Is Information Physical?

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1 Introduction

In 1961 Rolf Landauer proposed a solution to an old thought-experiment, the Maxwell's demon, by declaring that information is physical and that to delete one bit of information some physical work is needed [3]. His main argument was that information is inevitably inscribed in a physical medium, e.g. the charge of an electron, the position of a particle, its mass, etc. Information was not an abstract entity but exists only through a physical representation. This idea has become very popular in physics, and recently in popular science communication.

However, the thought is quite different from what the public normally think of as information: words in a book, an address or even something as abstract as the mood of a person in a given day. It is not quite clear what is meant by the physical nature of information, nor its significance as a useful concept to think about the world. However the idea also has critics, arguing that it does not bring anything new to the table, and that in the end all we have is energy and matter, what we choose to call it does not matter. In this essay I will cover these points in detail and discuss its relation to two theories of truth in epistemology; correspondence and coherence theories.

2 Historical background

2.1 Canonical definition

The primary definition of information in the Merriam Webster dictionary is

> *"The communication or reception of knowledge or intelligence",*

while in the Oxford English Dictionary we find

> *"Facts provided or learned about something or someone."*

Facts, knowledge and intelligence are also words that can be found in the dictionary, so it seems these abstract definitions does not help us much in understanding the meaning of the word information. The abstract nature of these definitions are reinforced up by the origin of the English word. It comes from the Latin word *informare*, which means to give form, or to form an idea of. Latin also has a related word, the word *informatio*, meaning concept or idea. In fear of falling into the black hole of etymology we stop here, and conclude that the word information is indeed abstract. However, one thing the definitions have in common is that they relate an exchange of some intangible measure (knowledge, intelligence, facts), either between individuals or between the world and the individual.

2.2 Maxwell's demon

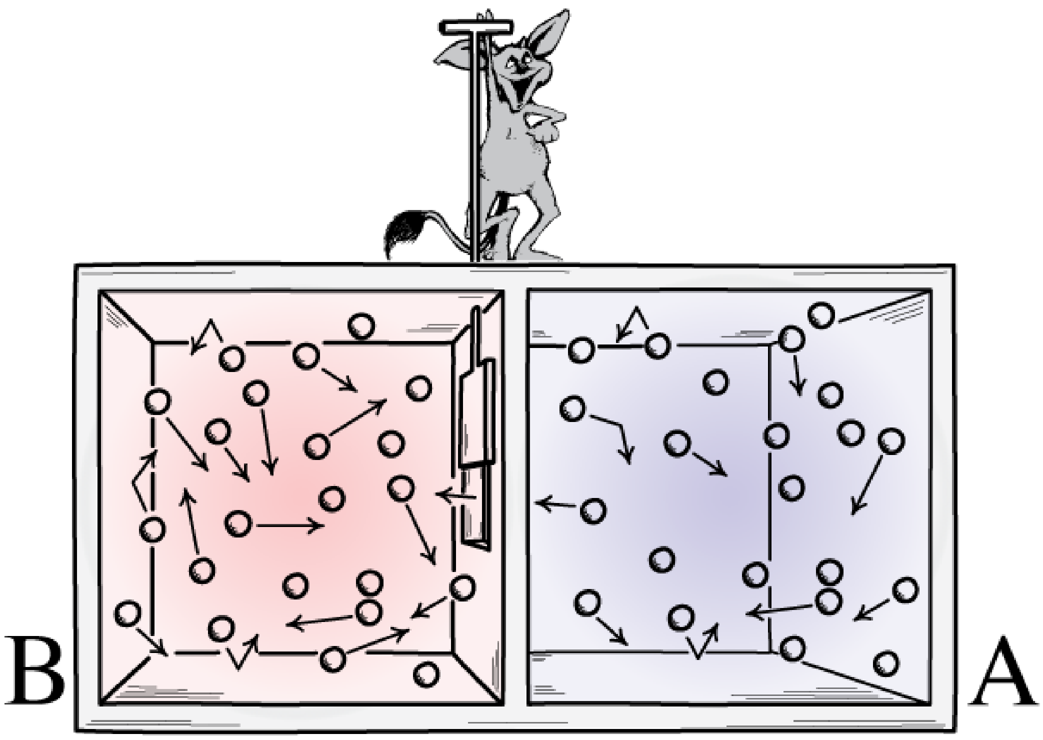

Figure 1: An illustration showing Maxwell's demon as he controls the particle exchange between A and B. Illustration adapted from [4]

The origin of a new definition of information is found in a letter from the Scottish physicist James C. Maxwell to the equally Scottish Peter Guthrie

Tait in 1867. What he described in the letter was the following thought-experiment:

Imagine a box with two compartments, A and B, and a hatch between them as shown in Figure 1. The box contains an ideal gas at equilibrium temperature, and the temperature is the same in either compartment $T_A = T_B$. The velocities of the particles in a gas at equilibrium are not all the same, but rather follows a distribution that Maxwell knew very well, since his name is in it; the Maxwell-Boltzmann velocity distribution. Some particles move faster than others, and therefore have higher kinetic energy. For an ideal gas temperature is just a thermodynamic average of the kinetic energy of all the particles. The task of the demon is to open the hatch and let "fast" particles (higher than the current average speed in the compartment) pass from compartment A to compartment B, while closing it to block the "slow" particles. Similarly it opens and closes the hatch for slow and fast particles, respectively, moving from B to A. As the demon dutifully perform his task, over time the fast particles will gather in compartment B and the slow ones in compartment A. Since temperature is as previously mentioned related to the kinetic energy of the particles, what we (the demon to be precise) have achieved is to create a temperature difference between the compartments, where $T_B > T_A$. Assuming that the hatch is well oiled, so that the demon can move it without expending any energy, we have just violated the second law of thermodynamics. One of its ten thousand formulations is that heat can never flow from regions of low to high temperature without expending energy, which is the exactly what the demon have just accomplished. If we now remove the hatch and put in a small turbine, high energy particles moving back from B to A would rotate the turbine and generate energy. After reaching equilibrium, where $T_A = T_B$, the state of the two compartment have returned to the initial state. The cycle is therefore a reversible process; a process that transform a state back to itself without expending any energy. The demon can now go back to work and by continuously repeating the whole procedure we create infinite energy from nothing; a most severe violation of energy-conservation.

It appeared to the physicists at the time that the violation arises because one does not account for the energy required by the demon to perform a measurement. In 1961 Rolf Landauer argued that a measurement can in principle be preformed without expending any energy [3]. Landauer further argued that the reason the demon violates the second law of thermodynamics was because the information obtained by the demon was not accounted for by Maxwell. For the Maxwell's demon to be considered truly reversible the state of the *entire* universe after the full cycle has to be identical to the initial state. When the demon measures the velocity of a particle to decide whether or not to let it pass through the opening, that information needs to be stored in a memory somewhere. The demon gains one bit of information per measurement, since it answers a binary question: the particle is either "fast" or "slow". Now in order for the cycle to truly reversible, this memory also has to be deleted since the initial state of the universe had no stored memory. Landauer showed that the deletion of one bit of information requires a minimum energy of $k_B T \log 2$, where T is the temperature and k_B is Boltzmann's constant, which now known as Landauers principle. This is exactly the amount of energy that can be extracted from Maxwell's demon per particle.

From 1991 to 1999 Landauer expanded on this idea in several papers (cites), and his view can be summarized by his following quote:

> *"Information is not an abstract entity but exists only through a physical representation, thus tying it to all the restrictions and possibilities of our real physical universe. Information is inevitably inscribed in a physical medium".*

In stark contrast to the abstract dictionary definition, Landauer argues that information can not exist without a concrete physical representation.

3 Implications for natural science

The ideas of Landauer generated much debate in the scientific community, at there is still controversy about the role of information in physical science. Modern technology have allowed us to create expermiments that have verified the validity of Landauers principle, and the debate of its relevance has obtained renewed attention [1]. How far can we push the idea that information is physical?

If information is physical, the laws of nature can be considered information processing. Lets say we want to find the force acting between two electrons. To do this we need to identify their mass, electric charge, and relative position; all of which can be recast into answers to binary questions. We put this information into the apparatus (laws of nature) and get some information back (their interaction force). The great success of computational science is exactly due to our ability to transform the laws of nature into information processing machines.

Also, consider the fact that what we call "the laws of nature", should rather be referred to as "the laws of nature as we known them today". Our understanding is of nature is limited to the sum of all the information we have obtained up until now. In the future it is possible that we discover that electric charge is not a fundamental quantity, but rather the result of some more complex underlying process which we do not yet have the technological ability to explore. If we consider electric charge as some amount of information, our interpretation of the laws of nature is not changed if we discover its underlying mechanism in the future; we have just updated our ability to store and access information. This leads us to perhaps the most fundamental question in the philosophy of science. What are we striving towards in science; to obtain the biblical God's ultimate conceptual understanding of the universe, or limit ourselves to best explain observed natural phenomena, using whatever conceptual framework we want, like Adam and Eve. I would argue that if we follow the latter philosophy, it is more honest to consider the electric charge as a unit of information. Trying to give more interpretation to it than that, seems meaningless before we have obtained the godlike understanding of the universe.

The interpretation of the wavefunction in quantum mechanics is a good example that may hinder our approach to godlike understanding. The mathematical framework of quantum mechanics is undoubtedly correct, giving excellent correspondence with experiments. But nobody really knows what the wavefunction *is*. Can we ever get a good *conceptual* understanding of something that appears to be probabilistic in nature?

4 Correspondence versus coherence theories of truth

There are many theories of truth in epistemology, but here we are limiting ourselves to the two that can be considered most relevant for our discussion of physical information. In correspondence theory of truth, truth is a correspondence with a fact, or more broadly speaking, a relation to reality [2]. This is the theory of truth that is most commonly applied in natural science. A statement, hypothesis or theory is considered true if it is in correspondence with our empirical observations. Using the theory in science can be considered idealistic, and can be associated with metaphysical realism. The truth of the statement *"The electron has an electric charge of* $1.603 \cdot 10^{-19}$ C *"* is empirically verifiable, and nobody would argue against its truth. However, when we make statements about the truth of scientific theories problems can arise.

In contrast, a coherence theory of truth states that truth of a proposition depends on its coherence with some other set of propositions[5]. Coherence theory is the theory of truth that is employed in mathematics, where truths and proofs are found in the internal consistency of propositions. The previous statement about the charge of the electron can be considered true in both coherence and correspondence theory, since the empirical verification is in coherence with the proposition. However, the main difference between these theories is that coherence theory never makes any reference to an objective reality. The statement *"The electronic charge is a real property of the universe"*, can be considered true in the correspondence theory of truth, while in the coherence theory of truth the question is ill defined as it references a reality that we can only observe indirectly. To measure the degree of coherence between a theory and the reality of the universe, we first need a way to directly access reality. However, if we could do that we would not need a theory in the first place.

There is also a time-dependence in the correspondence theory of truth in science. If, in the year 1900, we made the statement *"Atoms are elementary particles"*, scientists following the correspondence theory of truth (as most of them did at that time) would claim the statement to be true. Thereby they state in the physical reality of the universe the atoms are its smallest building blocks. However, if the same question was asked today the answer would be false. We now know that atoms are built up by quarks (which we now think of as elementary particles). A coherence theory of truth would not have this problem, since the question is ill-defined.

If we now go back to consider the matter at hand, the question of whether information is physical, we can put it in the light of theories of truth. Do we want to consider the laws of nature as some real access to the inner workings of the universe, or as some information processing machinery that can access, store and manipulate the information we can currently access with today's technology? I maintain that a proponent of the coherence theory of truth would prefer to think about the laws of nature as an information processing apparatus. This is because propositions in the informational view of the universe is always internally consistent, and their view on the ill-defined nature of propositions about reality is similar to one of the proponents of the informational physics camp.

Finishing thoughts

If information is physical, does that imply that information that is *not* physical cannot exist? Can information exist without matter, and can matter exist without information? In natural science this is still an open question. There is, as always, a middle ground. This essay about information has been in the context of natural science. In other sciences it is difficult to argue that abstract concepts like social order, equality and morality, is composed of physical information- instead of abstract information. Just because information is physical, it does not imply that the physical is information, nor that there does not exist an objective reality. Interpretation of the physical reality is just what the informational physics proponents want to avoid.

References

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