*COMPLEX SELF-ORGANIZED SYSTEMS*

# *SYNTROPY AND ENTROPY IN SELF-ORGANIZED SYSTEMS*

**(by Mario Ludovico)**

## *Preamble*

*These notes summarise the salient traits of a theory formulated (and published only in Italian language in 1988*(1)*) to describe and simulate for practical purposes the behavior of complex self-organized systems. The main aim of the theory was to provide professionals with a friendly usable means for simulating the effects of possible planning decisions on the evolution of complex systems such as, for example, urban, regional*(2) *and economic systems*(3)*.*

*The behaviour of systems of that kind is determined by the interacting effects of a very large number of decisions made at several different social levels, and usually requires complicated descriptions. A simplified conceptual representation of such a phenomenology is the subject of the theory.*

*However, it seems worth observing that – irrespective of the purposes for which this theory was initially formulated – most of the concepts and analyses it includes may be applied to any system whose components interact with each other in a way that cannot be considered as merely casual.*

*In the theoretical paradigm that follows, the use of mathematical instruments is limited to the mathematics currently taught in university faculties for engineers, statisticians, economists as well as urban and regional planners.*

*Specific computer software supplements the theory for practical exercises.*

## 0. Abstract

"System" in this text means any part of the perceived world that can be identified and represented as one particular set of mutually dependent events, to be – according to given criteria - distinguished from the other innumerable and different sets of events which may be identified in the Universe.

For the needs of this analysis, any system may be thought of as a set of particular different components that interact with each other under constraints or purposes that are proper to the system.

*Interactions* between elements of a complex system consist of more or less continuous flows of energy, forces, materials, people, commodities, services, information, etc. All

these flows, in a complex self-organized system, cannot generally be considered as random flows, since they are flows somehow intentionally generated and directed, i.e., *actions* with which an expected economic **intent** can be associated. The adjective "economic" has in this context a quite general meaning, which might exceptionally regard also systems whose components undertake actions only because of special environmental constraints[1].

This theory of systems in evolution develops the concept of *intentional interaction* between elements of the system considered. The adjective “intentional” does here mean that the actions may be considered as aimed at producing specific effects.

The theory is based on three fundamental assumptions concerning the nature of both the interactions considered and the intent associated with each interaction.

The theoretical construction develops by a probabilistic approach. The findings consist of a flexible set of models usable for tackling a number of particular practical problems. The principal theoretical result, however, is a method for describing and analyzing the evolution processes of complex self-organized systems according to a suitably simplified representation of them. For this purpose, a number of specific concepts have been introduced, such as, for example, the concept of "system structure " to quantify the *causes* of the system’s emergence, or "syntropy" (as opposite of "entropy"), to measure the system’s degree of organization, or "age of the system", or "stability", or “evolution stress” to measure the system’s degree of detachment from its initial equilibrium state, or “syntropy charge” to measure the self-organisation potential, or “fervour” to measure the evolution intensity in transition phases, and others.

The system’s evolution is represented as a stochastic process that consists of subsequent "cycles". Every cycle is described by *transition phases* that bring the system from an original unstable equilibrium state to either another unstable equilibrium state or to the system’s disintegration. At the end of each cycle, in fact, a change in the system’s structure is necessary for the system's survival and for making it possible the start of a new cycle. In an alternative, if no structural change intervenes, the system as such disappears or turns into something that remains undefined because substantially incompatible with the original system.

The *time* involved by such evolution process is discrete and expressed by the sequence of "phases" that determines every cycle. This is an "exterior reference time", which differs from the "intrinsic time" that determines the *age of the system.* The “intrinsic time” or “system age” is measured by the total amount of *disorder* (i.e., information entropy) produced by the system during its evolution process.

Various *phase parameters* (as partly mentioned above) are defined to assess the state of the system in every stage of its evolution.

The system may undergo *mutations* in consequence of either the emergence of new compatible components or the disappearance of existing ones.

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[1] The word *“economy”* comes from the ancient Greek words οἴκος (habitat) and νόμος (law), to indicate the constraints that regulate the behaviour of the elements proper to the specific environment considered.

## 1. Three basic assumptions.

**The first assumption** of the theory is that the *interaction flows* between elements of the considered system are *physically measurable*.

**The second assumption** is that a quantifiable *expected intent* is associated with each interaction.

**The third assumption** is that *all that is known* about interaction flows is expressed

*(i)* by the physical measurement of the flows,
*(ii)* by the formal definition of the relevant "intents", and
*(iii)* by those relationships, between any flow and other flows, which can be identified and expressed formally.

## 2. The first theoretical implications.

On the basis of those three major assumptions, the theory derives the fundamental equation that puts every interaction flow into a mutual univocal relationship with the "intent" that motivates the same flow. The equation is:

$$T_{jk} = h\,(O_j\,D_k / T)\,\mathbf{Exp}\,m_{jk}\,; \quad \text{(for all system elements } j \text{ and } k) \qquad \textbf{[1]}$$

where:

$T_{jk}$ is the measurement of the ***flow*****, i.e., interaction per time unit,** which is originated by element $j$ and bound for element $k$ ;

$m_{jk}$ is the measurement of the expected intent associated with the same flow;

$O_j$ is the total amount of flows generated by $j$ in the time unit considered;

$D_k$ is the total amount of the system flows that are bound for $k$ during the given time unit;

$T$ is the overall amount of flows generated by the system in the same time unit;

$h$ is a coefficient that depends on the equilibrium state of the system.

The following formal definitions concern some of the quantities introduced above:

$$O_j = \Sigma_k\, T_{jk}\,; \quad \text{(valid for any } j) \qquad \textbf{[2]}$$

$$D_k = \Sigma_j\, T_{jk}\,; \quad \text{(valid for any } k) \qquad \textbf{[3]}$$

$$T = \Sigma_j \Sigma_k\, T_{jk} = \Sigma_j\, O_j = \Sigma_k\, D_k\,; \qquad \textbf{[4]}$$

To pass from flow absolute measurements to *flow probabilities* it is sufficient to divide Equations **[1]** by total flow $T$, to obtain:

$$P_{jk} = T_{jk} / T = h\, P_j\, Q_k\, \mathbf{Exp} m_{jk} : \quad \text{(valid for all } j \text{ and } k\text{)} \qquad \mathbf{[5]}$$

which expresses the probability of flow from $j$ to $k$, once defined

$$P_j = O_j / T \;\text{, and}\quad Q_k = D_k / T \;. \qquad \mathbf{[5a]}$$

$P_j$ is the probability for element $j$ to generate a unit flow during the fixed time unit, while $Q_k$ is the probability for element $k$ to be the destination of any unit flow generated by the system during the same time unit[2].

It is also immediately seen, because of relations **[4], [5]** and **[5a]**, that

$$\Sigma_j \Sigma_k P_{jk} = 1 \;. \qquad \mathbf{[6]}$$

This equivalence indicates that the set of flow probabilities associated with the system can be considered as a *probability distribution*.

Equation **[1]** is obtained by maximizing the probabilistic uncertainty $E$ associated with discrete probability distribution **[6]**, under all the quantifiable constraints that affect this probability distribution as expressed by equations **[2], [3], [4],** and by the following equation

$$\Sigma_j \Sigma_k u_{jk} T_{jk} = U \qquad \mathbf{[4a]}$$

in which $u_{jk}$ is the average measurement of the *effect expected* in association with every flow $P_{jk}$ .

Intent $m_{jk}$ is the product of corresponding *expected effect* $u_{jk}$ with constant $\lambda$ , which is a Lagrange multiplier determined through maximisation of the probabilistic uncertainty associated with the probability distribution defined by equation **[6].**

The concept of *probabilistic uncertainty* is substantially the concept of *information entropy* defined by Shannon and Weaver(4) in 1949, and is expressed here by

$$E = -\, \Sigma_j \Sigma_k P_{jk} \mathbf{Ln} P_{jk} \qquad \mathbf{[7]}$$

("**Ln**" is the symbol for natural logarithm).

Function **[7]** (*uncertainty* or *entropy)* is the function that is maximized by *Lagrange multipliers method* under the constraints – as indicated above - which can be written to express *all that is known* about the considered interaction flows(5). (In its correct theoretical formulation, entropy must include a constant coefficient that has here been

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[2] The original *exterior* time unit is that allowed for in setting up the *original configuration.* Subsequently, when the system's evolution process is simulated, the proper "time unit" becomes each particular *phase* of the system. Therefore, concerning evolution, "flow probability during the given time unit" means "flow probability in the system's phase considered".

assumed as equal to 1. Probabilistic uncertainty, or entropy, is a positive quantity which is *always* associated with any probability distribution and can *only* be expressed through function **[7]** multiplied by a positive constant that depends on the base of the logarithms).

Given the measurement of any flow, an important implication of Equation **[1]** is that the quantification of the *expected intent* associated with it is also univocally determined. In fact, from **[1]** one obtains:

$$m_{jk} = \mathbf{Ln} T_{jk} - \mathbf{Ln}(O_j D_k / T) - \mathbf{Ln}\ h \text{ ; (valid or all } j \text{ and } k \text{ )} \qquad \textbf{[8]}$$

and it can be proved that

$$\mathbf{-Ln} h = 2\mathbf{Ln}(N/T) + (1/T)\ \Sigma\ (O_i\ \mathbf{Ln} O_i + D_i\ \mathbf{Ln} D_i). \qquad \textbf{[9]}$$

*N* is the number of elements that form the system. Coefficient *h* has no physical dimension and pertains to any "intrinsically unstable **equilibrium state**" in which the system can be described by Equation **[5]** (whereas *transition states - or phases* - which are inherent in *transformation cycles,* are described by Equations **[15]** to **[20]** of Paragraph 5).

The value for *h,* which may vary between 0 and 1, can be assumed as the probability for the system to change its state.

Intent $m_{jk}$ provides a measurement of the net mean "economic purpose" associated with respective flow $T_{jk}$. For the theory, the value of $m_{jk}$ may vary between $-\infty$ and $+\infty$.

The complete set of values $m_{jk}$ (i.e., the $N$x$N$ matrix $\{m_{jk}\}$) determines the *system's structure.*

From the theoretical point of view, it is important to remark that Equations **[8]** and **[9]** imply that the interactions between the components of ***any*** system may - to some degree and in general - be viewed as *intentional*, considering that $m_{jk} = 0$ (which means *no intent*) only if $h = 1$ .

It can easily be shown that $T_{jk} = (O_j D_k / T) = T / N^2$ when $h = 1$, whatever *j* and *k*. In fact, $h = 1$ characterises the state of maximum disorder, i.e., $E_{Max} = 2\mathbf{Ln}N$. See next paragraphs.

## 3. Other basic definitions.

If all probabilities $P_{jk}$ are equal to each other, the maximum value of uncertainty is associated with probability distribution **[6]**. In this case, the flow probability between any pair of elements is a constant expressed by $P = 1 / N^2$. Then, the maximum value of uncertainty is expressed by

$$E_M = 2\mathbf{Ln}N = H\,. \qquad \textbf{[10]}$$

However, $E_M$ cannot affect any system, since "systems" may form only if $E_M \neq H$.

The theory considers uncertainty $E$ as a measurement of disorganization (*disorder*) in the system and, therefore, $H$ expresses a theoretical *limit state* of the system, about which nothing remarkable can be said except that it is extremely unlikely or – better – substantially impossible. Such a limit state is also referred to as the system's *entropy potential.*

Relation **[10]** indicates that quantity $H$ depends only on the number of the different elements that form the system. This fact draws attention to the importance of the criteria adopted for describing the system.

In any state of the system, the difference $S$ between entropy potential $H$ and uncertainty $E$ is taken as a measurement of the system's degree of *organization* in that particular state, and is defined as the system's *syntropy.* Therefore, *syntropy* is

$$S = H - E\,. \qquad \textbf{[11]}$$

Syntropy provides a means for measuring the organization (*order*) in the system, and any change in the system's syntropy gives an indication on the overall "improvement" or "worsening" undergone by the system upon simulated (or recorded) alterations in its hypothesized (or observed) states, under the conventional assumption that *order* is better than *disorder.*

Also the probability distributions expressed by relations **[5a]** imply a probabilistic uncertainty associated with each of them. The set of the two discrete probability distributions $P_j$ and $Q_k$ is called "base of the system", and the summation of the relevant "uncertainties", as defined by

$$E^* = -\sum \left(P_i\mathbf{Ln}P_i + Q_i\mathbf{Ln}Q_i\right), \qquad \textbf{[12]}$$

is the "base entropy" of the system. In general, $E^*$ differs from $E$.

If, for any $i$, is $P_i = Q_i = 1/N$, then the base entropy becomes $E_M^* = H$, and therefore no system exists.

Thus, analogously to definition **[11]** above, it is also possible to define the "base syntropy" of the system as $S^* = H - E^*$.

Base syntropy $S^*$ is in general different from syntropy $S$, and the following relationship is constantly true:

$$E + S = E^* + S^* = H \qquad \textbf{[13]}$$

The following equivalence is true of any unstable *equilibrium state* of the system:

$$S^* = -\,\mathbf{Ln}\,h\,, \qquad \textbf{[14]}$$

and justifies the name of "stability" for base syntropy $S^*$. If $h = 1$, "stability" becomes nil, which occurs if the system's entropy is $E_M = H = 2\mathbf{Ln}N =$ maximum.

(Note: This conclusion conflicts with the properties conceptually associated with the maximum entropy of thermodynamics. According to classic thermodynamics, any isolated system – and the Universe itself – tends to a final equilibrium state that establishes at the maximum entropy level, because this state - from the thermodynamic point of view - is the most probable one. Instead, in the theory presented here, the maximum entropy state is extremely improbable for any system to the extent to which maximum entropy $H$ implies the absolute maximum instability, i.e., no equilibrium at all for the system.

At the opposite extreme, $h = 0$ is impossible, since it would otherwise imply a system consisting of an infinite number of components. See **[23b]** below).

## 4. A cardinal theoretical assertion.

Equations **[8]**, the number of which is $N^2$ (the square number of the system's components), together with Equation **[9],** show that all the needed information concerning the study system can be expressed through functions of the interaction flows.

From a practical point of view, this means that the significant amount of information concerning the state of the system can be obtained through any appropriate interpretation and processing of the data that quantify the flows.

However, and this is the fundamental methodological statement, all the information obtained from the theoretical analysis depends strictly on how the system has been identified and described. The theory does not provide any *true picture* of the reality to which the analysis refers, but *only* the logical implications of *a mental representation* of it.

## 5. Particular models and evolution equations.

If intent $m_{jk}$ is considered as depending on an *expected mean utility* given by the difference between an expected mean gross benefit $b_{jk}$ and an expected generalized mean cost $c_{jk}$, both associated with the same flow $T_{jk}$, then manipulations of Equation **[1]** lead to the definition of various formulas that find practical use also in econometrics as well as in urban and regional analyses. In particular, a set of gravity models can be derived with a view to describing interactions between settlements. Another possible use of this theoretical paradigm may regard the interactions between sectors of an economic system.

To note: Equations **[8]** and **[14]** lead to express every flow intent (or *expected utility*) $m_{jk}$ also as a function of the system stability.

In general, the most important equations provided by the theory are those which enable the analyst to simulate the system's evolution process. This is described by a sequence of "transformation cycles", each cycle developing through discontinuous states or "phases", which are changes in the system's state that occur always through discrete *quanta* of interaction flows.

In each phase of the transformation cycle, the state of the system is expressed by a set of parameters (*phase* or *state parameters*), amongst which *entropy* and *stability* are the most significant ones.

Any transformation cycle starts from an "initial phase" (also called "phase zero"), which is determined by any change - however small - in the original flow configuration that modifies the system's *base entropy* defined by Equation **[12].**

The *initial phase* is supposed to be preceded by an unlimited sequence of *virtual phases* (to represent the virtual past time with respect to *phase zero*), and followed by a finite sequence of *actual phases* that represent sections of the system's simulated future. In this connection, it is worth noting that "time" in this evolution process is expressed by two different concepts, which are not logically inter-related.

"Exterior time", as "reference time", is marked by the number of phases of a given phase sequence.

"Intrinsic time", as "age" of the system, is measured by the progressive amount of entropy produced by the system evolution process.

The equations that determine the probability distributions in the *virtual phases* ("the past") are as follows:

$$P_{j(f-1)} = \boldsymbol{\Sigma}_k P_{jk(f)} = Y_j \boldsymbol{\Sigma}_k Q_{k(f)} \mathbf{Exp} m_{jk}\ ;\quad \text{(valid for any } j\text{)} \qquad \textbf{[15]}$$

$$P_{jk(f-1)} = P_{j(f-1)} X_k \mathbf{Exp} m_{jk}\ ;\quad \text{(valid for any } j \text{ and } k\text{).} \qquad \textbf{[16]}$$

Instead, the equations of the probability distributions in the *actual phases* ("the future") are:

$$\boldsymbol{\Sigma}_j P_{j(f)} \mathbf{Exp} m_{jk} = Q_{k(f-1)} / X_k\ ;\quad \text{(valid for all } k\text{)} \qquad \textbf{[17]}$$

$$\boldsymbol{\Sigma}_k Q_{k(f+1)} \mathbf{Exp} m_{jk} = P_{j(f)} / Y_j\ ;\quad \text{(valid for all } j\text{)} \qquad \textbf{[18]}$$

$$P_{jk(f)} = P_{j(f)} X_k \mathbf{Exp} m_{jk}\ ;\quad \text{(valid for any } j \text{ and } k\text{)} \qquad \textbf{[19]}$$

$$P_{jk(f+1)} = Q_{k(f+1)} Y_j \mathbf{Exp} m_{jk}\ ;\quad \text{(valid for any } j \text{ and } k\text{)} \qquad \textbf{[20]}$$

In the equations above, from Equations **[15]** to **[20],** index $f$ identifies any phase of the cycle, phase zero included;

$Y_j$ and $X_k$ are non-negative values that remain constant with the system's structure $\{m_{jk}\}$ during each transformation cycle, and may be considered as obtained from the solution of the two following linear equation systems, respectively:

$$\boldsymbol{\Sigma}_j Y_j \mathbf{Exp} m_{jk} = 1\ ;\quad \text{(valid for all } k\text{)} \qquad \textbf{[21]}$$

$\Sigma_k X_k \,\mathbf{Exp} m_{jk} = 1$ ; (valid for all $j$) **[22]**

where $Y_j$ and $X_k$ are the unknown terms.

The $2N$ quantities $Y_j$ and $X_k$ are called "structure potentials", and it is proved that

$\Sigma\, Y_i = \Sigma\, X_i = h$ . **[23]**

The *structure potential* values range between 0 and 1.

Moreover, it is proved that

$h = X_j / Q_j = Y_j / P_j$ **,** (valid for any $j$). **[23a]**

Note: if $E = E_M = H$, then $h = 1$, and $Y_i = X_i = 1/N$, for all $i$ . **[24]**

Because of Equation **[23]**, ratios $Y_i / h$ and $X_i / h$ ( for all $i$ ) define formally two probability distributions. According to a reasonable interpretation, such ratios represent the probability for each element of the system to remain in its state of flow *generator* or *flow attractor*, respectively.

The theory does also prove that

$h = e^{E^*} / N^2$ ; **[23b]**

which explains why no system, in no state, can enjoy permanent stability (see **[12] -** for the definition of $E^*$ - and **[14]** for “stability”), unless the system consists of an infinite number of components. (The state of absolute maximum syntropy, according to definitions **[10]** and **[11]** above, is also expressed by $S_M = 2\mathbf{Ln}N = H$, while entropy $E = 0$ . However, from **[13]** and **[14]** we derive that $h = \mathbf{e}^{E^*} / N^2$. If $N = \infty$, then $h = 0$ , which means that there is zero probability of changing state. Instead, if $N < \infty$, as it is for the *normal consistence* of systems, $h > 0$ in all cases, whatever the value for $E^*$. This means that any identifiable system has always a probability to change its state).

Logic arguments prove that no system can attain its pertinent maximum syntropy or entropy state. Such maximums must only be considered as asymptotic limits.

## 6. Simulations and conceptual framework.

Simulations are possible only if a complete set of “original” interaction flows is given.

The observed original flow distribution provides the whole set of data that is necessary and sufficient to carry out analyses and to start simulations.

Conventionally, the theory considers any flow distribution obtained from surveys (or other observation operations) as the representation of an *original equilibrium state* of the study system. This original equilibrium state is intrinsically unstable, and the relevant observed configuration may be taken as a *mean configuration* around which the system fluctuates precariously.

"Intrinsic instability" means, in fact, that reversible fluctuations in the flow distribution around the original configuration are inevitable, and will sooner or later determine an *irreversible* alteration. *Any minimal* ***irreversible*** alteration in the equilibrium flow distribution (or in the relevant probability distribution), which modifies also the system's base entropy, generates a corresponding particular *initial* phase of the system's "transformation cycle",.

All simulations have to start with an initial phase, or "phase zero" ($f = 0$).

The *initial phase* of a simulation is an alteration - known by hypothesis – in the original equilibrium state. The resulting configuration is the *initial phase* of a transformation cycle, which comes from the *original equilibrium state* and will inevitably conclude with a change in the system's structure. At the cycle's conclusion, a more or less unstable new equilibrium state may be achieved by the system, but it is also possible that the transformation ends in the *collapse* (and disappearance) of the system.

If a new equilibrium state concludes the cycle, another transformation cycle is expected to originate from it.

Any irreversible alteration – however small – in the system's equilibrium - as quantified by the relevant base entropy - is necessary and sufficient condition to identify one particular transformation cycle amongst infinite possible cycles.

There is an important remark that concerns the different kinds of instability that characterise the *equilibrium states*, which identify both the *original state* and the *conclusive phase* of any transformation cycle, with respect to the instability of the transition phases internal to each cycle. The instability of *equilibrium states* depends on stochastic events, which may or may not happen, and whose nature and intensity are intrinsically unpredictable. Instead, once an irreversible change modifies such equilibrium states, the subsequent phases of every transformation cycle are necessary and univocally determined.

From a logical standpoint, any transformation cycle includes the phases that have *virtually* preceded the *initial phase* (i.e., *phase zero*), since this one is conventionally considered, by logic consistency, as the consequence of previous phases caused by "virtual" irreversible alterations of the flow distribution around the relevant *original* equilibrium state.

In simpler terms, any given *initial configuration* or *phase* is only a *transition phase* with its own *given* past history. In fact, as can be guessed through the meaning of Equations **[15]** and **[16],** an unlimited reverse sequence of phases can be described, which tend asymptotically to the given *original configuration* of the system.

That is why, from a theoretical point of view, the state described by the survey (i.e., the *original* configuration) is never seen as the *initial phase* of the evolution process, but only – with respect to the observer - as the "conventional unstable original equilibrium state" of a possible evolution in progress.

Therefore, in this context, the adjectives "original" and "initial" have quite different meanings. From the *original state* infinite different *initial phases* of different transformation cycles may alternatively and arbitrarily be defined upon an infinite number of possible different alterations in the given *original state* or *configuration*.

**As a conclusion, *original* and *initial* states do never coincide in the representation of an evolution process,** because any *initial phase* is always one of the *transition phases* in one of the many possible transformation cycles, whereas the *original phase* is unique as it represents the *original unstable equilibrium state* of the system.

The "past section" of any transformation cycle is described by its *virtual phases*, which form the reverse sequence of phases from *phase zero* back to the original equilibrium state; whereas the "future section" of the same cycle is represented by its *actual phases,* which form the sequence of phases from the initial one (included) towards the next *intrinsically unstable equilibrium state,* or, alternatively, towards the collapse of the system.

A "transformation" consists of changes in the values that express the "expected intents" (see Equations **[8]**), which form the structure of the system.

During a transformation cycle (which develops between the original equilibrium and the next one, if any), the structure of the system is supposed to remain unchanged, while the flow distribution varies ("deforms"), phase by phase, up to a critical phase, in which also the structure must change to allow the system to survive. The critical phase (*agony phase*) is that given by the last set of non-negative solutions obtained from Equations **[17]** or **[18]**.

The *leitmotiv* of the simulation is as follows: solutions $P_j(f)$ of *actual phase f* Equations **[17]** (i.e., the phases that form the future section of the cycle) provide the numerators of the known terms (right hand side) of phase $(f+1)$ Equations **[18],** whose solutions $Q_k(f+1)$, in turn, provide the numerators of the known terms of subsequent phase $(f+2)$ equations, and so on, until the *agony phase* is attained, which is the actual phase of the cycle sequence that provides the last set of *non-negative solutions.*

Since negative solutions, in terms of both flows and flow probabilities, are with no physical significance, it is assumed that the represented system *cannot exist further* in the phase that follows the *agony phase*.

Under the assumption that the system will survive, the new structure of the system is normally re-calculated in function of the flow distribution inherent in the "agony phase", by use of Equations **[8], [23b]** and **[23a].**

The assumption of survival, however, is not logically necessary: It may or may not be adopted, according to the nature and purposes of the simulation.

(Note: Equations **[15]** and **[16]**, which relate to virtual phases, do always and necessarily provide *non-negative* solutions for *all virtual phases.* The solutions (configurations) obtained from these virtual equations tend asymptotically to the configuration of the *original equilibrium state* of the system, through a reverse-time phase sequence. The theoretical number of phases of this virtual sequence is infinite, but the meaningful number of virtual phases is practically determined by the significant decimals of the solutions obtained from **[15]** and **[16]** ).

The process described by the simulation is that of activities generated by a system of expectations (the *intents*), which tend to be conservative but are necessarily modified, through feedback reactions, by the development of the overall system activity. If, at a certain point in the evolution, the necessary structure transformation does not occur, then the system exits from the area of conventional reality.

Once the cycle is concluded by a transformation, a new cycle can start. The cycle that follows assumes the flow distribution resulting from the preceding transformation as a *new unstable equilibrium state* in the system's evolution. In the same way, further cycles can follow.

It is worth pointing out that a potential maximum syntropy inheres in any defined system. The maximum syntropy value coincides with the corresponding maximum entropy value or "entropy potential" **[10]** of the system**.** In approaching its maximum syntropy, the system may substantially enter stationary conditions, which actually block any further development.

Further evolution (or involution) is then possible only if the system undergoes a *mutation.* A mutation occurs when the system must be re-defined because of major changes in its features, the nature of which *involves an increase or decrease* in the number of its elements.

A process of progressive (or regressive) functional differentiation within a system can be considered as a sequence of "mutations".

Should it be more convenient, the evolution process, instead of dealing with flow probabilities, can also be described by equations that address interaction flows in their physical dimensions, by use of values $T_{jk}(f)$, $O_j(f)$, and $D_k(f\pm 1)$ in Equations **[15]** to **[20]** in the place of respective probabilities $P_{jk}(f)$, $P_j(f)$, and $Q_k(f\pm 1)$.

## 7. Closed and open systems.

Any system can be thought of as either isolated or in connection with the remaining part of the universe (i.e., with the *external universe*). In the former case the system is called "closed", whereas it is called "open" in the latter.

For simulating the evolution of the study system it is necessary to establish whether it is an *open* or a *closed* system. The distinction is important, because simulations are possible only if all the system's *original* interaction flows have been identified and quantified.

Every element of the system is in general interacting also with itself (by *internal interaction* or *self-interaction*). Thus, also the *external universe,* if it interacts with the study system, becomes *de facto* an element of the system. However, while interaction flows within the original system and between this and the *external universe* can normally be identified and measured, it is usually impossible to measure directly the interaction of the *external universe* with itself.

In this connection, the theory explains why and how is it possible to quantify the *self-interaction* that pertains to the *external universe*. Such very special self-interaction is called "implicit flow", since its value is logically implied by the quantities that express all the other measurable flows of the study system.

Once the *implicit flow* has been calculated, the simulation exercise can be carried out as if it were concerning a *closed system*.

In some particular cases, the determination of the implicit flow - along with the interactions between the system and the *external universe* - may be omitted, if these interactions are considered as either negligible or not significant for the study purposes.

In most cases - as can be guessed – not only is the *implicit flow* significant, but it results in a figure that is enormous in comparison with the other flows of the system, because of the obvious differences in size between the study system and the whole *external universe*.

The quantity calculated for the *implicit flow* can be the subject of various interpretations. A reasonable interpretation is that this particular flow of activity may be seen as the *effect* brought about inside the *external universe* by the activity (and the evolution) of the study system.

Substantially, the *implicit flow* is a mere logic implication of the way in which the study system is identified and described. Once more, this fact draws attention to the nature of subjective conceptual representation that characterizes the set of theoretical instruments adopted.

More in general, it is worth remembering that the whole theory is the *representation of a way of thinking*. Certainly, it is not the *true* image of any objective reality.

## 8. Applications of the Theory.

Sporadic practical use has been made of particular models that can be derived from the theory introduced above, more often for transportation and traffic studies.

Two other major applications of the method have been made in Indonesia for analysing possible evolution processes concerning the city of Malang (about 750,000 inhabitants) and the economic system of East Java Province.

In the former case, the problem was to simulate credible physical developments of the city in consequence of hypothesized alternative localization of economic activities. The basic data set was provided by a survey on all-purpose origin-destination daily trips made by the population of the city and surrounding areas.**(2)**

In the latter case, a simulation was carried out to assess the probable effects of possible macro-economic policy decisions made in an attempt to overcome the grave crisis that hit East Java Province as well as the whole Indonesian Country in 1998. The recourse to this simulation method - by use of the basic data provided by the regional economic input-output matrix - seemed in that moment the most appropriate way to try short to mid-term projections. Usual statistical procedures, such as extrapolations or other statistical techniques related to projections, became unreliable to the extent to which the analysis had to be based on historical data series. In fact, it was necessary to observe that the intervened crisis broke the continuity of any statistical trend, since sudden and deep changes were occurring in the political, social and economic structure of the region and of the whole country.(3)

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