Article

Is Indeed Information Physical?

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Abstract

Information being a relatively new concept in science, the likelihood is pointed out that we do not yet have a good enough grasp of its nature and relevance. This likelihood is further enhanced by the ubiquitous use of information which creates the perception of a manifest, yet in fact, rather superficial familiarity. The paper suggests several aspects which may be essential features of information, or on the contrary, may not be so. In this regard, further studies are obviously needed, studies which may have to avoid with care various temptations to reductionism, like for instance the one claiming that "information is physical".

1. A Brief History

A highly influential American, Henry Ford liked to say about a century earlier that, well, history is bunk ... And he was both reflecting and forming a widespread American attitude to life, according to which all that counts is what counts: right now. In some so called Oriental schools of wisdom, the acme of one's enlightenment is supposed to be reached when one manages to live in the NOW, thus with no concern for past or future, and led only by the realization that the only thing which is real is indeed but the NOW. So it comes to pass, at long last, that West meets East in that present day supremacy of the "right now".

Well, the history of the slogan "Information is Physical" which seem to haunt wider circles of physicists is quite recent, and eminently Western. It was indeed launched by Rolf William Landauer (1927-1999), [1-3], and after a while it took on a momentum all of its own.

But why should one be at all concerned about such a slogan? Could we not simply let physicists, or for that matter, physics, gobble up yet another newcomer entity to science ? After all, there was seemingly no objection when quanta became, so to say, physical. Or when not much earlier - relativity got appropriated by physics. And these two events, and their subsequent trends, were in fact so overwhelming that they ended up even by operating the other way round.

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Indeed, nowadays, it is not only that relativity and quanta are physical, but rather that physics, real physics, serious physics, the very foundation of physics, is nothing else but relativity and quanta.

So that, should we really be surprised if one of these days, and not necessarily to the unreserved pleasure of many a physicist, we may end up with physics being informational?

And then, why not, given such a highly fluid, changing, if not even unstable situation, perhaps it is worthwhile for most of us concerned - whether we happen to be physicists, or not - to try to see what may really be the relationship between information and physics.

Let us, therefore, see in this regard some relevant record. Recently in [4], a tentative account of various views and definitions of the concept of Information were presented, among others fairly general concerns. One of the comments regarding Information goes as follows :

> Depending on the branch of science where investigation was carried out, Information got a large number of definitions:
>
> > Information is an indication of a content, obtained from external world in the process of adaptation to the world (Wiener)
> >
> > Information is a negation of the entropy (Brillouin)
> >
> > Information is the communication resulting in a decreasing of an uncertainty (Shannon)
> >
> > Information is a transmitting of a diversity (Ashby)
> >
> > Information is an originality, novelty,
> >
> > Information is the measure of a structures complexity (Moll)
> >
> > Information is a probability of a choice (Yaglom)
>
> Each of these definitions reveals one or another aspect of this poly-semantic concept.

Further, a list of what appear to be semantically different and no less than eleven definitions of Information are cited :

1. Philosophical encyclopedia : Information (lat. informatio an examination, a notion, a concept):

> 1.1. a report, a notification about a state of affairs or about something else that is transmitted by a person;
> 1.2. decreased, removed uncertainty as a result of the communication obtained;
> 1.3. a notation inherently relating to a control, the signals in the unity of its syntactic, semantic and pragmatic parameters;
> 1.4. transmission, reflection of the variety of any objects and processes (of alive and non-alive nature).

2. Information means some order, a communication is the creation of the order from a disorder or, at least, growing of the regulation that existed before the communication was obtained.

3. Information is the manifestation of the property of the objects of alive nature to reflect in the form of some mental sensations the movement of the objects in surrounding World.

4. Information is a quality of the objects, phenomena, processes in the objective reality, of man-made controllers, which lies in the capacitance to conceive an internal state as well as the state and the impacts of an environment and to preserve, sometime, the results; to transmit the data about the internal state and cumulative data to another objects, phenomena, processes.

5. Information is a philosophical category that is considered along with such as Space, Time and Matter. In the most common form information can be presented as a notation, i.e. a form of some relations between a source which communicates and a receiver which obtains a notation.

6. Information, as well as Matter, exists and has always existed information is some integral attribute of Matter and Movement which realizes a certain way of Matter existence and presents some measure of the changes which follow all processes occurring in the World.

7. (Weizscker, 1959, quoted in [6, p. 39]) Now many peoples begin to recognize that it is necessary to consider Information as something third that differs from Matter and Consciousness This is Platos Idea, Aristotelian Form, invested by such a way that the human of the 20-th century assumes to know

something new from it.

8. (Wiener, 1948) Information is information, not matter or energy. No materialism which does not admit this can survive nowadays.

9. The phenomenon of information is a multi-stage, irreversible process of coming into being of a structure in some open imbalanced system that begins at a random memorized choice which this system carries out when it transforms from chaos to an order, so the process is completed with a purposeful action according to an algorithm or program that are in accordance with the semantics of the choice, [7].

10. Information is some qualitative and quantitative characteristic of the level of reflection. Generally information is a quasi-force which is directed against disorder and chaos; in this sense it can not be separated from structure and regularity of material systems, [8].

11. If you are interested in the question "what is information?" and find corresponding definition in some book (which is, generally speaking, rather difficult since the authors usually keep from giving such a definition), then in great likelihood other authors will not agree with this definition, [9].

And then, as if to add to it, it is mentioned that [10] presents more than twenty different definitions of information, while to cap it all, a dissertation quoted in [11] lists no less than hundreds of definitions of information ...

In view of such a state of affairs, one may indeed risk to show a lack of awareness of relevant scientific literature when, merely upon a singular argument like that brought up by Landauer, one makes the total and life long commitment to the reductionist slogan "Information is Physical" ...

2. When it is quite silly to say that "A is B" ?

Regardless of the above, however, let us pause for a moment, and have a brief look at what may indeed be the elementary sine-qua-non conditions for a statement "A is B" to have any meaning at all.

Obviously, whenever the statement "A is B" is made, such a statement has no meaning, unless the entity "B" is well defined, and of course, it is defined a priori. Thus, in the case of the above reductionist slogan related to information, what is meant by "physical"

must be clearly defined in advance of stating that slogan, in order for that slogan to have any chance at all to avoid being a mere trivial nonsense.

Here however, one faces a manifestly serious problem. Indeed, the term "physical" has even during recent times proved to have a significantly changing and expanding meaning. Just consider how since Newton it got enlarged by incorporating electro-magnetism, relativity, atoms, quanta, particle physics, and so on.

And then, the question arises : is the reductionist slogan "information is physical" a latest re-definition of Physics, one that tries to further expand Physics by incorporating phenomena related to information, or on the contrary, that slogan is a mere claim in which the concepts of "physical" and "information" are only assumed to be defined in some vague and tacitly accepted ways, and Physics merely tries in some rather naive manner to appropriate a fashionable term in order further to buttress its prestige ?

If that reductionist slogan is a new expansion in the definition of Physics, then everything is all right, provided of course that the concept of "physical" is well defined, and defined so before that slogan is launched upon the innocent and unsuspecting world ...

Otherwise, as seen above, that slogan is quite nonsensical ...

3. An ever more Foundational role of Information in Physics

Regarding the nuanced, varied and deeper role of information, as well as entropy, in Physics, recent literature, such as in [12-57], can be relevant.

In this respect, in view of [34] 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 similar, albeit more complicated recent foundation of all of Quantum Mechanics based solely on information can be found in [35], while in [36], Quantum Field Theory is built up upon the concept of information.

Apart, however, from the above arguments, and of a surprisingly more fundamental relevance is the recent major discovery in [37]. According to it, if one is indeed to fall for any kind of reductionist sloganeering, then a far more appropriate one would be the *reverse* one, namely :

"Physics is but a mere sub-realm of Information"

Indeed, as B. Roy Frieden shows it in convincing and rigorous detail in [37], major theories of Physics, both Classical and Quantum, can rather directly be obtained from an optimization of suitable applications of the well known statistical concept of Fisher Information.
Not surprisingly, this approach - which renders so much of Physics to a mere discipline in the study of Information - seems to encounter a certain controversy on the part of a number of physicists, albeit one that has so far not been pursued deeply and widely enough by its opponents.

4. Is Physics indeed a mere Sub-Discipline of some other Science ?

Apart from [37], by far the most surprising challenge so far regarding the status of Physics among sciences has been brought about by the so called *Mathematical Universe Hypothesis*, MUH, suggested by Max Tegmark in 2008, [38]. And as it happens, that challenge has been received with some appreciation even on the part of those who may not agree fully with the MUH, [39, 40].

Not to mention that far more daring proposals are being made as well. One of the rather thought provoking ones is due to George Svetlichny, [41], in which nothing short of an identification between one's subjective world, and on the other hand, the curse of the good old Copenhagen Interpretation, namely, the so called collapse of the wave function is argued in some detail.

Now, one may indeed start to wonder : are the days of Physics as an independent and fundamental science numbered ?!?

No wonder that quite a number of physicists, even if perhaps more intuitively than consciously, rally around the slogan "Information is Physical", a slogan which may hopefully prolong for a while longer the present special status of their much beloved discipline ...

5. And now, back to Information, to what may indeed be so Special about Information ...

Back to [4], it is worth mentioning the no less than eight properties which they list as being specific to Information.

Here, we mention other specific properties of Information, [42]. For that purpose, it is convenient first to recall two important features of many of physical concepts, namely :

1. Simultaneous Presence

2. Total Involvement

Indeed, we can note a distinction between, on one hand, concepts such as :

mass, motion, velocity, acceleration, force, energy, electric charge, magnetism,

and on the other hand :

information and entropy

And for convenience, let us start with a Classical Non-Relativistic setup. Concepts of the first above 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, the very measurement itself of a physical entity corresponding to a concept of the first kind is nothing else but the result of a particular case of such a physical interaction.

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 of first kind, say, C, like for instance, mass, motion, velocity, acceleration, force, energy, electric charge, or say, magnetism. Then in a large variety of physical interactions with other physical entities, the entity E will in its various such interactions exhibit precisely the whole, and 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, and with nothing 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 still apply. What may change is the result of measurements which, of course, will depend on the frame of reference of the observers.

Coming back now to the concept of Information, as well as to 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.

In fact, the occurrence of information - unlike with the effective physical entities corresponding to concepts of the above first kind - can have an *optional* aspect.
To put is simply, even if somewhat brutally : when a stone of, say, 1 kg. falls on one's head, one is not free to say : sorry, I do not want it, or I only want 1 gr. of it. On the other hand, when one is faced with an information, one can often have the option to simply disregard it, consider only part of it, or why not, just misinterpret it.

Let us further note in this regard several facts pertinent to the instantiation of infor-

mation 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 usually 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 be interpreted in more than one way.

Namely, 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 usual 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 in 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, then 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 the mentioned literature, 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.

As a brief conclusion, we can note that, when speaking about Information and Entropy, we cannot automatically assume :

> the total involvement of the effective physical entity which may instantiate them,
>
> the existence in that instantiation of one and only one kind of Information or Entropy,
>
> a presence of a unique amount of Information or Entropy,
>
> the inevitability of having to receive and accept the whole of the Information or Entropy

the inevitability of a correct reception and acceptance of the Information or Entropy

6. Information : a New kind of Physical Interaction

In view of the above, we can note a new kind of physical interaction brought about by Information.

The effective physical entities E which correspond to physical concepts C of the above first kind, are involved in *usual* interactions upon entities S

(UI) $\qquad E \longrightarrow S$

which, among others, manifest simultaneous presence and total involvement.

The way effective physical instantiations of Information occur and may affect certain entities S

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