste into the environment. A life unit consumes energy, spends it to reduce entropy within its own domain or to organize something in the outside world, and spreads entropic waste into the environment by radiating heat and extracting material waste.

As with a heat machine, we can write the energy balance for the activity of a living creature. In fact in the last decade the popularity of weight watching made the knowledge of energy balance almost as common as balancing a checkbook. Data on the energy content of different foods is part of food labels and the approximate tables of energy expenditure during different types of activities is well publicized. From these tables everyone can see that brain work takes very little energy.

But it is exactly brain work which is responsible for the ordering component of human labor. I will call it the *low-entropic component* of labor and this term in further discussion stands for everything in human economic activity except energy—organization, information, initiative, planning, innovativeness and so on. And here the analogy between thermal machines and human creatures ends: both consume energy from the outside world, be it food or gasoline, both produce useful organized energy, both are lowering local entropy and both produce entropic waste. But in machines all these functions were set by those humans who invented and built the machines. Humans even in the simplest operation of producing useful energy, like turning the wheel of some mechanism, are guided by the brain so the informational component is there. It means that counting only the energy balance in the evaluation of human performance can be done only in cases of the simplest human work when the informational component in negligible. Yet, society did find ways to evaluate even the most complex intellectual work.

We see a gap between the physical evaluation of work—useful energy produced, and the economical evaluation of work—salary paid for work which is a combination of energetic and low-entropic components. My goal now is to see when and to what extent physical evaluation can coincide with economic evaluation.

For this we have to define economic behavior and discuss the simplest kind of such behavior.

What Is Economic Behavior?

We should look for the beginning of economic behavior no deeper than the simplest forms of life, leaving any exchange of matter and energy between objects of inanimate matter to traditional physics. In the manifestation of life of the single cell we can see the basic elements of economic behavior which include the consumption of energy and organized matter, production of organized matter and information, choice of what to consume and what to produce.

The goal of a living entity is to be. Where there are goals there are values. For acquiring those values certain actions are performed and certain energy spent which can be viewed as *payment by energy* for those values. It is not important for this discussion if those actions are completely predetermined or are the result of conscious choice.

There are two major classes of payments by energy which a living creature makes in order to acquire and incorporate values: internal and external. To acquire oxygen we contract the muscles of the diaphragm and spend a certain amount of energy— this is our internal payment for oxygen. To get nutrients from grass, a cow has to spend energy to chew, swallow and so on—this is the cow's internal payment for food. In this and similar cases payment is made by spending informed energy—will, be it the automatic will of organs or the conscious will of a creature. As long as the desired object of value is right there for the creature to consume, this kind of payment is internal and it is for biophysics, not for economics to study it. Of course some major rules are common for biology and economics: if the creature will spend more energy chewing food then acquiring energy from that food, the balance of energy will be negative.

Any external payment for acquiring needed resources can be viewed as an economic action and making such a payment in exchange for the desired values constitutes an act of economic behavior. Note that value and payment are valid characteristics even if there is no exchange between creatures but only with the environment. Value is a characteristic of anything which is needed or helpful for sustaining and the manifestation of life no matter how multifaceted that manifestation is. In the case of the simplest economic behavior, payment is the creature's energy expenditure for acquiring values.

Internal Reserves

For the possibility of economic behavior there is one more property of living creatures we have to mention: internal reserves. These reserves can be larger or smaller, allowing a creature's life manifestation for shorter or longer periods of time between acquiring portions of necessary resources. Without such internal reserves a creature would be a trivial machine processing certain resources. In other words, in order to be part of economic life we need to be alive for the duration of time which is needed to make a deal (act of economic behavior) be it a deal with the environment or with another creature.

Internal reserves do play an important role in normal economic life: often our bargaining position is stronger if the reserves are larger. In an economy as whole, reserves of resources of people, factories and countries influence prices. In fact, the theory of marginal utility is based on the fact that we do have reserves, be it internal or external.

Internal reserves actually bring the element of time into economic behavior. How much time we have in order to restore our reserves before they will become dangerously depleted, determines to the large extent how much we are ready to pay for resources. To some extent the reverse is true: by restoring our internal reserves we are buying time of life during which we will be free of the immediate worry about the depletion of reserves. From this point of view, we are in a much better position in life than a cow on a farm: we don't have to chew grass almost all the time as our internal reserves allow us to do other things in life than just to fill the burner of our heat machine. A generalization is in order here: external reserves play the same role as far as the time element in economic behavior is concerned.

Except for keeping itself warm, the human body generally does not get energy directly from the Sun as plants do[39] or from any other direct source of energy. Energy comes with food together with material components needed by humans and both are stored as bodily reserves. The availability of reserves is cleverly structured: nature provided us with few lines of defense against depletion. Our metabolism is such that energy is taken first

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39 There is a minor direct use of the energy of sunlight in some chemical reactions within the body, the synthesis of vitamin D for example.

from short time storage—usually carbohydrates, then from those cells in the body which specialize in storing fat, after that from muscle tissue and only as a last resort from vital organs. This list of physiological mechanisms in using reserves shows, by the way, that the need for energy restoration comes first, and only after considerable exhaustion of the reserves a healthy body needs restoration of the material components of the body. This provides justification for the simplified treatment of food as energy intake which I use below.

In pre-human economic behavior energy reserves vary in size from very little among one-celled creatures to considerable size among multi-celled organisms many of which have specialized cells for keeping reserves. Being a crucial part of the life sustaining mechanism, collecting reserves is not a purely mechanical ability of an organism. It is controlled by physiological mechanisms and in animals it is surrounded by a complex set of instinctive behavioral rules. Collecting reserves is good but not always good, as additional body weight can affect speed of movement, sexual attractiveness and bodily adroitness in general. Too big reserves increase the chances of passive survival, but decrease the chances of success in the active struggle for survival. Western economics produced the important concept of marginal utility which expresses in economic terms the discovery made by evolution: enlarging reserves must have its limit. As a result, the desire of an economic actor to enlarge collected reserves diminishes with its size.

As to external reserves, evolution experimented with it long before us: in the animal world some animals have a territorial instinct and the ability to defend their territory as a source of resources, and some species practice storing external reserves in the simplest form of hiding food. Humans in addition to guarding their territory, invented the collective guarding of stored reserves and then legal protection of it. This invention gave life to real economic relations as we know it.

Reserves And Entropy

From the entropic point of view, collecting reserves means lowering entropy as far as system M_E of eatable molecules is concerned. Indeed, molecules, which can be used by a creature as food, from the point of view of that creature, are spread randomly in the world. When a creature finds those molecules and then consumes and stores them in certain cells of its body, entropy of the system M_E decreases.

This is one more example of the subjective nature of entropy as far as the choice of elements of the system goes. Indeed, eatable molecules within the body of a mouse are very well organized there and from the "point of view" of the mouse, do not need any further decrease in entropy. Yet, for a cat those molecules are part of system M_E—catching and consuming the mouse is a subjective act of lowering entropy on the part of the cat.

The word "subjective" is primarily used in relation to human perception. The observation above shows that any creature decreases the entropy of system M_E. This means that any life form is subjective in its "point of view" about the world. The words "point of view" are not connected with the ability to view anything or with the ability to have an opinion. It expresses the fact that any life form is *subject* to certain activity in relation to the world. As such, a creature has the natural ability and inherent drive to keep the entropy within lower than outside its domain. It also has the ability and drive to organize the world. The simplest way for any creature to organize the world is to lower the entropy of system M_E or to say it simply, eating. Subjectively as it is, each living creature be it bacteria, plant or animal is the center of the world and the world's point of reference as far as the level of world organization is concerned. For a scientist who is experimenting in biochemistry, for example, his activity is the point of reference. Destruction of some living creatures for the sake of his work does not make the world less organized from his point of view. From the point of view of a fangus cell which is destroying a manuscript of ancient genius this destruction is also organizing the world.

This of course is true about collecting any reserves, internal or external: acquiring property in human society is lowering entropy in a system of things which can be considered as property. This entropy lowering activity is subjective too: from the point of view of an ignorant observer, when things are in warehouses they are better organized than when they are spread among consumers. Actually, the subjective view of consumers in this case is in agreement with the objective judgment of what is more appropriate for organizing the world: human property usually carries a certain amount of p-order and that p-order can hardly be realized if things are remaining in the warehouses.

CHAPTER 7:
Purely Energetic Model

Balance of Payment

Now we will revisit the discussion about the "early and rude state of society" which helped Adam Smith to introduce his labor theory of value. In fact our task now is even simpler than his, as he was preoccupied with human economy and defined *value in exchange* based on the quantity of labor. The following development of economic theories showed that value in exchange is much trickier to explain. Yet, the labor theory of value and its variations was used in economics for a long time and is best known from Marx's use of economics for his call for social revolution. This simplified theory of value became the ideological basis for the Russian revolution and as a result, for the creation of the socialist economic system in the Soviet Union and some other countries.

Many faulty theories in human history had some core of truth in them and so did the labor theory of value. The dramatic role of this theory in human history was the result first of inadequate generalization and then simplification to the extent of political slogans. In a way any theory is at risk of playing such a dramatic role after such a kind of treatment.

As Western economics started with this theory, I find it appropriate to begin my discussion on price with showing that in certain conditions this theory is quite correct namely when the low-entropic component of human activity is economically negligible. Then of course we will see that such conditions practically do not exist in human economy.

I will limit myself with a discussion of the energy exchange of a working creature only with the environment. Such a simple kind of economic behavior provides the advantage of the possibility to discuss physics and economics at the same time and practically without the interference of psychology which can make any theory rather fussy. This means that we will be able to see the physical foundation for the basic principles of economics.

This simplification of the *purely energetic model* will not affect the validity of my conclusions. Indeed, in real economic relations low-entropic factors play an important role because work and goods always carry a certain amount of order and potential order. Information about better methods of work i.e. the potential order of knowledge often saves the energy of laborers even in a primitive economy. In a well developed economy information and equipment is far more valuable for the overall performance of economy than muscular work. But if we discuss the simplest type of work when every creature has the same information, the low-entropic component can be discounted as it doesn't play a role in the relative value of a creature's input in the economy.

Let's say that the internal reserves of some creatures are large enough to sustain life for a number of days. To get daily food the creature digs out N roots a day with the energy content—value—of each root equals f. Work for digging each root equals w units of energy. We assume that the food is consumed at once after being dug out. Let's forget such factors as the need for energy and matter for the growth of an organism, reproduction and dancing after the work day. Still, being alive takes energy and that energy equals L per day.

We don't need to specify what kind of roots the creature is digging in our purely energetic model. The assumption is that the nutritious content of the roots provides for all the needs of the creature's body, not just energy, so we can discuss only energy without taking into account other useful properties of food which are attached to consumed energy.

Here is the daily balance of energy after digging N roots and consuming them, in this case when internal reserves are left unchanged:

$$N f = N w + L$$

This is pure physics: we can write the balance of energy for any physical process, be it the collision of billiard balls or the melting ice cubes in our cocktail. In fact this is the same physics which was already under discussion as we talked about heat machines:

Incoming energy = work + heat loss.

The heat loss L in this equation shows how much energy is spread out into surrounding space. From a purely energetic point of view our creature is a heat machine transforming the chemical energy of food into the mechanical work of digging and the thermal energy of heat loss due to the energy expenditures of being alive.

But this is not only physics, it is economics in its simplest form due to the fact that the creature has internal reserves—chemically stored energy R_0. If daily food brings more energy than was needed for sustaining life and performing work, then those reserves gain

$$\Delta R= (N f - N w - L).$$

Reserves also can be depleted and ΔR can be negative if it wasn't an economically successful day ($N f<N w+L$).

At the end of the day reserves are

$$R= R_0 + \Delta R.$$

Thanks to the existence of reserves, the creature to some extent is protected in case of bad luck or interruption in its economic performance—ΔR can be negative for some times. Obviously ΔR must not be negative day after day in the long run to prevent the internal reserves from depletion. But ΔR depends on two factors: the energy expenditures of being alive, which we concede to be constant, and the relative value of the food in comparison with the amount of work. So, the *short time rule* of economic behavior is:

if the work to get food is greater than the energetic contents of that food, this food is not worth getting: *f must be larger then w* so value $V_{food} = N f - N w$ of the acquired food will be positive. [40]

Natural Surplus

In addition to this requirement we also see that in the long run the value of food must be also high enough to cover L—the daily energy expenditures needed to sustain life. Otherwise reserves will be depleted and the creature will die. With N_{av}—the average number of roots dug per day, the average daily value

$$V_{av} = N_{av} f - N_{av} w - L$$

— must be not negative in the long run. This value I call the *natural surplus value* as it is what the creature gets from the environment after covering energy expenditures for its work and for sustaining life.

Positive natural surplus is the absolutely basic rule of long term economic behavior which is universally applicable and does not depend on the fact that we are dis-

40 Maybe it is a good occasion to warn the reader against a wide spread generalization: good rules of economic behavior are prescriptions and not descriptions of the behavior of living creatures who are in general much more complex than any economic model. Even this particular simple rule being obvious for the physics of the living body can not be taken as an absolute behavioral rule. Indeed, we do eat lettuce spending more energy for carrying it out of the store and chewing it than we will get by digesting it. Even among animals there could be plenty of reasons to spend energy for chewing food which is not worth chewing.

cussing a simplified model of purely energetic economic behavior.

Obviously this basic rule is the same in any economic exchange, be it an exchange with the environment or an exchange between people. It is true that humans live not by bread alone, that they produce their own values which are worth exchanging, but all human activity will stop if there is not enough energy to sustain life, that is if natural surplus V does not cover the energy expenditures for being alive.[41]

Humans actually have the ability to spend energy for work which is much larger than the energy needed to stay alive. This means that their ability to work for food is sufficient for even quite an unfriendly environment, where getting food requires a lot of work. Also, social needs—reproduction and cultural customs like taking care of the elderly and disabled, taking care of priests, soldiers and rulers—led to the requirement that L in the above formula must be much larger than the minimal life sustaining energy for one person. As social relations developed, a more complicated redistribution of the natural surplus made the picture of economic life quite complicated even at the dawn of the development of human economy. But no matter how far this development progressed and what values besides food are put in the market by humans, the first law of thermodynamics—law of

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41 In modern societies outside of the areas of warm climate, food is not only a source of energy for the body, in fact we need to eat much less than previous generations had to because we are heating our houses. We get that non-food energy from Nature be it from wood, oil or nuclear power. Again, the balance of energy for spending work in order to produce heat from fuel must be positive be it digging for coal or cutting wood. Combine the natural surplus of food and non-food energy $V_{food}+V_{fuel}$ must be positive and big enough to cover the energy spent for being.

energy conservation defines the unshakable basic requirement of macroeconomics be it for a small group of hunters and gatherers or for a giant nation of our time. (The help of other sources of energy for heating houses or for doing work by machines is calculable and does not distort the picture).

Price In Purely Energetic Model

Energy is the firm bridge between economics and physics as the energy conservation law works in any sphere of human activity as well as in the inanimate world known to us.

Prices are a different story as the energetic cost of production is only one element among those which affect price. The picture is simple and quite physical only in the case of a purely energetic model with an abundance of roots at any time and digging work as the only payment for it. That payment is the price of the root and energy is only the currency:

Price of root = energy spent for digging.

This price is paid by the creature to the environment, and it doesn't matter that the environment doesn't gain anything from this transaction. (When we pay a certain price to a merchant it doesn't matter to us if he will throw that money in the garbage). In traditional economic terms this price paid to the environment is also the cost of the production of a root.

It is important to note that price in this model is numerically independent of value but the choice to pay that price depends on value and we did assume that roots are worth digging.

Price And Scarcity Of Resources

Now let's go to the real world where there is no abundance of eatable roots. Let's count not just energy w spent for digging each root but also energy to find the root—q (in our model it can be simply energy spent on walking).

With average N roots dug daily, the balance of energy is

$$N f = N w + N q + L.$$

Obviously term Nq can affect the creature's chances of survival. We see how the *scarcity* of resources in the simplest model affects the price paid by the creature to the environment: now the price of the root is w+q and q on average depends on the frequency of roots along the creature's daily path. (in the case of an abundance of roots q is negligible)

Let k be the quantity of roots per unit of area and Q—energy spent for one mile of walking. If the creature's daily path is d mi. long and if the creature can spot a root from distance b/2 mi. on both sides of path, then the creature covers area bd with its daily search and will find N= k(bd) roots. The energy spent for finding daily roots is Qd. So finding the price of one root is q =Qd/N=Q/(kb) and the overall price of one root is

$$p = w + Q/(kb)$$

In economic terms the price is higher when the supply—density of roots k in our case—is lower. This fact is one of the basic in real economic relations. Our model illustrates the fact that the dependence of price on supply is simply connected with the probability of finding the product and not necessarily with the decision of the merchant.

Demand as Consumers Competition

Economics gives the general picture of price dependence on the basic cost of production (analogous to w in our model), the factor of scarcity (reflected by k here) and the demand for a particular product. So far we were dealing with one creature without competition. In real life wherever there are resources, there are usually many creatures after them. This fact was recognized on an instinctive level by many species of animals: territorial instinct existed long before humans introduced property rights for land.

Let there be D creatures searching for roots in area A sq. mi. and extracting DN roots per day. The initial density of roots equals k_0 so there is $K_0 = Ak_0$ roots in the beginning. Apparently the density of roots will diminish as the creatures dig and after T days be equal

$$k = K_0/A = (K_0 - DNT)/A = k_0 - (DNT/A)$$

so the price of a root

$$p = w + Q/(kb) = w + Q / [\, b(k_0 - (DNT/A))]$$

will grow with the quantity of diggers.

The result is understandable: the price grows with diminishing probability to find the product and that probability goes down with increasing demand. At some point there is an “equilibrium” price for certain conditions of supply and demand.

Simplicity Of Purely Energetic Model

On the example of a purely energetic model we illustrated the nature of price, its dependency on supply and demand and its numerical independence of value.[42] No exchange between parties was introduced and no choice was given to our root digging creatures. Behavior was purely instinctive (programmed), price was measured in units of energy and value was viewed as pure energy. All digging creatures were buyers in this model, buyers from the environment, the digging work being payment. No sellers were involved in the deals, yet I showed the main picture of price dependence on supply and demand. Outside of declared simplifications the model is not only realistic as far as the economics of exchange with the environment goes, but also provides for the possibility of precise measurements of price and value without the fussiness of psychological assumptions.

In any discussion of the economic behavior of humans when an exchange is involved, there are always elements which can not be measured the same way physical quantities are. Economists are usually dealing with measurement in monetary units which are always relative and depend on the value of money at a given place and time. Even in the pre-money era of human economy, any barter deal depends on the comparative value of at least two products. Also, a multiplicity of factors plays a role in a real economy such as the knowledge or presumption of a buyer's or seller's mood, needs and goals, knowledge about the existence of substituting products and its prices and so on.

Those who study economics have good reason to be amazed how economic theories manage to attack such a complex subject as human economy despite the fact that it is getting more and more complex literally as we speak. Recognition of this fact should not prevent us from ana-

42 Supply and demand functions can vary depending on the circumstances, of course. Here I just showed that they exist in absence of an exchange between creatures.

lyzing the basis of those theories from the point of view of physics and to show that in many cases the development of economics relied too heavily on the analogy between human labor and energy with undermining the low-entropic component of economic activity. A purely energetic model is an illustration as to which extent economics can use an analogy with classical mechanics. As we will see, this analogy should be abandoned when the low-entropic component—information, choice etc.—is not negligible in the economic process.

Price And Choice

Let's make our model richer by introducing the element of choice as to what roots to dig. In the area with an abundance of roots let there be deep and shallow roots with the energy to dig each one w_1 and w_2 and an energy content f_1 and f_2 correspondingly. (No energy is spent for finding roots). If a creature digs per day N_1 deep roots and N_2 shallow roots then the equation for the daily natural surplus is

$$V= f - w - L = [\ N_1\ (f_1-w_1) + N_2\ (f_2 - w_2)\ ] - L$$

The condition of survival as established before is that V must be not negative in the long run. Apparently the creature is at the mercy of circumstances if there is no way to know which root—deep or shallow—it is digging. The balance will depend on the relation between work and the energy content of deep and shallow roots.

If the creature can recognize the kind of root before digging, it is in a position to make a choice. The immediate thought which *comes to us* is that the roots for digging must be chosen in such a way that the natural surplus will be *maximized*—instincts acquired during the long process of evolution and reason refined by reading economic books did train *us* to try to find an optimal solution. We can not however automatically assume the same about our creatures or even about real humans.

All we can assume on the basis of observation of many living creatures is that they are inclined to reach *better results for less work*. Such a choice will lead to the maximization of the natural surplus only in the simplest cases. Indeed if deep roots are less nutritious —

$$f_1 - w_1 < f_2 - w_2$$

— one should stay away from deep roots. Or if the nutritious value of deep roots overrides the larger work to dig $f_1 - w_1 > f_2 - w_2$—one should choose deep roots.

Such a simple maximization of the natural surplus can be done and in fact is done by animals constantly—after all domestic cats like to catch birds, but they eat cat food or go after a mouse as it is more economically feasible. Those cats who didn't learn this simple economic principle presumably did not survive, if they ever existed.

Here we are at a crucial juncture as far as the philosophy of economics goes. Indeed, in a purely energetic model, the natural surplus is analogous to the *utility function* which is widely used in economics. Some authors use related concepts like benefit or welfare function. The wide spread assumption is that economic actors, given budgetary restrictions and prices, choose goods and their quantities in a way that the utility function will be maximized. There are also maximization assumptions about other economic characteristics. Later we will see that such assumptions are related to the use of a mechanical analogy in mathematical economics and that the low-entropic component of economic activity definitely can not permit such approach. Here I discuss to which extent one can justify the assumption of any maximization of behavior even without the low-entropic component.

The length of the working day plays the role of a budgetary restriction in our model. Within that restriction the creature must choose which roots to dig and it can be crucial to survival. In the case of

$$f_1 - w_1 \text{ close to } f_2 - w_2$$

one could make measurements and calculate. But roots do not come with labels as in a supermarket showing calorie content. With no sophisticated measuring equipment at hand and with nessesety to make the choice between values which are close to each other, the creature actually left to random choice. Some creatures may not survive if small mistakes can affect the margin of natural surplus. This might refine the genetic pool of a creatures' species as far as the ability to make a correct diagnosis and correct choice. Or it might not. In such a case non-survival of some creatures will not help evolutionary perfection. The choice is not crucial at all if the margin of natural surplus is large enough to allow for considerable mistakes in choice.

We conclude that the maximization of natural surplus is possible only in obvious cases but even with a narrow margin of natural surplus, creatures may survive despite mistakes.

CHAPTER 8: Mechanics and Mathematical Economics

Principle Of Work Minimization

If the maximization of natural surplus is possible only in the simplest cases one might expect that some kind of rule guides a creatures' behavior in the search for food. Without being over-presumptuous, I can assume that such a general guideline exists: *getting better results (energy content of food) for less work is preferable.*—this is a realistic loose rule without the demand to achieve perfection in minimizing work.

This is as far as the use of extremal principles of classical mechanics can go in characterizing economic behavior and only in a purely energetic model.[43] We see, that even with the loose rule of work minimization, biological behavior is very far from the extremal principle of rational choice which economists subscribe to humans: minimization of losses and maximization of gains.

I have to explain here the special property of maximization or minimization. Many things in society or in Nature can be measured on average: we are familiar and comfortable with data about the average consumption of meat or computers, or of the average working time of people. We even can predict certain economic facts "on average".

But maximization can not be done on an average basis. If I usually maximize my utility function, but didn't do it yesterday, we can not say that on average I achieved

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43 The extremal principle did play a role on the genetic level of course, finding an economical configuration of a bee comb for example, but not on a level of behavioral choice.

maximization. In measuring the consumption of bread, deviation from the average in one case can be neutralized by opposed deviation in another case. But any deviation from maximum is always below maximum and can not be neutralized by deviation in another case. Surprisingly, some authors do refer to maximization on average.

Instead of some extreme principle for behavior, I acknowledged the existence of the loose rule of work minimization, which does not mean reaching the minimum of energy expenditures but the general inclination to spend less energy. We can take a bold step further and extend this rule into the energy minimization principle, remembering of course that the result will be idealized and might be not even be close to reality as the process of extrapolation might be full of surprises. The point is that as mechanical property, energy at least theoretically can be submitted to this kind of extremal principle.

The low-entropic component of economic activity is different: there is no corresponding extremal principle in physics about lowering entropy. The only rule about entropy in general is the second law of thermodynamics which prescribes maximization of entropy of an isolated system, there are no general rules at all about the level of lowering entropy in part of the system.

Life had to find not only its own ways for the creation of order but also its own rules about the local reduction of entropy and production of p-order. So when I stated that there is just the loose work minimization principle, I acknowledged that life did not invent strict rules about the ways a life unit is lowering entropy and to which extent it is doing so. When an economic theorist assumes that there are extremal principles in human economic behavior, it is equivalent to the declaration that the evolution of life finally did manage to create extremal principles for lowering entropy. This is a far reaching philosophical assumption and it is not correct.

Limitations Of Mathematical Economics

Classical economics started with valuable observations of peoples' economic behavior, as a mixture of descriptive science and political wishes about ways society is functioning or should be functioning. Starting in the mid-nineteenth century, economists used mathematics more and more and nowadays one can not go too far in economics without mathematical models.

The problem with the use of mathematics, particularly differential calculus, is that calculus is dealing with functions and equations. Applications of calculus require some anchors in the real world to which we can tie our mathematical descriptions. Indeed, in classical mechanics we have conservation laws for energy, momentum and moment of momentum. Whatever the behavior of matter we discuss, be it the movement of planets or a particle of dust in a vacuum machine, we can write equations on the basis of those laws. We assume with confidence that the mass of a planet will not change without reason and that a particle of dust will not get energy from nowhere. We also know certain minimum and maximum principles which are valuable tools permitting us to use variational calculus in order to come out with equations describing a particular process.

Starting with Pierre de Fermat of the seventeenth century, extremal principles were among one of the most valuable tools in physics and in mechanics in particular. The principle of less action of de Maupertuis developed particularly by Hamilton, states that a particle moving in the field of force will choose one and only one path which requires minimal action.

The history of the development of classical mechanics was a great symbiosis of scientific observations and calculus, as calculus to certain extent developed to satisfy the needs of mechanics. In the nineteenth century classical mechanics in many ways become the model for many scientific applications of calculus. In fact, classical mechanics has affected educated people in their perception of the world: many expected that there are laws governing the world and they are as simple and clear as in mechanics.

Economists for many decades kept believing in the human ability to find simple deterministic laws which govern the economic process. The history of mathematical economics shows the extensive influence of classical mechanics on the economists' approach to studying society.

How was such an extensive use of mechanical analogies possible in economics—the area which can not account for a single conservation law or for clear laws of human behavior?

Social statistics does show certain patterns of behavior when we study society as whole. This certainly gives the impression that no matter how multifaceted or even erratic individual human behavior can be, society's behavior is guided by certain trends. Of course, it is just that, trends. In order to deal with trends mathematically one has to develop a probabilistic approach and deal with the fact that such an approach will not give certain answers or certain recommendations.

Economists take one step further and instead of dealing with trends or probabilities subscribe certain laws to human behavior in the economic process. Those laws often are still very similar to the laws of classical mechanics.[44] The maximization of the profits of a corporation is one of the major principles. As far as consumers go, ac-

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44 There are voices among economists calling for a more extensive use of the analogy of economics and thermodynamics as well as systems theory.

cording to economic theories, they also behave not erratically but in such a way that their utility function reaches maximum. This is direct and rather primitive mimicking of extremal principles in mechanics. Those principles did prove their usefulness in physics, but how far can we go subscribing it to human behavior?

Spencer's Brand Of Darwinism

Two concepts of Charles Darwin transformed the nineteenth century views on living matter. First, that species do originate. Some paleontologists and biologists suspected it before, but Darwin gave a loud voice to this idea. Second—that species originate as the result of competition for survival. This competition between living creatures takes many forms, be it the flexibility of genetic adaptation to changes in the environment, the ability to kill each other, the ability to acquire advantageous elements of behavior and so on. I do not pass judgment here if this competition is the reason for the appearance of a new species indeed—as science goes deeper into the genetic nature of organisms other hypotheses are under consideration now.[45] But it can be accepted that the struggle for survival and natural selection do play a role in shaping the world of living matter. Economic competition—the struggle for food when resources are limited is one of the major tools of natural selection.

One may very well agree that existing species, including humans, acquired certain instinctive elements of behavior which help in such competition. These instinctive patterns of behavior most likely play a role in the contemporary economic behavior of humans and of course

45 See: Elizabeth Pennisi, Molecular Evolution: How the Genome Readies Itself for Evolution., *Science,* 08-21-1998.

should be recognized by economists together with relying on same use of reason of humans.

It is appropriate to note here that there is a serious distortion in the perception of Darwin's theory expressed in the well known slogan "survival of the fittest". This slogan actually belongs to Spencer and expresses much more than just a simplification of Darwin's original views carefully presented in his original edition of *Origine of Species*. There is a lot of over-dramatization around evolution theory and this slogan is one example.

Spencer's slogan produces the impression that there is competition for the best in evolutionary process, like in the Olympic games. There is nothing like that if we examine reality closer: although some tests of fitness are part of life especially in sexual reproduction, the actual rule of natural selection is that only the most unfit leave the scene, the rest of the unfit organisms are not only surviving but also depositing their not most advantageous genes into the genetic pool and those genes give origin to new kinds of complexity. Unscientifically speaking, *it is not a big deal to survive if one has perfect genes for survival*. The challenge is to survive with less than perfect genetic material and it exactly such success in survival that may be a reason for originating new evolutionary lines and creating new forms of complexity by the discovery of new genetic possibilities. Genetic perfection simply might not give reasons for changes at all. Compensation for imperfections can lead to new evolutionary achievements.

We shouldn't fool ourselves as to our own ability of survival: no matter how complex we are and how clever we are protecting ourselves from environmental mishaps, old-fashioned one-celled creatures are still billions of times more fit to survive as a species then we are. From this point of view the evolution of a species is actually driven by finding ways for unfit biological entities to survive, and not by survival of the fittest.

Summarizing, if the concept of natural selection can be expressed in one thesis, it should not be "survival of the fittest" but *non-survival of those most unfit whose genome did not find ways to compensate for unfitness.*

What is important for our discussion on economics is that this cautious interpretation of natural selection puts a limit on the expectation of what instincts of economic behavior we acquired as a result of our ancestors' success in survival. Spencer's simplified approach to evolution actually opened the door to extremal principles to be subscribed to the behavior of living creatures. It corresponded very well with building mathematical economics after classical mechanics as a model: if mechanics and evolutionary theory both operate with extremal principles it was easy to extend variational calculus into the sphere of economics.

Maximization of Utility Function— End of Evolution

As I mentioned before, the use of calculus in economics is possible only if we have some anchors to tie acts of economic behavior to mathematical principles. If analyzing a consumer's behavior, we simply write tables of what was bought today by people and at what price, it will be useful for those who can analyze this huge amount of information but it will not give us a clue as to what will be bought tomorrow. In order to deal with this problem mathematically, economics came out with *utility function* which sums the quantity of goods bought multiplied by the prices. The assumption is that consumer behavior is guided by maximizing this utility function within budgetary restraints.

It is very easy to agree that when budgetary limitations are very strict, many humans will buy most needed goods, the utility of which can be evaluated by an outside observer. Even then, expectations of maximizing utility function would be based on Spencer's brand of Darwinism, not on real human behavior, not on an understanding of *survival despite mistakes*. What is more, the maximization of utility function is based on the implicit proclamation that evolution ended, that only the "fittest" did survive and now they behave in accordance with the ultimate survival principle—maximization of utility function. Indeed, even if we accept Spencer's principle, how do we know that all consumers, behaving as they do in reality, will actually survive?

Place Of Reason

If there is no biological basis for extremal principles in describing human behavior, maybe we can save the concept of maximization of utility function by relying on the reason of humans? Many do believe that human behavior is directed primarily by reason and affected mainly by culture and social environment and not by nature.

The operational classical assumption in answering the question "how it should be" is that in production and organizing exchanges humans are guided by rationality and reason which includes explicit knowledge of goals, methods for achieving those goals and criteria for human satisfaction about their performance. One might doubt that humans can be rational to the degree assumed in many theories about economic enterprise, but at least such an assumption of rationality is based on the fact that pre-human economy, which derived from instinctive behavior (be it building a nest or gathering food) was too primitive in comparison with our economy. As humans surpassed other species exactly in developing reason and not instincts, it is natural to count reason to be responsible for ways of elaborate production and exchange.

There is no doubt however, that even in highly organized activities humans often behave instinctively or apply reason unreasonably. What is more, there are plenty of situations with insufficient information or are just too complex for making reasonable decisions, in which case, humans have to rely on their "gut feeling", intuition, random choice or astrological signs. But generally reason is a valid foundation for formulating how human economy should be built. A critique of overrelying on reason in the study of corporations and individual behavior often concentrates on the "very limited information-gathering and computing capacity of human beings and their associated computers"[46] The question before us though, is not the limited capability of our reason but the validity of using mechanics-like extremal principles in evaluating order and p-order. Widely used optimization procedures in calculating ways of business activity by economists are of the same nature as extremal principles in mechanics. Optimization can answer questions about the best use of materials, energy or energy dense labor, but, in general, not about the production of p-order which depends on creativity.

There are two additional arguments which can be suggested in support of unlimited use of the assumption of reason as far as a theory of business activity goes. First is that activity is performed by the business elite of our species. It sounds not too democratic but the fact is that only a limited percentage of the population organizes businesses, the rest serve as employees, even in societies where the possibility to become an entrepreneur is open to everyone. One might very well assume that this busi-

46 Herbert A. Simon, "Theories of Bounded Rationality" in *Models Bounded Rationality*, MIT Press 1982, vol. 2, p. 408.

ness elite has certain qualities which makes them different from others and interpret those qualities as having something to do with the use of reason.

Second, in theories of corporation economists are dealing not with small family businesses, but with large collective enterprises whose behavior can be quite different from that of individual humans.

Even if we accept that reason is the leading force as far as the question of "how it should be" is concerned, can we stretch our belief in human reason to interpret a consumer's behavior?

Existing theories of consumers' choice are influenced by decision making theories, often called utility theories, which are based on the rational approach that losses should be minimized and gain maximized.

As much as this theory is valuable for developing principles of computer behavior, they have limited use for a description of humans. Psychological research shows, that people often make "wrong" decisions even in the simplest cases, when probabilities are known—a fact which irritates utility theorists to the point of complaints that people are irrational. One researcher noted:[47] "People (you and me included) violate rules of rational behavior because of ignorance, cognitive limitations, and psychological concerns." Another author stated: "It appears that most humans are condemned to second-rate thinking when uncertainty is concerned". [48]

No doubt there is plenty of use of reason in choosing what to buy, but generally the wants of consumers, to the largest extent, are governed by primary instincts as well

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47 Rakesh Sarin. "What Next for Generalized Utility Theory" in *Utility Theories: Measurements and Applications*, Ward Edwards, ed., 1992, p. 144.

48 Ronald Howard. "In Praise of the Old Time Religion", Ibid, p.30.

as social instincts such as mimicking the behavior of others or the desire to distinguish oneself from others. There are also habits, customs, addictions, memories of prior satisfaction or disappointment—all motivational luggage which we carry through life and which greatly interferes with our rational judgment.

Circular Logic of Maximization

Until now I was talking about utility as quality, which can be evaluated by an outside observer. But there is plenty of sociological data to show that people often don't spend money according to what can be viewed as the best utility even when budgetary restrictions are strict - there are people who would buy poisonous drugs or alcohol or tobacco instead of food. And there are those who will economize on food in order to buy books or to achieve a fashionable complexion.

As to consumption with less than strict budgetary restrictions, consumers give us a wide spectrum of erratic acts or patterns of behavior.

In fact, there is an element of consumers' behavior which is not reflected in utility function but definitely affects their budget—the act of shopping which may give pleasure by itself and can be very therapeutic for some people.

And here comes the strongest argument against belief in the maximization of utility function: people can be directed in their consumption by the manipulations of advertisers. Indeed, if power tools are advertised by a female showing cleavage or cigarettes by a macho looking cowboy, can we still believe that consumer behavior is directed by some kind of extremal principle?

Critique of the maximization of utility function is not new. In order to deal with the fact that consumers often behave not in accordance of the best utility, this correction was introduced: utility should be interpreted as subjective. In other words, a consumer buys in accordance with a personal understanding of utility. Actually this correction made all use of utility function even less logically justified.

Indeed, if utility is understood as representing the degree of actual usefulness uniformly defined in some way, then the maximization of utility function can be persuaded as the theoretical idealization of existing or supposed tendency in consumer behavior. Such an idealization would still bring us to the wrong conclusions but in cases of strict budgetary restrictions we might come close to reality.

But if utility is introduced as completely subjective for each consumer, then there is an implicit definition that utility is something which maximizes the utility function of each consumer and all concepts lose sense. We might as well introduce the "function of niceness" and state that nice behavior is that which subjectively maximizes that function.

After all these philippics against the maximization of utility function, I should remind the reader that economic theorists didn't have much choice except to introduce extremal principles. The simple recognition of the tendency in consumer behavior to get better utility, or any other loose rule, would not produce equations. One needs extremal principles to use variational calculus at least in economic models which are built similar to classical mechanics. And this is the main problem of economic theories: the subject of study has to be simplified in order to make chosen mathematical methods applicable. Simplification is not unusual in science as reality is often much more complicated than mathematics can handle.

What is fundamentally wrong with this particular simplification in economics is that it tries to describe in mechanical terms processes of massive creation of order and potential order by mathematical methods which are more or less applicable only to the simplest human activity—spending energy for getting energy. My purely energetic model can be made more complex to cover the activity of many creatures with many commodities, with mutual exchange and prices also expressed in energy units. The loose rule of work minimization can be replaced with some approximation by a strict minimization principle in order to get mechanic-like equations. But this is as far as such a mechanic based economic model can go. The low-entropic component of economy, the creation of multifaceted order and p-order can not be the object for mechanics-like theory and certainly can not be subjected to extremal principles.

Western economics started with the labor theory of value. Labor was the representation of human energy input into the economy and in that time, disregarding the low-entropic component was somewhat justified in many segments of the economy. By the time mathematical economics blossomed in the end of nineteenth century, it was already obsolete in its assumptions about human behavior because a purely energetic component of economy was becoming more and more negligible.

CHAPTER 9:
Low-Entropic Economy

Not By Energy Alone

My root digging creatures behave as working robots which equally possess information about where and how to dig. For that reason the informational (low-entropic) component of their activity will not affect the price of roots even if the creatures will start exchanging roots for work and roots for roots. A purely energetic model is only one where the labor theory of price can work at least by defining the basis for the price of exchange.

Now imagine that an old and weak creature (or just a lazy one) has better knowledge about areas of rich vegetation and can direct diggers to places where there are more roots. As we are sure that somebody invented the wheel, we can be sure that in the distant past some knowledgeable creature did start a new era of economic relations by demanding and getting tangible rewards for his (or even likelier, her) information. It was the monumental discovery of the possibility of getting food practically without spending energy as energy spent for thinking is negligible compared with digging. And most likely there were other clever creatures who got their daily portion of roots by searching for good areas to dig, by organizing the group so energy would not be wasted for repeated searches in the same places and so on. One can speculate about a variety of deviations of a primitive economy from the above purely energetic model. All these innovations meant that the low-entropic component of economy was starting to play a role when information, organizing the work force and p-order of producing tools became rewardable values in human society.

“Rewardable” is the key word here. Indeed, the low-entropic component of behavior was present in a purely energetic model but everyone possessed the knowledge of how to find and dig roots so that knowledge was not an element of economic exchange, not a source of economic inequality or a reason for reward. Among animals, information of better places or methods to hunt also has value but it is not an object of economic exchange (although it may play a role in the group’s hierarchy).[49]

There are many ways for low-entropic factors like information, initiative, organization, innovations and other forms of p-order to interfere even with the simplest economic activity. Organizing the protection of diggers from fierce animals or fierce neighbors or even from unfriendly spirits also became a rewardable low-entropic factor, as it lowers the entropy of a chosen territory by providing insulation from unwanted elements just like the membrane of a cell protects the cell from the invasion of undesired molecules. We already discussed how insulatory automatism find its way to develop from being useful to a one-celled organism to being a part of the social institutions of nations.

Until low-entropic values became rewardable, an economy like our purely energetic model was simple physics. The energy of food can be measured in energy units according to the rules of physics, but information and organization requires a new set of rules for measurement. Physics has a choice—it simply shies away from such problems of too complex systems. Economics

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49 In relation to the study of the Russian criminal world I discussed Russian *artel’*—an old form of group labor activity based on equal labor and equal split of pay. According to *artel’s* unwritten rules the low-entropic component of an activity (marketing, organizing &c) was not rewarded at all—only labor was counted. See Valery Chalidze, *Criminal Russia*, Random House 1977, p.37-44.

has to deal with it and this is the point where we enter the gray area between science and the millennia of human experience. Science can construct a variety of ways to evaluate the p-order of information and organization and measure it in *ad hoc* invented units.

Human experience is rich in rewarding p-order with p-order: respect, prestige, glory, ticker tape parades—vocabulary related to non-economic rewards is extensive. But human experience also tells us that in ordinary cases evaluation should be somehow related to the amount of energy economized thanks to the use of p-order and that measurement should be done in energy units as thinkers need food together with glory. Units of food for practical purposes is equivalent to units of energy. So, the core of difficulties of economics as a science is its historically developed custom to measure entropic entities—order and p-order in units which originally were used to measure the energy of work. This heretical custom is unthinkable for a physicist, but an every day problem for an economist. Of course, as a low-entropic segment of an economy develops, the economic measurement device—money—acquires more and more quality of p-order itself, but it is still the same measuring unit which was used to measure the energy of work. Now the reader can see the labor theory of value in a different light: it was of limited use even in a relatively primitive economy, it was wrong as economy developed, but so far is was only a scientific theory of *economic value* (not price!).

Evaluation of the low-entropic input in economy is difficult *per se*, but there are also social considerations, as the amount of payments for p-order should be acceptable from the point of view of the various strata of society and must be in harmony with the overall natural surplus of society.

Anthropology gives us many examples of the redistribution of natural surplus with energy payments for low-entropic values so even in the most primitive groups it would be difficult to find a purely energetic model in action. Still, the conclusion to which we came after a discussion of that model, is as unshakable as the energy conservation law in thermodynamics: the natural surplus of society can not be negative in the long run. At the dawn of economic development natural surplus was bordering negative territory more often than in these days. No doubt that there were many cases when providers of low-entropic components of the economy had to prove their usefulness to society over and over in order to keep the low-entropic component rewardable.

The rise and development of the low-entropic component of the economy was not always based on contracts and on the understanding of those who provide the energy of their labor—often brutal force was used to force people to work while others would organize that work, provide information, tools, protection and other p-order components. In a way, one may view the anthropology of economy as the development of two interconnected economies in society: segments of society who dealt with low-entropic and labor components of the economy were quite separate.

In fact, the time for an anthropological study of humans is by no means in the past. The dispute about what is more valuable—labor or organization and information—can not be discarded as antique. As recently as in the late nineteenth century, Marxist theories of surplus value based on the labor theory of value won the sympathy of many people and many intellectuals still hold it in high regard. As recently as the early twentieth century the Russian revolution undertook the task of creating an economy based on the ideological idolization of human labor while undermining the value of the low-entropic component. This led to a peculiar scale of salaries in the Soviet economy with intellectual work often less rewarded than the physical.[50] Despite loud political proclamations, the Soviet economy didn't manage to base itself on the labor theory of value as huge resources had to be used for organization and other p-order components.

Still we can not be sure, that the Russian or Chinese revolutions were the last major revolt of energy vs. p-order as far as the organization of economy goes.

Equivalency, Free Market And Fairness

The purely energetic model of an economy can take into account only payments by energy for energy (work for food, food for food, work for work, and work for food). At least theoretically there are equivalents which can define the energetic price of work and food and for this reason there could be the expectation of some level of *equivalency in exchange*. We can enhance this principle by accounting for the gradual saturation of internal reserves (diminishing utility), influence of value in defining price, influence of levels of supply and demand. This will bring us to a scheme similar to the theory of marginal utility. Still if energy plays the role of currency in the deals, the economic theory behind such deals can have anchors connecting it with calculable characteristics of reality.

In an economy with a growing low-entropic component, there are no clear equivalents for defining the price of p-order. As far as energy comparison goes, one actually can get something for nothing. Soldiers can be fed for

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50 Interestingly enough, this economic experiment is mainly known for its attempt to create a planned economy, not for its main ideological characteristic—a labor based scale of rewards. Actually this was the source of the necessity to plan: one couldn't leave the economy to be self-regulated with such an unnatural scale of rewards, so it had to be planned and politically regulated.

years waiting for enemies to come, groups may get life saving technological advice from one of the working members without rewarding him or to the contrary, an organizer could be rewarded for sloppy organization as there is usually no control experiment as far as organization goes. There is no precise way to define rewards for low-entropic entities in an economy, there is not even the shadow of equivalency in exchange between energy and p-order.[51] What is more, the recognition of the value of a low-entropic component in the economy required some level of abstract thinking and there is no assurance that all people have reached this level, even by now.

With a growing culture and the growing role of p-order in economic relations, practical economics left the realm of a calculable purely energetic exchange and now have to deal with the evaluation of order and p-order. These qualities are so enormously multifaceted, that one would have difficulty making a list of them even as far as a primitive society was concerned. Even if such a list could be made, how would one put a price tag against each entry?

The value of p-order is literally everybody's guess. In fact this is exactly what we have now as the measuring device of order and p-order in well to do economies: if there are plenty of people to make a guess and plenty of orderly products to make a guess about and if everybody is under the protection of the law which prevents forced exchange, then we call it a free market mechanism and have no reason to complain about the results of such an evaluation. (This guessing game is more reliable than democratic elections because the participants have to pay for their guesses, otherwise their opinion doesn't count.) But there was a long period in the history of humankind

51 Was Thomas Edison rewarded properly for his invention of the electric light or Norbert Wiener for his ideas in cybernetics?

between the possibility of using energy based standards of exchange and the establishment of a free market for evaluating the low-entropic components of goods and services.

During that period two opposite concepts of evaluation in exchange were developed: fairness and unfairness.

Unfairness is a simple and quite practical concept as to the large extent it eliminated debates about value: whoever had the power to dictate prices, did it. This method usually is not referred to as the “unfairness concept” but this is what it is, a method to solve the evaluation problem from the point of view of just one side in the deal without the goal to satisfy another side. Asymmetry of economic deals became handy in using this method of evaluation. Those who did run the low-entropic segment of economy which included ruling, defense, ownership and so on, usually were in the position to dictate. We know plenty about the harsh conditions of labor and luxurious existence of these economic dictators in the past. We disapprove of such a system of economic relations on moral grounds especially if force and cruelty were used. But moral judgment has nothing to do with rational economic evaluation and we are not in a position to define if and in which cases p-order was overvalued and labor was undervalued except in cases of forcing laborers to work with a negative natural surplus. This note reminds us again about the almost complete absence of a universal scale for the measurement of p-order.

With the development of free market ideology and practice, it is still very rare that laborers can dictate the price of anything, but at least those who define prices are many and they can freely compete. (Belief in the underevaluation of labor in the past led to a sort of affirmative action policy: the law prohibits producers to fix the prices of goods, but permit trade unions to fix the price of labor.)

The power to dictate prices in chosen cases still belongs to the state—a free market did not change that. So the concept of unfairness is alive and well as far as dictating the price of money (interest rate), the price of an orderly society and defense (taxes) and occasional interference by price control legislation.

Fairness is a very vague concept but it provids some kind of guidance. Indeed, how are people to switch from a purely energetic economy into accommodation of even the simplest p-order component? Let's say one creature gave to a group his secret of a better way to find roots. As a result, each member of that group gets one additional root per day. If the value of information does not exist as a concept in the perception of that group, there could be no reward for that learned secret at all. Yet, if the group understands that information should be rewarded, a refusal to reward it would be considered unfair. On the other hand, if that knowledgeable creature would demand that all the natural surplus of roots extracted, thanks to his information, will be given to him, that would be considered unfair also as diggers did participate in this venture.

The concept of fairness can not give a much more definite evaluation but at least it gives upper and lower limits for a variety of fair evaluations. In practice, as we look back on the historical development of human economy, the concept of fairness worked mostly between friends or among groups of equals with the help of knowledge of the precedents. In a contemporary economy and legal life, if the market or government did not establish a price on something, appraisers will approximate the price and call it fair market value. Occasionally fairness is referred to by those who dictate price, as for example in cases of taxes on excessive profit. Fairness also can become a slogan used by those who rebel against the dictate of prices.

Both of these non-market mechanisms have advantages. The concept of unfairness provides for a definite evaluation and limits the immediate possibility of conflicts. Fairness gives lower and upper limits of evaluation and helps to eliminate conflict by compromise. History shows, one might believe, that eliminating and resolving conflicts is far more important for the economy than precision in defining prices.

Even more valuable for the success of the collective ordering activity of society is understanding that in an economy with a high share of the low-entropic component, prices simply can not be defined and can be only agreed upon.

Solid Behavioral Assumption

After my critique of bold behavioral assumptions used in economic theories, the question arises: what do we know for certain about humans that can serve us as guidance in economics. The loose principle of work minimization can be used in many cases but it covers the energetic side of human activity, not the low-entropic. Yet, from our discussion about life we learned that a life unit exists because it is programmed to create order. It appears that for most species the main effort to create order is limited by the level which is needed for survival and reproduction. Humans are quite active in creating order outside of their immediate domain and a good part of that activity is economic, along with creating and preserving behavioral order within the community. Is there a general rule which can describe the amount of order created by humans?

The following is a symbolic presentation of any creature's life time balance of order and p-order together (exchange with other creatures except for offspring is not included). Letter O stands for order and p-order together:

O_b—at the moment of birth,

O_p—produced by a creature during its life time,

O_e—taken from the environment,

O_u—used through life time,

O_o—given to offspring,

O_w—transferred to the environment as waste of the creature's functioning (waste of one creature can be a source of food for another as it still carries some order).

O_d—transferred to the environment with the dead body of creature.

The following balance of order is not an equation and the sign ⊕ is not an arithmetical plus for at least two reasons:

1. we can not reliably measure different kinds of order and p-order in numbers
2. there is no conservation of order and p-order and no rules of addition.

Still we know that order consumed and created by a creature and the symbol ⇒ means the relation between the two.

$$O_b \oplus O_p \oplus O_e \Rightarrow O_u \oplus O_o \oplus O_w \oplus O_d \oplus \Delta O$$

O_w and O_d—are interesting terms responsible for most of the order of inanimate matter which was produced by life, be it in the atmosphere or on the surface of our planet: we know that Oxygen is a waste of plant activity, the excrements of animals are rich in food for bacteria and for plants, carbon dioxide produced by animals' breathing is food for plants and so on. Life forms feed each other with their waste and with their dead bodies and at the same time organize inanimate matter around in a way which would not be as it is without life. (Indeed a high percentage of oxygen in Earth's atmosphere is a clear sign for an alien observer that this is a planet with life, as Oxygen being chemically active would not stay in free form for a long time without life forms producing it constantly)

The last term of this non-equation ΔO is what is left after the death of a creature from its own ordering activity, not as a by-product of its material existence. It can be called the orderly legacy. In the animal world it appears that for most species $\Delta O=0$. Of course there is the occasional use of old birds' nests or underground passages produced by those who lived before. There are continuous uses of bee hives or ant hills. We may say that evolution did experiment with the term ΔO before we made significant use of it. The overall picture is that humans are the only species which elevate the importance of the term ΔO to the level when their life would be hardly possible without order created by thousands of previous generations be it language, information, social or material order.

The combined effect of term ΔO is possible mostly through preserving information about discoveries and the experience of previous generations. There are of course durable goods and structures as well as social structures which can be used after the death of their creators, but the real "reason for wealth of nations" in a culture, be it information about how to create things or how to organize humans and how to make them create an even more orderly legacy. That information is saved for future use in the form of writing or other means of recording, but most importantly, in the form of an educated population, education being all that humans know: language, manners, crafts, rules of civilized interaction and so on. Many elements of this orderly legacy survived trough millennia and are actually responsible for the fact that this or that society still exists.

So if we are looking for solid behavioral assumptions, here is the "legacy rule":

society possesses order and p-order created by previous generations.

This rule is absolute as there is no society without legacy. But it is not trivial. Indeed, the twentieth century gave many examples of disregard for this rule by political inventors who were trying to rebuild societies be it in Germany, Russia or China. In each case the rebuilders did not take into account how deeply the orderly legacy of previous generations is imprinted in the minds of people.

Growing Legacy Rule

Civilization will cease to exist if ΔO of all previous generations will suddenly disappear. A less absolute rule of human behavior comes from the consideration that producing order is in human nature. Indeed we can not say that the existing legacy was produced due to some special reason only in the past. Society produces legacy and that legacy of order is being added to the order achieved before.

Order produced by individuals and society is noticeable every day and ΔO can be estimated for any interval of time. Having almost no other choice as to use a crude way to measure it in money units, we might as well accept econometrics figures of GDP as the measure for part of ΔO keeping in mind that "money is not everything" and the development of culture is to the large extent not expressed in GDP. No matter how we estimate orderly legacy the additional rule is that for any reasonably large interval of time ΔO *is larger than zero*.

Fluctuations aside, this means that order in society, including the order of all things produced, is growing.

I used the words "reasonably large interval of time" to cover the fact that there are wars, epidemics or other disasters. Such fluctuations can be taken into account in applications of the rule.

Use of the word "rule" implies that it is a rule for a theorist evaluating the development of society, not a prescription for individual behavior. There are plenty of those whose legacy ΔO is close to zero—they are simply users of civilization, not builders. There are also nations or tribes which use a previously collected legacy but almost don't enlarge it for the following generations—we may say that such civilizations are stagnant but we should be careful as there could be forms of growing potential order unknown to us or unnoticed by us.

There are even individuals or groups whose legacy is negative due to the destruction of order from our point of view. It does not however diminish the overall growing legacy of humankind even in the case of considerable destruction of material order, be it buildings or machinery as the main legacy of previous generations is information.

Overall the *growing legacy rule* is well supported by observation of historical development and can serve as a part of the foundation of economic theories.

What It Means For The Economy?

If the orderly legacy of society is growing it doesn't mean yet that everyone gets its share of the material or informational wealth of society. It took a millennia to realize that reasonably equal access of all people to the use of society's legacy is advantageous for the economy. As often happens among humans, there was a struggle before it was understood: a struggle between those who tried to preserve extreme inequality and those who advocated for extreme equality. The productive compromise was gradually accepted only in the last centuries by Western civilization (indeed, only one and half centuries ago slavery did exist in the US).

Simplifying, I can say that the material legacy was left to a large extent outside of egalitarian sharing. Yet, the informational legacy of humankind and the possibility to use that information and produce a legacy of any kind is largely open to everyone and it is for everyone to choose what to make of it. These three corner stones of Western economic civilization: private property, the spread of education and freedom of enterprise so far prove to be the best combination of social rules as far as economic activity goes. (In fact, the speed and acceleration of legacy production these days is such that most likely we are entering a completely unknown stage of social existence.)[52]

The simplest way to evaluate the influence of a growing legacy on the economy is to compare prices for goods for a large period of time, let's say last 10,000 years. The relation of prices for various goods was changing during that period, many new goods appeared including goods which substitute for one another. In the absence of a standard currency throughout human history it is difficult to make a judgment about the long term dynamics of prices. Even for the time covered by economic record this is a difficult task. Still there is one commodity which hasn't change much since prehistoric time—it is a day of physical labor. One may argue that the humans of the past were stronger and more durable than now, that the working day was longer, or that now the price of unqualified labor is unreasonably high due to legislative inter-

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52 It is interesting to note that for millennia there were observations by those with an inquisitive mind about the different natures of material and spiritual values. Although this dichotomy was usually formulated in the form of a contraposition of human and divine entities, we can reasonably interpret it as an intuitive recognition of higher levels of p-order in addition to order and p-order which is part of every day human and animal existence. It was usual that many philosophers lamented that humans are not paying enough attention to spiritual values. It might be said that the time of celebration of spiritual values finally came as information and its production is more economically valuable than simple goods which satisfy our basic needs.

ference which sets the minimum wage, but this doesn't matter too much for a rough evaluation. And this evaluation tells us that for a day of physical labor contemporary humans in developed countries get incomparably more goods and services than they could get ten thousand years ago. So, despite gloomy complaints about inflation, we can conclude that thanks to the accumulation of legacy practically everything is getting cheaper.[53] This result could be expected as good technology provides for cheaper production, but it is not trivial because it means that the advantage of technology is not kept for the use of those who own the means of production.[54]

Mechanism Of Prices Decline

The anthropology of economy keeps us in the dark as to a detailed account of the development of human customs of economic exchange so a certain amount of speculation is justified. Such speculation though should be checked against reasonable assumptions about human behavior. The main assumption should be that on average a producer would not systematically make disadvantageous deals—the role of natural selection in the business world can be assumed with even more certainty

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53 There could be exceptions as far as rare commodities are concerned, gold and diamonds for example. Also the quantity of land is limited and for that reason the price of land grew over the centuries, but evaluation of price dynamics for land would be difficult as there was practically no free market for land except in recent centuries.

54 It is also not a trivial conclusion due to the wide spread political slogan: "the poor are getting poorer...." The trick of a contemporary economy (unlike the economy of the past) is that in the long run the rich can get richer only if the poor will get richer. In fact the social status of having, means less these days than of producing.

than in a discussion on evolution. This rule is similar to the long term rule for positive natural surplus which we discussed before.

As liquidity is one of the components of value, one would expect that a producer will prefer to produce things with liquidity in mind.[55] Also he will try to exchange his product for something which has a higher or the same liquidity as that product. As it is known historically, various commodities played the role of an exchange medium and high liquidity was the common characteristic of all of them.

Let's suppose commodity A is chosen by the community as the medium of exchange. Due to the desire of the producers to produce things with higher liquidity, there will be the desire to produce commodity A directly without getting it through an exchange. If cattle play the role of money, one would try to raise more cattle, in the case of gold, one will try to find more gold in the ground by searching, by conquering new lands or by developing better technology of extracting.

At least about gold we know that it is exactly what was happening. Price is always a relative characteristic. As any commodity, gold had a price even in times when a gold coin was the main money unit. The price of gold of course was not measured in those units but in relation to other commodities—gold got cheaper as prices for the rest of the commodities grew after a big influx of gold.

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55 Produced things carry p-order for users but that p-order can not manifest itself without users. The producer must put goods in a position where the p-order of those goods can be manifested, i.e. he must find people who will participate in an exchange deal. This is an important quality of orderly things which is complementary to their p-order—readiness for manifestation of that p-order. The analogy with inanimate matter is that a crystal of table salt is not ready for manifestation of p-order if it is not surrounded by atoms which can be organized.

Inflation was caused not by the caprice of producers who raised prices, but by the reduction of the price of the exchange medium.

Obviously there are limited possibilities to finding more gold. But there are commodities for every day consumption (lets say B, C, D) which are almost “as good as gold” as far as liquidity goes. The following process most likely was repeated many times throughout history. The desire of producers to increase liquidity did drive them to choose production of more liquid goods. As the supply of commodities B, C, D grew, prices were pushed down by the market and producers were forced to find ways to produce them more cheaply. Activization of the production of high liquidity goods is similar to an attempt to find more gold. The influx of gold into the economy brought inflation of gold; increased production of a certain commodity leads to inflation of that commodity.[56] So, regardless of the medium of exchange, if there is free choice of what to produce, the choice will be made more often in favor of more liquid commodities and this will push prices for those commodities down until the attractiveness of high liquidity will be offset by the disadvantage of a low price for that commodity. Then it would be the turn of others, maybe less liquid commodities, to be put through the same process of cheapening. All this was accompanied by a growing use of technology and creating

56 People still understand that different commodities can play the role of medium or the role of standard of prices especially when money is changing values. When I visited Latvia in 1958, more than fifteen years after the USSR annexed this country, people often compared the existing prices of goods with the price of butter in order to get a perspective of the new scale of prices.

a production process which could survive despite gradually falling prices on almost everything that can be produced.

I say "almost" because there are goods production of which practically wasn't touched by technological advancement, like hand made pottery, harnesses and so on. As they became less used and less liquid, prices actually might go up.

Throughout history there are many examples of how producers defended themselves from the "invisible hand" of this market mechanism which caused *commodity inflation*: producers of a certain commodity were trying to limit price swings or limit the possibility for new people to start production, in other words, they were trying to limit the freedom of the market. This is a good illustration of the fact that it was indeed a free market which was responsible for the cheapening of almost everything. And it is the growing legacy rule, the human desire to produce order and p-order that is behind the free market.

CHAPTER 10: Value vs. Price

Unobservable Value

In the previous chapter, I discussed producing and exchanging economic values without actually defining what is value in general. It was easy to count nutritious value—the energy content of the roots dug by our creatures and compare it with the energy needed to dig and to sustain life. As far as perceiving values, those creatures were more or less within the realm of the labor theory of value: "Goods are worth to us what they cost in labor, and what, therefore, their possession saves us in labor" as Friedrich Wieser put it.[57]

In this sense, the economics of the stone age, if ever formulated would be much closer to physics then contemporary economics—estimating value was almost the same as defining price. With the development of a low-entropic segment of the economy and growing culture, humans discovered that an enormous variety of material and informational objects has many kinds of value. There is no catalogue of things which have value for humans and there is no undisputed way to measure value. We can observe only the *relative value* which depends on the level of needs and market conditions. This relative value is expressed in price and price is an observable characteristic which from the point of view of a positivist philosophy is real. There is of course the theoretical notion of marginal utility which is behind price, there is the notion

57 *Natural Value* by Friedrich Wieser, translated by Christian A. Malloch. English Edition, 1893.

of utility which is behind marginal utility, but value as a primary characteristic was pushed out from economic thinking and economic textbooks. From the scientific point of view this made all economic approaches collectively subjective, depending on the opinion of the market participants. Rightfully so, as far as the behavior of those participants goes, but one should not lose perspective and forget that the value of things exist independently of the market.

Evaluation of values is subjective but values are objective in their most important quality: they are low-entropic, they are orderly and often carry potential order. It is only due to the impotence of our present scientific ability that we can not objectively calculate the value of one pound of bread and compare it with the value of one pound of painting of an artist which might be fashionable at any given time and for that reason his painting could be sold for a higher price than the bread.

In a way the situation is similar to what occurred in the early age of atomic physics when atoms were still hypothetical entities. As recently as the end of the nineteenth century some thinkers, like Oswald, were quite passionate against the assumption of the existence of such unobservable objects. This was done in the name of positivist thinking. This philosophy rejects concepts and characteristics which are most likely imaginary. But there are objects and characteristics which we can *not yet* observe or measure. The value of complex order and p-order is one of such characteristics.

Evaluation of Values

The great paradox we have to deal with in the scientific analysis of an economy is the fact that order and p-order *can not be measured by one parameter*, yet for many centuries humans were measuring a variety of types of order and p-order of goods and services by exactly one parameter—price expressed in money or other exchange media. As we saw earlier in the example of the payment for stacking wood, in simple cases measurement of order by money has the basic qualities of scientific measurement: it is more or less proportional to the quantity of ordering work and more or less uniform. But the economy deals with a huge variety of types of order and p-order and generally economic measurement is all but scientific—it is often not proportional and not uniform at all. My goal here is to analyze why such measurement is possible, how far roughness of this measuring goes and how it affects the economy.

The idea of measurement in our mind is connected with sophisticated procedures and high precision—this is what we learned in school together with elements of science. But in reality the task of measuring anything including complex order is actually not difficult at all if we don't expect precision. The question is: how imprecise it can be, which kind of mistakes are tolerable and which are not; in other words, if the *margin of tolerance* is great enough we can measure anything with any tools and standards.

When we want to be precise about imprecise measurement, the margin of tolerance is expressed in the form of + or - D, where D is the maximum acceptable deviation. If we hear that now it is noon with + or - one hour of tolerance of mistake we conclude that it is somewhere between 11 a.m. and 1 p.m. But this is already an example of precision despite the fact that the margin of tolerance is rather large.

Our language bares reminiscence of a time when all measurements humans performed could be described in the terms " big" or "small". The introduction of more precise measurement with the use of certain standards brought a new era in human intellectual development and led to the creation of geometry for land measurement, weight measurement for commerce, time measurement for navigation and so on. In everyday life though we are still comfortable with a rather wide margin of tolerance and expressions like a “big tree” or a “deep paddle” still make sense to us despite our technological ability to give a more precise estimation.

In addition to estimation with positive and negative deviation, there is the possibility of measuring with an open ended margin of tolerance. If I plan to drive a truck under a certain bridge I don’t need to know the height of that truck, I just need to know that it is lower than the bridge and it doesn’t matter how much lower. If any measuring procedure, no matter how unsophisticated, can give me the answer, that would be acceptable.

Expressing the result of measurement in numbers goes very well with evaluating simple things as length, electric current or the intensity of light. On the other end of the scale of complexity there are religious concepts, mathematical theories and poetic achievements. We might agree that a certain informational or emotional object has value but there is no way we can express that value in numbers nor characterize its complexity in numbers. Between these most complex objects of value and simple measurable things there is a large area of economically significant values which has to be measured somehow as those values are the subject of exchange between people. There are no actual standards for measurement, there is a very vague understanding of desired precision, but the necessity to measure economic values was so pressing that humans did come out with methods to measure those values and that the methods are so good that people are paying money in accordance with such measurement.

This evaluation of complex order in numbers (prices) is the latest achievement of life. For many millions of years living creatures were evaluating each other's complex p-order—will and nutritional value—by non-numerical methods and were doing it quite successfully judging by the fact that many creatures survived long enough to reproduce.

One may actually describe the history of life in terms of narrowing the margin of tolerance in basic measurements. Pre-human behavioral history of life shows that on some stage of evolution the ability for measurement appeared and at first it was measurement with an open ended margin of tolerance.

It is important to note that I am talking about measurement as part of the behavior of a living creature as a whole. On the atomic and molecular level measurement is performed as part of the physical processes including those inside of living cells. Indeed, if there is a particle inside of competing force-fields one may view the movement of a particle as the result of an automatic measurement of the resulting field (if that particle is able to measure that particular field—neutrons for example appear not to be able to measure an electric force field, but electrons do). To some extent we can use this analogy to describe the behavior of living creatures in the competing fields of attractive smells of food: if there are no other factors to affect the choice, the creature will run or crawl in the direction of the stronger or more attractive smell. The great difference between creatures and the particles is that the fields affect the trajectory of a particle but the particle can pass both sources of the field and go somewhere else. Living creatures have a goal actually to reach the source of smell and reward itself by eating.

Pre-Economic Evaluation

In economic evaluation we are dealing mostly with such down to earth qualities as price, utility of consumers' goods, liquidity of produce etc. Value in the broad axiological meaning of the word is not reflected in the tables of commodities' movement.[58] Still, we often have a very good sense of what is valuable among material or immaterial things regardless of the economic evaluation. We are trying now to enter the world of values immeasurable in numbers and a natural question to ask is: should non-numerical evaluation be the subject of scientific discussion? The consideration here is simple: set S_e of things which have economic value is only a subset of a much wider set S of things which have value. Under certain circumstances some elements of S can become part of S_e in which case those things will have a price tag attached to them. In other words there are plenty of things on Heaven and Earth which have value but which nobody would buy, or which is not yet for sale or the selling of which is unimaginable to us. Values not measurable in numbers should not remain unnoticed by science just because there is no way to put a price tag on them.

As we perceive things in the world subjectively, namely from the point of view of life in general and our life in particular, the primary diagnosis of order and potential order or diagnosis of threat to order is behind our feeling of value.[59] The next step is answering questions

58 Yet when we evaluate corporations, broader values are taken into account like its good name, potential for research and development and so on. This is just to remind the reader that even in economics we can not always clearly define what constitutes value and how to measure it.

59 It is important to remember that a threat to our subjective order comes from both: factors which are orderly by themselves, like an evil will or

about usefulness, neutrality or harm and this next step is dealing not just with a certain object in isolation but in its relation to us. Then comes economic evaluation.

Here is a simplified list of the stages of evaluation:

1. Primary perception of order and p-order.—no numbers can be subscribed to measurement. At this first stage of evaluation we are not corrupted with the question of danger or usefulness. We perceive a plant's seeds as orderly no matter if they are poisonous or useful to us. We perceive a piece of crystal or a piece of Neolithic ceramics on the ground as orderly despite the fact that these objects in most cases do not have any economic value.

2. Next question: what it is to us: useful, neutral or harmful. Our instincts and previous experience provide some basis for this diagnosis.

When there is evaluation there is a need for managing mistakes. In the first two stages of evaluation the margin of tolerance can be very large but we should over-evaluate rather than under-evaluate as we (living creatures in general) must manage our mistakes in a safe way. We would rather mistake a big rock for a sleeping bear and a piece of rope for a snake, than *visa versa*. If there is only a consideration of safety, the margin of tolerance of mistakes can be arbitrarily large and open ended: just run from anything unknown and most of the creatures who can run often do exactly that. Evolution did provide for certain mechanisms which diminish the danger of mistakes: unknown things are evaluated as po-

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the activity of a competitor and from disorderly factors like high kinetic energy be it a fire or collision with asteroid. Evaluation of the disorderly factor can be based on an estimation of how much order that factor can destroy and it is exactly that type of evaluation which insurance companies are supposed to be good at.

tentially dangerous will—this is most likely the original source of animalistic religions among humans.

Yet, a living creature can not go too far with evaluating everything by the presumption of maximum threat, so there is the ability of further study for continued evaluation. The goal of living creatures is to find both: a safe and an advantageous place in the hierarchy of living creatures. For that reason the margin of tolerance in evaluation can not always be open ended as there will be nowhere to run if a creature will run from any unknown object and will not make some objects known. So there is pressure to narrow the margin of tolerance and this is what primary knowledge is about: estimating the place of things on a scale one end of which is maximum danger, and another is usefulness. The margin of tolerance can be large but not open ended except in the most severe cases: when there is no time to study the unknown it is better to over-evaluate and run. As we see, the ability to measure potential order, especially will, existed long before humans invented measurement in numbers.

3. The next stage is estimating utility in an economic sense. Economists use imaginary units "utils" to perform such an evaluation. Animals manage without numbers but many certainly have knowledge of the hierarchy of things as far as utility goes: there is more and less attractive food for example. Without the ability to measure (not in numbers of course) such a hierarchy of food wouldn't be possible.

Mistakes management on this stage is provided by a higher evaluation of utility when there is immediate need, by collecting reserves for future use and by the natural limitations of the ability to collect reserves. Indeed, once a certain object is evaluated as useful, the margin of tolerance in over-evaluating it can be infinite. In the case of animals nature puts a limit on this open ended over-evaluation: the ability to store fat in a body for a rainy day is limited. With humans Nature didn't have enough practice so there is no natural limit for collecting wealth by humans.

4. The final, specifically human, stage in evaluation is defining the price which we are willing to pay or not—number of dollars or hours of work can be used here.

Economic Evaluation

On this stage evaluation is conducted on an entirely different procedural basis than in previous stages: mistake management here is done by competing parties—by the buyer and seller (unless one of them dictates prices using force in which case we wouldn't call it evaluation). Ideally, both, the buyer and seller, would like to over-evaluate what they have. If the buyer over-evaluates his money and the seller over-evaluates his goods, the condition is set for narrowing the margin of tolerance and defining the price for a particular deal. We can not say that price, which is found this way, is correct as there is absolutely no outside standard for correctness, but once the deal is done, that price exists and both, the buyer and seller are agreed on the margin of mistake.[60] The birth of the market was actually a transition from one-sided mistake management to dual mistake management—establishing a price by agreement when the margin of tolerance was pressed from both ends. Until this stage, evolution provided for mainly one-sided measurement of order and p-order and it was measurement with an open ended tolerance or a wide margin of tolerance.

60 Actually, I should say: agree in practice: many people are familiar with after-deal sorrow and the memory of the previouse "over-pricing" or "under-pricing" can affect peoples relations for the future or even initiate legal disputes. Yet the vast majority of deals are done once they are done.

As we see, evaluation by defining price is the latest invention in methods of measurement of order and p-order. Pre-economic evaluation was unavoidable for living creatures. Non-numerical evaluation among humans still plays a role as many things have to be evaluated despite the fact that they are not or not yet on the market. Such evaluation is a subject for study by axiology and axiology has no choice as to deal with a wide margin of tolerance due to the absence of two parties who would narrow that margin. (It is not a big deal of course to find two parties for evaluation, the trick is: will the parties have opposing interests and—more importantly—will they be willing to pay money according to their evaluation.)

Referring to my previous discussion on the maximization of utility function, I can point out now that we are dealing here with the same quality of behavior: generally no creature has the ability for precise measurement of p-order or will the same way it does not have the ability for precise maximization or minimization. There is a loose preference of work minimization and there is the ability of evaluation with a certain, often large, margin of tolerance. The only way to express evaluation in numbers is to achieve the collision of interests of the buyer and seller which causes the margin of tolerance to be pressed from both ends in which case they can arrive at a certain number—the price for a particular deal. If many people will arrive at the same number then we'll agree to call it the market price and accept it as a measure of value for certain goods and services at a certain moment and for certain conditions. In this sense the price of an object expresses combined characteristics: the level of order or p-order of that object relative to other orderly things and the usefulness for preserving our own order and p-order. It is a crude method of measurement of order and p-order but in most cases we don't have anything better.

CHAPTER 11: Mystery of Money

Why Is Money Valuable?

Interestingly enough, the peculiar procedure of economic measurement is opposed to the methods of measurement in science. Indeed measurement in science is based on the impartiality of the measuring technician. Measuring by money is actually based on the bias of everyone involved. What is more, in science units of measurement are presumably stable, yet money as a standard of economic measurement is constantly changing value.

Before I discuss the instability of money, the following question should be answered: why money generally retains value despite many reasons for value variations, why we somehow expect money to be stable despite the knowledge that it is not?

The utility of a certain consumable commodity be it cattle or sheep skin when that commodity played the role of money was an understandable reason for that money to retain value. In the case of gold or paper money rarity, social convention or respect for the government which issued the money can be the reason behind the fact that such things can start playing the role of money but not yet the reason why that money will retain its value.

The actual reason for money to remain valuable is the fact that people want more of it and once they get it, they choose to hold it and not give it away easily. Once a certain symbol like money is accepted by humans as the representation of order, it finds itself under the protection of an innate drive to guard the acquired order and increase it if possible. The value of money is connected with the main quality of life itself—a desire to lower entropy and to safeguard the achieved reduction of entropy. In this sense holes in our pocket have the same significance from a life guarding point of view as holes in a cell's membrane which lead to insufficient protection of a living cell from an orgy of outside entropy. Life is local order, life's goal is to protect and to increase order. We are back to our discussion on the second law of thermodynamics: our struggle for low local entropy will be lost if we don't protect the achieved order and money, which represents that order, must be held at least temporarily as a defense against us becoming an object with growing entropy.

There are needs which can be satisfied by giving away money, there are many temptations and traps set by those who want us to part with our money. Yet the desire of people to keep money and spend it mainly when necessary, in most cases prevails and thanks to that, and not thanks to government decrees, money loses its value only gradually and some times may even gain in value. This is the main reason for money to retain value and that reason comes from the physics of life itself. The social and economic question is how this reason holds against many factors which push the value of money down.

Indeed, reckless spending by people would ruin the monetary system in no time. We may say, that the influence of life's goal to guard life, to protect local order from destruction, gives us the ability to guard our money and this is a stronger element of our behavior than even many moral or even religious prescriptions. It is interesting how this desire to hold money (and property in general) survived throughout centuries despite many dissenting moral teachings including one of the mightiest religions humankind ever knew—Christianity. Indeed, Christ's rebellion against embryonic financial enterprise as he "poured out the changers' money, and overthrew the tables..." (John 2:15) characterizes the early position of the Christian sect in Israel. Christ's words: "sell all that thou hast, and distribute unto the poor, and thou shalt have treasure in heaven: and come, follow me." (Luke 18:22) actually prescribed a life without money as money would lose value if given away on a massive scale.

This and many others' dissenting moral systems were apparently produced as a protest against material inequality and until Marx and his followers did not have a basis in economic theory. As we saw, Marx's approach was primarily energetic and did not properly take into account the organizational and informational components of the economy. One has to note though that even in an economy with a negligible low-entropic component the desire to hold money is also crucial for the economy. In such a stage of the economy money represents labor (energy) to a bigger extent that in a developed economy and cautious spending of money represents the principle of work minimization. One may reasonably expect that the human ability to measure energy, order and p-order by money is higher when there is a simple connection between the amount of money and the quantity of hours of work. Using money as a measuring device for higher and higher levels of p-order increases the possibility of erratic mistakes in measurement.

In any case, for money to be a measuring device there are the following rules:

1. everyone wants to get money

2. everyone holds it or exchanges it for goods or services in extent of the amount which corresponds with the desired value of those goods or services.

Rule one is not absolutely crucial as some people may choose not to play this measuring game at all and become hunters and gatherers in a forest or on the city streets. Rule two is crucial as giving up money for not deserving values certainly devaluates money.

Each person who participates in economic life is actually a member of the giant jury which evaluates money and the economy's produce every day. If I put $1000 in a bank it is not safe there simply because of FDIC insurance—that insurance will cover my dollars in numbers only, not in value. Actually my savings depends on the verdict of hundreds of millions of people to decide what that $1000 will worth tomorrow. My real insurance, as far as the value goes, is the hope that the value of my savings will be judged by a non-impartial jury because if I lose, then members of that jury will also lose the value of their money.

Over-Pricing of High Levels of P-Order

In the last centuries money less and less represents the energy of work and simple p-order as higher and higher levels of p-order are introduced by technological development. The simple rule of economic evaluation which I suggest to accept as the *overpricing postulate* is that the

margin of mistake in evaluating higher levels of p-order is bigger than when we are dealing with the energy of work or low levels of p-order.

The following consideration will support this postulate. When a market defines the price for simple work, there is at least a lower limit for that price—a worker must be paid enough to survive with his family otherwise we will not have an economy at all. Pure physics gives us some minimal standard of price in this case. A developed society chooses to pay quite a higher price than that minimum, but at least we know the lower end of the spectrum of our choices and the margin of tolerance is not open ended. This lower end is an actual bridge between the possible arbitrariness of human judgment and scientific evaluation. With payments for a highly qualified creative activity society usually does not take into account such a minimum—the issue here is not survival, but the considerable reward which will attract people to achieve a high qualification and share the fruits of it with society. So there is no connection at all with anything outside of the arbitrary decisions of the market and for that reason we should expect a higher uncertainty in the evaluation in such cases.

The same goes for the evaluation of devices which produce higher levels of p-order. The economic effect of a simple machine which can replace a few workers can be easily calculated. Not so with an automated line of production which replaces thousands of workers. The same goes as far as the evaluation of corporations which are sophisticated devices producing p-order: swings of the stock market are evidence to uncertainty in evaluating corporations.

Price tags for many technological achievements and for corporations are often the result of guesses even if there is clever analysis in reports written in support of such guesses. Western societies, especially of the last century, are in new and unknown territory as far as the evaluation of higher levels of p-order are concerned.

Having said that about the growing margin of imprecision in measuring higher levels of p-order, I have to address the question why imprecision is most likely lead to over-evaluation. One answer to that is that creating higher levels of p-order is similar to dealing with an unknown will in jungles: we have a tendency to over-evaluate the unknown. A more practical answer is that if an entrepreneur under-evaluates work and devices which create higher levels of p-order, development will go slower, and he might lose to his competitor. New technological development is usually connected with the promise of a high return on invested capital so over-evaluation is often considered to be worth the risk.

Evaluating Money

For a long time it was thought, starting with David Hume of the eighteenth century, that the level of prices is determined by the quantity of money in circulation (quantity theory). Such a view is reasonably based on a consideration similar to the general supply-demand dependence of prices: if there is a high probability to get money, the price of money will go down. The tricky part is that money is circulating among people, the velocity of circulation affects the quantity of money and that velocity can vary considerably depending on many other factors such as the general level of production, taxes, consumer's confidence and so on. What is more, money is created by society through credit and promises. This old picture of the quantity theory wasn't too helpful during the Great Depression (which brought its revision by Keynes[61]), but belief in a connection between the money supply and inflation still plays a role in economic theories. This is fine, except for the fact that the exact nature of this connection is not established.

And here we have to remind ourselves about the Achilles heel of any economic theory. One thing is to observe and make conclusions about inflation on the basis of the past experiences of society. It is another thing to direct development and to regulate certain processes. Even with

61 John Keynes. General theory, General Theory of Employment, Interest and Money.

a reliable knowledge of hydrodynamics we can not always regulate the flow of a river: water under pressure can dig an underground channel to compensate for our interference. With millions of factors playing a role in society's life and just a few factors open for regulation, there is no theory which can assure us that it can put certain society's trends under control. The history of monetary control in the twentieth century is full of drastic mistakes and the question remains: were those mistakes made due to wrong regulatory moves or they were due to the regulators' belief itself that manipulations with the interest rate can regulate the value of money. Indeed, the interest rate should be viewed as the price of renting money and not necessarily a characteristic of the value of money. The recent case of a negative interest rate in Japan gave us two valuable lessons. First we never know what twist to expect from economic development. Second, interest rates may be not connected with the value of money at all as yen did retain its value quite well during short time of the negative interest rate.[62] One can artificially make money too expensive or too cheep to borrow, but one can not predict how a jury of economic participants will evaluate money.

Mixing Energy and Different Levels of P-Order

As we saw, on the simplest stage of the development of human economy, labor can be treated as pure energy and so can food which is a reward for labor. We can not treat the low-entropic component of economy—order and p-order—as energy. Nevertheless, this is exactly what is happening in a contemporary economy constantly—both,

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62 Sheryl Wudunn "Zen Banking: Some Interest Rates in Japan Drop Below Zero", *New York Times*, November 7, 1998.

simple labor and food, which are primarily energetic entities, are exchanged for money and the same money is used to pay for high levels of p-order. The result for a student of economics is that price can not be defined with any certainty as we could do it in a purely energetic model when we used measurement in energy units. The possibility of a physical basis for measurement comes to the end here as p-order can not be measured as simple as energy and prices depend on the decisions of people.

It doesn't mean though that physics is not applicable in a qualitative approach. Indeed, energy and entropy are different properties of any physical system, be it gas in a vessel or a community of living creatures on a planet. The low-entropic component of an economy itself presents a mixture of different qualities: it can be simple potential order (p_0-order), as of the will of a worker stacking wood or the activity of a robot sorting vegetables, or it can be many higher levels of p-order. Indeed, those who produce robots possess p-order of producing p-order.

An example from computer programming can illustrate different levels of p-order. The zero-level (p_0-order) is a program which can sort numbers—it simply produces an order. Then we can create a program which will produce programs able to sort numbers—this is level p_1-order. We can go farther and create a program of level p_2-order which produces a program of level p_1 and so on.

With the technology of a pre-industrial age it is not too difficult to outline the hierarchy of p-order. It can be done on the basis of the economic chain of command: unqualified workers apply energy, their foreman directs this energy telling workers what to do (p_0), an engineer directs the foreman (p_1), a financier explains to the engineers what he wants (p_2) and in most cases this chain did not go much further being topped by rulers who were responsible for overseeing all levels of p-order in society.

Observing economies of the past, we see that producers of different levels of p-order were rewarded according to their position in this hierarchy of p-order and in fact they belonged to a rather separate social strata. It went together with the scale of prices on consumer's goods. A consumer basket for simple survival was mainly affordable for laborers. Any sophisticated goods containing a high level of order, as well as the means of production, required buyers from a higher social strata.[63]

We can say that rewards for different levels of p-order production in the past were more reflecting the *value of p-order of different levels* than these days even if we estimate the value of p-order only on a basis of the immediate economic effect. Indeed, the knowledge of one foreman can save a lot of the energy of laborers. The knowledge of one good architect was saving a lot of energy and materials compared with the architect who would build an unsafe building. But as we saw in the example of digging roots, price may not reflect value at all. If there is a good supply of people who can produce p-order, there is no reason for the price of their work to remain high.

With the spread of education, with technological information being free after the patent period has expired, with technology developed so high and with the acceptance of democratic customs in society, the social and economic stratification connected with the production of different levels of p-order is much less noticeable. People who use mostly energy in their work, let's say collecting garbage in a city, can be paid an amount of money comparable to those who create automated industrial operations on a high level of p-order. In consumption, the level of stratification is also much lower than in the past: com-

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63 Needless to say that many people who didn't produce any p-order enjoyed high social status due to relations with producers of p-order but this is outside our interest in this discussion.

puters which can be instruments of a high level of p-order can be bought for the same price as a few weeks of a family's food supply.

We see here the mixture of energy and p-order being measured by the same units—dollars in our case, and that measurement often doesn't even reflect the hierarchy of potential order. It is certainly heretical from a physics point of view, but even from the point of view of economics different units for measurement of different levels of p-order could be justified due to the fact that the margin of mistake in evaluating higher levels of p-order is higher than in the case of evaluating energy or simple p-order.

Creating Money

The drive to produce whatever has more liquidity is understandable. If a certain commodity plays the role of money then the desire to produce that commodity directly does not surprise us. We also can expect governments openly or secretly to print money when they are short of it. But society also came out with a way to create money without producing anything physically.

As a useful economic practice it was probably discovered in the middle ages somewhere in Europe by some dishonest jeweler who abused the trust of those people who were giving him gold for safekeeping. Instead of safekeeping it, he started to loan that gold to other customers for a fee. Imagine the surprise and anger of some nobleman who gave that jeweler his coins in order not to lose them in gambling, if he would find out that the jeweler himself is gambling with those coins! Still it is exactly what was happening and the calculation of such a jeweler for most of the cases was correct: there is quite a low probability that one day all the depositors will come and demand all their money. Still, the word "dishonest" I used to characterize such practice was appropriate as there was no FDIC insurance at that time and there was no real guarantee of safety for such a use of someone else's money. We know about many bank failures throughout history so the people's trust was actually abused.

It took extensive economic thinking to understand that what such jewelers were doing at the dawn of European capitalism was actually creating money without the royal privilege to mint. The same creative technique is in use now with symbolic paper money which we deposit in the bank. Theoretically, the exact form of money doesn't matter, such creation of money could be done even if cattle played the role of money although this technique will not actually increase the physical quantity of cattle. In our time in addition to the traditional use of money deposited in the bank, there are also a variety of newly invented financial instruments which are used to create money. Even a simple contract with the promise to pay in the future does, to some extent, create money as the party in the contract behaves as if it has that money before it actually receives it.

Mechanism of Inflation

The loss of the value of money—inflation—is one of the most discussed questions in economics especially because in the view of many people inflation of money is a threat to the stability of economic life.[64] This is a rather peculiar view and might be connected with the ambiguity of our perception of stability. Indeed for the economy to

64 How can inflation exist at the same time as everything is getting cheaper, as was shown before? To put it simply, everything is getting cheaper, but money is often getting cheaper more quickly than goods.

develop it should not be stable yet stability is perceived mostly as a defense from chaos.

What people usually mean when they want stability is not to be betrayed as far as their expectation goes, they want reliability of values. Indeed, the exchange of obligations is part of reliable economic relations. If there are quick changes in value of things, especially during the duration of the deal, there is not to much incentive to enter the deal. One would not like to pay for a sack of potatoes in advance and later receive a sack of rotten potatoes. Nor send to the customer a sack of good potatoes and later receive the payment in rotten money. For many people the reliability of a deal is to go further: money collected for old age is part of a deal with society and there is an understandable feeling of being betrayed when that money loses value. So inflation also creates political problems.

As one can expect, no single cause for inflation was ever found. If, as it is commonly perceived, we are dealing with evil here, it is a multifaceted evil and there is no way to predict when it will strike harder and due to which combination of factors. In fact, dramatic revelations of the seventies when a combination of recession and inflation occurred, reminded us that there is no such thing in the economy as a one to one relationship between any of the economic variables. It was strongly believed that the Phillips curve correctly represented the negative relationship between unemployment and an increase in wages.[65] The reasoning, supported by previous developments, was that when unemployment is low, businesses have to compete for qualified cadres, have to increase wages and this triggers inflation. Yet *stagflation*

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65 For discussion see Milton Friedman, Unemployment Versus Inflation?: An Evaluation of the Phillips Curve.

of the seventies in many Western countries showed inflation despite a recession.

The Phillips curve however should not be neglected for future use. It goes along with the line of reasoning I presented here about the growing imprecision as we are dealing with higher levels of p-order. Except for the most unqualified laborers, cadres for the economy constitute p-order, qualified cadres constitute higher levels of p-order. As we saw from the reasoning above, there is a larger chance of overpricing high levels of p-order than simple work and this is what is happening during competition for qualified cadres. But there are also other parts of the low-entropic segment of the economy which represent high p-order and which are at risk to be priced erratically including whole high-tech corporations.

With that reasoning about erratic pricing and the Phillips curve as an example mainly supported by past experience, it is justified to blame a good part of inflation on the segments of the economy which are dealing with higher levels of p-order. It is even more justified as we know that the creation of higher levels of p-order is on the cutting edge of the economy and is heavily financed by money created by credit.

But this is just a technical reason for inflation. The deep and real reason for inflation is the knowledge of a jury of economic actors that more money has been created than was justified by the creation of values in society. Money is not orderly by itself, it represents order in society and society manages to know if the balance of this representation with the creation of order is violated. This was the reason why I had to discuss not only prices but also the values behind them.

As it is life's property to achieve and to guard order, there is society's ability to evaluate money as the representation of order. Through millions of steps which we can not follow, society guards the value of produced values and adjusts prices expressed in money according to the value of that money.

Separation Of Money

If there would be separate kinds of money for each level of p-order, erratic pricing for higher levels of p-order would have a less inflationary effect on the rest of the money. Only the exchange rate between different kinds of money would fluctuate. Can we, at least theoretically divide the money circulating in different segments of the economy? Such a task is impossible as low-tech production these days is mixed with high-tech in many ways, the chain of interdependence of the means of production got quite long and it is not always clear where it starts and where it ends. What is possible though is to discuss separately the consumer's money ($C) and business money ($B). If such separate money would exist it of course would be exchangeable but the rate of exchange would vary depending on the level of erratic pricing of higher levels of p-order in the business sector and the creation of business money through credit and other financial instruments.

In a way such a separation of money existed in a past when silver was money mostly for the masses and gold circulated mostly among those with the means of production. The separation was not perfect of course and the rate of exchange was often tied to the cost of production of these two metals or other factors.

The history of the Soviet economy gives a more interesting example of such a separation: there was cash for consumer's and bank money (called *beznalichnyi raschet*) for industry. Authority was quite careful not to mix these two. There was no rate of exchange of course as there was no free financial market but bank money could be spent by the managers of industry only for production needs. We can not judge how this system of money separation worked in regulating inflation as the Soviet economy had prices set by government, but it is interesting to note that during the erratic transition of Russia to free market relations, that industrial bank money got mixed with consumer's money uncontrollably, flooded the market of foreign exchange and among other factors caused a sharp drop in the ruble's value.

In the West the division between consumers and producers money does not exist per se, but for all practical purposes, business money is kept largely out of circulation in the consumer's market except for employees spending or partly spending their salaries. Indeed, the amount of money tied in industry is so huge that if a few big corporations or a few tycoons would want to corner the market of vital consumers' goods they could do it.

There is also sometimes a separate treatment of industrial money and consumer's money in economic theories. There is also a completely different approach to raising prices in the consumer's and industrial markets. Indeed, inflation is counted on the basis of the prices of consumer's goods. Let's take a period of the US economy with quite low inflation 1988-1998 and imagine that there were two separate kinds of money $B for business and $C for consumers. With relatively stable consumers' money business money was fluctuating considerably in value. The stock market was moving actively mostly up which shows that the average price of businesses rose considerably. Value of businesses during this period did grow of course, but not as much as the average price of a corporation. It means that there was high inflation of $B for this period and it was not recorded by econometrics which counts inflation only for the consumer sector. This also means that the production of business money $B was quite active during that period.

We see that in the case of separate $B and $C, the exchange rate between these sub-currencies would vary noticeably during the named period. Economic catastrophe would be inevitable if that part of $B which was produced without the creation of corresponding values, would be spilled to the consumer's market at a rate of one to one.

Fortunately for the economy this one to one exchange on a large scale is almost impossible for two reasons:

1. The business money of those who own corporations exists in the form of nice looking papers—stocks—which can cost a lot but only when not many people try to convert it to real dollars: the exchange rate depends on exchange activity.

2. There is almost no need for owners of big businesses to use their business holdings and credit for buying consumer's goods as usually they have enough $C to satisfy their needs. The amount of $B they are holding is for savings, for playing with the development of industry or for hierarchical status, not for every day bread and butter.

Massive exchange of $B for $C can be explosive. Collective fear of destabilization and not luck of $B usually prevents mighty people from playing a game with such conversion. Still, there is the story of the Hunt brothers in the seventies who tried to corner the silver market. The fact that government interference followed this attempt, shows us that market forces are powerless in cases of the attempts of some businessmen to play such a game.

Saying that, I do not try to undermine the self-regulating ability of the free market as many economists led by Keynes did during and after the Great Depression. The self-regulating ability of the free market should not be questioned on the basis of large swings in market history. In fact large swings are part of self-regulation and in a way are proof of self-regulating ability. The Great Depression produced a lot of theories as to why it happened but speculating about numerous factors should not make us forget that the fall of the stock market was the reaction of a self-regulating market on the creation of money which went way ahead of creating the values behind that money.

The problem is that it is exactly the risk of large swings that is not acceptable for humans. They would rather be regulated by the government than submit themselves to such a risk.

How Over-Created $B-Money Reaches Consumers?

Putting aside economic terrorism, like driving a certain segment of the market to the corner, I should discuss how normally $B is converted to $C. It is part of normal economic life when it is done through the payment of salaries or payment for supplies—the assumption is that the money in such cases is exchanged for values and this shouldn't create abnormal inflationary pressure. Of course, there could be competition for highly qualified cadres with over-payment as already mentioned, but this explanation of inflation is not sufficient for all cases. Generally we may assume that if members of society's financial elite create an additional portion of $B without value behind it and play with it among each other it does not yet create inflation. If only part of $B is converted to $C and there is value behind that part of $B, this is also not inflationary. Market forces including the desire of people to hold money and not to exchange it for non-corresponding values limits the activity of exchange of $B for $C.

But there are taxes in society and the government does not distinguish between $B and $C. Through the mechanism of taxes, a good part of $B enters the consumers' market in the form of salaries paid to government employees, financing social programs and buying goods for the government. Through this mechanism the government takes money, behind which there is not yet enough value, and exchanges it for real values. I am not claiming that this is the full answer to the mystery of inflation, but it is an important factor which should not be disregarded. This is especially important when a portion of inflated $B gets converted to $C through government social programs when some segment of the population receives payment from the government not in exchange for creating values.

It appears that the economy somehow senses danger that business money can be over-created and inflated by over-pricing of higher levels of p-order. Self-regulating economic life does what it is possible to do for preventing the massive mixing of business and consumers' money. Yet through taxes these two sub-currencies are uncontrollably mixed and the market has to react by discounting the value of money in general.

Monetary Control

As Western countries entered an era of producing higher and higher levels of p-order with a higher probability of erratic pricing, it is quite possible that noticeable inflation has to be the *modus operandi* of economy. After all, the use of money for centuries was tested as a valuable tool of human economic relations only for dealing with organized energy (work) and lower levels of p-order. Understanding the relation of money with what we are measuring by it—energy and potential order—can help either to be aware of the shortcomings of this measurement or improve this measuring device if we want to use in the future.

It is accepted by economists that the over-creation of business money can be inflationary. Different countries practice different ways of credit control. In the US the prevailing method of controlling inflation is through the interest rate: once the Federal Reserve board announces raising or cutting the rate, banks follow and more or less money is created through credit. There are of course still other instruments for the creation of money, but control of the interest rate is believed to be effective if economic activity has to be suppressed. No doubt this method works to some extent, but it is analogous to injecting medicine which has a side effect. We may have an inflammation only in one finger, but the whole body will be subjected to the side effect of that medicine. Indeed, my discussion on the role of different levels of p-order in the economy showed that higher margin of tolerance in pricing higher levels of p-order is the source of erratic pricing. Through control of the interest rate the government suppresses all economic activity to prevent inflationary pressure created by overpricing only in some parts of the economy.

IN CONCLUSION: The Unpredictability of Will and Physics

When the wind blows in our face we bend against it, not with it as a flag post would. Simply because we are creatures with a will and not merely objects put into motion according to the laws of mechanics, we are excommunicated from the temple of physics. Our will—which is informed energy—is capable of deviating from the prescriptions of physical laws in general, although not in details. We are able to produce our own kinetic energy when it is needed, without waiting until a collision with another body passes momentum to us. Without violating the laws of physics in detail, we produce our own laws for our macroscopic behavior.

This context presents a fascinating question: will physics one day accept willing bodies into its sphere of its study? Until we know the answer, we can at least look how far the laws of physics actually regulate ours and our society's behavior.

For many years the traditional topic for passionate debate among scientists and moralists has been whether we are masters of our behavior, or whether and to what extent we follow biological prescriptions—instincts—as animals do. My goal was to go one step further, to the following inquiry: what are the inevitable consequences of the fact that we are built from matter, and how much is our willing behavior (together with instincts) defined by the laws of physics?

"Physical" usually means pertaining to the study of matter and its properties. In this sense there is physics behind everything that humans can do, because humans are built from matter and they spend energy in all their actions. It is obvious, for example, the hydraulics of the blood or the number of calories spent by a human in performing work is a subject for physics. But this is only the simplest application of physics to human actions. What truly opens the door and permits a physicist to enter into the study of human activity and social problems is the concept of entropy and order.

Indeed, life itself is an ordering process, a process that goes against the direction a system of matter particles is supposed to go in an inanimate world. For this reason alone life is an intriguing subject for physical study; and life posesses will, which in its own microcosm acts as if it creates its own physical laws.

I am very far from suggesting that human behavior or social life should be treated as problems of physics and nothing else. I doubt that the day will come when we are able to evaluate human laws or political decisions purely on the basis of the prescriptions of physics. Yet there is an influence of physical requirements on individual and social behavior, and developing this area of inquiry can be fascinating. I believe that my short excursion in economics was an example of such a possibility.

The obvious reason to reject human will as a physical property is its unpredictability. Physics does not like that. Of course, some development has occurred in the minds of physicists since the time of mechanistic philosophy, when the world was celebrated as a precise clock built by the Creator. Physics has learned about the irreversible behavior of multi-particle systems. Later the particle-wave duality of physical objects has prompted some thinkers to discuss even the possibility of the free will of electrons.[66] Indeed, from an experiment with the diffraction of electrons we know that the path of an electron can be predicted only probabilistically and not precisely, as would be expected in classical physics. Still, the

66 My recollection is that Heisenberg used this expression.

overall behavior of an electron is defined by a specific, calculable range of probabilities of being in certain points of space at a certain time. Is there an analogy to be made to the probabilistic knowledge of human will manifestation?

Yes, because statistically we are predictable in many ways. There are quite precise numbers of how many suicides, murders, auto accidents and so on will happen next year; or how many babies will be born and how many people will die. An alien observer without any knowledge of human nature could record a periodic increase in traffic in the morning and at the end of working day the same way he could record the periodic rises in the tide and the movement of the planets. An alien who cared to look more closely could record as a physical event the fact that a tea cup appears on the table of an Anglophile every day at five o'clock in the afternoon. One can continue this list for one's own exercise, and see how much predictability there is in human behavior.

Still, this list of predictable patterns cannot cover even a small portion of human activity. Over all it is unpredictable—or at least we like to think so. If human will is informed energy, then this is why physicists resist accepting it as an object of study: historically physics dealt just with non-informed energy, energy that is channeled according to outside laws. Human will, by being informed, can channel itself according to its own goals and preferred ways. This is an obstacle for physics, at least physics as it is historically known.

But there is also a problem of measurement. As we saw, the level of order in physics can be measured quite precisely. There is a bulk parameter—entropy—which in most cases tells us how a particular level of disorder in a system influences other physical properties of the system. There are parameters of crystals which characterize precise types of order. There are also measurements of deviation from order, such as the density of dislocations in crystal, for example. All these achievements in the measurement of order are the result of hard work, of course; but they also result from careful choice in the objects of study and careful choice in the types of order to be studied.

In fact, it is the most primitive types of order that have been chosen by physicists as objects of study which, alas, is how far science has gone in its ability to describe order. In recent years much attention has been focused on finding methods to characterize complex systems and complex order. I chose not to discuss these embryonic methods of characterizing complex order as I am more concerned with the quality of potential order of a system. Indeed, analyzing properties of potential order of different levels be it in biology, law or economics looks to me as a promising way to uncover more connections of the behavior of humans and their society with basic principles of physics.