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News and Views

On the Second Law of Infodynamics from Cosmological Thermodynamics

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Abstract - This communication article was stimulated by the author's private discussions in relation to his recent publication of the second law of infodynamics. These valid observations deserved a response, which is the objective of this article. In particular, the derivation of the second law of infodynamics from cosmological thermodynamic considerations appears to have a point of weakness that requires further discussion, as detailed in this article.

Keywords - Information entropy; Second law of infodynamics; Entropy of the Universe.

1 Introduction

The second law of thermodynamics describes the evolution of entropy over time, stating that the entropy of an isolated system can only increase or remain constant. This is applicable to the evolution of the entire universe, and Clausius stated, "The entropy of the universe tends to a maximum". Within Shannon's information theory framework, while examining the time evolution of information systems such as digital data and genomic information systems, a new fundamental law of physics has been proposed and demonstrated, called the second law of information dynamics (infodynamics) [1]. The second law of infodynamics describes the time evolution of the information entropy of systems containing information states, stating that it must remain constant or decrease over time, reaching a certain minimum value at equilibrium. Mathematically, the second law of infodynamics is expressed as:

$$\frac{\partial S_{Info}}{\partial t} \leq 0 \tag{1}$$

However, uncovering this surprising new law of physics has massive implications for all branches of science and technology. Following its initial publication [1], the applicability of the second law of infodynamics has been expanded to other systems, being demonstrated not only in digital data information systems and genetic information systems, but also in atomic physics explaining the Hund's rules [2] of electronic orbital occupations, and also explaining the bizarre abundance of symmetries in the universe [3].

Most importantly is the fact that the second law of infodynamics appears to be easily derived from cosmological thermodynamics as proposed in [2,3]. Essentially the current scientific consensus is that we live in an infinite universe that is in continuous adiabatic expansion. The first law of thermodynamics states that energy can neither be created, nor destroyed, i.e. energy is conserved. Using Clausius' sign convention, the mathematical differential form of the first law of thermodynamics is:

$$dQ = dU + dW \tag{2}$$

where Q is the net heat energy supplied to the universe, W captures the work done by the universe in all possible forms, and U represents the total internal energy in the universe.

However, the universe does not exchange heat with anything, expanding adiabatically, so (1) becomes:

$$0 = dQ = dU + dW \tag{3}$$

In the original publication, the relation that links heat to entropy, , was used, where S is the total entropy of the universe and T is the temperature. Since T has a non-zero value as dictated by the third law of thermodynamics, it was concluded that dS = 0. This implies that the total entropy of the universe must be constant. This constant entropy does not violate the second law of thermodynamics, which allows the entropy to be constant over time, or to increase. However, in an expanding universe, the entropy will always increase because more possible micro-states are being created via the expansion of the space itself / universe (see Fig. 1).

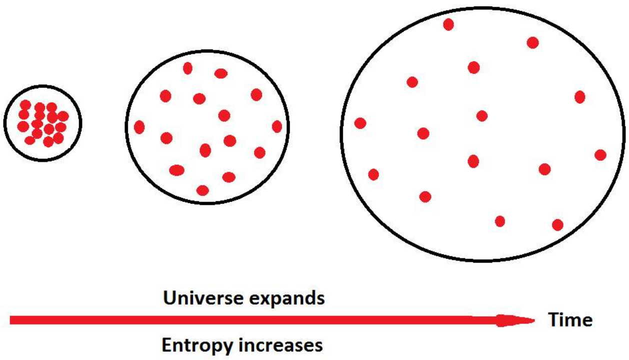

Figure 1: Schematic of a physical system expanding in time and producing ever-increasing entropy. Image reproduced with permission from IPI Publishing, Ref [3].

Considering that the entropy budget of the universe contains an unaccounted entropy term can solve this conflict between the requirement for the entropy to remain constant and the ever-increasing entropy due to the expansion of the universe. This entropy term must balance the total entropy budget of the universe in order to ensure that the overall entropy remains constant over time. It was proposed that the missing entropy term is the entropy associated with the information content of the universe, or the entropy of the information states within the universe. Writing the total entropy of the universe, S as the sum of the physical entropy and the information entropy, $S = S_{Info} + S_{Phys}$, taking a time derivative, and imposing the condition dS = 0, we obtain:

$$\frac{\partial S_{Info}}{\partial t} + \frac{\partial S_{Phys}}{\partial t} = 0 \tag{4}$$

Since $\frac{\partial S_{Phys}}{\partial t} \geq 0$, i.e. physical entropy always increases over time according to the second law of thermodynamics, then the increase in the physical entropy must be balanced by the decrease in the information entropy over the same time interval, recovering the second law of infodynamics, $\frac{\partial S_{Info}}{\partial t} \leq 0$.

2 Main issue

The main criticism of this approach was the fact that we used the relation $dQ = TdS = 0$, which in reality is only valid for reversible processes. Applying this to an adiabatically expanding universe is a commonly used approximation, but a more rigorous approach would have to use the relation for irreversible processes, i.e. $dQ \leq TdS$. The condition dQ = 0 still applies, but we can no longer infer that dS = 0, which would nullify the requirement for the introduction of the information entropy. Here we offer a solution to this conundrum that allows maintaining the validity of the second law of infodynamics.

3 Solution

We start by separating the energy of matter and the energy associated with the information in the universe, while imposing dQ = 0, so:

$$dQ_{Phys} + dQ_{Info} = 0 \tag{5}$$

Hence:

$$-dQ_{Phys} = dQ_{Info} \tag{6}$$

The second law of thermodynamics requires that the physical entropy increases (irreversible) or remains constant (reversible):

$$dQ_{Phys} \leq TdS_{Phys} \tag{7}$$

According to (7), we could re-write the inequality into an equality equation as:

$$dQ_{Phys} = TdS_{Phys} - dU^{Loss}_{Phys} \tag{8}$$

where dU^{Loss}_{Phys} is the energy loss in the irreversible process. If the process would have been reversible, then $dU^{Loss}_{Phys} = 0$ and $dQ_{Phys} = TdS_{Phys}$. We now assume a similar relation for the information process, so:

$$dQ_{Info} = TdS_{Info} - dU^{Loss}_{Info} \tag{9}$$

Combining (6), (8) and (9) we get:

$$TdS_{Phys} - dU^{Loss}_{Phys} = -(TdS_{Info} - dU^{Loss}_{Info}) \tag{10}$$

Dividing by T on both sides and rearranging, we get:

$$dS_{Info} = -dS_{Phys} + \frac{dU^{Loss}}{T} \tag{11}$$

where $dU^{Loss} = dU^{Loss}_{Phys} + dU^{Loss}_{Info}$. We recall that the second law of thermodynamics requires that $dS_{Phys} \geq 0$. Differentiating (11) in respect with time we get:

$$\frac{dS_{Info}}{dt} = -\frac{dS_{Phys}}{dt} + \frac{d}{dt}\left(\frac{dU^{Loss}}{T}\right) \tag{12}$$

Case 1: Reversible process and adiabatic
$dU^{Loss} = 0$, so from (12) we obtain by time differentiation the second law of infodynamics, $\frac{\partial S_{Info}}{\partial t} \leq 0$.

Case 2: Irreversible process and adiabatic
$dU^{Loss} \neq 0$. Assuming both terms dU^{Loss} and T are time dependent, then (12) becomes:

$$\frac{dS_{Info}}{dt} = -\frac{dS_{Phys}}{dt} + \frac{1}{T}\frac{dU^{Loss}}{dt} - \frac{dU^{Loss}}{T^2}\frac{dT}{dt} \tag{13}$$

Because $\frac{dS_{Phys}}{dt} \geq 0$, the first term on the right-hand side of (13) is always negative or zero, so because of the "–" sign. The second term is always negative or zero, because the loss decreases over time, $\frac{dU^{Loss}}{dt} \leq 0$ and $T > 0$ all the time. Please note that dU^{Loss} is a positive quantity, but its rate of change is decreasing. The third term is negative or zero all the time, because T must decrease over time, so this becomes positive or zero all the time because of the "– " sign in front of it. However, the positive contribution of the third term can not offset the negative contribution of the first two terms, because it scales as $1/T^2$, and the rate of T change is also negligible or very small. Hence, according to the analysis of (13), $\frac{\partial S_{Info}}{\partial t} \leq 0$ is always valid. Moreover, if we impose T = constant, which is a reasonable approximation even over large periods of cosmic time, then its time derivative becomes zero and the third term (the positive contribution) vanishes, guaranteeing the second law of infodynamics condition, $\frac{\partial S_{Info}}{\partial t} \leq 0$.

4 Conclusion

This work was stimulated by private discussions related to a few previously published materials on this topic. The main concern raised was the fact that the derivation of the second law of infodynamics from cosmological thermodynamics assumed a reversible process. While this is a valid approximation, the queries received were related to the validity of the approach when considering irreversible processes. Here we managed to demonstrate that the second law of infodynamics is derived identically regardless whether a reversible or irreversible process is considered.

References

[1] Melvin M. Vopson, S. Lepadatu; Second law of information dynamics. AIP Advances 1 July 2022; 12 (7): 075310. https://doi.org/10.1063/5.0100358

[2] M. Vopson, The second law of infodynamics and its implications for the simulated universe hypothesis, AIP Advances Vol. 13, issue 10, 105308 (2023). https://doi.org/10.1063/5.0173278

[3] M. Vopson, Reality Reloaded: The Scientific Case for a Simulated Universe, IPI Publishing, ISBN 978-1-80517-057-0, (2023). https://doi.org/10.59973/rrtscfasu