Aspects of Information in Physics

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Dedicated to Marie-Louise Nykamp

Abstract

Two somewhat overlooked aspects of information, namely, *total involvement* and *simultaneous presence*, are presented, aspects that may be useful in theories of Physics.

1. Information and Physics

Concepts such as mass, motion and velocity have from times immemorial been in a form or other in human awareness, and thus one may say, also in Physics, whatever stage in the empirical or theoretical development of the latter one may refer to. Contrary to that, however, the concepts of acceleration, energy, entropy, and even more so information, are quite recent. In this regard, it is amusing to recall, for instance, that Aristotle believed velocity to be proportional to the force exerted upon an object. And it took until Newton's Second Law to realize that, in fact, it is acceleration, that is, the velocity of velocity, which has that proportionality property.
As for energy conservation, nearly another two centuries passed after Newton until it was introduced in Physics, not long before the concept of entropy.

Information, and the principle of information conservation, [23], came to Physics around the middle of the 20-th century. No wonder, therefore, that - contrary to what many may believe - information is still a less than sufficiently clarified subject, and consequently, the relationship between information and physical phenomena and processes may benefit from further clarifications.

In this regard, it may be useful to keep in mind the following, formulated so clearly in [2], namely :

"The main problem with thermodynamical arguments is that the laws of thermodynamics are usually formulated in a natural language and have a common sense character. To apply them to some subtle problems one needs more rigorous formulations, than those found in most textbooks. This is particularly important in quantum theory, which often seems to be far from a 'common sense'..."

Let us point to two recent developments which may help in hightening the awareness about the more subtle and fundamental ways information may relate to physical phenomena and processes, as well as theories.

In view of [7], for instance, it may be noted the need for a considerable care which should be exhibited whenever the concept of information is used in Physics. Indeed, as it turns out, the whole of Quantum Mechanics can be reconstructed from no more than three axioms with clear physical motivation, the first of which is called

- *Information Capacity* : All systems with information carrying capacity of one bit are equivalent.

A somewhat earlier, yet no less fundamental role information may play in Physics was presented in [11,12], where major theories of Classical and Quantum Physics proved to be obtainable as expressions of information. In fact, a principle of *Extreme Physical Information*, or EPI, which uses the classical concept of Fisher Information from Statistics, proves to point to a unifying structure that underlies much of the present theoretical constructs in Physics.

For further views on the nuanced, varied and deeper role of information in Physics, recent literature, such as in [1-25], can be relevant.

2. Simultaneous Presence and Total Involvement of Physical Entities

We can note a distinction between, on one hand, concepts such as mass, motion, velocity, acceleration, force, energy, electric charge, or say, magnetism, and on the other hand, entropy and information. And for convenience, let us start with a Classical Non-Relativistic setup.

Concepts of the first kind can not only be measured, and thus be associated with appropriate unique numbers, but their effective physical instances, that is, the given physical entities which instantiate such concepts, can be brought into a variety of physical interactions with other effective physical entities. Indeed, measurements of such entities corresponding to concepts of the first kind are themselves nothing else but results of particular cases of such physical interactions.

Now, an essential feature of such physical interactions, a feature without which the very possibility of measurements would cease to exist, is the following. Given a specific physical entity E instantiating one of such concepts, say C, like mass, motion, velocity, acceleration, force, energy, electric charge, or say, magnetism in a large variety of physical interactions with other physical entities, the entity E will in its various physical interactions exhibit the very same uniquely determined amount of what is described by the concept C.
For instance, a mass of 1 kg will in a large variety of physical interactions manifest itself with all of its mass of 1 kg, and thus, with nothing less or more than 1 kg. Certainly, in terms of Newton's Law of Universal Attraction, for instance, that mass will attract every other mass, say, m, with the force $f = Gm/r^2$, where G is the gravitational constant and r is the distance between the two masses.
After all, measurement in Classical Physics is essentially based on that feature of physical interactions. And this is precisely why in Classical Physics one does not face a "measurement problem", unlike it happens in Quantum Physics.

Let us call by *total involvement* the above phenomenon typical for effective physical entities which instantiate concepts such as for instance mass, motion, velocity, acceleration, force, energy, electric charge, or say, magnetism.

A second phenomenon related to various effective physical entities is the possibility of the *simultaneous presence* of several instantiations of physical concepts within the same given effective physical entity. Indeed, a given effective physical entity can at the same time instantiate, for instance, both mass and motion.

Clearly, in the case of such simultaneous presence there may, even within a Classical Non-Relativistic setup, be a certain relation between the concepts instantiated, such as for instance between mass, velocity and energy. However, such a relationship is obviously not always compulsory.

Within a Relativistic setup in Classical Physics, both total involvement and simultaneous presence apply. What may change is the result of measurements which, of course, will depend on the frame of reference of the observers.

3. Entropy and Information

Coming to the concepts of entropy and information and its various effective physical instantiations, however, the situation changes significantly.

For instance, the smallest possible amount of information, namely, one single *bit*, can be registered on a physical entity given by, say, a mass of 1 trillion kg, or on the contrary, it can be conveyed by one single photon. Also, the same bit can be registered on two physical entities which are at rest with respect to one another, or move with considerable velocity. Similarly, the energy of a physical entity upon which a single bit may be registered can range within very large limits. And so on.

Consequently, the instantiation of information by an effective physical entity need *not* necessarily occur with a total involvement of that entity.

Let us note in this regard several facts pertinent to the instantiation of information by an effective physical entity.

First, presently it is not known how small it may in the limit be the effective physical entity capable to convey one single bit of information. Of course, Quantum Physics can suggest some lower limit which is related to the Planck scale. Yet it would be a highly unsafe bet to consider that the present state of Quantum Physics is indeed the ... Final Theory of Physics ...

Second, when an effective physical entity conveying one single bit of information is larger than the mentioned assumed to exist lower limit, then typically a part of that physical entity is redundant in the process of conveying that bit. On the other hand, and as noted, a similar redundancy does not happen when a mass interacts with another mass, or some other interaction takes place between effective physical entities corresponding to concepts of the above first kind.

Third, given a physical record on an effective physical entity of a certain amount of information, that information can often be interpreted in more than one way. Furthermore, the very existence of that record as a piece of information depends on an a priori convention about the way it is recorded and about the way it is read. On the other hand, in the case, for instance, of a mass interacting with another mass, there is neither a need, nor a possibility to interpret that mass in any other but a unique way, since there is one and only one way which exists as relevant, namely that mass being a mass. Consequently, there is neither the need, nor the possibility to make any a priori convention about that mass, other than being a mass prior, during, and following that respective interaction process.
Or to put it simply : when, for instance, a human messenger delivers a certain information, the race, sex, age, or for that matter, say, religion of that person is irrelevant, as long as the message itself is conveyed

precisely.
On the other hand, when by some accident, that human messenger happens to fall off a cliff, all of his or her mass, that is, nothing less and nothing more, will be involved in the process.

Fourth, two different amounts of mass cannot be instantiated, thus be simultaneously present as a total involvement, in the same given effective physical entity. And the same goes for the other concepts in the first above category.
On the other hand, a given effective physical entity can simultaneously instantiate more than one information, and obviously can do so without total involvement in at least one of the cases.

Fifth, as seen in [7], the information carrying capacity of an effective physical entity is of a fundamental nature since it can be involved in one of the three physically motivated axioms which reconstruct the whole of Quantum Mechanics. Therefore, one should not disregard the above issues of total involvement and simultaneous presence when dealing with the information instantiated by effective physical entities.

As for the kind and the amount of entropy in a specific effective physical entity, they clearly depend on an a priori concept of information with which the respective concept of entropy is to be uniquely associated. For instance, if we have a meeting hall capable to seat, say, 100 people, then we can, among other situations, have the following two different entropies : first, we are only interested in how many people are in the hall, or second, we are also interested in the sex of the people in the hall. Needless to say, if we consider the age of the people, or any other possible features, then we are led to corresponding different entropies.

It follows that the above phenomena mentioned related to effective physical instantiations of information have an inevitable bearing upon the effective physical instantiation of entropy as well.

In conclusion, when speaking about entropy and information, we *cannot* automatically assume

- the total involvement of the effective physical entity which may instantiate them, or

- the existence of one and only one kind, and even less so, of a necessarily unique amount of information or entropy in that effective physical entity.

References

[1] Abramsky S : Big Toy Models: Representing Physical Systems As Chu Spaces. arxiv:0910.2393

[2] Alicki R : Quantum memory as a perpetuum mobile of the second kind. arxiv:0901.0811

[3] Beggs E J, Costa J F, Tucker J V : Limits to measurement in experiments governed by algorithms. arxiv:0911.3836

[4] Brunetti R, Fredenhangen K : Time in quantum physics: From an external parameter to an intrinsic observable. arxiv:0909.1899

[5] R.S. Calsaverini R S, Vicente R : An Information Theoretic Approach to Statistical Dependence: Copula Information. arxiv:0911.4207

[6] Caticha A : From Inference to Physics. arxiv:0808.1260

[7] Dakic B, Brukner C : Quantum Theory and Beyond: Is Entanglement Special? arxiv:0911.0695

[8] Facchi P : Quantum Zeno effect and dynamics. arxiv:0911.2201

[9] Ferrari C, Gruber C : From mechanics to thermodynamics: an example of how to build the thermodynamics laws. arxiv:0911.3342

[10] Finkelstein J : One-way speed of light? arxiv:0911.3616

[11] Frieden B R : Physics from Fisher Information, A Unification. Cambridge Univ. Press, 1998

[12] Frieden B R : Science from Fisher Information. Second edition. Cambridge Univ. Press, 2004

[13] Jankovic M V : Geometrical Interpretation of Shannons Entropy Based on the Born Rule. arxiv:0909.4995

[14] Jennings D, Rudolph T : Comment on Quantum resolution to the arrow of time dilemma. arxiv:0909.1726

[15] Jordan M, Calude C S, Svozil K : Is Feasibility in Physics Limited by Fantasy Alone?. arxiv:0910.0457

[16] Kimura G, Nuida K, Imai H : Distinguishability Measures and Entropies for General Probabilistic Theories. arxiv:0910.0994

[17] Mitra A : Quantum Information Paradox: Real or Fictitious? arxiv:0911.3518

[18] Pankovic V : BLACK HOLES - A SIMPLIFIED THEORY FOR QUANTUM GRAVITY NON-SPECIALISTS. arxiv:0911.1026

[19] Pawlowski M, Paterek T, Kaszlikowski D : A new physical principle: Information Causality. arxiv:0905.2292

[20] Scarani V : QUANTUM INFORMATION, Primitive notions and quantum correlations. arxiv:0910.4222

[21] Short A, Wehner S : Entropy in general physical theories. arxiv:0909.4801

[22] Spaans M : Gravity and Information: Putting a Bit of Quantum into GR. arxiv:0909.1243

[23] Susskind Leonard : The Black Hole War, my battle with Stephen Hawking to make the world safe for Quantum Mechanics. Back Bay Books, New York, 2008

[24] A Tane J-L : Simplified Interpretation of the Basic Thermodynamic Equations. arxiv:0910.0781

[25] Zeh H D : Open questions regarding the arrow of time. arxiv:0908.3780 Sep09