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SYNTROPY: DEFINITION AND USE

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By this article, my aim is to provide an idea about the practical use of the concept of "syntropy", particularly in the field of social and economic studies.

The word "syntropy" is nowadays commonly used, though in a competition with "negentropy", the other term adopted – perhaps in a less correct way – to express the same or an analogous concept. Both words are since the past century used to mean that quite special *mode* by which energies of various kind concur in promoting either biological phenomena or other natural spontaneous processes, which are in an apparent disagreement with the overall tendency of matter to degrade. The overall tendency to degrade was given evidence and defined in the 19th century through the formulation of the concept of "*growing entropy*".

It seems to me that the diffusion of the term "syntropy" is not associated with a commonly accepted meaning for this word, because there is no univocal definition of the concept. There is a formal statistical definition of "syntropy", according to which "syntropy" is seldom used as "deviation from the norm". In my view, and allowing for the historical origins of the word, the appropriate meaning of "syntropy" is the "degree of internal organisation" that characterises any system of events. This is basically the sense the word was given by Italian mathematician Luigi Fantappiè (1901-1956),[1] who did also coin the word.

I deem it impossible to grasp the concept of *syntropy* without having assimilated the concept of *entropy*, since – as I'll try to show – not only are the two concepts in a strict mutual connection but *entropy* and *syntropy* are also *complementary* concepts**:** In other words, where it is possible to measure a level of entropy there is a *complementary* level of syntropy.

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[1] Luigi Fantappiè , *Principi di una teoria unitaria del mondo fisico e biologico,* Humanitas Nova Editrice, Rome 1944.
In the same year, Austrian physicist Erwin Schrödinger (1887-1961) published an essay, *What is Life? The Physical Aspect of the Living Cell*, Cambridge University Press (U.K.), in which he used the expression "negative entropy", also giving its formal definition (Chapter 6, Para. 7). The concept was later referred to by other scholars with the word "negentropy".

Therefore, I wish to apologize for my long introduction, in which I linger on the meaning of “entropy”, whose use is often inaccurate and source of misunderstanding.

1. Entropy in Thermodynamics

Thermodynamics is not a simple branch of physics, and it seems difficult to many to get familiar with the concept of “entropy”. This concept was formulated by Rudolf Clausius (1822-1988), and its implications have been largely developed since the second half of the 19th century.

In the 20th century the concept of “entropy” has also been adopted in other technical disciplines, following the re-shaping of the concept in probabilistic terms as provided by Ludwig Boltzmann (1844-1906). Boltzamnn’s formulation helped interpreting “entropy” as a measurement of *intrinsic disorder* in the state of any physical system. In thermodynamics, a state of *disorder* is viewed as the *chaotic uniformity* that establishes when an isolated physical system comes to a condition of *thermal equilibrium*.

I deem it useful to start discussing first this aspect of “entropy”, prior to defining the concept of “system”, with a view to introducing later the concept of “syntropy” in a smoother way.

Thermodynamics does essentially address principles and techniques aimed at utilizing heat (thermal energy): the possibility of utilizing heat decreases with the diffusion of its uniform *chaotic* distribution. Instead, thermal energy becomes more and more utilisable (for instance, to produce mechanical work) with the gradient of its concentration inside any physical system.

Adjective “chaotic” is important in specifying the degree of uniformity in the heat distribution, as I’m going to explain later on.

Thermal energy coincides with the summation of the individual kinetic energies of the molecules of which any matter consists. Material molecules are in a permanent agitation, with an average agitation speed that depends on the matter’s average temperature. Actually, as per a fundamental definition of dynamics, the square agitation speed times half the mass of the molecule is the kinetic energy of each molecule, and the *temperature* of matter *is* the *average kinetic energy* of its molecules.

Thus, summarising the concepts**:** "Heat" is the summation of the kinetic energies of all the molecules of which any material body consists. "Temperature" is the *average* kinetic energy of any molecule belonging to the material body.

There is no counter indication if one adopts the concept of temperature as a *density* of thermal energy, i.e., as "amount of heat per mass unit".[2]

In thermodynamics, entropy is a quantity that depends on the physical state of the system considered**:** for instance, if it is a fluid, entropy depends on how density, pressure, temperature, volume, gravity potential, etc., are distributed inside the fluid. These quantities, which determine the level of entropy, are generally variable quantities, usually mentioned as "state parameters".

Classic thermodynamics doesn't deal with absolute values of entropy, since it focuses instead on the *entropy variations* that occur in *spontaneous transformation processes* undergone by material systems.

In thermodynamics, *entropy variation* is defined by the formula (a very simple ratio between two quantities) used by Clausius to introduce the concept. The two quantities relate to a spontaneous transformation process and are:

(i) the amount q of thermal energy, which transfers from any section of a material system to any other section of the same system, the first section being at a higher temperature with respect to the other section:

(ii) the temperature T at which the system establishes its thermal equilibrium at the conclusion of the process.

The ratio that defines *entropy* ***variation*** is expressed by $V_E = q:T$. Any interpretation of the concept of entropy must allow for this simple formula.[3]

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[2] There is no conceptual difference in considering temperature either as the average kinetic energy of any individual molecule or as the density of thermal energy per mass unit. Concerning temperature, there is to remark that the term has never been given a univocal and precise definition. The scientific definition of "temperature" is actually an operational one, in that it is a quantity measured with various kinds of thermometers, according to the specific technical context regarded. As to its *physical dimension* (see also subsequent Footnote **4**), temperature is in some cases quantified in energy units.

In the light of the preceding definition, it's perhaps easier to understand why entropy does continuously tend to grow when *spontaneous transformation processes* are involved. Indeed, during any transformation, there is a continuous transfer *q* of heat (or of other forms of energy) from some sections to other sections of the system. Therefore, quantity *q* can never be nil until the process ends with an equilibrium state.

1.1 Entropy, Age and Time

The unceasing increase in the amount of entropy during any physical transformation process has led to consider entropy as the transformation's degree of *irreversibility*. Thus, one may associate the concept of "age" with that degree of transformation irreversibility.

The *age* of any material system, as measured in terms of entropy generated by its transformation processes, has substantially nothing to share with the concept of "time" used in physics, and with the *time* currently used for common practical purposes in our everyday life. In simple words, *thermodynamic age*, which inheres in the *ageing* of any material system, cannot be properly measured with clocks.

The *physical dimension* for the *age* regarded by thermodynamics is energy divided by temperature, whereas the physical dimension for *time* is distance divided by speed.[4] This is an important remark, which points out the different *physical nature* of *age* with respect to *time*: *age* involves energy and/or mass, *time* neither mass nor energy. Moreover, *entropy,* or *age*, is

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[3] The physical nature of the quantities that define ratio V_E may lead to the following interpretation, amongst other possible ones: Considering that no energy is conceivable without the vehicle of the relevant mass, the inexorable increase in the entropy level is a measurement of the *increasing amount of matter* in the system that exits the transformation process and becomes the system's "deposit" of *idle energy.*

[4] **A useful note for whom has lost familiarity with the language of physics.** Sometimes, specialist languages can be misleading, because of terms that – in a correct English – might be replaced by other more appropriate ones. It's the case of "physical dimension", which could suitably be substituted with "*physical quality*", or "*physical character*", or the like. Almost all of the quantities addressed by physics can be characterised by numerical powers of three basic "*physical dimensions*" (or "*physical qualities*"): These are "mass", symbolised with [M], "length" (or "distance") symbolised with [L], and "time", symbolised with [T]. For example, the *physical dimension* for quantities that express "volumes" is the "third power of a length" [L^3], the dimension for "speed" is "length divided by time" [L / T], the dimension for "force" is "mass multiplied by acceleration" [ML / T^2], the dimension for "energy" is "force multiplied by length" [ML^2/ T^2], etc. Moreover, there are *dimensionless* quantities, usually expressed by ratios between two homogeneous quantities, like – for

always a positive parameter, never less than zero, whereas *time* of physics is a parameter that may be given either positive or negative values. *Time* is a parameter associated with *reversible processes*, whose description is symmetrical with respect to any reference frame, whereas *entropy* (or *age*) is a parameter inherent in *irreversible processes,* which are not symmetrical with respect to that same reference frame.

However, according to practical needs and in most cases, there is no serious inconvenience if one uses *time* as a parameter for *age*, since the use of clocks and calendars is a noticeable simplification also in describing irreversible processes. Provided that one keeps oneself well aware that *time* taken for *age* (i.e., the use of clocks to measure entropy) becomes a one-way and irreversible quantity too.

The opposite, i.e., the use of *entropy* to measure *time* of mechanics, wouldn't make sense in almost all cases.

The practical use of *time* for *age* establishes a relationship between the positive *trend* of the former with the natural *trend* of the latter, but one should never assume that there is a direct and regular proportionality between these two quantities. For example**:** the *age* of a rock, which is exposed only to gravity and to meteorological phenomena, grows very slowly in a comparison to the stone's *time* duration. At variance with this example, the process of generation, life and disappearance of some sub-atomic particles is considered as a long-lasting event, though it is measured in nanoseconds. Thus, also the age of a 120-year old person is considered as an enormously long-lasting life, though its *time* duration is negligible if compared with cosmological times.

The graph here below shows how the growth of *age* should be viewed in a comparison to *time*.

Time can linearly vary according to two opposite directions, whereas *age* grows constantly in a quite irregular way, though never dropping its varying quantity below levels already achieved.

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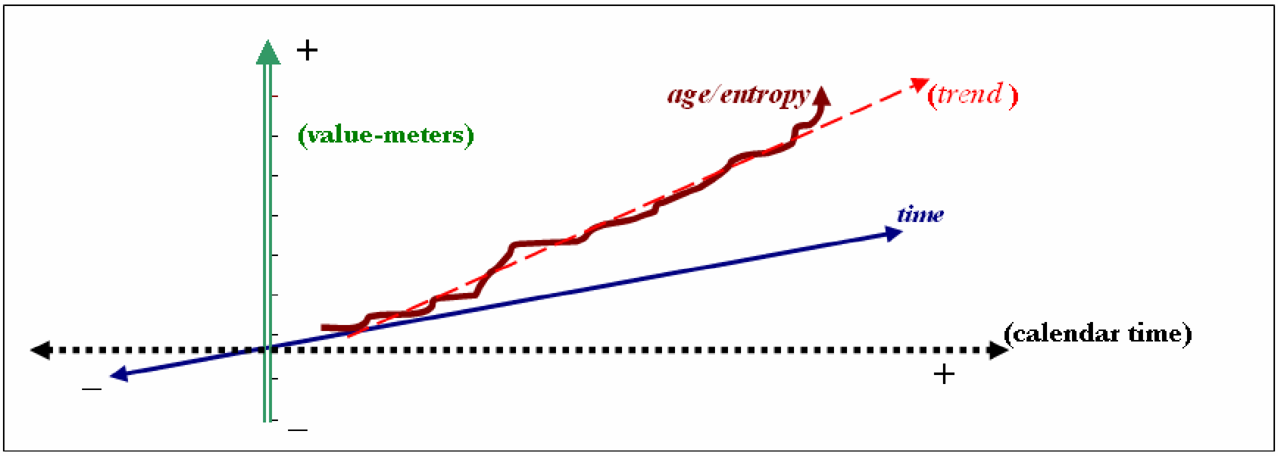
example – ratios between two masses, or between two forces, etc. In physics, *dimensionless quantities* are symbolised with number "1" in square brackets, i.e., by [1].



An intense and complicated debate has developed since decades about what time is or how it should be understood. Ilya Prigogine (1917-2003) and his school of thought have devoted many mental energies to the issue, and several interesting aspects of the question have usefully been put into evidence.

It seems to me, however, that part of the complexity attached to this issue is artificial and can be bypassed. Prigogine bets on a unique kind of *one-way time*, which should be considered as inherent in any event, irrespective of its mechanical or biological nature. [5]

In my opinion, as partly expressed above, there is an initial self-deception, which consists of using *one* same word to define *two different* concepts.

The use of clocks does only provide conventionally "regular" reference motions. These reference motions, which are expressed in ***length units*** or in ***arc degrees*** gone by the clock's hands, are *compared with the lengths* gone by other objects in motion.

Instead of keeping the route of the clock's hands as a reference length, one might follow the suggestion that comes from General Relativity: In describing motion, the *fourth reference co-ordinate*, which measures the *motion duration*, can be the length (in meters or yards) gone by a beam of light while the observed object shifts its position from one point to another.[6]

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[5] Prigogine addresses this issue in almost all publications of his. Substantially, he states that no phenomenon can be considered as a reversible event. Every event is a *process* characterised by *state fluctuations*, and these can be properly addressed only through a probabilistic approach, which takes them into the paradigm of statistical mechanics, i.e., into the field of evolution and irreversible processes. Which inevitably leads to the one-way nature of *time*. (In this connection, see also Paragraph 2 ahead).

[6] In General Relativity, the *fourth dimension* is expressed by product ct, in which c is the constant speed of light, and t is a measurement of *time* whatever. The *dimension* for ct is "length", in symbols $[ct] = [L]$. This means that the relativistic

Furthermore, *time* - at variance with *age* - can also compare *distances* gone by an object in motion with *volumes* of sand or water dropped by a clepsydra, which means that *time* can also be measured in ***litres*** or ***gallons***, and makes it clear that *time* is only a way to measure any motion by means of any other "regular" reference motion.

Quite a different approach to the use of clock is considering any clock as a *process*. But the *ageing* of the clock has no conceptual relation with its function of *time-meter.*

There is an innate language conditioning, which - since our birthday - makes us believe that the pace of our growing age is measured in astronomic cycles as well as in number of laps run by the clock's hands; which in the end persuades us that *age* and *time* mean substantially the same thing. However, if we pose ourselves in front of a mirror keeping a clock-face beside our face we could see that the reflected clock-hands can easily invert the direction of their motion, but we could never see our face rejuvenating, as long as the clock-hands may go. *Time* is symmetrical with respect to any reference frame in space, the *age* of our face is not.

I have repeatedly used "spontaneous" as an adjective of "process", but the meaning of this adjective – as far as the subject is thermodynamics – must be confined within the bounds of the processes that are fully controlled by the laws of physics, which includes thermodynamics.

The expression "spontaneous process" takes a different meaning if used in dealing with biological events. Whence the need to analyse that other kind of "spontaneity" whose nature seems in conflict with the inexorable law of entropy, while this law remains instead at work in all physical phenomena.

Any physical transformation involves transformation of energy. Energy, in material systems, is generally present in various forms, each form being characterised by a different level of quality. Thermal energy (heat) is at the lowest level of quality. The irreversibility of physical processes consists of the *degradation* of the involved energy, whose forms decay

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fourth dimension is ***not*** "time" but "length", expressed in meters (or yards or kilometres), just like the other three space dimensions known as *length, width* and *height*. (It's common experience, for example, to use *a clock to calculate distances* while travelling on a highway at a constant speed). Therefore, all the co-ordinates necessay to describe the motion of any object can be made homogeneous with each other; whereas in classical mechanics *time* was a heterogeneous parameter, an through the tendency of all energies to turn into thermal energy.

If heat is the only form of energy involved, then the irreversibility of the process is closely related to the degree of heat diffusion inside the material system. This enters its maximum entropy state when the whole energy has become heat and every element of the system is at the same temperature.

In a thermal equilibrium state, or maximum entropy state, flows of energy from higher quality or concentration levels to lower levels are no more possible; this lack of energy gradients is just the reason why further spontaneous transformations are impossible for the system. Therefore, for any system that is perfectly isolated in the universe, thermodynamics establishes that no spontaneous physical transformation is possible in a state of maximum entropy.

2. Entropy as "most likely state"

It's interesting to observe that for thermodynamics entropy grows with the temperature of a system in thermal equilibrium, whereas – for the *Third Principle* – ***entropy is nil*** when the system's equilibrium temperature is absolute zero (0° K). However, at this extreme temperature, the system should also be void of energy and therefore incapable of any spontaneous transformation**;** which would contradict the expectation that "nil entropy" means maximum potential of spontaneous transformation.

This apparent contradiction sheds light on the importance of the *disorder* that is intrinsic to thermal equilibrium states. The state of matter at high and very high temperature is characterised by more and more *chaotic* diffusion of molecular kinetic energy, which implies the tendency to a uniform *probability distribution* of the molecules physical states inside the relevant volume of matter. A persuading example of such a tendency in the molecular behaviour may be guessed thinking of the possible state and position of individual molecules in a volume of gas at high temperature.

An important theoretical confirmation of entropy as "state of disorder" came from the work

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"intruder", which didn't allow one to describe physical events in a mere geometrical way, i.e., in terms of length co-carried out by Ludwig Boltzmann, whose statistical version of thermodynamics proved that the entropy of isolated systems tends to grow because “state of higher entropy” means *state of higher disorder*, and states of the kind are statistically the most probable ones. Whence also the proof that the level of entropy is a function of the *probability of disorder* that develops inside the systems.

(A short break for terminological clarification seems here advisable, to remind the average reader of the lexicon proper to mathematical language. The word “function”, in mathematics, summarizes an expression composed at least by eight other words, and is used to mean any “*quantity that is determined by other variable quantities*”. For example, saying that ***z*** is a *function* of ***x*** and ***y*** is a way to say that any value for ***z*** **depends** on how the values for ***x*** and ***y*** may vary. There are infinite ways in which any quantity may depend on other quantities, but these ways are always mathematically specified, according to case).

Thanks to Boltzmann we can now avail ourselves of a more significant definition of entropy.

The *macro-state* that characterises the overall physical state of a system (as this depends, for instance, on the internal distribution of density, pressure, temperature, gravity potential, etc.) can be determined by many different combinations of many different *micro-states*. These are the individual physical states of the molecules of which the system consists.

When the system’s *macro-state* is of *non-equilibrium*, the possible molecular *micro-states* have different *probability of occurrence* for different molecules, though various combinations of different micro-states may result in the same macro-state for the system as a whole.

By a coarse similarity used only for exemplification purposes**:** five balls which are equal to each other in weight, but distinguished by five different colours, can variously be distributed over the two pans of a balance, in order to obtain – for example – the particular position of the balance pointer caused by three balls placed on the left pan and two balls on the right

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ordinates only. I deem this is an important clarification brough by General Relativity as to the meaning of *time* in physics.

pan. This particular position of the pointer in the balance is taken as the analogue of the system's macro-state. One can obtain the same result changing repeatedly the position of the colours (the analogue of the micro-states) while keeping always three balls on the left pan and two balls on the right pan of the balance.

Instead, in a state of thermal equilibrium, all the possible micro-states, which can determine the same macro-state, have an equal probability to occur. This *common probability value* is expressed, for each micro-state, by $P = 1/W$, where W is the total number of possible micro-states.

Boltzmann has proved that the entropy level in a state of thermal equilibrium is expressed by

$$E = -k \, \mathrm{Ln}P = -k \, \mathrm{Ln}(1/W).$$

In this formula, "E " represents the maximum level of entropy for a system in a thermal equilibrium state, "Ln" means "natural logarithm", and "k " is a constant positive value, referred to as "Boltzmann constant". The physical dimension for k is energy divided by temperature (which should result in the dimension of "mass", the same as for entropy), while probabilities are always pure numbers.

It has previously been observed that ***entropy can in no case be less than zero.*** In the formula above there is the logarithm of a probability. In all cases, probabilities are positive values ranging between zero and 1. Probability is zero when the relevant event is impossible**;** probability is 1 when the relevant event is unique and certain.[7]

As known, logarithms of numbers greater than zero 0 but less than 1 are negative numbers. For example**:** $\mathrm{Ln}(0.6) = -0.5108256$.

The sign "**–** " ("minus") before constant k in the formula for entropy E is used to turn the negative value of the logarithm into a positive value.

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[7] Logarithm of zero gives *minus infinite* ($\mathrm{Ln}\ 0 = -\infty$). Logarithm of 1 is zero ($\mathrm{Ln}\ 1 = 0$). Logarithm of negative numbers give *imaginary values*, which cannot be used in this context.

Using properties of logarithms,[8] the same formula can be written also in this way:

$$E = -k\,\mathrm{Ln}(1/W) = -k\,(\mathrm{Ln}\,1 - \mathrm{Ln}W),$$

whence, accounting for Ln 1 = 0, it's immediately seen that

$$E = k\,\mathrm{Ln}W.$$

The reformulation, due to Boltzmann, of deterministic concepts of classical physics through a probabilistic approach has led to consider the not negligible role played by the observer that tries to describe nature in an objective way.[9]

Statistical mechanics, as promoted by Boltzmann's theoretical work, has primed quantum mechanics, perhaps the most important scientific and philosophic revolution of the 20th century.

Actually, the probabilistic version of the concept of entropy is an assessment of the system's state as made by the observer, rather than a description of the system's state in itself. The many billions of individual microstates, relevant to the many billions of molecules that form the system, are neither *random states* in themselves nor states *intrinsically* equivalent to each other. Each microstate is in any case the result of physical interactions that obey the laws of classical mechanics, though such interactions – *as a fact of matter* – cannot

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[8] The logarithm of the *ratio* between two numbers, a and b, is given by the difference between the logarithm of a and the logarithm of b, i.e., $\mathrm{Ln}(a{:}b) = \mathrm{Ln}a - \mathrm{Ln}b$.
As to the logarithm of numerical powers, remember that $\mathrm{Ln}(a^c) = c\mathrm{Ln}a$, and $\mathrm{Ln}(1{:}\,a^c) = \mathrm{Ln}(a^{-c}) = -c\mathrm{Ln}a$.

[9] The conceptual system of classical physics, in which Relativity shall also be included (whatever the opinion of philosopher Karl Popper on the subject) represents nature by a *mechanistic paradigm*, in that the interactions between components of matter are considered as chains of causes and effects, which – at least in principle – can be identified and calculated, provided that all the involved initial and/or final conditions (the so-called "border conditions") of the events to describe are known. The many-year controversy between Einstein and the "indeterminist school" of Bohr and Heisenberg (often referred to as "Copenhagen School") focused on the idea, maintained by Einstein, that the "*indetermination*" about the state of atomic/sub-atomic particles was only due to the constraints imposed by the inadequacy of the investigation, with no reason for doubting the substantial *deterministic* character of the physical events at atomic and sub-atomic scales. On the contrary, for Bohr and the indeterminist school, the *indetermination* concerning the state of atomic and sub-atomic particles must be considered as *intrinsic* to that scale of those events, which escape *in principle* (i.e., not because of technological constraints) from any deterministic description and representation.

be individually described.

The *statistical* problem doesn't inhere in the molecules individually considered, but in the impossibility for the observer to follow and describe their behaviour in detail.

Even macroscopic operations, such as the measurement of the temperature of any given volume of fluid in thermal equilibrium, pose problems of a statistical nature. In spite of any sophisticated technology, each measurement operation is affected by a different degree of precision, which in practice cannot exceed the capacity of the measurement instrument; so that the final measurement result is actually a subjective decision rather than the *true* temperature ot the fluid. This means that it's the observer who establishes the significant degree of approximation for his measurements, and decides that the temperature is everywhere uniform within the given volume of fluid.

It's the start of a subversive change in the scientists' attitude. It's perhaps the first time in history in which scientists feel impelled to recognise that the real world in itself is substantially different from what technical instruments and specialist languages can investigate and represent. In scientific activity, the recourse to the use of concepts and techniques of the theory of probability means the awareness of impassable limits to our knowledge of nature. These limits inhere in the observer, and impose an inevitable amount of subjective uncertainty in all "objective" descriptions of the real world. Therefore, one thing is the shared consensus on the *objectivity* of a theory, quite different thing is to assume that any *objective* theory can describe and represent how the real world does *objectively* work.

Later, quantum mechanics had even to introduce the issue of the *unavoidable interference* brought by the observer into the *behaviour* of the events under investigation; which - in 1927 - led Werner Heisenberg (1901-1976) to formulate the "uncertainty principle" that – on the one hand – laid the basis of quantum mechanics and – on the other hand – subverted the philosophy of scientific activity at every scale of investigation.

As Heisenberg explains, at the scale of sub-atomic physics, any investigated system includes both the observed particles and the observer with his laboratory equipment, in a whole made of interacting components. In a sphere like that, observations and analyses can only be carried out by a statistical approach, while deductions, calculations and predictions can only be of a probabilistic nature.

3. Probability, Subjectivity, Information

Thanks to mathematician Andrei Nikolaevic Kolmogorov (1903-1987), theory of probability has undergone in the 20th century a complete axiomatisation, which makes this theory a formidable instrument for analysis and prediction in many different fields of research. “Axiomatisation” means that “probability” is addressed as an abstract mathematical quantity, with neither physical dimension nor reference to any physical reality. Probability is a concept that lends itself to be treated in mere logical processes, because it expresses a simple criterion to assess the *degree of truth* either concerning statements formulated in abstract languages or concerning the occurrence of expected real events.

However, in the application of the theory, there is often the problem of translating the abstract concept of probability into a number that is useful for practical purposes. This problem gave rise to a school of thought of which mathematician Bruno De Finetti (1906-1985) was a major representative. According to that school, degrees of subjectivity are always associated with assessments of probability, which implies an intrinsic degree of unreliability in any reasoning that develops by means of probabilistic criteria. De Finetti, in particular, has extensively discussed *the use* of the concept of probability, with an accurate argumentation to prove that any assessment of probability is based on the amount and on the quality of the information that is available about expected or guessed events.

Usually, the assessment of probability values regards a so-called “probability distribution” among a set of interconnected possible events.

It’s a “probability distribution” if the sum of the values of the assessed probabilities is equal to one. Typical example (the study of which, by the way, has historically originated the theory of probability) is the *probability of show* distributed among the sides of a dice in the relevant game of chance. If the dice is not rigged, the probability of show during the game is the same for all the six sides of the dice, and is equal to 1/6 (one sixth). Therefore, the summation of the six probabilities of show is equal to 6/6 (six sixths), i.e., equal to one.

If the dice is rigged, the distribution of probabilities among the six sides of the dice is uneven, and changes in the values of the probabilities depend on how the dice has been rigged. Nevertheless, the sum of the six different probabilities remains still equal to one, whence a *probability distribution* is still associated with use of the dice in the game. Obviously, in gambling, the cheat - who knows how the dice has been rigged - enjoys a greater amount of information with respect to other players that are unaware of the trick. Thus, the cheat's bet has a comparably greater possibility to succeed. Such a situation may also be described by stating that the cheat, in making his stakes, is affected by *less uncertainty* with respect to the other players.

Mathematician Claude Shannon (1916-2001) must be acknowledged for having provided in 1949 the theorem that proves that there is a unique and quantifiable *amount of uncertainty* associated with every probability distribution.

4. Entropy as Statistical Uncertainty

Shannon's theorem, which univocally assigns a well-defined amount of uncertainty to any probability distribution, has provided science with an important instrument, perhaps still to be appreciated to the appropriate extent. He has introduced a new concept in the theory of probability, formally perfect, which noticeably enhances the potentials of this very fertile branch of mathematics.

It's worth showing in mathematical symbols the simple formula that defines the *statistical uncertainty* associated with a probability distribution.

Let's go back to the example of the dice. Six numbers, ranging from 1 to 6, one number per side, distinguish the six sides of a regular dice from each other. Throwing the dice in the relevant gambling, the probability of show, when the dice stops on the floor, is 1/6, the same for each side of the dice. Therefore, it is possible to write $p_1 = p_2 = p_3 = p_4 = p_5 = p_6 = 1/6$, where $p_1 , p_2 , \dots , p_6$ are the probabilities of show for side 1, side 2, …, side 6, respectively. As seen, these probabilities form – by definition – a "*probability distribution*", because their sum is equal to 1.

According to Shannon's theorem, the *statistical uncertainty* " U " associated with a probability distribution relevant to six possible events (like those concerning the dice) is expressed by the following relation:

$$U = -h\,(p_1 \,\mathrm{Ln} p_1 + p_2 \,\mathrm{Ln} p_2 + ... + p_6 \,\mathrm{Ln} p_6)\ ,$$

in which h is a constant value that depends on the base of the logarithm used.[10]

In some applications of this definition of uncertainty, constant h has no special significance and is assumed equal to 1.

In gambling with a regular (non-rigged) dice, expression "$p\mathrm{Ln}p$" has the same value for all the probabilities of the distribution, for these probabilities are equal to each other, i.e.,

$$p\mathrm{Ln}p = p_1\mathrm{Ln}p_1 = p_2\mathrm{Ln}p_2 = ...\ p_6\,\mathrm{Ln}p_6 = (1/6)\mathrm{Ln}(1/6) = -\,0.298626.$$

Therefore, assuming $h = 1$, *uncertainty U,* as expressed according to the above definition is

$$U = -6 \text{ x } (p\mathrm{Ln}p) = -6 \text{ x } (-\,0.298626) = +\,1.791759.$$

Instead, if the dice is rigged, for instance with number 3 printed on two sides of the dice, the probability of show for 3 in the game is 2 x (1/6) = 2/6 = 1/3, while the probability of show for the remaining four sides of the dice remains equal to 1/6, which is obviously less than 1/3. So modified,[11] the distribution is now characterised by a value of *uncertainty* that is less than U calculated above and becomes

$$U' = -[(1/3)\mathrm{Ln}(1/3) + 4\text{x}(1/6)\mathrm{Ln}(1/6)] = -(-0.366204 - 1.194506) = +\,1.560710,$$

which is clearly less than $U = 1.791759$. However, it is important to remark that there is less uncertainty only for the cheat, who knows how the dice is rigged. For the players who are

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[10] Operator "logarithm" may have whatever base. Euler number $e = 2.7182818…$is the base of natural logarithms; number 10 is the most common base for logarithms used in engineering, and number 2 is the base for logarithms used in information theory; but no theoretical constraint limits the choice.

[11] Note that also in the modified distribution the sum of the relevant probabilities equals 1.

unaware of the trick the uncertainty remains as before, i.e., equal to *U.*

Then, the morphology of the dice imposes constraints on the probabilities assessed by the players, which means that the evaluation of probability is subjective, for it depends on the information available to different players.

The possible events relevant to dicing are finite in number (6 events) and strictly interconnected, so that – as to gambling – one may consider the dice as a *system of events*, in which the occurrence of one event excludes the possibility of occurrence for the other ones.

If the dice is a quite regular one, *uncertainty* $U = 1.791759$ is the **maximum uncertainty** it is possible to associate with the six probabilities, because these are equal to each other. This is the general case, in that the uncertainty associated with a probability distribution achieves its maximum value when all the probabilities are equal to each other. Obviously, such a maximum value depends on the number of the probabilities belonging to the distribution.

If N is the number of the possible events, these are *equiprobable events* if all of them have the same probability of occurrence, as expressed by $P = 1/N$. Then, the relevant **maximum uncertainty** is given by

$$\boldsymbol{U_{max}} = - N\,(1/N)\,\mathrm{Ln}(1/N) = - \mathrm{Ln}(1/N) = \mathbf{Ln}\boldsymbol{N}\,,$$

considering the property of logarithms, by which $-\mathrm{Ln}(1/N) = -\mathrm{Ln}N^{-1} = -(-\mathrm{Ln}N)$.

It can immediately be observed that the formula for this maximum uncertainty is formally identical to that given by Boltzmann for the entropy of a system in thermal equilibrium (remember $E = k\,\mathrm{Ln}W$), including the presence of a constant factor, “h “, not shown in the above formula for U_{max} only because I have assumed $h = 1$ for the sake of writing simplicity. In the formula for U_{max}, number N of the possible events regarded by the relevant probability distribution corresponds to number W of the possible microstates of maximum entropy in thermodynamics.

It should not be difficult to guess that the similarity between the two different situations is not only formal but also conceptual. Actually, the mathematicians that deal with the theory of probability deemed it obvious to adopt the term “entropy” as a synonymous of “statistical uncertainty”. The interesting consequence of this fact is that the concept of entropy has entered the practice of many different disciplines, with the possibility of a direct measurement of entropy in all the cases in which the “behaviour” of a system can be described through probability distributions.

The only substantial difference between entropy of thermodynamics and statistical entropy *might* be seen in the physical dimension: the dimension for the former is energy divided by temperature, whereas the latter has no physical dimension, being a pure number.[12]

Entropy as a pure number offers a limitless sphere of applicability of the concept. As a pure number, in fact, *statistical entropy becomes a significant qualitative measurement of the state of the system*, irrespective of the physical nature of the system considered.

In the light of the preceding notes, it's worth going one step back to the principles of thermodynamics, according to which the entropy of any material system grows with its temperature and vanishes when the system's temperature drops to the value of zero degrees Kelvin (-273.15° C). One can give an explanation for these principles using the concept of entropy as *statistical uncertainty*, which clarifies the relationship between the *objective state* of the system observed and the *subjective instruments* that are at the observer's disposal.

For clarification purposes, let's avail ourselves of schematic but not inappropriate examples.

Suppose that the observer, through a microscope, can observe two molecules, each of a different type of gas. The two molecules are confined inside a small transparent box. The task is to record in every given instant the state of the molecules in terms of the respective position and momentum. The two molecules enter the small box with given initial directions and momentums. All the physical characteristics of the two molecules and of the box are also known.

The observer can use, along with the microscope, also a special video-camera for recording – instant-by-instant – what is going on inside the small transparent container, in order to couple the observation times with the respective positions of the two molecules.

If the initial speed of the two molecules is not too high, not only both the observer and the

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[12] This point can be questioned, if temperature is expressed in energy units: in which case, also the entropy of thermodynamics becomes dimensionless, like a pure number.

camera have no difficulty in recording how the motion of the two molecules develops inside the small container, but the observer can also use the available basic data and the whole conceptual outfit of classical mechanics, with the relevant mathematical instruments, to calculate the momentums and the positions of the two molecules with a satisfactory precision.

If additional molecules of other different gases are subsequently introduced into the small transparent box, and the speed of the newly introduced molecules increases with the number of the molecules introduced, the situation becomes more and more complicated for both the observer and the camera, not only because of the increasing speeds but also because of the rapidly increasing number of collisions between the molecules. Not only becomes more and more complicated the determination of position and speed of each molecule but also the respective identification. The increasing agitation of the molecules inside the small transparent box coincides with the growth of the temperature of the gas mixture. Whatever the observation instruments, there will be a certain temperature level at which the information from the gas mixture becomes confused to such a point not to be any more utilisable to the observer for his initial purposes: should he be requested, for example, to assess the probability that, at a given instant, one particular molecule passes the geometrical centre of the box, the only possible answer would be that such a probability is the same for all the molecules in the box.

At that point, the observer's capacity to describe in detail the situation created by the molecules inside the small container is affected by the maximum degree of uncertainty. Nevertheless, it is not licit to make the *objective* individual state of the molecules correspond to the *subjective* condition at which the observer is arrived, to mean that it's not licit to suppose that the laws of mechanics have disappeared in correspondence with the disappearance of the observer's capability to follow the behaviour of each molecule inside the box.

The *maximum entropy* that the gas establishes at that point is actually the entropy concerning the *state of information* at which - against his will – the observer has come to find himself.

For a confirmation of this interpretation of the concept of entropy, let's see now what happens if the temperature of the gas mixture inside the box is brought down to zero degrees Kelvin. As the temperature decreases, the molecular agitation decreases too, until it stops completely at the absolute zero temperature. At this extreme point every molecule would keep its own steady position inside the volume of the box, so as to allow the observer to determine the state and the identity of each molecule with an absolute precision. The information needed by the observer would then be complete, *no uncertainty* would affect his observation, which means that the *statistical entropy* associated with the system would vanish together with the system's *thermodynamic entropy*, according to the Third Principle, which was postulated in 1906 by Walther Ernst (1864-1941), before the proof provided by Boltzmann's statistical thermodynamics.

In this connection, it's worth reconsidering Boltzmann's statistical definition of entropy**:** at zero degree temperature, every molecular microstate is no more in a *probable state*, for its state is *certain* for the observer. In probabilistic terms, any *certain possibility* is measured by number 1**;** therefore, at zero degrees Kelvin, symbol "Ln(1/*W*)" in Boltzmann formula becomes "Ln1 **=** 0", since *the state is certain* for every molecule, and the system's entropy is nil.

Probabilistic uniformity, when it describes the maximum entropy state for a system at a high temperature, cannot be considered as corresponding to an *objective* uniformity in the temperature of the system, because this uniformity cannot be proved true for each individual molecule that participates in the thermal agitation. The concept of maximum entropy as maximum disorder, as previously seen, comes from this practical impossibility. Therefore, *maximum entropy* is equivalent to *maximum confusion in the state of the information* about each element of the system observed.

The *uniformity* may be more or less *chaotic*, according to the utilisable information the observer can get from his observation until the system shows any degree of describable order. This is what leads to understand why the probabilistic *uniformity at zero degrees Kelvin* definitively ceases to be "chaotic", and is instead a description of a perfect order, the distribution of the system's microstates becoming detectable in its unique steady configuration.

The thought experiment discussed above, however, is actually impossible to the extent to which zero degree Kelvin is an unattainable temperature. The reasons for this impossibility are both in the energy intrinsic to every molecule[13] (which, in turn, is in itself a rather complex system) and in the intrinsic instability of the physical space in which every material component is immersed. The cosmic microwave background of common knowledge would be sufficient alone to prevent material particles from keeping perfectly still, i.e., void of kinetic energy; without considering the inevitable impact of the radiation energy that would necessarily be sent against hypothetically still particles to detect and record their state. That is why the concept of *nil entropy* must be considered as a theoretical limit only, with no corresponding physical reality.

The residual content of energy in matter at any low temperature is sufficient to make it likely the start of spontaneous transformation processes; moreover, it may be argued that the overall physical condition determined by a low-temperature environment does actually favour the formation of complex material systems, including biological systems.[14]

In the opposite direction, there is no theoretical idea of a temperature that is high enough to determine an impassable maximum for entropy. Mathematical developments of chaos theory, along with some sophisticated experiments that followed, proves that matter, even at the "maximum" level of its "apparent" disorder (which means, at the highest level of confusion for the observer), can always establish internal structures of order that condition the behaviour of its components.

In the preceding sections of this article I've drafted the main arguments that have led to assume "*degree of disorder*" as the substantial meaning of the concept of entropy. It seems now licit to ask whether it is possible to identify different *degrees of order* left – in any material system – by the *different degrees of disorder* associated with the system's states.

Before trying an answer to the question, it is worth pausing at the meaning of the word "system".

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[13] According to quantum mechanics, even at zero degrees Kelvin any material component detains an intrinsic kinetic energy, which is referred to as "zero point energy". In this connection, note that quantum mechanics considers all "elementary particles" of matter as *also consisting* of the respective associate waves.

5. System

Any study subject that engages human intellect is case-by-case defined through different modes of concentration and distribution of mental attention.

The attention first “delimits” the subject and then “configures” it according to “components” or “elements”. In accomplishing these mental operations, the observer uses the identification and analytical instruments provided both by his mother tongue and by specialist languages and techniques.

In other words, the perception of any object or set of objects occurs both through a physical contact (i.e., through senses and instruments) and through languages that can represent and describe the object perceived. It’s just through the language that one can determine the modes of concentration and distribution of his attention.

The *linguistic institutions*, which pre-exist individuals and generations, not only determine a shared communication medium between different observers, but also - to a very large extent - *a shared way in which the world is perceived*. It’s a physiologic *datum* that transcends individual mental attitudes and induces many to believe *naturally* that each of the terms and concepts, which belong to the languages used, are *objectively* corresponding to *things*, these being therefore perceived as objects that *pre-exist per se*.

The above premise intends to introduce the assumption that the identification, the definition and the description of whatever “system” is substantially a linguistic operation of a subjective nature.

Any “obvious” distinction, like that between a system defined as “refrigerator” and another one defined as “gasoline pump”, becomes perhaps an impossible operation within the Neolithic culture of tribes recently discovered in previously unexplored recesses of New Guinea. But, beyond this extreme example, any educated member of our civilisation, should he suddenly be dropped onto a quite unknown and never imagined environment, would find it problematic or impossible to identify “different objects” or “systems of different objects”.

Let’s go back to the example concerning a “gasoline pump”. The image, as provided by

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[14] It’s one of the theses sustained by Schrödinger in his essay “*What is life? The Physical Aspect of the Living Cell”*, previously cited.

these two simple words, is perceived with small differences among people who are used to see gasoline pumps and to employ them to fill car tanks. The mental image can isolate this kind of object from any possible context and enables any person to represent it graphically. The images of a gasoline pump drawn by a sample of various persons would be little different from the sketch made by a ten-year child, but all the sketches would easily be interpreted by anyone as “image of a gasoline pump”.

Nevertheless, the “gasoline pump” perceived and represented in that way is a drastic simplification of the reality regarded. Not only is the object “gasoline pump” something intrinsically different, in its mechanical consistence, from the commonly perceived image, but it is also an inseparable component of a much larger and complicated system constructed to carry on a specific function. The pump is only one of the many “outlets” of a system that includes underground tanks, tank trucks, electric power generation and distribution network, oil wells and refineries, road network, car users, plus an ample range of environmental components, such as ground, atmosphere, sunlight etc. To understand what all this means, it would be sufficient to see an object like the one commonly perceived as a “gasoline pump” in a hotel bedroom.

Nevertheless, there is no reason for disappointment if “gasoline pump” remains a common daily locution to express the concept, as it is familiar to the man in the street and to ten-year old children. The true point is – in general – the *use* of the meaning of words that one intends to do.

After having pointed out that impending snares affect the language on which our knowledge is based, it is time to try a definition of “system” apt to discourage dissension.

The “system” meant in this article is a set of material components, each of which is identifiable and definable by means of whatever language**;** these components are perceived by the observer as connected with each other through detectable and measurable interactions. All the components of the “system” can be represented as elements included in one of two distinct groups**:** one group is referred to as **“main system”,** the other group is mentioned as **“external universe”.** The components of the “external universe” are not individually identified, but only mentioned as a whole. Actually, all that is not identified as a component belonging to the “main system” shall be considered as inherent in a unique "external component" connected with components of the "main system". Once made the meaning of this distinction clear, nothing prohibits considering also the "external universe" as one special component of the "main system". The role of the "external universe" is of a fundamental importance for any identified "main system". This is a point to be borne in mind constantly, with a view to avoiding conceptual and logical errors in addressing "isolated systems", especially when attention is drawn to events that seem in disagreement with the Second Principle of thermodynamics.

It's again convenient resorting to a concrete example, in an attempt to clarify how entropy in involved in biological processes as well as to point out how a "biological system" should be identified and defined.

Let's consider a "system" consisting of a glass container (which shall later be hermetically closed), in which a vegetal seed is put together with a handful of wet soil and an atmosphere of oxygen and carbon dioxide in appropriate proportions. If the container is kept at a constant temperature, the seed develops exploiting the surrounding materials and following the "biological programme" of the seed's genetic code. It will be observed that those material will organise in the differentiated forms of a small plant, giving so evidence to a process characterised by a decrease in the system's entropy. The process seems showing that phenomena contrasting the Second Principle are possible. But it's a misleading impression, for the "system" has been defined in a wrong way. In fact, if the "system" were **completely isolated**, i.e., if the "system" had no exchange of energy and materials with the relevant environment, the seed would develop its biological programme until its own resources, along with the resources initially provided by the materials inside the container, are available, through the process that - on the one hand - produces organised matter and – on the other hand – dissipates heat within the isolated container.

However, once all the resources of the "system" had been expended, the implementation of the seed's biological programme would come to a stop, and a decay process would inevitably start for the "system", showing a decomposition of the forms of the organised matter in association with a relevant rapid increment in the amount of entropy, up to a final condition of disorderly equilibrium.

The development process could instead continue - beyond the utilisation of the resources initially available inside the container – suitably providing the "system" with energy, mainly light necessary to photosynthesis, together with soil, water, oxygen and carbon dioxide, i.e., with all the constituents indispensable to the growth of the plant. In this case the "system" (which so becomes a "main system" as per the relative concept previously defined) is no more isolated: It's immediately understood that the "system" to consider cannot be only that inside the glass container. *That* "system" is only the section of the universe on which our attention did initially focus, in the belief that it's actually possible to isolate parts of the world from the relevant *external universe.* There is also to remark that ***most*** of the energy and of the materials spent to feed the development of the seed turns into dissipated heat, which corresponds to a noticeable production of entropy. Thus, the diminishing entropy in the "main system" (as shown by the observed vegetal development) is largely compensated by the overall increment in the entropy of the *real system* to consider, which includes the "external universe".

As a conclusion, it is immediately realised that there is always an "external universe" that acts as an inseparable component of any possible "main system", and that *local* drops in the entropy level do not invalidate the Second Principle, as also proved by a large number of experimental tests and calculations carried out about study-examples of the kind.[15]

6. Syntropy

From now on, it's convenient to use the definition of *statistical entropy* as given by Shannon's formula (see Paragraph **4**), adopting symbol "*E* " for entropy in whatever form expressed.

Shannon's formula can be written in a simpler and more practical way by use of mathematical symbol "**Σ**" (capital "sigma" of Greek alphabet), which – in mathematical notation – means "sum". Example: the addition of 3 different quantities a_1, a_2, a_3 (i.e., the

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[15] One might ask whether it is possible to consider the Sun, or any other star, as an *isolated system.* The answer is "no". Star formation depends on the activity of the *cores* of galaxies, and the formation of matter is basically due to the stars' activity, while also the *cores* of the galaxies are *states* of the so-called "empty space", which is instead anything but "the void". The cosmic space must be considered as the unlimited reservoir of a basic *essence*, call it "energy" or "ether", "by which all

mathematical expression for $a_1 + a_2 + a_3$) , can be written as $\sum_{i=1}^{3} a_i$, which is read “sum of the a_i, with index i varying from *1* to *3* ”.

Therefore, Shannon’s statistical entropy can also be written in the following way:

$$E = -h\sum_{i=1}^{N}(p_i \operatorname{Ln} p_i)$$

in which N represents the [usually very great] number of the possible events relative to the probability distribution considered. If number N is known and fixed, and if it’s also assumed $h = 1$ for the sake of writing simplicity, then the above expression becomes simplified as follows:

$$E = -\sum(p_i \operatorname{Ln} p_i).$$

By use of symbol “**Σ**”, also the concept of “probability distribution” can simply be expressed as

$$\sum p_i = 1 .$$

The above formula for entropy E can be applied to any system, for any probability distribution p_i , and for any number N of respective possible events.

As previously seen in Paragraph **4**, maximum entropy (E_{max}) characterises the state of a system when the internal distribution of the interactions between the system’s components is represented by a uniform probability distribution, i.e., when all the interactions have the same probability $p = 1/N$ to occur, where N is the number of possible events (i.e., the number of possible interactions). Then, in that case, the system’s maximum entropy is expressed by

$$E_{max} = -N\,(p \operatorname{Ln} p) = \operatorname{Ln} N .$$

It has also been shown that any *non* uniform probability distribution, which is characterised by interaction probabilities that *don’t* have the same value (it’s sufficient that *one* probability

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events are born and fed, and into which everything will turn at the end of its own cycle, according to necessity”, as per the only differs from the remaining ones), brings the system's state to a level of entropy lower than E_{max}.

Thus, for any value of entropy E which is less than E_{max}, we can associate a new quantity with the state of the system**:** It's a positive quantity given by a *difference* expressed with symbol "S " and defined as follows:

$$S = E_{max} - E = \mathrm{Ln}N - E\,.$$

We can call this quantity "**syntropy**", because number S measures what of the system's state has been taken away from disorder.

In other words, if the system's entropy E is *not* the possible relevant maximum entropy, it means that the *disorder* does not affect the system completely, and that a certain *degree of order* – as expressed by S – qualifies the system's state.

Then, given the above definition for "syntropy", it's possible to see that – whatever the state of the system – the sum of its entropy and syntropy is a constant value, which is proper to each system and *depends on the number of the possible events* that characterise the system. This is immediately visible after moving entropy E from the right hand side of the preceding equation to the left hand side, to write

$$S + E = \mathrm{Ln}N\,,\ \textit{constant.}$$

The clear meaning of this relation is that any increment in the disorder of the system corresponds to an equivalent decrease in the system's order, and *vice-versa*.

Constant quantity "LnN" is referred to as "entropic potential" or "transformation potential" inherent in the system, and is in general symbolised with "H " when the value for N is not specified.

It's important to note that "entropic potential" H shall not be considered as the maximum value for the system's entropy only, since it also represents the possible maximum value for

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cosmic image of the ἄπειρου ("*the Indeterminate*") conceived by Greek philosopher Anaximander in the VI Century b. C.

the syntropy in the same system; as it can immediately be seen if in equation $H = S + E$ entropy E is nil.[16]

6.1 Negentropy: What Does It Mean?

By the way and briefly, it's worth commenting on the term "negentropy", which is also commonly used to mean something analogous to what is here meant by "syntropy".

I don't know how the concept of *negentropy* could be defined in a way that is – for analogous purposes – different-from and alternative to the concept of *syntropy*. Those who use the word "negentropy" – as far as I know – do not indicate any precise formulation of the concept. Sticking to the word, "negentropy" should mean a quantity whose significance is expressed by a numerical value *opposite* to that of "entropy", and in mathematics "opposite value" means "quantity qualified by opposite algebraic sign". That is actually what Schrödinger suggested in 1944, upon a harried and questionable interpretation of Boltzmann's statistical formulation of "entropy".

Thinking that "negative entropy" can explain or describe natural phenomena of order formation and self-organisation appears as a misleading idea, because such a definition of order leads to contradictory implications.

According to the definition of entropy, as so far accepted and recalled, "disorder" means amount of *unusable energy* or *chaotic uniformity* in the state of a system. This *disorder* tends to vanish when entropy, which is always a positive quantity, tends to zero: correspondingly, the "order" in the system tends to its maximum level. The order internal to the system is reflected by a highly differentiated distribution of the probabilities of interaction between the system components (if N is the number of the components, N^2 is the relevant number of possible interactions).

If entropy is multiplied by "–1" with a view to defining "negentropy" as a measurement of "order", it happens that the "**order**" in the system **tends to zero**, i.e., *it tends to disappear*,

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[16] It is proved that both *maximum entropy* and *maximum syntropy* (and - therefore - also *zero entropy* and *zero syntropy*) are only theoretical limit-values that cannot be achieved by any system.

when the internal organisation of the system components achieves its highest degrees of complexity; while, in the other direction, the system's order tends *also* to decrease towards a minimum value expressed by a quite uniform distribution of interaction probabilities. Consider that "negentropy" is a *negative quantity,* and negative quantities *decrease* with the increment of the respective *absolute* numerical value.[17]

Summarising: Given a system of N^2 interactions between the N components of a system, "negentropy" – meant as "negative entropy" – implies that the system's internal *degree of organisation* is **both** *non-existent* when negentropy is nil, **and** at a *minimum level* when negentropy equals "$-2\mathrm{Ln}N$ ". The logical disagreement between such two states of the system is evident and makes "negentropy" a fuzzy concept.

In current languages, concepts of *order* and *disorder* do normally hint at "relations between things", at configurations of objects of a set that can potentially be in *alternative* states, i.e., in *possible* states viewed as "opposed" (to mean in mutual contrast) only because of different *degrees* of *recognisable structure* in the relations between the objects. Any *state of order* in the set *doesn't deny* the *state of disorder*, but – to the contrary – uses the idea of "disorder" as "lower degree of order" with respect to the same objects put in *alternative states* that can exhibit any greater amount of information to the observer. Substantially, with no change in the number and quality of the objects of the set, *order* and *disorder* are only *ways to compare* different combinations of relations between the objects.

Any process of transformation of matter may be viewed either as an activity that moves equal or similar objects toward *systems* that consist of "synthesized and differentiated things", or – to the contrary – as an activity of demolition and homogenisation of "different things" in a set of objects that are equal or similar to each other.[18]

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[17] For example, –5 is *less* than –2; –100 is *much less* than – 7, etc.; whence "**zero" is the greatest value** in the whole infinite set of negative numbers (i.e., "0" is greater than –2, –5, –100, etc).

[18] An analogy is useful: Building up houses, factories, churches, theatres, schools, hospitals, etc., of a town means to use *bricks* – which are all equal to each other – for transforming equal objects into a system (synthesis) of things that are *different* from each other by shape and function. Demolishing and homogenising those buildings means to reduce them to a set of bricks steadily equal to each other and void of any recognisable function.

On the basis of the above premise it is possible to develop a general theory of the systems that are formed by interacting components.

In analysing the evolution of a system, the theory shows a way to describe "progressive" and "regressive" transformations of the system in terms of increasing or decreasing internal organisation, respectively.

7. Description of the Behaviour of a System

Aware of the caution that is necessary in defining any study-system, we can now focus our attention on those processes, both of a biological and of a social nature, which develop forms of matter and energy organisation.

Sticking to the definition of system introduced in the beginning of Paragraph **6,** any system can be described as a set of different components (identified as such by the observer), which depend on each other through recognisable and measurable interactions.

Within any conventional time unit, each component of the identified system is both source and destination of interactions whose intensity does in general vary from pair to pair of components. This can be observed between biological as well as non-biological components.

The behaviour of non-biological systems is dominated by the *determinism* of a relatively simple mechanics (proper to the *mechanism* of physics), also when the observation, because of practical conditions imposed by the levels of the observation scales, must renounce *deterministic* descriptions and recourse to statistical and proba-bilistic methods of analysis.

Some sort of *constrained determinism* is instead observed in biological and social systems, so that the system behaviour – though utilising the "laws" of non-biological determinism – is subject to a framework of constraints. These constraints work as a *programme* because of their capacity of conveying the effects of deterministic rules toward a hierarchical selection and grouping of interactions between components of the systems. In this way, the system components come to form a structure of "organised" sections differentiated from each other by character and function, up to the composition of *complex organisms*, which – from a *mechanistic* standpoint – are intrinsically unlikely. Moreover, some of such complex organisms have the amazing property to evolve toward forms of higher and higher complexity.

However, also the formation and the evolution of the most complex organisms undergo the impact of chance, whose effects may partly be eluded by the "program" and partly modify it. Accidental modifications in the "programme" may either *corrupt* the "programme", making it no more effective (with subsequent decomposition of the organism), or *mutate* the "programme" in a way that allows the organism to resist the accident and to continue its evolution through an *adaptation* process.

(Nevertheless, as so far experienced, chance does sooner or later prevail over "programmed" processes of any kind, and *adaptation* – though showing an increasing chance-resistance in a growing number of cases – is in the end overwhelmed by chance, i.e., by the domain of entropy. In a partial attenuation of this image of fate, it seems possible to affirm that "*improbable processes*" that lead to complex systems can rise from "chaotic" states of matter and energy through major stochastic deviations from states of entropic equilibriums, *which are never stable*. Thus, the triumph of chance should never be considered as a general and definitive end of the story, but only as a *local* and *cyclic event*. Proliferation, as a property of living species, might be taken as a provisional example that corroborates the thesis).

The capacity of organising matter and energy, which is proper to the evolution processes that are characterised by a *behaviour programme*, is always associated with the dissipation of most of the involved energy; so, the amount of order achieved is over counterbalanced by the production of a corresponding amount of *disorder.*

Summarising: a "system", like that defined - for example - by a complex organism, must always be considered as formed by the specific components of the complex organism ***and*** by the respective external environment, here referred to as "external universe".

The salient property of any system is that all its components are *active*. A banal example, concerning a relatively simple system, may help clarify. A stone under sunlight transforms a large part of the received radiation into heat, which then it transfers to the environment both through direct contact and by reflection of the light. Part of the light absorbed by the stone and the interaction with atmosphere activate physical and chemical processes among the stone's components. To conclude that nothing in nature may be considered as completely idle and passive.

The interactions that relate to any system are both those that occur between different components of the system and those of each component with itself.

In this connection, it's worth remarking that also the "external universe", which is one of the system's components, develops inside itself an amount of activity that is *caused* by its relationship with the "main system". It's also **important to remark** that the "external universe" relevant to the identified system is *only* that part of the universe that undergoes the influence of the particular "main system" addressed.

Upon the assumption that the interactions between the system's components are all identifiable and measurable, the description of the system's behaviour becomes simpler than one could expect. In analysing any system, the observer is used to focus his attention only on those interactions that are deemed significant.

Then, in describing a particular behaviour of the system, it is supposed that the interaction flows, as observed in a given time unit, are methodically measured by use of a measurement system that makes all interactions homogeneous quantities, in order to make them comparable quantities. Which also implies the possibility of calculating – as necessary – the total amount of interactions produced in the system per time unit.

Subsequently, all the individual interaction flows can be converted into *interaction probabilities*, to exploit the analytical advantages provided by the mathematical properties of probability distributions. Besides any possible discussion on the *meaning* of this kind of probability sets, the *percent values* expressed by such probabilities are significant enough to justify the relative use in the analysis. Actually, interactions expressed in the form of "probabilities" are particularly useful to the purpose of associating quantities like *entropy* or *syntropy* with the system's states.

7.1 Shape of the System and “constrained Uncertainty”

The description of the behaviour of a system depends principally on the criteria adopted for identifying its components.

The identification of the components does also determine the distribution of the interactions within the system.

For example, if the task is to analyse the behaviour of a human social system, the shape of the system depends on whether this is considered as formed by individuals or, instead, by different groups identified by class of characteristics shared by individuals. Suppose that the interactions are expressed in terms of exchange of information in any form. Though the *total amount* of interaction, per any given time unit, depends only on the number of persons involved, it is clear that *the distribution* of the *interaction flows* between components varies from a system whose components are individuals to a system whose components are groups of people, because of the changes in the number and size of the system’s components. The importance of the preceding remarks is in that it’s the observer what determines a first basic level of *order* in the system observed, just through the identification of the components that form the system. Therefore, it’s the observer that establishes the *shape* of the system, on which the *measurement* of the interaction flows will depend.

I am now trying to clarify the meaning of what I’ve affirmed above, starting with a scheme of unit-flow distribution within a hypothetical system consisting of 6 components.

The scheme is shown by the table below, in which letters ***a, b, c, d, e, f*** represent the system’s components. The series of “1” in the horizontal lines (the *rows*) of the table indicate the intensity of the flow (for the sake of simplicity, every interactions flow is made equal to 1) sent by each component to the other components of the system, so that the series of “1” in the vertical lines (the *columns*) of the table represent the flows received by each component. (The unit-flows that are disposed along the table’s diagonal - on light yellow colour background - show the set of “self-interactions”, i.e., the interactions of each component with itself).

1	1	1	1	1	1	→	6	***a***
1	1	1	1	1	1	→	6	***b***
1	1	1	1	1	1	→	6	***c***
1	1	1	1	1	1	→	6	***d***
1	1	1	1	1	1	→	6	***e***
1	1	1	1	1	1	→	6	***f***
↓	↓	↓	↓	↓	↓		↓	
6	**6**	**6**	**6**	**6**	**6**	→	**36**	***Tot.***
a	***b***	***c***	***d***	***e***	***f***		***Tot.***	

Such a system presents quite a uniform distribution of interaction flows, as it's also typical of any system about which the observer lacks information. Apart from the exemplification choice of a uniform interaction distribution characterised by unit-flows, any other *uniform* distribution of flow intensities would be converted into a unique identical *probability distribution*, which – for any six-component system – would consist of interaction probabilities all equal to 1/36.

The entropy associated with a system of events like that described by the table above is *the maximum entropy* that can be associated with the system, and is expressed by the system's "entropic potential", whose value - using Boltzmann's equation – is in this case

$$H_6 = \mathrm{Ln}(6^2) = 2\ \mathrm{Ln}6 = 2 \times 1.79176 = 3.58352.$$

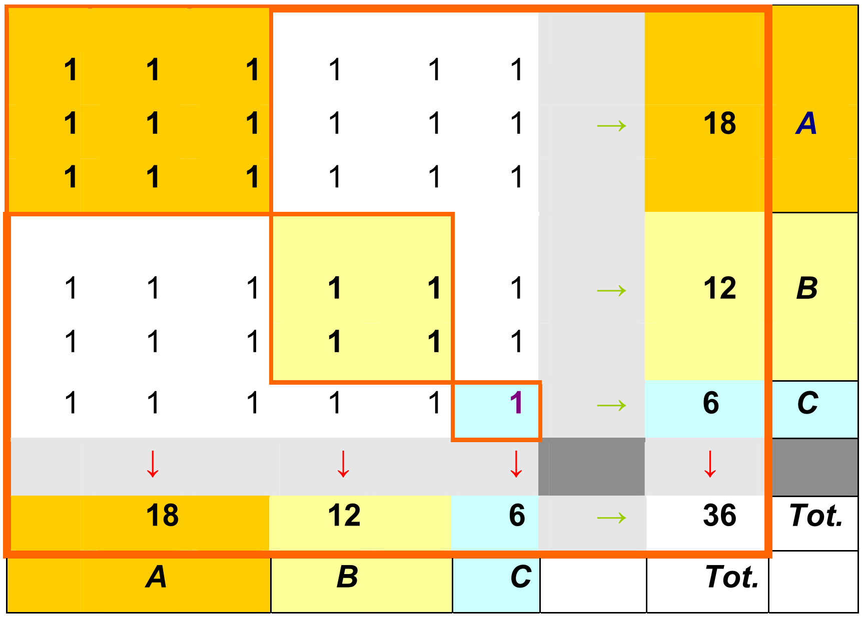
If Shannon's formula is applied to the probability distribution relative to the same system, all the probabilities being equal to 1/36, the entropy calculated as "statistical uncertainty" results in

$$E_6 = -36 \times (1/36)\mathrm{Ln}(1/36) = 3.58352 ,$$

to verify that *entropy* and *uncertainty* do actually coincide, i.e., that $H_6 \equiv E_6$.

At variance with the previous situation, suppose now that some kind of available information allows the observer to group the same components of the system in 3 – instead of 6 – *new* different components identified as ***A, B, C***, in the way that will be shown by the table that follows. In the new table, which modifies the preceding one, component ***A*** groups previous components ***a, b, c***; component ***B*** groups previous components ***d, e,*** whereas previous component ***f*** remains alone to form the new component ***C.***

In the system so re-defined, the interaction flows between ***A, B*** and ***C*** are no more equal to each other**:** ***A*** sends 6 flow units to ***B***, 3 flow units to ***C***, and retains 9 flow units for itself. Component ***B*** sends 6 flow units to ***A***, 2 flow units to ***C***, and retains 4 flow units for itself. In turn, component ***C*** sends 3 flow units to ***A***, 2 to ***B***, and retains 1 unit flow only for itself. The account of the flows arriving in each component is symmetrical to that.



1	**1**	**1**	1	1	1			
1	**1**	**1**	1	1	1	→	**18**	***A***
1	**1**	**1**	1	1	1			
1	1	1	**1**	**1**	1	→	**12**	***B***
1	1	1	**1**	**1**	1			
1	1	1	1	1	**1**	→	**6**	***C***
	↓		↓		↓		↓	
	18		**12**		**6**	→	**36**	***Tot.***
	A		***B***		***C***		***Tot.***	

The probability distribution that corresponds to the new flow distribution is given by the following series**:** 6/36, 3/36, 9/36 (relative to ***A***)**;** 6/36, 2/36, 4/36 (relative to ***B***)**;** and 3/36, 2/36, 1/36 (relative to ***C***). The sum of these probabilities is obviously equal to 1.

By application of Shannon's formula for **entropy** one obtains:

$$E_{ABC} = -[(6/36)\mathrm{Ln}(6/36)+(3/36)\mathrm{Ln}(3/36)+(9/36)\mathrm{Ln}(9/36)+(6/36)\mathrm{Ln}(6/36)+ +(2/36)\mathrm{Ln}(2/36)+(4/36)\mathrm{Ln}(4/36)+(3/36)\mathrm{Ln}(3/36)+(2/36)\mathrm{Ln}(2/36)+(1/36)\mathrm{Ln}(1/36)] = = 2.02288\ .$$

The **entropic potential** relative to this new system of 3 components is given by

$$H_{ABC} = \mathrm{Ln}(3^2) = 2x\mathrm{Ln}3 = 2.19722\ ,$$

which, as expected, is greater than entropy E_{ABC} calculated above. In this case, at variance with the previous case, the system's entropy doesn't coincide any more with entropic potential. The difference between the two quantities, expressed by

$$S_{ABC} = H_{ABC} - E_{ABC} = 2.19722 - 2.02288 = 0.17434\ ,$$

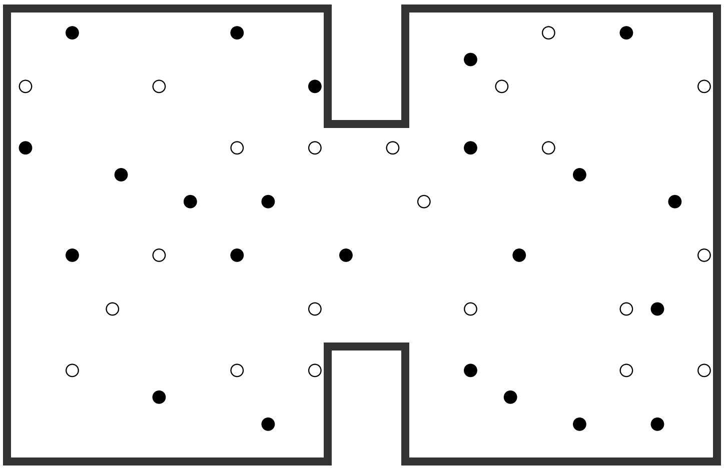
is the *amount of order* that has been introduced by the observer in reshaping the 6-component system into the 3-component one. Substantially, it's the effect of the *amount of information* that has become available to the observer.

Some important conclusions can be drawn from the preceding considerations.

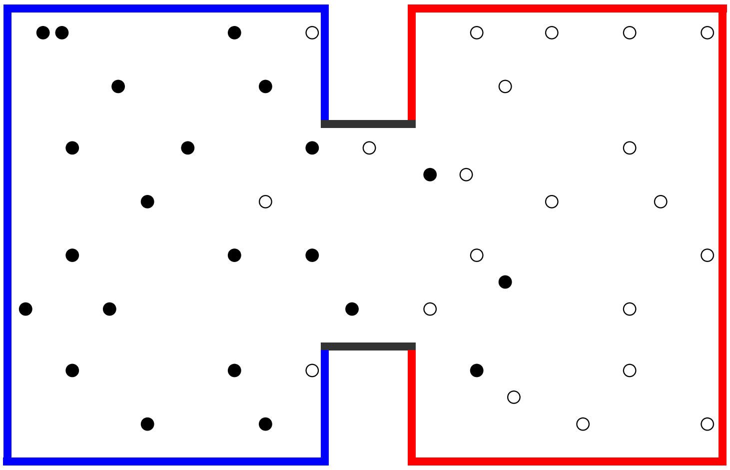
The first one is the following: in any *state* of the system, the "natural" tendency to disorder is partly checked by the presence of "constraints", which drive the system toward a *behaviour* whose randomness declines with the number of different "constraints" affecting the system. In the preceding example, the only information used by the observer has implied a constraint to the shape of the system. This is not banal, for the *amount of order* in the system is detected in connection with the *constraints* to which the system is subject *according **also** to the observer's knowledge.*

To help us grasp the importance of constraints in determining the behaviour of real systems, it's worth making at least one example, which puts – without excluding – the role of the observer in a shade.

Consider the following system: a mixture of hydrogen and nitrogen is put into two interconnected containers. If the temperature is the same for both containers, the molecules of the two gases blend together randomly, so that the mixture distributes within the two containers almost uniformly. See the scheme here below.



Instead, if one of the containers is warmed up so as to make its temperature higher than the other's, the molecules of the two gases separate, with one of the two gas gathering in one container and the other gas in the other container, as schematically shown by the graph below:



In this way, the system has been subjected to a *thermal constraint*. On the one hand, in doing so, energy is spent and dissipated to determine the difference in the temperature of the two containers; on the other hand, the system achieves a certain *degree of order*, in the form of a marked differentiation in the positions of the two gases. (The phenomenon is known as “anti-diffusion”).[19]

In general, the various characteristics of different molecules *constrain* these to respond in different modes to the action of external agents, with the consequence that different kinds of interactions cause different effects, which in turn work as *additional constraints* with respect to the properties and the behaviour of different kinds of matter, and so forth.

In analyses that concern social and economic systems, in particular, the importance of *constraints* is given evidence by the possibility these offer to solve problems otherwise impossible of solution, according to procedures based on the determination either of the *maximum amount of constrained entropy* or – equivalently – of the *maximum degree of syntropy* the study system is allowed to achieve under the given constraints.

7.2 Using Entropy and Syntropy: a Practical Example

Out of physics, one example of practical use of the concepts of entropy and syntropy, as discussed in the preceding paragraphs, regards the analysis of economic systems and the description – as possible on the basis of hypothetical (or actual) measures of economic policies - of *probable* evolution processes for such systems. I deem this digression useful to point out the *operational* aspect of the concepts introduced, with a view to minimising the dose of abstraction that is normally associated with unusual theoretical terminologies.

Schematically, any modern economic system consists of a many different activities, which exploit various resources, including manpower, to produce commodities and services bound for the *internal* market (i.e., for the market formed by the “main system”) as well as for the

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[19] This example has more than once been used by Prigogine during conferences of his.

external market (i.e., for the "external universe"). In turn, the "external universe" does also sell some of its resources and products to various activities of the "main system".

Econometrics is an important discipline that applies statistical and mathematical techniques to the analysis of economic activities. This branch of economics has also started, during the 20th century, methods for the quantitative study of any national economic systems accounted for as a whole.

Economist Wassili Leontief (1905-1999) developed a method for the analysis of very large economic systems, which soon became renowned and adopted, for decades, by the national statistical bureaus of most advanced countries. Leontief's method allows for the systemic relationship between the production proper to each economic activity and the purchase of resources that are necessary to the production.

Leontief proposed a simple direct proportionality between the amounts of purchased production factors and the amount of the relevant final product. By this criterion, he could construct a numerical table (matrix) of *inter-industrial relations*, which basically consists of proportionality coefficients, usually mentioned as "*production technical coefficients*", to be assumed as constant values.

The idea is simple. Example**:** to produce and sell one ton A of steel, it is necessary to buy K kilograms of coal, I kilograms of iron mineral, W watts of energy, M hours of manpower, F dollars of financial services, T dollars of transport, etc. Leontief's method assumes that the numerical ratios defined by K/A, I/A, W/A, F/A, T/A, etc., keep constant with time, quantities K, I, W, F, T, etc., being in turn products of other activity sectors of the same economic system. The assumption can be summarised saying that the purchase of these quantities vary in a direct proportion to the variation in the quantity of the final product A regarded. In principle, it's quite a reasonable assumption.

Therefore, analogous obvious considerations apply to any production activity in the system**;** so that a set of simple linear equations can be written to describe the system of relationships by which each activity is tied to all the other ones. In this way, it is possible to calculate, for example, the extent to which the product of the whole economic system depends on alterations in the production of any individual activity sector. [20]

In order to establish all the numerical values of the *production technical coefficients* it is necessary to carry out an initial statistical survey to see how the product of each activity sector distributes among the other sectors. Unfortunately, one of the major inconveniences that affect Leontief's method is just the need for relatively frequent updating statistical surveys.

However, Leontief's method, known as *Input-Output Analysis*, involves technical problems relative to the hypothesis of direct proportionality between purchase of resources and production (i.e., the proportionality between *input* and *output*), as well as to the hypothesis of "constant" technical coefficients.

First issue: The hypothesis of direct proportionality between *input* and *output* is quite reasonable and acceptable if it regards the activity of one single factory, farm, service, etc.. But it becomes more and more questionable – because it doesn't respond any more to the truth – when every "economic sector" does group a large number of activities that may be considered as akin to each other, but which do also differ from each other because of

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[20] One only sample equation should be sufficient to make the criterion clear. Consider an economic system formed by *N* different economic sectors, indicated with "*1*", "*2*", "*3*", … , "*N*". Assume that the amounts of the yearly sector productions are symbolised by $x_1, x_2, x_3, \dots, x_N$, respectively.

According to Leontief, it is possible to establish a **fixed ratio** between every sale from any economic sector "*i*" to each other sector *1, 2, ..., N*, as follows**:** X_{i1}/X_1, X_{i2}/X_2, ..., X_{iN}/X_N , since **each unit sale** X_{i1}, X_{i2}, ...,X_{iN} from Sector *i* is in a fixed proportion to the **unit amounts of product** X_1 , X_2 ,..., X_N of the buying sectors *1, 2,*...etc. Therefore, the *actual amount* sold by Sector "*i*" to each other sector is just one portion of what "*i*" produces, i.e., a portion of its overall product x_i. Thus, the sales of x_i can be expressed in terms of amounts *needed* by each other sector in relation to the overall amount of its own product. Adopting monetary units to homogenise the measurement of whatever product, one can use the above **constant ratios** to calculate how much resources each sector needs to buy from Sector "*i*" to implement its own planned production.

Sector *1,* to produce x_1, needs to purchase from "*i*" an amount of resources given by $(X_{i1}/X_1) \times x_1$; for Sector *2,* it is $(X_{i2}/X_2) \times x_2, \dots$, for Sector *N* it is $(X_{iN}/X_N) \times x_N$.

In this way, all the sales of Sector *i*, summed up altogether, give the overall amount of the production of this sector. The situation in then summarised by the following simple equation**:**

$$x_i = (X_{i1}/X_1) \times x_1 + (X_{i2}/X_2) \times x_2 + \dots + (X_{iN}/X_N) \times x_N \,.$$

It's now clear how the total production level x_i of Sector *i* may vary in consequence of changes in the productions x_1 and/or x_2 , and/or x_3 , etc., of other sectors. Identical reasoning is applied to every other sector, to write the set of equations that describe in precise quantitative terms the interdependence between all the activity sectors of the economic system.

differences in production technology, in innovation or seasonal sensitivity, etc.

Leontief's method necessarily requires that the identification of each *economic sector* include as many production centres as possible, with a view to limiting the description of the system by use of a number of equations not exceeding – at the worst – one hundred or little more. It's a method that cannot be applied to a system whose components are identified in every single activity (one sector per each type of farm, one sector per each type of mine, one sector per each type of factory, one sector per each type of office or shopping centre, and so on), because the matrix of the inter-industry transactions would otherwise become monstrously large, regarding thousands of interacting components. The relevant set of equations would also become unmanageable, even by use of super-computers, because of additional limiting conditions of an algebraic nature, which can in no case secure significant solutions to the equations.[21]

If the equation set is not too large, the algebraic inconveniences can somehow be managed through cycles of reiterated adjustments and corrections in the values of the technical coefficients, in conjunction with simpler or more appropriate re-aggregations of activity sectors. This becomes practically impossible (and is in no case advisable), if the number of sectors and equations is too high. Let alone the difficulty of detecting and measuring millions of interaction flows.

Second issue**:** Once the grouping of economic activities results in a "reasonable" number of different sectors (say fifty to sixty sectors), the hypothesis of linear proportionality between *inputs* and *outputs* reveals a misleading conceptual strain, especially if it is associated with the hypothesis of *constant* technical coefficients of proportionality. In practice, the only way to measure inter-industry transaction flows is through the statistic of the relevant monetary payment flows, which obviously reflect the continuous fluctuations of the market prices. As known, the *value* of any production factor is quite a different thing with respect to the *price* of the factor. It is possible that the *quantities* of production factors (i.e., the respective production

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[21] Systems of linear equations may provide either positive or nil and negative solutions, the solutions of the latter kind being of no significance and use with reference to economic production activities. Unfortunately, there is so far no mathematical theorem to prove the existence of general conditions that could secure positive solutions only.

values) necessary to yield a unit of any final product remain constant for a relatively long period, but it's unlikely that also the respective prices keep constant during the same time. But just this is the point**:** if the technical coefficients of proportionality are not constant quantities, Leontief's method makes no sense, either from a logical or practical point of view.

Third issue**:** *Input-Output Analysis* is "static". Once an alteration in one or more of the sector productions has been introduced in the equation system, the "response" of the economic system is as if it were immediate. In other words, Leontief's method is not fit for describing the reaction chain of effects that promote a possible evolution of the economic system, as it is instead expected in consequence of modifications in the behaviour of one or more of the system's components. The effects described by the method are all simultaneous and definitive, in a certain, immediate and stable restoration of the system's equilibrium after any possible attempt at modifying it.

Naturally, as many have proposed and tried, the *input-output* analytical scheme may be complicated at will, through the introduction of additional hypotheses and by the aid of various mathematical techniques. On such a path, however, far from making the method more effective, one enters an entanglement of mathematical procedures, which rest on questionable assumptions basically deprived of concreteness.

Leontief's substantial idea becomes much more fertile if one approaches the study of large economic systems by a probabilistic approach and through the use of the concepts of entropy and syntropy. These concepts are quite appropriate in describing an economic system, which is the most visible example of aggregation, organisation and development of human communities, i.e., the largest example of biological societies.

I'm now trying to show, through an extremely schematic example, how the mentioned alternative method can tackle the analysis and the description of a national economic system. Suppose the national economic system as consisting of 5 different sectors, each of which groups economic activities that may be considered as mutually related as to the kind of the sector's final products. A "classical" grouping of sectors of an economic system is as follows:

Sector 1, or *Primary Sector,* which groups activities such as mining, agriculture, forestry, breeding, fishing;

Sector 2, or *Secondary Sector*, which groups all industrial activities, including craftsmanship and power production;

Sector 3, or *Tertiary Sector*, which groups all kinds of services to the community, including public administration, trade, financial services, transport and telecommunication, tourism, education, military service, etc.;

Sector 4, or *Labour*, or also *Families*, which includes all the individuals of the community, viewed both as manpower and as consumers;

Sector 5, or *Foreign Sector*, which includes all kinds of activity coming from abroad in exchange for that part of the other 4 sectors' produce that is bound for foreign countries.

The number of "mutually related" activities included in each of the above listed sectors is so high to make Leontief's approach void of sense.

In adopting the alternative probabilistic method it is worth exploiting all the statistical data that are normally available. Then, one may suppose that for each sector of the first 4 sectors of the 5 listed above it is possible to know the following:

(i) *total amount* (in monetary terms) of the gross six-monthly produce;

(ii) *total amount* of economic production factors purchased from other sectors during the same period;

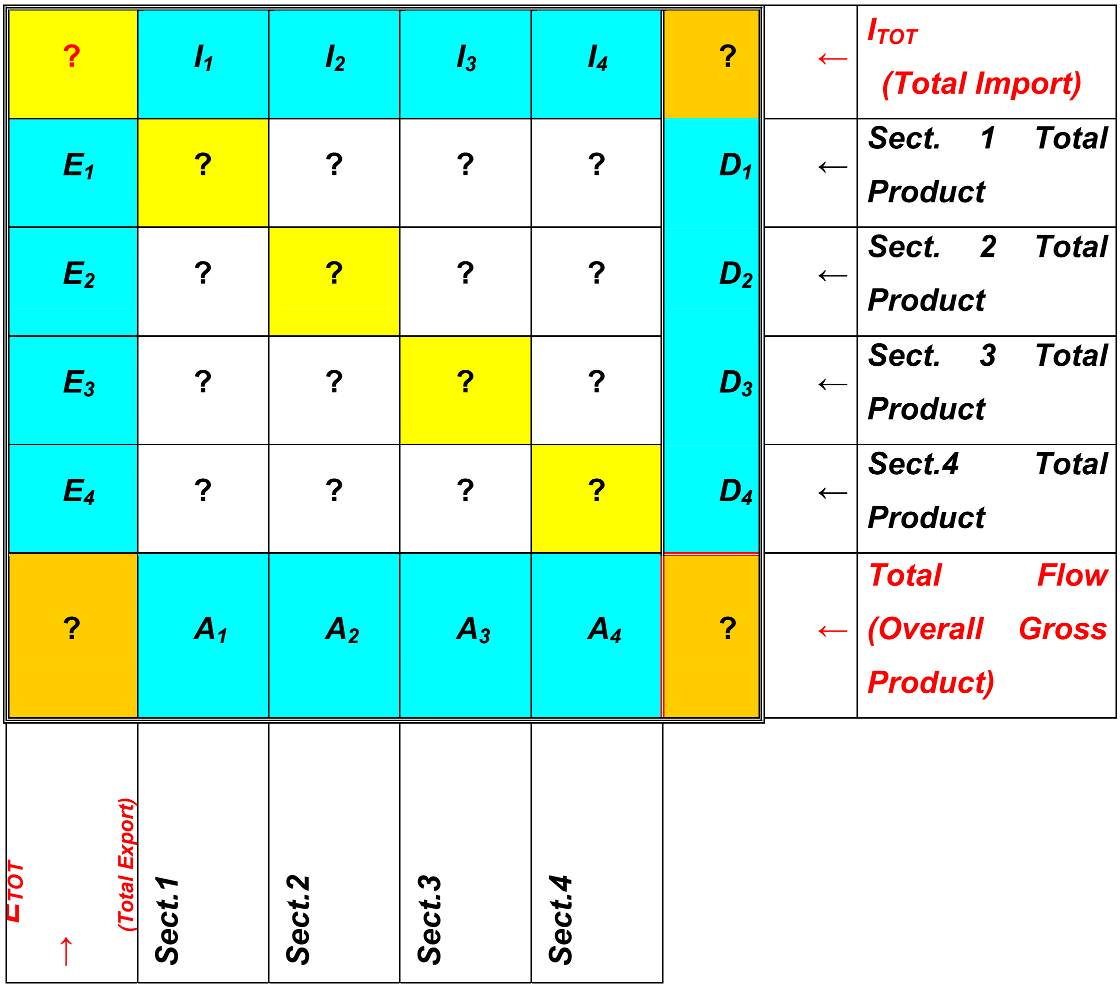
(iii) six-monthly commodities/services sold to the *Foreign Sector*;

(iv) six-monthly purchase of commodities/services from the *Foreign Sector*. To note: the transactions between each sector with the *Foreign Sector* are the only *inter-sector flows* actually known;

(v) *average unit price* of each sector product as recorded during the six-month period.

It is expected that data of this kind are actually available at any national statistical bureau.

It's useful to summarise and represent the situation to analyse by means of the usual input-output table, as indicated here below:



?	I_1	I_2	I_3	I_4	?	←	I_{TOT} *(Total Import)*
E_1	?	?	?	?	D_1	←	***Sect. 1 Total Product***
E_2	?	?	?	?	D_2	←	***Sect. 2 Total Product***
E_3	?	?	?	?	D_3	←	***Sect. 3 Total Product***
E_4	?	?	?	?	D_4	←	***Sect.4 Total Product***
?	A_1	A_2	A_3	A_4	?	←	***Total Flow (Overall Gross Product)***
E_{TOT} ↑ *(Total Export)*	***Sect.1***	***Sect.2***	***Sect.3***	***Sect.4***			

In this table, the letters printed on blue background represent the known quantities. Column D_1, D_2,…etc., represents the total productions of the 4 sectors of the "main system", including the respective exportations to the "external sector" (i.e., to the *Foreign Sector*), which are represented by column E_1, E_2, …, etc.

The upper row of the table represents the import, I_1, I_2, …, etc., from the *Foreign Sector,* as distributed among the 4 main sectors, while the bottom row, A_1, A_2, …, etc., represents the total purchase made by each sector from all the other sectors to produce D_1, D_2,…, etc.

Most of the question marks in the table represent the *unknown quantities* sold by each sector to each other sector of the "main system". In particular, the question marks along the table's diagonal - highlighted in yellow colour - indicate the *unknown quantities* that are sold (retained) inside each sector. The question mark in red colour in the upper left corner of the table represents the *unknown amount of transactions* made inside the *Foreign Sector* in consequence of the sector's relation activity with the 4-sector "main system".

The question marks in the three corners with ochre colour background represent 3 *unknown total quantities*, as can easily be understood through the relevant captions.

Then, suppose that nothing else is known to the analyst, apart from the *data* indicated in the table above, with the only addition of the average unit prices per sector production units, as mentioned in point **(v)** of the preceding list.

As to any economic system, it is licit to suppose that the *boost to produce*, or the *cause* of the economic sectors' production, i.e., what could in general be referred to as "**the intent**" of the production activities, is in the *expectation* of *benefits***.** It is also licit to assume that the *average expected benefit* is a quantity that can be expressed as a function of the average unit price of the produce of each sector. It's a way to say it is licit to suppose that the *interactions* between economic sectors *are not randomly distributed*, but occurring in view of expected effects. Obviously, everybody knows that the production of any thing, be it a fruit from cultivated land or an hour of human work, aims at pursuing economic ends, which consist of clearly identifiable benefits.

An interesting aspect of the proposed approach, as proved by the relevant theory, is the following**:** once an appropriate *average amount* of "intent" (which in general differs from one interaction flow to another) can be associated with each interaction unit, it is possible to determine**:**

(a) all the *most probable* unknown interaction flows between the system's sectors, including the *self-interaction flows* (i.e., the amount of sector production retained inside the same sector) and – in particular – the self-interaction flow relative to the *Foreign Sector*;

(b) the overall amount of the system's production, which includes the production of the *Foreign Sector* to the extent to which this is regarded by the activity of the "main system";

(c) the logic procedure that enables the analyst to describe **all** the *most probable* evolution processes of the system, under any given or hypothesised condition.

These determinations are possible in the form of *probabilistic assessments*. The mathematical procedure adopted for the purpose consists of searching those values of the interaction probabilities that obey the set of known constraints, while the probability distribution - because of the incompleteness of the available information - is affected by maximum uncertainty. The same criterion can be expressed also in the following alternative way: the distribution of the interaction probabilities is such to express the maximum *syntropy* of the system that matches the conditions imposed by the known constraints. The known "constraints" are in the form of *constraint equations* that involve the *unknown probabilities*.[22]

The practical importance of the preceding statements can just be seen in carrying out the analysis of an economic system, after a comparison between the enunciated *probabilistic method* and Leontief's *deterministic input-output analysis.*

Leontief's method requires the calculation of the *production technical coefficients.* It's a number of constant values given by the square number of the economic sectors. If the economic activities of a country, as per the preceding example, are grouped in 5 distinct economic sectors, then the number of the technical coefficients is 25. To calculate these coefficients, it's first necessary to carry out a direct statistical investigation aimed at identifying

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[22] It's a classical problem of mathematical analysis, known as *determination of a constrained maximum value for a function of variables.* In this case the "function" may be either the entropy or the syntropy associated with the probability distribution that characterises the system, the interaction probabilities being the variables.

the transaction flows between the five sectors. That's the only way to apply Leontief's method, whose basic purpose is to calculate 4 *sector overall productions* at most, given the overall production of the 5th (any sector of the 5 considered). Summarising, the method needs 26 certain data to determine no more than 4 unknown quantities.

Yet, the method doesn't allow the analyst to make any logical simulation of the system's evolution processes, while it requires a frequent recalculation of the technical coefficients, which are "constant" only by hypothesis and are instead prone to change within short time intervals. The method, like a few other ones adopted for analogous purposes, is based on the assumption that any economic system has an intrinsic tendency to equilibrium, thanks to an internal mechanism capable of neutralising any accidental alteration in its pre-existing state**.**

To the contrary, for the *probabilistic* method, which uses the concepts of entropy and syntropy, any economic system is *intrinsically unstable*, with the consequence that any minimal permanent alteration in the system's equilibrium implies a chain of feed-back effects that lead to the transformation of the system's structure.

In utilising this method, one takes advantage also from the ratio of *data* to *unknowns to be determined*, which is noticeably less than the analogous ratio in the *input-output analysis* founded by Leontief.

Referring to the same hypothetical 5-sector system, the *probabilistic* method needs to know the 16 data on blue background in the preceding table, plus 16 "mean expected benefits" (these are the "intents" that promote the economic transactions between sectors and form the system's *structure*). On the basis of these 32 data, 20 *probable interaction flows are* the *unknowns* that can be calculated*.* Therefore, the comparison can be summarised as follows**:** for the *deterministic input-output analysis*, the ratio of the 26 *data* to the 4 *unknowns* is 26/4 **=** 6**.**4 ((i.e., **6.4** data per unknown). For the *probabilistic method*, the corresponding ratio is instead 32**:**20 **=** 1.6 (i.e., **1.6** data only per unknown).

Both methods are based on the solution of systems of linear equations.

Then it's easy to guess that the advantages that can be enjoyed through the use of the probabilistic method increase with the size of the system. For example, if the system consists of 50 components, the deterministic method needs at least 2501 data to calculate 49 unknown at most (ratio *data* to *unknowns* 2501/49 **= 51.04**); whereas the probabilistic method needs 2597 data to calculate 2405 unknowns (ratio *data* to *unknowns* 2597/2405 **= 1.08**). [23]

However, as just mentioned above, the most important aspect of the probabilistic approach is the possibility of simulating origin and development of evolution processes undergone by the system.

All the preceding statements can obviously be proved only through a complete exposition of the relevant mathematical theory. [24]

8. The Syntropic Evolution of a System

The salient characteristic of the probabilistic method is in considering that no system can attain a permanent equilibrium state, to mean that permanent stability is a condition *intrinsically* impossible for any system.

This kind of analytical approach is based on the principle that any system of natural events is in itself an unstoppable "dialectic" process between *order* and *disorder,* between *syntropy* and *entropy.* Any equilibrium state that can be observed shall always be considered as *intrinsically unstable*, as an *accidental* and *ephemeral* stasis.

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[23] According to algebra, *N* different equations that involve a given set of unknowns can **univocally determine** the values for the unknowns only if the number of these is also *N*. If the number of the unknowns is greater than the number of the available equations, the equations provide *an infinite number of solutions* that match the conditions imposed by them. Which means, in practice, no possibility of utilising the available equations.

Instead, the probabilistic approach, under conditions relevant to probability distributions only, provides a method *not to* determine *univocal* solutions, but to find a unique set of values for the *most probable solutions* relative to the relevant equations, when the number of these is less than the number of the unknowns to determine. It's worth stressing that both the unknowns and the "solutions", in such a case, are probability values.

[24] The full theoretical explanation, including examples of practical application, can be found in a book by Mario Ludovico, *L'evoluzione sintropica dei sistemi urbani*, Bulzoni Publisher, Roma 1988-1991. A summary of the theory is in www.mario-ludovico.com/pdf/syntropy.pdf .

For exemplification purposes, let's proceed on still using the preceding example of the hypothetical 5-sector economic system. The produce flow distribution among the five sectors (i.e., the system *interactions*) may show slight fluctuations around average values, in correspondence of small oscillations in the prices around average values too, because of system alterations that could in a wide sense considered as "seasonal effects". Alterations of that kind have no influence on the overall functionality of the system, which can therefore be considered as in an equilibrium state, until price and flow fluctuations keep the relevant average values substantially constant with time.

Instead, the system reveals its *intrinsic instability* as soon as the price-of or the demand for any sector production changes irreversibly, however small the change may be. Any event like that would irreversibly modify also the production volumes of other sectors, thus causing a sequence of chain-effects, which is the study subject proper to the probabilistic approach introduced by the preceding notes. Then, *any persisting alteration* – however small – in the configuration of the interaction distribution *starts an irreversible evolution process* in the system.

The new method includes equations apt to describe and calculate the overall series of changes that involve the system's interaction distribution, up to the determination of the *necessary* transformations in the structure of the system. The process develops according to *transformation cycles*, which bring the system from *unstable* equilibrium states to other *unstable equilibrium states*, which are characterised by different levels of syntropy, i.e., by different levels of internal organisation. The process, as described by the mathematical simulation, has a "dramatic" development, since in every situation in which the system *needs* to transform there is also a chance for its disintegration.

In simpler words, the *actual transformations* in the system are those that imply changes in the system's *structure*; as seen, this structure consists of *the set of expectations* (the *intents*) that works as an "engine" in the system. A sequence of convenient changes in the structure of the system is indispensable to the system's survival. In the evolution of any system, there is a series of crucial points, at which either the system changes its structure suitably or incurs its disintegration.

In between two subsequent equilibrium states (also referred to as "**stationary states**"), the evolution process is described by *transition phases*, in which the system's *configuration*, i.e., the interaction distribution, allows for changes in the flows that do not involve changes in the system's structure. However, there is always a "critical transition phase" that concludes every "transformation cycle". The description of the system cannot proceed beyond that "critical" phase, because the solution of the simulation equations leads to *complex values* (imaginary numbers) that logically relate to a "no more existing system"**; unless** the calculable changes in the system's structure, as associated with the critical phase, allow the simulation to establish the intervened conditions for the system's survival.[25] Such conditions describe the newly achieved "stationary state" of the system, from which subsequent transformation cycles may start either according to chance or according to programs.

The sequence of the "transition phases" of every transformation cycle shows how the system's contents of syntropy and entropy vary from phase to phase, most often through ample oscillations in the respective values. An impressive collapse either of syntropy or – more often – of entropy is in most cases associated with the last and "critical" phase of every cycle.

The system's evolution is *development* if the "stationary states" of the sequence establish at higher and higher levels of syntropy. It's instead *decay* if the sequence shows "stationary states" that establish at higher and higher levels of entropy.

It's also possible that the described evolution develops according to alternate sequences of "development" and "decay", with alternate sequences of different stationary states at higher and lower levels of syntropy**:** As it might be the case when simulating the alternate effects of good or bad socio-economic policies implemented.

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[25] The *structure* that "rescues" the system can always be calculated, either on the basis of the interaction flows proper to the "critical phase", or else on the basis of the interaction distribution relevant to any other phase of the same cycle. The choice is strictly depending on the nature and purpose of the simulation exercise. The possibility of choosing the most convenient transition phase for transformation purposes is particularly important in planning activities, in which the simulation can in this way suggest the most appropriate components and functions to be selected for promoting development. In such cases, the choice of the transition phase that transforms the system's structure is obviously based on the level of syntropy that the transformation can secure.

The analysis does also show that a higher syntropy level implies a *higher degree of stability* for the system, “stability” meaning here “lower risk of putting the system’s organization in jeopardy”.[26] It is an important theoretical result, for it seems possible to argue that the end of the system’s complexity consists of *higher degrees of stability.*

Actually, higher syntropy means higher complexity, as this is shown by systems characterised by an ample range of different activities, which are as more differentiated by function as more mutually interdependent. One significant aspect of complexity is that the “main systems” of complex systems, along with the respective higher degree of complexity, achieve higher degrees of *autonomy* with respect to the “external universe”**.** Higher degree of autonomy means also greater *self-protecting capacity* against possible external or internal events – be these immanent or accidental – which can jeopardise the system’s existence.

The *degree of complexity* of any system finds its limit in the value of the entropic potential associated with the system, because the entropic potential depends on the number of *different functions* performed by the *different components* that characterise the system.

When the system’s syntropy approaches the value of the system’s entropic potential, the system enters a stage of relative stagnation. It’s a particular state that can be broken - either by accident or by program - by the emergence of special new conditions, which lead the system to undergo a “mutation”. There are *progressive mutations* as well as *regressive mutations.*

A **progressive mutation** occurs because of the *emergence*, inside the “main system”, of one or more new components, which perform kinds of activity that are not performed by any one of the system’s existing components**.** An emergence of the kind implies an extension of the system’s size.

Instead, a **regressive mutation** occurs if one or more of the existing functions of the “main system” disappear, with no replacement, along with the respective components, thus also reducing the system’s size.

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[26] As to the concept of “stability” in this context, see following Paragraph **8.1**.

It may obviously happen that a “regressive mutation” is ineffective, when the disappeared functions are simultaneously replaced by new emerging ones**;** and it may also happen that one or more “progressive mutations” occur after one or more “regressive mutations” have occurred, or vice-versa.

One of the interesting conclusions provided by the theory of syntropic systems concerns the *actual meaning* of the concept of “syntropy”. If one denotes with F the *total amount* of the ***effects*** that are ***expected*** in association with total amount T of the system’s interactions, the system’s syntropy, S , can also be expressed as $S = F/ T$.

To make it clearer**:** if it’s an economic system, then syntropy S expresses the *mean expected benefit associated with any interaction unit.*

It is worth mentioning that a number of other parameters are considered beside entropy and syntropy, which are useful *indicators* of the conditions that characterise the state of the system during its evolution. Such indicators are said “phase parameters”, and are especially useful in the practical applications of the theory for an evaluation either of the *effectiveness* of a progressive evolution or of the damaging consequences of a regressive evolution. Actually, both *improvement* and *worsening* in the system’ state may imply different *costs*, which can make the improvement more or less effective, and the worsening more or less onerous, respectively. One of the *phase parameters* is the *degree of wear-and-tear*, which measures the resource dissipation and loss of effectiveness undergone by the system during its evolution.

The total amount of entropy produced by the system during its evolution is the measurement of the system’s *age.*

There are a number of other parameters, such as “stress”, “fervour”, etc., each working as an indicator with its specific significance and usability.

8.1 Syntropy, Stability, and Impossible "Chaos"

In the preceding paragraph, I have introduced the concept of "stability" as a quantity related to syntropy. I deem it useful to linger on the subject to avoid possible misunderstanding.

As previously stated, every complex system may be viewed as a set of interacting components. Each component generates and receives flows of interaction.

Let's call "**output**" the *total amount* of flows generated by each component, and "**input**" the *total amount* of flows received by each component, "flow" meaning "quantity of interaction (generated or received) in a conventional time unit".

In the hypothetical 5-sector economic system of the preceding example, the *outputs* were denoted with the "*Ds*" and the *inputs* with the "*As*", all these symbols being affected by a numerical index to relate each of them to the relevant sector.

The set of all quantities *As* and *Ds* , taken all together, is referred to as "**the system's base**".

The system's "**stability**" depends on the distribution of the sector *outputs* and *inputs* in relation to the system's total interaction activity, to say that the stability depends on the configuration of the system's ***base***.

Given any system of interacting components, it should be evident that the sum of the *outputs* is always equal to the sum of the *inputs.* It's worth to fix this point by the simple equivalence expressed by

$$\sum_{i=1}^{N} D_i = \sum_{i=1}^{N} A_i = T$$

in which T is the system's total interaction activity (i.e., the sum of all the system's interaction flows), and N is the number of the system's components, "external component" included. After division of the above equivalence by T, the following obvious relations can be written: $\sum_{i=1}^{N}\frac{D_i}{T}=\sum_{i=1}^{N}\frac{A_i}{T}=1$.

In this way, two new probability distributions have been defined, one of which regards the set of *output probabilities* defined by ratios $\frac{D_i}{T}$, and the other one regards the set of *input probabilities* defined by ratios $\frac{A_i}{T}$.

Therefore, it is possible to associate an *entropy* (i.e., a *statistical uncertainty*) with each of the two probability distributions. Let's call "*output entropy*" the former and "*input entropy*" the latter, according to the following formal definitions

$$E_{out} = -\sum_{i=1}^{N}\left(\frac{D_i}{T}Ln\frac{D_i}{T}\right), \text{ and}$$

$$E_{in} = -\sum_{i=1}^{N}\left(\frac{A_i}{T}Ln\frac{A_i}{T}\right),$$

respectively .

The system's "**base entropy**", denoted with E^*, is the ***sum*** of the two above entropies, i.e.,

$$E^* = E_{out} + E_{in} .$$

In preceding Paragraph **6**, the system's "entropic potential" has been defined by

$$H = 2\mathrm{Ln}N .$$

Therefore, in correspondence with the "base entropy" just now defined, it is also possible to identify the "**base syntropy**" given by the difference between the entropic potential and the base entropy, as follows **:**

$$S^* = H - E^*.$$

It can be proved that this quantity indicates the degree of ***stability*** of the system. Making this definition explicit, ***base syntropy*** *S** (or *stability S**) can also be expressed by

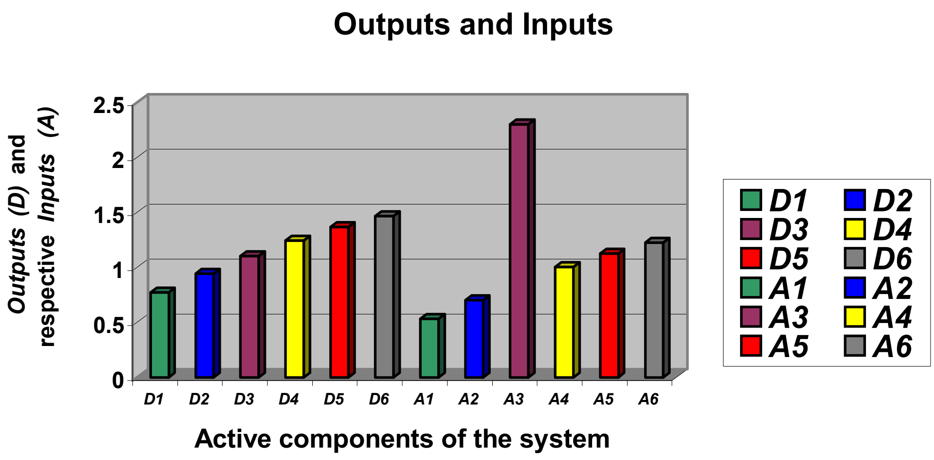
$$S^* = \text{Ln}\left(\frac{N^2}{e^{E^*}}\right),$$

in which *N* is the number of the system's components and *E** is the relevant "base entropy". From this formula it's easy to deduce that the system's degree of stability tends to grow both with the number of *different* components and with the lessening of the base entropy. In this connection, it's significant to note that the greater the number of *different* components the greater the system's complexity.

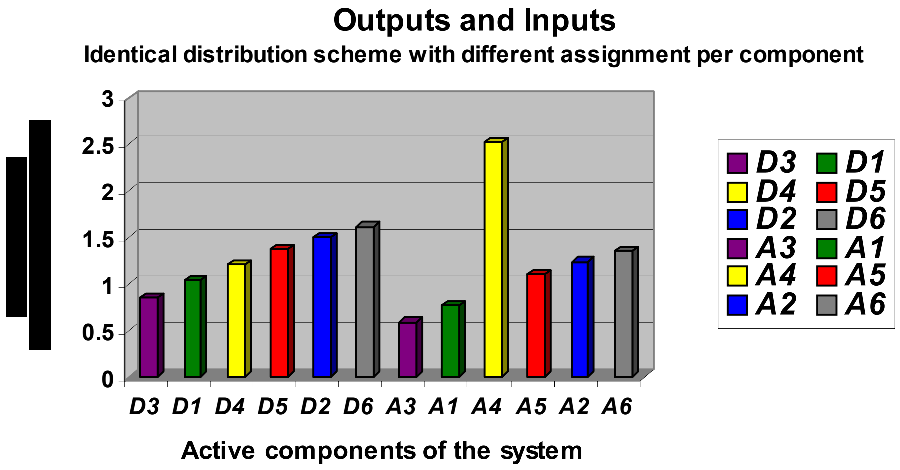
It can also be proved that the system's stability is in a direct relationship with the system's syntropy *S*. However, the *stability* (which is only defined by the ***base*** *syntropy*) may remain constant in association with different levels of the syntropy *S* relevant to various configurations of the interaction flow distribution. Actually, the distribution of the N^2 interaction flows between the *N* components of the system may vary in infinite different ways with no change in the respective ***base*** *syntropy.* This reflects the fact that each *output*, as well as each *input*, results from the addition of *N* interaction flows, whose individual values may change while keeping their sum constant.

Moreover, the distributions of the *outputs* and of the *inputs* may in turn change too, provided that the respective ***base*** *syntropy* remains constant to keep the system's stability unchanged.

Consider now a system that consists of 6 different components (i.e., *N* **=** 6), in which the 6 *outputs* and the 6 *inputs* present a distribution like that shown by the table below:



The above distribution scheme *as such* may remain unchanged even if there are alterations in the *output* or in the *input* values relative to individual components. In the next table, alterations are shown in the individual amounts of *output* and *input:* for example, the previous *output* and *input* of Component 1 (i.e., D_1 and A_1) have now been assigned to Component 3; the previous *output* and *input* of Component 2 (i.e., D_2 and A_2) have now been assigned to Component 1, and so on.



What remains unchanged is the way in which the *outputs* and the *inputs* form the partition scheme of *percents* of the system's total activity *T*. (By the way, to stress the importance and the prevalence of the *scheme* over the individual quantities regarded, in the new table all the *outputs* and the *inputs* have also undergone a 10% increase with respect to the values indicated in the previous table). The *persistence of the percent partition scheme* is the necessary and sufficient condition to keep both ***base*** *entropy E** and ***base*** *syntropy S** unchanged. Which obviously means keeping the system's *stability* constant.

The correctness of this statement can easily be guessed, considering that the *output* and *input* distributions reflect the respective *probability* distributions, which are all that matters in determining the system's ***base*** *entropy* and ***base*** *syntropy.*

The preceding remarks show how the components of a system may exchange the importance of the respective roles without compromising the system's stability. It's a feature of flexibility proper to complex systems: these can cope with sudden difficulties encountered by some of their components, through a balancing supplement of functionality (or *hyper-performance*) provided by other components.

It's now worth going back to the equation that defines the stability (*S**) of any system, with a view to pointing out an important logical implication of the concept.

Consider a system *with no detectable internal organisation*, as it happens when the assessed interaction probability between any pair of components is the same as for every other pair of components, including all the "self-interaction" probabilities: an example of such a situation is given by the first table of previous Paragraph **7,** regarding a hypothetical 6-component system**.** Let's refer to any state of this kind as to a "chaotic state". The ***base*** of any system of that kind is characterised by two particular *output-input probability distributions*, with which two *identical* entropies can be associated and expressed by the following equivalence:

$$E_{out} = E_{in} = -\sum_{i=1}^{N}\left(\frac{N}{N^2}Ln\frac{N}{N^2}\right) = -N\,\frac{N}{N^2}\,(\mathrm{Ln}\,1 - \mathrm{Ln}N) = \mathrm{Ln}N\,.$$

Thus, the entropies of the two *semi-bases* [27] of any "chaotic" system are identical to each other.

As previously seen (refer to the first formula in Page 32), ***base*** *entropy* E^* is the sum of entropies E_{out} and E_{in}, so that *– in the case of a "chaotic" system –* ***base*** *entropy* E^* becomes

$$E^* = E_{out} + E_{in} = \mathrm{Ln}N + \mathrm{Ln}N = 2\,\mathrm{Ln}N\,,$$

which coincides with the "entropic potential" of the system (remember $H = 2\mathrm{Ln}N$). Therefore, according to the definition given for the system's *stability* S^*, the *stability* of any "chaotic system" is expressed by

$$S^* = H - E^* = 2\,\mathrm{Ln}N - 2\,\mathrm{Ln}N = 0\ .$$

It's a remarkable result, for it shows that ***the stability of "chaos" is nil.*** In other words, no system can either persist-in or enter a state of maximum disorder. Paradoxically, it's right "chaos" the state of maximum instability. This also clarifies the concept of "maximum disorder". Should such a state be possible, then it would be characterised by an absolute uniformity in the behaviour of the system's components, so making these not distinguishable from each other. **To conclude that no system exists without recognisable differences between the components of which the system consists.**

Thus, through simple logic reasoning, it is possible to ascertain that the identification of any system implies also and necessarily the identification of a "structure" that binds the system's components to each other *because of* the respective behavioural differences. The "structure" is always a network of relationships between different roles. Whatever the nature and the state of the system, its active elements exhibit similarities and differences in their individual condition, which inevitably leads to determine the formation of aggregations into

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[27] The *output set* is one of the two "semi-bases", and the *input set* is the other semi-base of the system. Therefore, the system's *base* consists of the union of these two *semi-bases.*

components and separations between components, with the subsequent modification in the intensity and distribution of the relevant interactions. In turn, alterations in the relationship network establish “constraints” to the behaviour of the whole set of the system’s components, so starting evolution processes that may bring the system organisation to higher degrees of complexity or, to the contrary, to its decomposition.

The preceding considerations should allow anyone to accept that any apparent equilibrium state is intrinsically unstable. That’s why the concept of “stability” – far from meaning “static state” – takes in this context the specific meaning of the *probability* for the system not *to modify its state.*

In this connection, it’s worth recalling the objections to Boltzmann’s entropy raised by physicist Josef Loschmidt (1821-1895) and by mathematician Ernst Zermelo (1871-1953).

Though persuaded of the necessity of adopting a molecular interpretation of entropy, Loschmidt based his objection on the symmetry of the laws of mechanics with respect to the inversion of the time direction: Whence there must be the possibility of processes opposite to those that bring systems to maximum entropy states, with the consequence that states of increasing order – or decreasing entropy – shall necessarily be allowed for.

The objection raised by Zermelo is instead based on a theorem proved by mathematician Jules-Henri Poincaré (1852-1912). The theorem proves that interacting particles (whatever their nature), whose interactions occur through forces depending on the particles’ spatial positions, modify their overall configuration almost periodically, in that the same configuration re-appears necessarily – and alternatively – according to determinate time intervals. The theorem excludes the possibility of proving the irreversibility of physical processes on the basis of mechanics, for any possible physical state tends to reconstitute periodically.

Boltzmann replied to Zermelo remarking that the time necessary to any macroscopic system to complete the full cycle up to the reconstitution of its initial state is longer than the universe’s age; so, Zermelo’s objection has no practical relevance.

Nonetheless, the justified objections raised to the Second Principle of thermo-dynamics have cast doubts as to the irreversibility of physical processes. Also quantum mechanics and, more recently, theory of chaos show that no definitive certainty shall be associated with the Second Principle.

In the light of the foregoing, it seems appropriate dismissing the idea that the final state of every physical process shall consist of the static equilibrium proper to maximum entropy states. On the contrary, the probability of inverting the entropic tendency does certainly increase with the entropy level itself, especially when the system's state approaches the system's entropic potential, which – as seen – is a state of "absolute instability". Inversion of the tendency implies the beginning of *syntropic* processes, by which systems become more and more complex and "stable". In any syntropic process, *stability* means capacity to preserve both the functions and the connections between the active components, rather than capacity to preserve the individual components in their respective roles. In a complex system, it's the *system of functions and connections* that which matters, whereas any active component may be replaced by any other component that can take over the role from the replaced one. This aspect of complexity makes it clear *how* the system's components shall be considered as *different* from each other, independently of the respective individual nature and/or feature.[28]

Thus, it's reasonable to affirm that syntropic processes appear spontaneously and necessarily, though syntropic tendencies may seem to be less showy and less impelling than entropic tendencies. Finally, it seems also evident that there is an immanent "dialectic" between entropy and syntropy, *at least* because it's impossible to conceive any idea of "disorder" without the complementary idea of "order".

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[28] A banal example: An industrial factory is a "main system" in which some roles previously performed by human workers can be taken over by machines, while the control on labour performance changes into control on machine performance. The functions remain notwithstanding the radical changes in the nature of some of the system's components.

9. Conclusions

Every form of knowledge is tied to the use of languages. These are the basis of our mental and material representations of the world’s physical reality with which we are in touch, nay, in which we are fully immersed.

Our inborn inclination to notice “norms” or “regularities” in the events we observe or perceive belongs to tendencies that are intrinsic to the cosmos, which is right what we perceive as such (κόσμος, “universal order”) in an opposition to all that is not yet perceivable as “order” or “regularity”.

We are used to observe the formation of complex physical systems that develop along with the symptoms of their eventual decomposition, whence our need to understand the reasons for the raise of those systems and for their subsequent conversion into self-demolition processes.

We are still at the dawn of the reasoning human species, which is still affected by epidemics of faulty imagination, due to the metaphysical basis of any attempt to rationalise our painful ignorance. This is the source of myths that should help us tackle undesirable events we dread, but our mythologies are instead throughout the world the cause of havocs that are much worse than those we should overcome thanks to the practice of our myths.

Since a couple of centuries, the scientific analysis of a few observed phenomena allows us to control them. *One* of the salient traits of scientific method is the use of mathematical calculation, which permits reliable forecasts in a noticeable number of cases, together with a widespread possibility to reproduce the phenomena that are subjected to our control.

Mathematical calculation is a system of procedures based on the logical exploitation of *similarities*, *analogies* and *tautologies.* It provides us with an instrument – often inadequate – to check (as far as possible) the damages caused by *ideologies* and by *mythologies.*

Luigi Fantappiè, who was a mathematician of a renowned creativity, felt – like a few other contemporary scholars – the necessity to boost the power of logic and mathematics beyond the very limited horizon of the events that physics, chemistry and biology could so far put under human control. The amazing complexity, the irresistible development, the inexplicable origin of grand biological cycles are the paramount challenges met by our need to understand, to represent and to control. If thermodynamics can to a large extent persuade us of the necessity of more or less precocious decay of every system that forms and evolves, nothing can instead persuade us of the *necessity* of the raise of complex systems, which seem capable of escaping the probability laws that inexorably govern both thermodynamics and the other phenomena addressed by physics and chemistry.

Fantappiè passed away in his fifties, and had perhaps no time to translate his concept of "syntropy" from a preliminary philosophical definition into a mathematical formulation suitable for rigorous logical elaboration and/or calculation purposes. In accepting the heritage of his work, as also done by a few others, I have tried to take over the task of developing the subject in view of practical ends, in the way I've partially summarised in this article.

The general premise is very simple: Today's knowledge allows us to associate a level of entropy with any state of any system, by use of a precise mathematical formula. If the entropy level is not at the relevant possible maximum, then it must be assumed that a "balance of non-entropy", i.e., some degree of "order" can be also associated with the same system. Such a "balance" is taken as a measurement of the "syntropy" inherent in the state of the system. In this way, "syntropy" remains defined as a quantity complementary to entropy, so that the sum of syntropy and entropy gives a constant value, which indicates the *transformation potential* (the "entropic potential") proper to the system.

No doubt, mathematical language is among the few effective languages to use for description purposes, and it certainly is the most effective language to use for calculation purposes. In presenting the formula that makes syntropy the quantity complementary to entropy, I've also mentioned some relevant logical implications. Among these, there is the analytical instrument that describes the *probable* evolution of social or economic systems observed in phases of *lost equilibrium*, though considering that any "equilibrium state" is a conventional and transitory condition, which inheres in our language mechanisms rather than in the real world observed.

The approach to the subject, as proposed here, must basically be considered as a methodological proposal. No method can acquire scientific character until it is proved effective in repeated applications to real cases.

As far as my personal experience is concerned, the method has well responded to my technical needs in performing professional tasks. The method could reveal its unique properties especially in a comparison with other methods commonly used to make predictions relative to the expectable behaviour of complex socio-economic systems. The results obtained from those applications have always consisted of *sets of different possible options* submitted to decision makers, who were much more important and powerful than a consultant like me. Which means that I cannot yet indicate any objective verification of the appropriateness of those solutions to the relevant problems encountered.

There are schools of thought and research, particularly the one that refers to the activity and the teaching of Ilya Prigogine and collaborators, which have worked out other methods to deepen the study of complex systems. The complex phenomena that seem to escape the Second Principle of thermodynamics have been called “dissipative structures” by Ilya Prigogine, because of the large amount of entropy *spent* in the formation of organised material systems. A new discipline, referred to as *Synergetics*, has originated from those researches. It involves complicated analytical methods and aims at ambitious targets, though the theorems of Synergetics have not yet been applied successfully to the study of macro-systems.

I’m here below indicating a few bibliographic references in addition to those provided by the footnotes of the foregoing text. The additional works mentioned are not of a specialist nature and offer a relatively easy reading to people interested in widening their knowledge in related subjects, in consideration of the ample range of basic concepts that are inevitably involved by any discussion concerning entropy and syntropy.

Essential References

- W. Heisenberg, *Physics and Philosphy*, first published in Italian (*Fisica e filosofia*), Il Saggiatore, Milano 1961

- F. Bonsack, *Information, thermodinamique, vie et pensée,* Gathier-Villars, Paris 1961

- I. Prigogine, *Le leggi del caos* (*The Laws of Chaos*), Italian edition, Laterza, Bari 1993 (It's a collection of lectures delivered at various Italian Universities and Cultural Institutions)

- J.P. Crutchfiel, J.D. Farmer et al., *Il caos,* in " Le Scienze" magazine, n° 222, February 1987

- J.S. Walker, C.A. Vause, *Ricomparsa di fasi,* in "Le Scienze" magazine, n° 227, July 1987.

(There are also a number of texts by I. Prigogine and G. Nicolis which are not easy to read, though the subjects and arguments addressed by the authors are largely repeated passing from one text to another. The language is of a specialist nature. However, some chapters of those texts are a remarkable contribution to contemporary scientific understanding. I limit myself to mention the two following books only:

- *Self-Organisation in Non-Equilibrium Systems*, John Wiley & Sons, New York-London-Sydney-Toronto, 1977-1981

- *Exploring Complexity. An Introduction*, R. Piper GmbH & Co., Munich 1987)