# Heat transfer, entropy and time perception: Toward finding a possible relation between subjective and objective time

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ABSTRACT

The interaction between subjective and objective time is an ambiguous issue in physics and psychology. Here, I try to describe these two timing systems within a common framework. To this aim, I will use thermodynamic entropy, which is a parameter that can create the arrow of time in physical systems (i.e. universe and brain). In the universe, which can be thought of as a closed system, heat transfer (dQ) is always positive and it leads to an increase in entropy (dS > 0). The positive dS leads to the generation of the irreversible arrow of time. Given that dS is constant, the time units have a similar direction and magnitude. In contrast to the universe, the brain is an open thermodynamic system which transfers heat to its surroundings. In this system, dQ and dS can become negative. This causes a reversible timing system and time units can be laid along different arrows and have different magnitudes. Theoretically, this mismatch can cause different timing in the brain and universe.

## Background

As I was sitting by the Marmara seaside in Istanbul and watching the glittering reflection of the moonlight on the sea, with time seeming to stand still, I asked myself if time can be defined as internal or external? Time, however, appeared to me to be comprised of, or divided into, two types or systems. The first could be the external timing system that, in my example, appeared via the moonlight motion on the sea as a continuous change in the external world. This version of time, as a physical parameter, can be scaled by the transition frequency of a cesium atom in an atomic clock – this was created in modern physics according to a four-dimensional space-time continuum [27]. In the physical world, the variation of this parameter is directly related to speed [27] and entropy [9].

The second timing system would be the internal subjective time that is generated by brain activity. The generation of an internal sense of timing is a vital subjective ability involved in the production and integration of the other senses (e.g., vision and audition) and movement. Despite the possibility of the existence of objective external time, there is no exact measurable scale for internal timing and estimation of time in the brain. This is because these measurements are polluted by cognitive and psychological attributes such as emotion, personality, cognitive load, mood, etc. [16]. These two time systems are frequently compared by the brain at any given moment, during which the brain adjusts our sense of time (for example when we look at an external clock and compare its reading with internal sense of time).

In physics [18,28,19,26] and psychology [1,12,16,21,20], a vast literature has been devoted to describing these two timing systems. However, just a few studies have addressed the relationship between subjective and physical time [3,2,12]. The most important model in psychophysics is the Scalar Expectancy Theory (SET), which suggests a linear relation between psychological magnitude of perceived time and physical time [14]. Although SET has been conserved for a wide-range of durations (from multi hundreds milliseconds to multi thousands), several violations from SET have been reported in different studies and different durations [15,22]. Other models [8,17,16] have been proposed in terms of the relation between subjectively perceived time and objective time. At this time, there is no clear answer to the question of whether two systems, instead of one global timing system, are responsible for constructing time? If two systems are indeed responsible for this feat, how are they mapped onto each other and which relationships exist between them? For the purposes of these considerations, let us continue with the idea that there are indeed two separate timing systems that make the internal and external times, as suggested separately in physics and psychology. My aim for the exploration of this idea is to ultimately find a common concept that can change both timing systems.

## Scalar or vector timing

The vector property of time was first suggested by Einstein in 1905 [27]. We start with the first postulate of Einstein as stated in his theory of special relativity, which asserts that physical rules should be conserved in all physical systems [27]. Here, we deal with two physical

systems: the world outside the brain and the brain. Previous studies in physics have shown that physical time (objective time) is a vector parameter with direction and magnitude [17,27]. However, a considerable number of studies in psychology predicted a modulated biological clock in the brain (modulated models) that can create time with a cumulative property as a scalar [20,1,16]. According to these descriptions, internal and external time systems have completely different natures which raises the concern of finding a logical relationship between subjective and objective time. But, according to the postulate of Einstein, time should be the same in all physical systems: either an "external" world or the brain as part of the physical world.

Recently, we proposed a model for time perception that shows that internal time can be constructed as a vector [12]. Time as a vector has a magnitude that can be created in a specific module, as predicted by modulated models, and also has an arrow. We predicted that the arrow of subjective time can be formed by topological properties of functional brain networks [12,13,11]. This is in agreement with the network state depended timing model proposed by Karmarkar and Buonomano [17]. The model shows that nonlinear properties of internal timing cannot be totally described by scalar and modulated models, but that also higher order states of cortico-cortical networks can be involved in the perception of time [17].

### Entropy in the universe and the time arrow

The concept of time direction, which can be thought of as a pro-verbial arrow, was developed by Sir Arthur Eddington in 1928. Eddington asserted that universal time has an arrow and that this arrow is defined in terms of entropy [18]. In extending further these assertions about time in the universe, others have suggested that time will travel in a certain direction when the entropy is increased [19,26,28]. Specifically, this idea demonstrates that time has a forward direction while entropy is increasing. Based on the definitions and laws from classical physics about entropy (and the second law of thermodynamics), the differential form of entropy is directly related to heat transfer:

$$dS = \frac{dQ}{T} \tag{1}$$

where $dQ$ is the heat transfer and $T$ is the temperature. This equation indicates that an isothermal energy exchange in a closed system (a system without energy or matter exchange with its surroundings) leads to an increase in entropy. As a result, if we consider the universe as an isolated, closed system, the entropy of the universe should be said to be increasing while the universe reaches a global thermal equilibrium (a situation with $dQ = 0$ and a maximum of $S$).

However, modern cosmology proposes that the initial state of universe was a hot, homogenous gas with thermal and chemical equilibria (maximum thermal and chemical entropy). This field suggests that the main reason for increasing entropy has to do with gravity. In particular, hot, homogeneous gases are thought to have a very small gravitational entropy and gravity is thought to have led to the construction of stars, galaxies, as well as black holes [9]. In modern cosmology, the universe is passing in a period between start forming and stop forming of the blackholes and expands by decreasing the energy and increasing the entropy. In this framework, the maximum entropy of the universe (the entropy of a black hole) is directly related to time and by estimation maximum entropy of blackhole is associated with [9]:

$$\max S_{BH} \approx k \left( \frac{t}{10^{-43}\text{s}} \right)^2 \tag{2}$$

where $k$ is the Boltzmann constant, $t$ is time passed from the initial state of the universe and $10^{-4}$ s is the time when the universe contained the energy of one Planck mass unit (the minimum possible energy of the universe at its initial state). According to this estimation, there is a direct, positive relationship between time and entropy of universe. Inversely, the maximum entropy is said to rapidly reduce when the

system goes backward in time (as a possible state for reducing of entropy) [9].

As described above, both classical physics (i.e., the second law of thermodynamic and Eddington's description of the time arrow) and modern cosmology (i.e., blackhole formation and Planck particles) frameworks predicts the increase of entropy while time passes in a feedforward manner in the universe (in our description: external world). (In contrast to the idea of a forward-directed time arrow, the backward time arrow has also been predicted by both frameworks; it will occur when there is a decrease in entropy. However, it is impossible in the present state of the universe [9].

### Brain entropy and perceptual time

The brain can be defined as an open thermodynamical system [5]. An open system exchanges volume (*V*), the number of particles or units (*N*), pressure *(P)* and temperature (*T*) with the surroundings. In the thermodynamic view of the brain, we can assume that *V, N* and *P* remain constant at least for adults and across short periods of life (e.g., one year). However, animal studies have indicated that cortex temperature can change through local stimulation on the order of 0.5 °C (which has also been estimated for human cortex) [29]. On the other hand, cerebrospinal fluid (*CSF*) and blood play the role of cooling system in the brain, as the brain continuously exchanges heat with its surroundings. Also, heat can be transferred via brain tissue, the skull and through the scalp. In this case, the differential equation of energy in terms of entropy and temperature is:

$$T = \frac{dU}{dS} \bigg|_{V,N,P}$$

where *V, N* and *P* are constant.

The above equation predicts that entropy of an open system (e.g., the brain) can be decreased. If we consider internal time as a psychological issue that can be generated by neural activity (as described in Section "Background"), this time system is related to brain entropy (because the brain is a physical system that follows the general thermodynamic rules). The decrease or increase entropy in different moments (time steps of external world) can produce a mismatch between brain entropy and entropy in the universe (entropy of brain can either increase or decrease, whereas entropy of the universe always increases). The mismatch of entropy between these two thermodynamic systems subsequently leads to mismatch in the two timing systems. In terms of the components of the brain and these assertions, brain activity generates heat and increases entropy that induces forward directed time (in the same direction as time in the universe). On the other hand, the heat exchange between central nervous system and the surroundings via CSF can produce backward directed time.

By considering the vector conceptualization of time, each moment is presented by a vector (with magnitude and direction). Since the variation of universe entropy is constant for short time scales [9] (i. e., $10^6$ years, which is approximately the amount of time that mammals have existed), the time period of human life is passed with the unified vectors (Fig. 1) in the external world. However, the time vectors generated within the brain can get the different directions against the universe time vectors. Each short backward movement in time may be related the generation of working memory that is actually a short passage to the past of universe time [3].

### Psychophysiological proof

Previous psychological studies have indicated that significant subjective time distortions are closely related with changes in brain metabolism [7]. As a result, it seems that overestimation of short intervals may be associated with higher global activity in the brain and vice versa. An example of this was given by the finding that time is
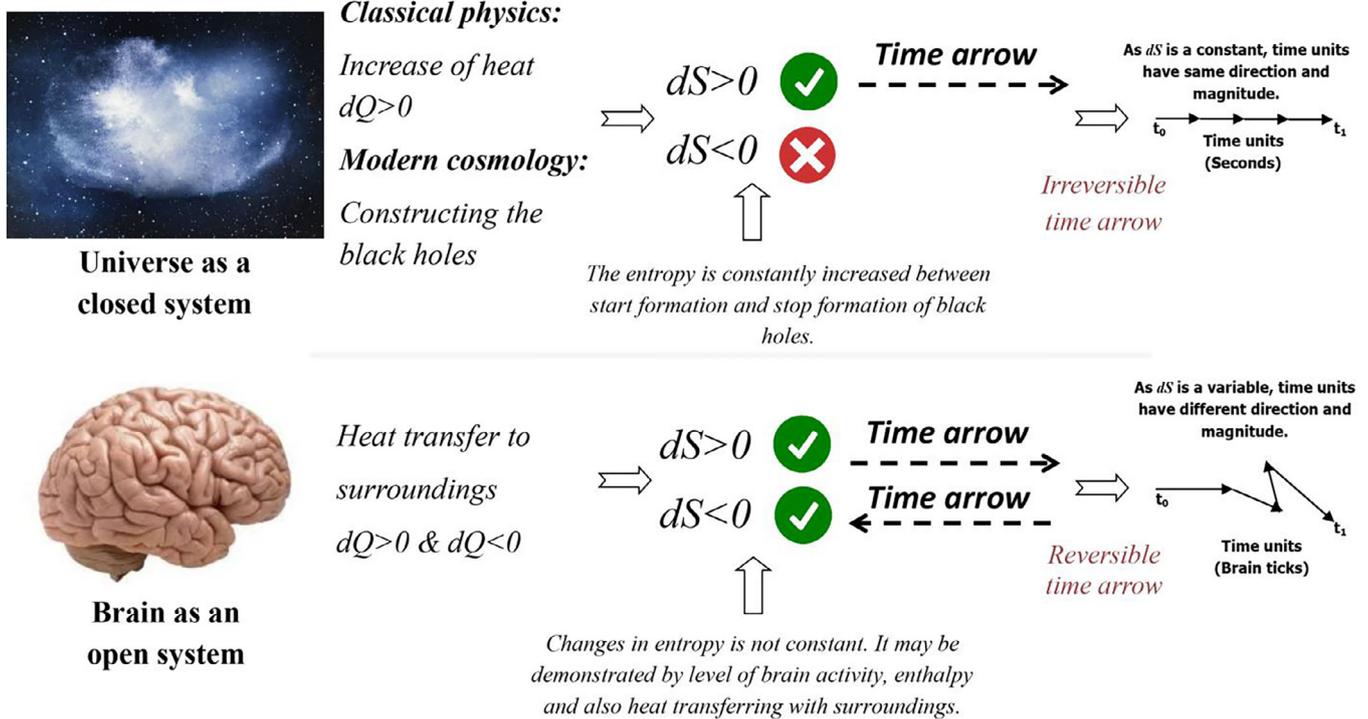
**Fig. 1.** Two timing systems: universe vs. brain. In the universe, as a closed system, $dQ$ is always positive and then $dS > 0$ (classical view). The modern cosmology also asserts that universe entropy is increased between start and stop formation of black holes. The positive $dS$ causes to generate the irreversible arrow of time. As the $dS$ is constant, the time units have similar direction and magnitude. In the brain, heat transfer with surroundings occurs. Then, $dQ$ and $dS$ can become negative. This causes a reversible timing system and time units can be laid in different arrows and magnitudes.

compressed during and just after the saccade [23,24]. Neuroimaging studies have been shown that the blood oxygen level-dependent (BOLD) signal in specific brain regions is decreased during saccade production [4]. The similar situation for perceived time and BOLD signal is also observed when a stimulus has been presented repeatedly [25]. The inverse relationship between perceived time (for brief intervals, e.g. 100 ms) and the BOLD signal is also conserved for bigger stimuli in comparison of smaller ones and also for brighter in comparison to darker (for more detailed review see [8]). Since the BOLD signal predicts the temperature of brain tissue [29], one can infer that a change in blood signals may be associated with the variation of brain enthalpy (the oxygen-glucose reaction in the brain at regular temperature of brain (i.e., 37 °C) releases 470 kJ of enthalpy per mole of $O_2$) [29]. Enthalpy ($H$) is linearly related to entropy through the consideration of Gibbs free energy ($G$):

$$\Delta G = \Delta H - T\Delta S \tag{4}$$

The brain uses Gibbs (metabolic) free energy to form order from chaos when constructing perceptual neural networks [6]. In this discipline, the free energy principle has been suggested by Friston [10] who explains that the brain tends to minimize its free energy to survive [10]. If we take this into account, during each perceptual interval (a brief interval on the order of hundreds of milliseconds), the final value of free energy ($G_2$) should be lower than the initial value ($G_1$). This principle leads to $\Delta G = G_2 - G_1 < 0$. So, Eq. (4) is satisfied if:

$$\Delta H < T\Delta S \tag{5}$$

This means that an increase in enthalpy may lead to an increase in entropy. Since enthalpy is directly related to the amplitude of the BOLD signal [29] and higher amplitude of BOLD is related to the over-estimation of time, it can be deduced that there is a direct relationship between the overestimation of time and an increase in entropy. This is consistent with the physical relationship that suggests the existence of a direct relationship between the passing of time and increased entropy (Eqs. (1) and (2)).

## Conclusion

Through the consideration of the above statements, the concepts of objective time (that is generated and passed in external world) and subjective time (that is produced and perceived as an internal sense) are reconciled through the description of a similar framework using entropy. In this view, the variable $dS$ in the brain can lead to subjective time distortions in contrast to time distortions brought upon by the universe. How the brain results in the production of such distortions can be directly investigated through empirical investigations by measuring perceived time and heat transfer in the brain, simultaneously.

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## Conflict of interest

There is no any conflict of interest in authorship of this article.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.mehy.2018.11.018.

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