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Symmetry, order, entropy and information

György Darvas

Symmetrion
and
Institute for Research Organisation of the Hungarian Academy of Sciences
P.O.B. 994, Budapest, H-1245 Hungary
darvasg@helka.iif.hu

Abstract: Conditions of applicability of the laws established for thermodynamic entropy do not necessarily fit to the entropy defined for information. Therefore, one must handle carefully the informational conclusions derived by mathematical analogies from the laws that hold for thermodynamic entropy.

Entropy, and the arrow of its change are closely related to the arrows of the change of symmetry and of orderliness. Symmetry and order are interpreted in different ways in statistical thermodynamics, in symmetrology, and in evolution; and their relation to each other is also equivocal. Evolution is meant quite different in statistical physics and in philosophical terms. Which of the different interpretations can be transferred to the description of information?

Entropy, introduced by Shannon on mathematical analogy borrowed from thermodynamics, is a mean to characterise information. One is looking for a possibly most general information theory. Generality of the sought theory can be qualified by its applicability to all (or at least the more) kinds of information. However, I express doubts, whether entropy is a property to characterise all kinds of information.

Entropy plays an important role in information theory. This concept has been borrowed from physics, more precisely from thermodynamics, and applied to information by certain formal analogies. Several authors, having contributed to the FIS discussion and published papers in the periodical *Entropy*, emphasized the also existing differences in contrast to the analogies. Since the relations of entropy - as applied in information theory - to symmetry are taken from its physical origin, there is worth to take a glance at the ambiguous meaning of this term in physics in its relation to order and symmetry, respectively.

1 Preliminary remarks on the necessity of raising the discussed questions

One of the main sources of the misinterpretation of the meaning of entropy (borrowed from physics) stems from neglecting the conditions of the applicability of the Second Law of thermodynamics. Another one stems from disregarding the differences in the interpretation of entropy when it is applied to a local subsystem, the universe and to a well-fenced closed system. Further, entropy is often interpreted in respect of evolutionary processes. Evolution of single-phase physical systems differs from those where more phases are present, on the one hand, and also from the evolution of the universe in its philosophical meaning, on the other. One can understand these differences in the relation of the concept of evolution to order and symmetry. Making clear these relations helps to avoid misleading conclusions when the notion of entropy is applied outside physics either to characterise evolutionary processes or for information.

2 Entropy and evolution

Evolution of a physical system means, how does the given system develop from an initial state to another, later state. If the system is closed, this means, it is not affected by any outside action during the observed period. One speaks about single-phase systems, if it consists only of one type of matter, like a certain atom, or molecule. The Second Law of thermodynamics, which is so often cited when entropy is mentioned, is formulated for closed, single-phase systems. It states, that such systems tend towards an equilibrium state, which is defined in the thermodynamics as the less ordered state of its constituents. In other words it says, that the entropy of such a system reaches its maximum when the system reaches a stable equilibrium state. The law can be applied for multiple-phase systems also, provided that the conditions are applicable to each constituent phase separately. One must consider, that the conditions are very strict, especially the prescription that the system be closed. We often meet such – in scientific terms not certainly strict – formulations, which say, e.g., that entropy cannot decrease. Among certain conditions it can. Those *ex catedra* formulations neglect the conditions, which limit the applicability of the statement; also that the prohibition of the entropy's decrease must be understood in the average of an investigated period of time; and that fluctuations are allowed. There are situations, when just such, maybe rare or small, fluctuations deserve the attention of the scientists, and are put in the focus of their investigations. (E.g., formation of biological molecules, and living systems are typically such.) Therefore, *entropy decrease does not mean the violation of the Second Law, rather the violation of the conditions, where it can be applied.*

Evolution of the universe is understood as a sequence of emergences, when new qualities come into being. This is a non-physical, philosophical approach to the notion of evolution. There are two types of emergencies. One, when a new thing, a new quality is *create*d intentionally by ourselves, and another, when *self-organising* processes, governed by laws of nature bring into being new things, new qualities (like higher hierarchical level physical structures, biological molecules, living matter, e.g., cells, etc.). How do self-organising processes work?

3 Emergence and self-organisation

We saw, that the evolution of physical systems, at least in a thermodynamical – and focused on formulation by entropy – treatment, did not allow the emergence of new – physical – qualities. Why? Emergence assumes, that the elements that are present in the system, compose a new material structure. Such a process may spontaneously take place in a negligible small segment of the system, first only in one copy. Being negligible small, it may not certainly change the physical properties of the larger system, within it emerged. It can be considered as a fluctuation in the steady processes of the larger system, although it forms a locally stable entity. (E.g., a few atoms form a new molecule in a gas, like ozone; or when the first RNA, the first protein, etc. molecule appeared.) This new entity, as a new material quality represents a new phase within the system, moreover, it is highly ordered in thermodynamical sense. Its emergence took place in a negligible small segment within the parent system, and this negligible small segment now represents a new subsystem, a new phase within the larger one. The formation of the new quality, i.e., its emergence, demanded energy, and the new entity took this energy from its environment. Its environment is the surrounding region of the larger system. Since the emergence assumed an energy (and admittedly other extensive, and also intensive quantity) exchange between the emerged new entity and the parent system, the new subsystem must be considered as *an open system*.

Small, open subsystems disappear in the sink of the universe. They are usually neglected for this reason. In fact, they *cannot be* neglected! There follows, that the larger parent system has now an open boarder inside (around the new subsystem). These inside boundaries are open, thus the large system can no more considered closed either. One cannot exclude the local events from the global approach. And really, the emergence in its small segment may locally have decreased entropy.

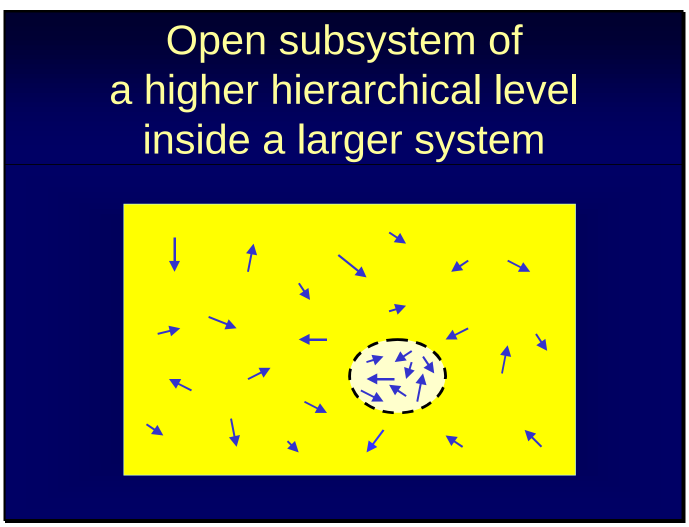

Figure 1: Parent system and its open subsystem.
(Broken line marks the open boarder between the larger and the local systems.)

Notice that wherever emergence takes place through a self-organising process, the Second Law of thermodynamics, and the related statements on entropy cannot be applied. This statement is quite different from saying that "the 2nd Law is violated", or it "is not valid". Simply, among the given conditions it cannot be applied. Emergence can take place always in physically open local systems. In philosophical terms, the evolution of the universe is a consequence of a series of emergencies taken place in negligible small segments of the universe, where the conditions to apply the Second Law are not present, and entropy may decrease. The universal evolution is determined by processes in negligible small open segments, as fluctuations of steady processes of physical systems.

4 Order and symmetry

Each system has certain symmetries. For example, a regular triangle has three symmetry axes and a 3-fold rotational symmetry.

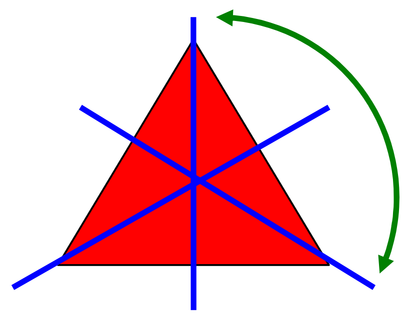

Figure 2: Symmetries of a simple system:
Regular triangle with 3 symmetry axes and 3-fold rotational symmetry.

As constituents of a compound system, the same systems may lose a few of their symmetries, which they have owned as individuals. For example, the regular triangle shown in Figure 2 may compose a system together with three further ones (cf., Figure 3), and as constituents of this compound system they preserve only one symmetry axis each.

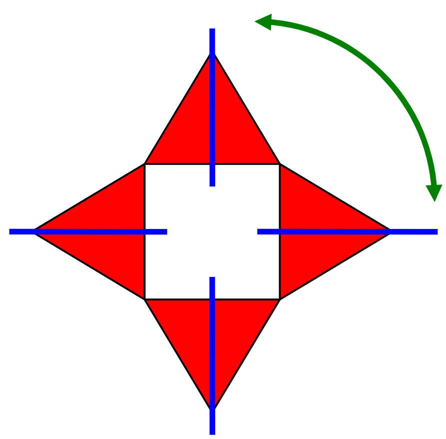

Figure 3: Symmetries of a compound system. As constituents of a compound system the regular triangles preserved only one symmetry axis each.

However, there appear new symmetries in the compound system – cf., the symmetry axes of the square formed by the four triangles, and a four-fold rotation symmetry.

This simple example is subject of a more general set of regularities, that I called the *laws of symmetry breaking*, formulated in (Darvas, 1998a, 1998b, 2004) for the role of symmetries in the evolution of matter and the emergence of new qualities, including *the law of correspondence between the ontological levels and their potential symmetry properties.* They were derived from the experience of science observed in the evolution of matter from primary forms to higher levels. (Darvas, 1987 and 1998b) discusses in details, what concepts – from among the several candidates having been introduced in the literature to fulfil this role – are most suitable for the characterisation of and distinction between levels. According to this set of laws, given symmetries tend to decrease during the evolution. The full set of the cited laws of symmetry breaking marks the arrow of self-organising processes in matter. As a convention, it is accepted as an arrow of evolution.

The arrow of evolution is meant in respect of time. Although there are other conventions, too,[1] according to the here mentioned convention, the arrow of evolution coincides with the arrow of time[2]. This is stated in agreement with the conditions of the Second Law of thermodynamics, according to which (a) in a closed system, where (b) no phase transitions take place, the physical processes evolve in one direction. (Referring to the Second Law we remember to the conditions (a) and (b), and the limits of its applicability, as discussed above.)

[1] In accordance with Boltzmann's approach, the thermodynamically defined direction of time does not depend on whether the investigated system is expanding or contracting, and whether it is subject of further physical interactions. Nevertheless, Ne'eman (2003, and already in 1969, 1970, Aharony and Ne'eman 1970a, 1970b) identified *seven time-arrows*, attributed to five different physical and two non-physical phenomena, which can define independently the flow of time. Among these seven, the *thermodynamical arrow* is only one, and there is one connected with the *evolutionary drive* (in *philosophical* sense, including everything from cosmogony to epistemology), one with the *universal expansion*, one with the *radiation and the advanced or retarded potentials*, one with the *CPT conservation* (resulting from the dependence of simultaneous *CP*- and *T-violation*s), one is the *gravitational arrow* (the action leading to the formation of black holes), and one is the cognitive inner human *sense of duration*. This paper treats the relation of the first listed two arrows of time.

[2] Arrow of time. Time is arrowed in one direction - at least in global terms. Locally one can speak about time-reversed processes. What does this mean? This means, that certain physical laws allow reversible processes. More precisely, if we can record the consecutive physical states ψ_A, ψ_B and ψ_C, at the moments t_A, t_B, and t_C, where $t_A < t_B < t_C$, then we may observe the process $\psi_C \longrightarrow \psi_B \longrightarrow \psi_A$ at the moments t'_C, t'_B, and t'_A, where $t'_C < t'_B < t'_A$. In the latter case, the clock assigned to the measuring instrument paces counterwise the clock on the wall of the lab, i.e., a larger system. That means, a 'reversed' time always postulates the existence of a 'lab' time (or 'global' time), compared to which its direction is reversed. We can choose from among the following two statements: either our process is the same in both cases and the local time (in which it took place) was reversed, or we state, that we observed two opposite processes compared to the same, global time. (Note, that in strict sense, the reversed process can never be completely the “same”, since different quantities, composing the object's state vector, behave in different ways under time-reflection, e.g., for classical mechanics there is a flip of velocity, and for quantum mechanics a complex conjugation.) Compared to the other processes observed in the same lab, it seems more correct to insist on the first statement, while in philosophical terms the latter seems more acceptable.

As the above cited laws state, a system evolves in the direction where its symmetry decreases. Constituents of a symmetric system are ordered.

The more its constituents are ordered, the more symmetric is the given system, and *vice versa* (Figure 4). When the system's symmetry decreases, there will decrease its orderedness too.

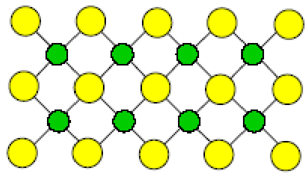

Figure 4: A crystal structure: symmetric lattice arrangement.

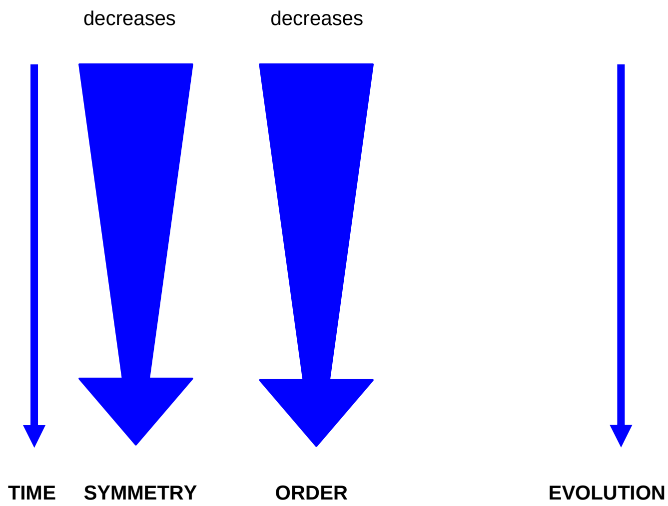

Figure 5: Symmetry and order.

5 Entropy and order

The second law of thermodynamics, as Boltzmann formulated it, says that when a system evolves in the direction of statistically lessening order of its constituents, its entropy increases. And usually systems evolve towards lessening order of their constituents.

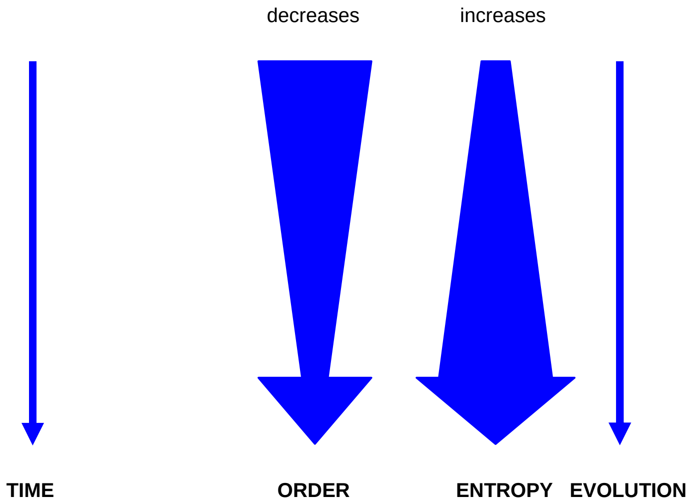

Figure 6

6 Entropy, order and symmetry

In the following we will focus on the role of order; namely compare, what we have stated on the relation of the arrows of time, evolution, *symmetry* and *orderedness*, as well as of the arrows of time, evolution, *entropy* and *orderedness*. The arrows of the five properties seemingly coincide in the two statements (cf. Figures 5 and 6 on Figure 7). This coincidence makes us happy and satisfied.

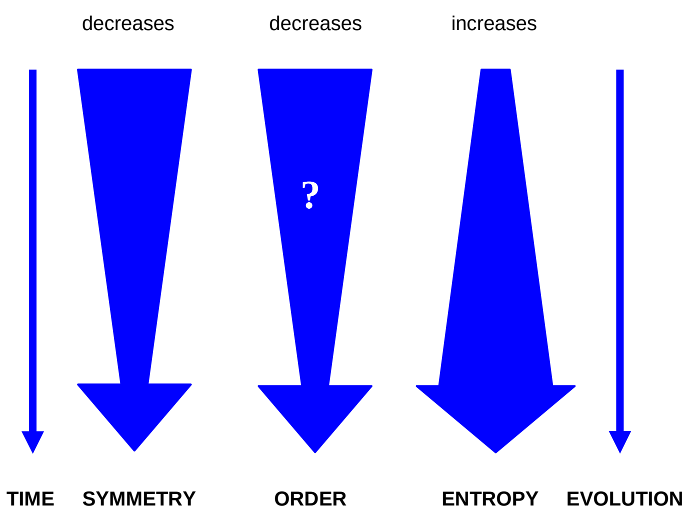

Figure 7

Nevertheless, we should question the arrow of the orderedness. Why? We show below, that there are conceptual differences between the approach of symmetrology and statistical thermodynamics to the arrow of orderedeness. There is a difference in the interpretation of the 'orderedness' in the compared two cases shown on Figure 5 and Figure 6. Let's analyse, when do we speak about a 'more ordered' and a 'less ordered' system? We will show, that we use this term in different meanings according to our symmetrological concept and in statistical thermodynamics.

Our concept on the *relation of symmetry and orderedness* has its roots in crystallography. According to this, the most ordered state of a solid is, when its all constituents are placed in equal distances in a crystal structure. A crystal represents certain symmetry. In these terms any other arrangement of the molecules, which fills the space *less equidistant*ly represents less symmetric and *less ordered* (i.e., more chaotic) systems.

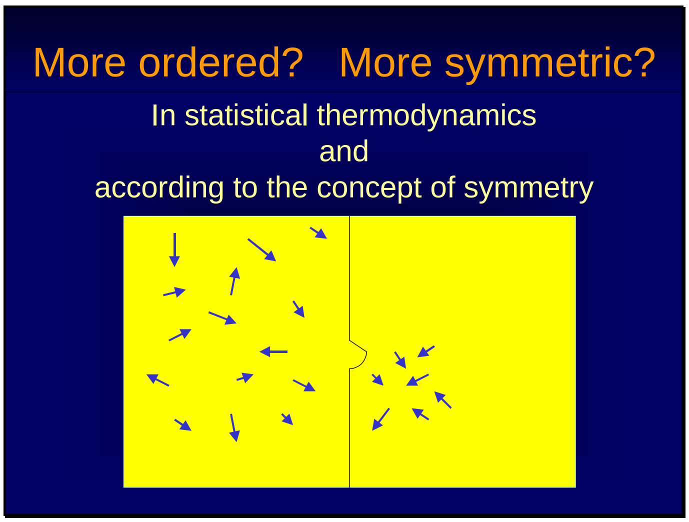

Figure 8

According to statistical thermodynamics, where the *relation of symmetry and entropy* roots, gas molecules, filled in a segment of a box (right box of Fig. 8), represent a more ordered state. When the system is left alone the molecules of the gas fill the box almost equidistantly (left box of Fig. 8). In contrast to crystallography, in statistical thermodynamics that latter *more equidistant* arrangement is interpreted as a *less ordered* state of the system.

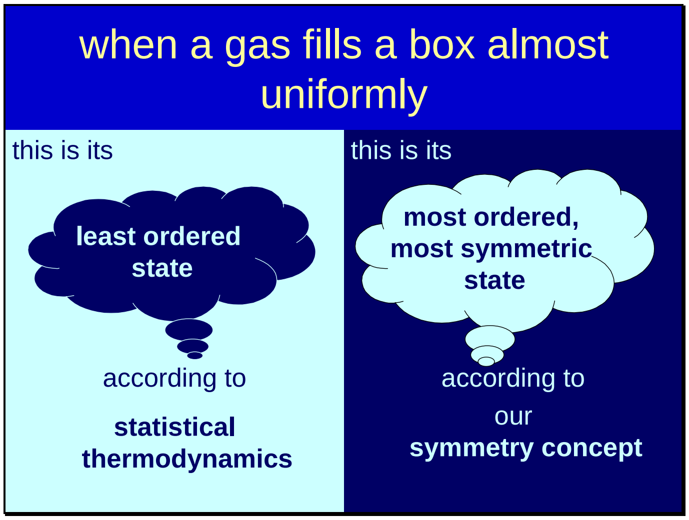

Figure 9

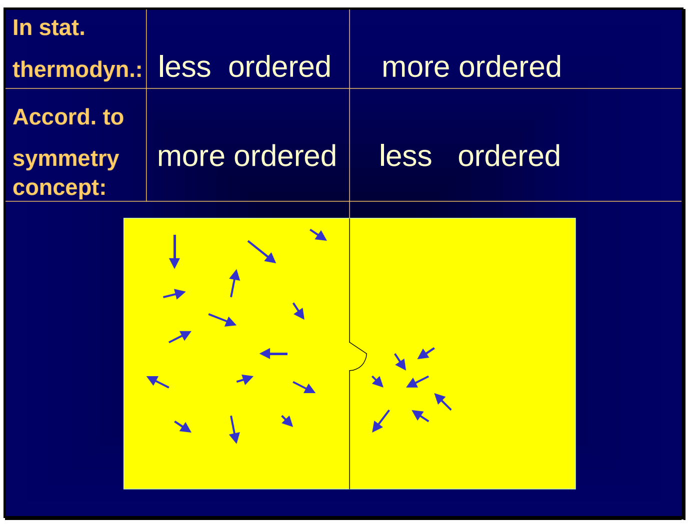

Figure 10

These contradicting statements hold because we had not used the terms in the same meaning, and yet, the table in Figure 7 showed a concordant coincidence of the arrows. How could it happen? There is something behind, what we did not take into account. This is the nature of the self-organising processes that we discussed on the relation of evolution and entropy in Chapter 2.

7 The interpretation of the arrows of symmetry and entropy - in the light of the change of order - in global and local processes

As we showed afore, when a process of phase transition, or emergence of a new material quality takes place in a small segment inside the system, that part of the system will form an open subsystem of the larger one. Both the larger system, and this small local environment of the system will no more be closed, and the whole system will no more be homogeneous (in qualitative terms). The larger system can – in principle – widened to get identified with the universe. Emergence, as we saw, takes place in such a local environment that represents a relatively negligible volume compared to the universe. During this process of self-organisation, when a higher hierarchical level is under formation locally[3], within the wider, global system, the following property-changes can be observed.

	Globally		Locally	
	In thermo-dynamic terms	In symmetric terms	In symmetric terms	In thermo-dynamic terms
symmetry	↑	↑	↓	↓
order	↓	↑	↓	↑
entropy	↑	↑	↓	↓

Table 1

(1) When we speak about the evolution of the system as a *thermodynamic* one, we consider a closed, *global* system, where we neglect any possible process in small environments, any possible emergence, and the possible appearance of any new phase. We consider only a single hierarchical level from among possible material qualities. In this global thermodynamic system entropy increases, order decreases, and symmetry increases. (Cf. column 1st.)

(2) Investigating the same *global* system now in *symmetrological* terms entropy and symmetry are found to increase again, and – as we showed above – now order will also detected to increase. (Cf. column 2nd.)

(3) Now let's investigate the local system (the higher hierarchical level and its environment), where self-organisation proceeds. In *symmetrological* terms *locally* order will decrease, and so will do symmetry. Since this is an open system in interaction and energy exchange with its surrounding environment, entropy may locally decrease. (Cf. column 3rd.)

(4) In the same *local* open system, in *thermodynamic* terms order will be considered as increasing, while symmetry will be detected to decrease again, and – on the same reasons as in symmetrological terms – entropy may also decrease. (Cf. column 4th.)

[3] Locality will be meant in this paper not as a space-coordinate dependent property, rather as one interpreted in a given segment (environment), being relatively small compared to the universe. Global properties will be interpreted in the universe, or at least in closed systems, large enough compared to the number and extent of the entities filling it.

These were four potential conceptual options (cf. Table 1). However, there are only two of them, which have reality. We generally speak about *global* processes in *statistical thermodynamic* terms, and about *local* processes in *symmetrological* terms. They were presented on the Figures 5 and 6. The former corresponds to the real thermodynamic processes (evolution of single-phase, closed physical systems), while the latter to the processes of self-organisation. When we speak about evolution, in the global case, we understand the evolution of the given physical system. In the latter (local) case we mean the evolution of the matter (in its widest sense), including the emergence of new material qualities. The two evolution concepts are not the same.

Table 1 shows that the arrows of orderedness coincide in the two realisable cases, although the conceptual references are different. The arrows marked by bold-framed boxes in Table 1 show those seen in the Figure 7. You see, the coincidence of the arrows of order is accidental in Figure 7, because it was taken from two different conceptual reference frames. In Figure 7 we merged the column 1 and the column 3 of the Table 1.

8 Transition from a system to an emergent new one

To draw some consequences, let's look back to the Figures 2 and 3, when we counted the available symmetries of the graphical triangle illustration that was held for all regular triangles, globally. When we stated the decrease of the number of symmetries in the compound, four-triangles-formed system, it was held for the locally organised system, relative to the individual triangles before the emergence of the new quality. The decrease in the symmetry characterised the process of the emergence, and not the preceding system investigated in its qualitatively intact state.

Something similar could be said about the entropies of the global and the local systems. *The arrow of the entropy characterises one of the systems, and not the transitions from one system to the other*. Since emergence takes place in an open segment of the space (in many cases in a small-number-constituent system, not suitable to apply statistical laws for it), which is in material interaction and energy exchange – and admittedly exchange of further extensive and also intensive physical quantities – with its environment (note: an open system is not only in thermal non-equilibrium with its environment), one cannot state automatically the increase of entropy.

When one speaks about thermal-death as a result of the evolution in the universe, one neglects this fact: entropy increase of the universe is stated for a physical universe, moreover restricted to those in which no emergence of new qualities takes place. True, emergence takes place in negligible small segments of the universe, and yet, all the evolution of the universe can be booked on the account of these processes.

The lack of differentiation between the different interpretations of evolution in closed physical systems on the one hand, as well as in local subsystems and in the universe on the other hand, belongs to the arguments for the meaningless of the so called thermal death.

Returning again to the interpretation of our basic notions, we saw, that in thermodynamics one speaks on the evolution of physical systems, in which no phase transitions (no emergence of new material qualities) takes place - this is one interpretation of the concept of evolution. And there is another interpretation, when we take into account emergent processes too - this is the evolution of the universe in philosophical terms, although with several consequences to the evolution (sequence of emergence) of the physical entities as well. The two evolution terms are marked with the same word, but they denote different concepts. Now we can add, that one of them denotes processes *within a single,* closed *system*, where no emergence takes place, the other denotes *transitions between two* (or more) *systems*, representing different material qualities, and belonging to different hierarchical levels.

9 Difference in the global and local properties

In short, when we compared the experienced arrows of order, symmetry and entropy on Figures 5 and 6, we operated in two different conceptual reference frames (cf. the columns 1st and 3rd in Table 1). When we merged the two experiences in Figure 7, in accordance with our above conclusions, the coincidence of the arrows of orderedness turned out to be accidental. We merged the columns 1st and 3rd of the Table 1. This was not correct. Global and local properties should be interpreted in different ways. Some coincidences in the arrows shown in Fig. 7 may occur accidentally, as wee see in the second row of Table 1, and not by causal reasons. Also, the arrows of symmetry and entropy (rows 1st and 3rd) may coincide in the different columns; however, these coinciding directions may be opposite depending whether they were meant globally or locally.

We use the conditional 'may', because in local, open-system processes we cannot make a definite statement on the arrow of entropy, at least we should allow its decreasing value as well. In self-organising processes the arrow of entropy may locally decrease. Emerging (sub)systems (and so all living systems) are such (i.e., in a non-equilibrium state, e.g., the process of protein synthesis). This fact does not contradict to the Second Law of thermodynamics, because, as we already mentioned, it holds everywhere, only the conditions do not prevail everywhere for its functioning. Since these are processes taking place in open systems, it is meaningless to apply the Second Law, which was formulated for closed systems.

Based on the different interpretations of order, and its relation to the directions in the change of symmetry and entropy in different conceptual frameworks, we can state, that the evolution of the universe depends first of all not on the majority of the phase-transition-less physical processes that happen in the universe. Emergence of a new quality once in a minor volume of the universe may play determining role. Global evolution of the universe is the consequence of local symmetry decreases, local decreases of orderedness, and possible local decreases of entropy. Thus the global evolution is determined by local events.

10 Entropy and information

When a mathematical analogy is borrowed from a different domain of phenomena, one must investigate the conditions of its applicability. There is especially important to make clear these limits in the original domain before applying the analogy in a new field. This determines also the limits of the possible conclusions derived by the help of the application of the notion of entropy in information science.

When one applies the mathematical analogy to introduce Shannon entropy for characterising information, one must determine which of the above interpretations is applicable to make further conclusions. One must put the question to her/himself, separately in each case,

- which conceptual reference frame the investigated problem is in?
- Does our information exist in a closed or an open system?
- Is the given information interpreted in a concrete system, or does it characterise a transition from one system to another?
- Do we apply information to a local or a global system?

We often refer to symmetry considerations in information theory. Now,

- is our information concept closer to its thermodynamic reference frame, or to the symmetrological one?

To apply the analogy of the entropy definition is not enough to apply also the laws of thermodynamics to information theory, without investigating the existence of the other conditions where those laws are applicable in the original theory. Any concrete conclusion applying entropy analogies can be drawn only when one answered these questions, specified to the concrete investigated system and appearance of information. This makes the palette of information more colourful, and also more differentiated.

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