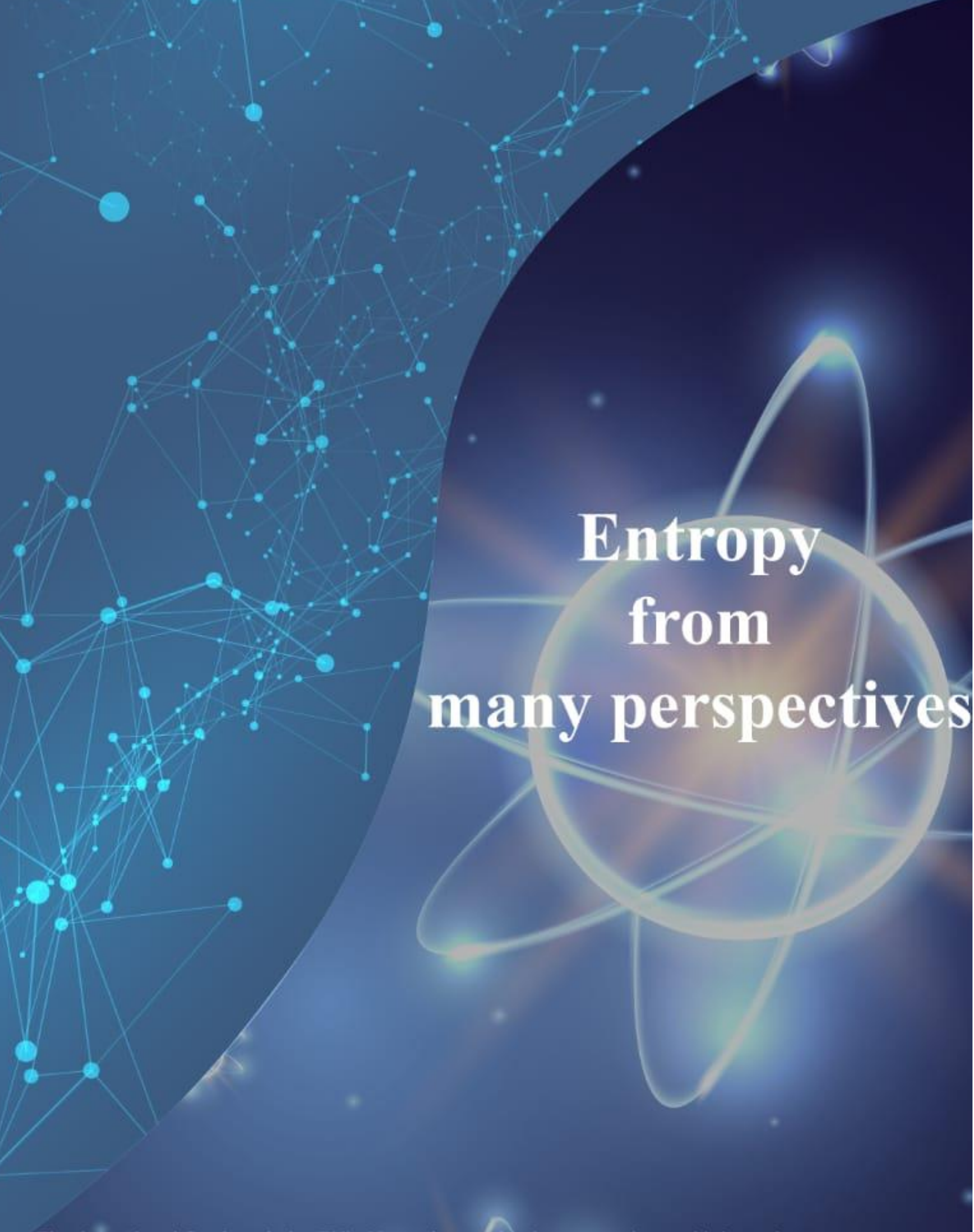

Entropy from many perspectives

Thanks to Ahmed Gouda and Alaa Eldin Manaa for any visual representation on this journal

Entropy from many perspectives

Author: Eman A. Abodaher

Abstract

Entropy is an elusive concept that has been studied widely in different domains of science. This paper aims to present the definition and evolution of the concept of entropy from engineering thermodynamics to life sciences and how it is integrated with many applications. Entropy was introduced by Rudolf Clausius in thermodynamics as a measure of heat transfer. Ludwig Boltzmann relates the microstates of a thermal system with its macrostates. The concept of entropy proved to be very powerful as many researchers extended its semantic area and the application domain. Claude E. Shannon introduced the concept of information entropy. This concept solved many engineering communications problems. Today, many researchers in economics and entrepreneurs use this concept for analyzing different phenomena such as ion collision. Well-understanding of entropy from many perspectives would cause a great difference in many science fields and actually in the applied world of them.

Keywords: Entropy, Thermodynamic Entropy, Information Entropy, Microstate, Macrostate.

I. Introduction

Why does life become complicated as time passes? There is no definite answer to this question, but it is known that “entropy” is the hidden force that complicates our life. The more disordered something is, the more entropic it is considered. In short, entropy can be defined as a measure of the disorder of the universe, on both a macro and a microscopic level. Entropy provides evidence for the existence of time. The “Arrow of Time” is a name given to the idea that time is asymmetrical and flows in only one direction. It is the non-reversible process wherein entropy increases. You can notice the effect of entropy in many situations in your daily life, for example, while drinking a cup of tea, it becomes colder as time passes. Because heat transfers from high-energy concentration to low-energy concentration.

This process happens randomly based on the probability of what is supposed to happen which is equilibrium. The industrial revolution is generated by technologies that were based on the transformation of heat to mechanical work. So, engineers made great efforts to understand the nature of heat and its transformation into mechanical work. The concept of entropy was used to formulate the second law of thermodynamics. Today, this concept is used in many research domains for evaluating the probability distributions of different variables in many complex systems that undergo change. In this paper, the concept of entropy is explained in three domains of science: engineering thermodynamics, statistical mechanics, and life sciences showing how it is worthy to be understood.

II. Entropy in engineering thermodynamics

In the 19th century, the development of heat engines requested a new theoretical foundation to help engineers designing efficient heat engines. However, heat proved to be a new phenomenon that could not be explained by using classical Newtonian physics. A new research domain called thermodynamics was developed focusing on thermal processes and the transformation of thermal energy into mechanical work. In the beginning, by using metaphorical thinking, scientists explained thermal phenomena considering the existence of a weightless and invisible fluid called caloric. Heat represents a transfer process from a body with a higher temperature level toward a body with a lower temperature level. As Atkins remarks, “In thermodynamics, heat is not an entity or even a form of energy: heat is a mode of transfer of energy” [1]. This process can be used metaphorically to understand how knowledge transfers and in particular, knowledge sharing. Knowledge can be transferred only from a person with a higher level of knowledge to a person with a lower level of knowledge. Knowledge transfer is an irreversible process, as heat transfer is. The transformation of heat into mechanical work to power engines is supported by the second law of thermodynamics. Lord Kelvin formulated this law taking into consideration the need for two heat sources to produce mechanical work: “No cyclic process is possible in which heat is taken from a hot source and converted completely into work” [1]. In other words, heat can generate mechanical work if the energy is transferred from a heat source with a high temperature to a heat sink with a lower temperature. To describe more accurately that process, Clausius introduced in 1865 the new concept of entropy.

Mathematically, the variation of entropy (dS) of a thermal system with the variation of heat (Q) at a given temperature (T):

$$\mathbf{d}\boldsymbol{S} = \frac{\mathbf{dQ}}{\mathbf{T}}$$

Here, the symbol “d” stands for a very small variation in heat and entropy, at the absolute temperature (T).

The complicated nature of entropy is due to the complicated nature of heat and related thermal motion of the material structure. The uniqueness and universality of entropy come from the fact that all processes in the universe, at all time and space scales, are due to forced displacement of mass-energy, forcing of energy transfer from higher to lower energy potential. Therefore, the spontaneous processes are due to work-potential forcing.

III. Entropy in statistical mechanics

Meanwhile, the statistical definition which was developed later focused on the thermodynamic properties which were defined in terms of the statistics of the molecular motions of a system. While Rudolf Clausius was looking at the macroscopic world, Ludwig Boltzmann was looking at the microscopic world and tried to find a link between the two worlds. He was interested in the behavior of gas molecules. He observed that each thermodynamic macrostate of a gas can be defined in terms of the probability distribution of the microstates generated by the motion of the gas molecules. Let us consider a certain volume V of Gas containing N molecules, contained in a vessel at temperature T and pressure P. Assume that W is a measure of the number of ways that the molecules of a system can be arranged to achieve the same total energy. Thus, W depends on the probability distribution of the molecules at a certain moment within the volume V. The correlation between the probability distribution of the N microstates given by W and the gas macrostate is represented by the entropy S:

$$\mathbf{S = k \log W}$$

Mathematically, it is obvious that both formulations for entropy given by Clausius and Boltzmann are equivalent. Clausius' entropy is focusing on the thermal energy transfer, while Boltzmann's entropy is focusing on the probability distribution of the microstates for a certain macrostate of a thermal system changing. In a solid body, the degree of motion of molecules is very low, which indicates a low entropy. In a fluid, the motion of molecules is much higher and thus the fluid can flow within a given geometry; its entropy is higher than that of a solid. In a gas, molecules have a very high degree of motion, leading to a high level of entropy. This situation made many scientists make connections between order and disorder through entropy. Whenever the disorder of a system is increasing resulting from a change, its entropy is increasing. [1]

IV. Entropy in life sciences

The information entropy

It is defined as the measurement of the degree of chaos, denotes the chaoticity of a system. The idea of information entropy is very general and can be applied to a great variety of problems if one finds some distributions of the system connected to quantities of interest. The theorems proved that the Shannon information entropy is equivalent to information chaoticity carried by message, which means that the larger the information entropy of a system, the larger chaoticity it contains. Shannon formula of entropy was similar to that of Boltzmann:

$$\mathbf{H = -k \Sigma\, pi \log pi}$$

Where H is the information entropy, k is a constant, and pi represents the probability of the event i to be produced. The logarithmic function is considered in base 2. Thus, when the system contains only two events, and their probability appearance is equal, then H = 1 bit (bit comes from binary digits, i.e., 0 and 1 used in the Boolean logic). [2]

After Shannon opened the era of information, information entropy has found important applications in the fields of probability theory, number theory, astrophysics, life science, and so on. The information entropy theory is applied in characterizing dynamical systems between regular, chaotic, and purely random evolution. Though the definition of Shannon information entropy shares the form of entropy defined in thermodynamics, it avoids the limitation required for a physical system by thermodynamics and measures the chaotic evolution and loss of information in the dynamical evolution of a system. This advantage makes it a good tool to study the dynamic processes of physical systems. These features of Shannon information entropy theory make it a favorite in the study of nuclear reaction, with the characteristics of the dynamical evolution of nuclear matter. In general, the processes of heavy-ion collisions are divided into three stages. (See Fig. 1)

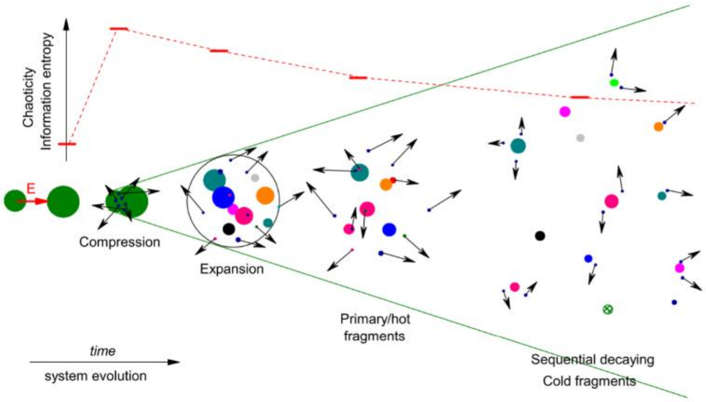

Figure 1 Schematic drawing for the time evolution of nuclear matter in a heavy-ion collision, and chaoticity change in the process (red bars connected by dashed line)

They include the collision and primary fragments formation, and the following de-excitation. Considering the projectile and target nuclei firstly in the liquid drops, the collisions result in multifragmentation, which makes the chaoticity increase.

The multiplicity information entropy was applied to study nuclear reaction, which shows that the information entropy of the system shows a trend of firstly increase and then decrease along the colliding time, where a liquid-gas phase transition occurs. As a useful tool to measure uncertainty in a random variable that qualifies the expected information contained in a message, a constructive criterion will be provided by the Shannon information entropy for setting up probability distributions based on partial knowledge. It also suggests new observations and provides new methods to study the system evolution in a heavy-ion collision by avoiding the physical limitation on the system state (whether in an equilibrium state). [3]

Management entropy

Due to the universal properties of entropy, its usage does beyond the scope of thermodynamics. The Law of Entropy states that to bring a system back to its original state, it takes more energy than what was required for a disorder to happen. To illustrate, imagine you have a jar of purple, red, and yellow marbles in your car. The marbles are perfectly organized in columns. This is possible because you've used separators to keep the marbles from mixing. One day you decide to take out the separators. Eventually, as you continue driving, the marbles in the jar will get all mixed up. It will take a lot more work to organize them again in color columns than the energy that was required to mix them up. And the bigger the jar and the more marbles, the bigger the mix-up and the more work it will take to organize them again. But, why am I writing about this? Because I think there are important lessons about leadership and change, we can derive from this natural law. According to the principle of increase of entropy and its application production, entropy can be regarded as a state function of a system.

The more entropy the system has, the more uncertainty it has.

Several factors affect the entropy of the system:

1. The number of factors that made up the system. When other things being equal, the system scale is larger, the entropy is larger.
2. Types of factors and the relation between them, the relation between the factors in the system are more complicated, the entropy is larger.
3. The number of useful information in the system. Less entropy in the system indicates that it has more useful information.
4. The speed of absorbing information from outside is relatively direct to the ability of acceptance. If the speed of development goes beyond the ability of adaptation, the entropy increases. [4]

VI. Conclusion

To sum up everything that has been stated so far, it is obvious that entropy has many perspectives in different domains of sciences and still has the same meaning. Since 1865 theory of entropy was put, and then developed by Boltzmann for statistical mechanics, entropy became a well-known concept especially after the mathematical theory of communication developed by Shannon. Thus, information entropy stimulated researchers from many fields of science. Engineers use it to reach the most efficient and powerful engines. Entrepreneurs learn a lot from looking at physics. Much like the Universe, businesses tend to chaos. If left unchecked, this can lead to an end that is more of a whimper than a bang. And finally, entropy will increase in all scenarios.

VII. References

[1] Atkins, P. (2010). The laws of thermodynamics: a very short introduction. Oxford, UK: Oxford University Press.

[2] Kostic, M. (2014). The Elusive Nature of Entropy and Its Physical Meaning. Entropy, 16(2),953–967. doi:10.3390/e16020953

[3] Ma, C.-W., & Ma, Y.-G. (2018). Shannon information entropy in heavy-ion collisions. Progress in Particle and Nuclear Physics, 99, 120–158.doi:10.1016/j.ppnp.2018.01.002

[4] Jing, D. (2012). The Study on Business Growth Process Management Entropy Model. Physics Procedia, 24, 2105–2110.doi:10.1016/j.phpro.2012.02.309